SIEMENS

SIMATIC

S7-1200, S7-1500 PID control

Function Manual

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Introduction

1

1.1 Purpose, conventions and supplementary information

Purpose of the documentation

This documentation will support you in configuring and programming control tasks with the S7-1200 and S7-1500 automation systems.

Basic knowledge required

The following knowledge is required in order to understand the documentation:

- General knowledge of automation technology
- Knowledge of the industrial automation system SIMATIC
- Experience of working with STEP 7 (TIA Portal)

Scope of the documentation

This documentation applies to the use of SW controllers on the CPUs of automation systems S7-1200, S7-1200G2 and S7-1500 together with STEP 7 (TIA Portal). Additional SW controllers that are not covered in this documentation are available for the use of S7-300 and S7-400 with STEP 7 (TIA Portal). Section Overview of software controller (Page 44) gives a complete overview of all SW controllers in STEP 7 (TIA Portal) and their possible applications.

Conventions

Observe notes marked as follows:

NOTE

The notes contain important information on the product described in the documentation, on the handling of the product or on part of the documentation to which particular attention should be paid.

Industry Mall

The Industry Mall is the Siemens AG catalog and ordering system for automation and drive solutions based on Totally Integrated Automation (TIA) and Totally Integrated Power (TIP).

Catalogs for all automation and drive technology products can be found on the Internet (https://mall.industry.siemens.com).

See also

Topic page "SIMATIC Technology - PID Control: Overview and important links"
https://support.industry.siemens.com/cs/ww/en/view/109751051
(https://support.industry.siemens.com/cs/ww/en/view/109751051)

1.2 Guide to the Function Manuals documentation

1.2.1 Information classes Function Manuals



The documentation for the SIMATIC S7-1500 automation system, for the 1513/1516pro-2 PN, SIMATIC Drive Controller CPUs based on SIMATIC S7-1500 and the SIMATIC ET 200MP, ET 200SP, ET 200AL and ET 200eco PN distributed I/O systems is arranged into three areas.

This arrangement enables you to access the specific content you require.

You can download the documentation free of charge from the Internet (https://support.industry.siemens.com/cs/ww/en/view/109742705).

Basic information



The system manuals and Getting Started describe in detail the configuration, installation, wiring and commissioning of the SIMATIC S7-1500, SIMATIC Drive Controller, ET 200MP, ET 200SP, ET 200AL and ET 200eco PN systems. Use the corresponding operating instructions for 1513/1516pro-2 PN CPUs.

The STEP 7 online help supports you in the configuration and programming.

Examples:

- Getting Started S7-1500
- System manuals
- Operating instructions ET 200pro and 1516pro-2 PN CPU
- Online help TIA Portal

Device information



Equipment manuals contain a compact description of the module-specific information, such as properties, wiring diagrams, characteristics and technical specifications.

Examples:

- Equipment manuals for CPUs
- Equipment manuals for interface modules
- Equipment manuals for digital modules
- Equipment manuals for analog modules
- Equipment manuals for communication modules
- Equipment manuals for technology modules
- Equipment manuals for power supply modules
- Equipment manuals for BaseUnits

General information



The function manuals contain detailed descriptions on general topics relating to the SIMATIC Drive Controller and the S7-1500 automation system.

Examples:

- Function Manual Diagnostics
- Function Manual Communication
- Function Manuals Motion Control
- Function Manual Web Server
- Function Manual Cycle and Response Times
- PROFINET Function Manual
- PROFIBUS Function Manual

Product Information

Changes and supplements to the manuals are documented in a Product Information. The Product Information takes precedence over the device and system manuals.

You will find the latest Product Information on the Internet:

- S7-1500/ET 200MP (https://support.industry.siemens.com/cs/de/en/view/68052815)
- SIMATIC Drive Controller (https://support.industry.siemens.com/cs/de/en/view/109772684/en)
- Motion Control (https://support.industry.siemens.com/cs/de/en/view/109794046/en)
- ET 200SP (https://support.industry.siemens.com/cs/de/en/view/73021864)
- ET 200eco PN (https://support.industry.siemens.com/cs/ww/en/view/109765611)

Manual Collections

The Manual Collections contain the complete documentation of the systems put together in one file.

You will find the Manual Collections on the Internet:

- S7-1500/ET 200MP/SIMATIC Drive Controller (https://support.industry.siemens.com/cs/ww/en/view/86140384)
- ET 200SP (https://support.industry.siemens.com/cs/ww/en/view/84133942)
- ET 200AL (https://support.industry.siemens.com/cs/ww/en/view/95242965)
- ET 200eco PN (https://support.industry.siemens.com/cs/ww/en/view/109781058)

1.2.2 Basic tools

Tools

The tools described below support you in all steps: from planning, over commissioning, all the way to analysis of your system.

TIA Selection Tool

The TIA Selection Tool tool supports you in the selection, configuration, and ordering of devices for Totally Integrated Automation (TIA).

As successor of the SIMATIC Selection Tools , the TIA Selection Tool assembles the already known configurators for automation technology into a single tool.

With the TIA Selection Tool , you can generate a complete order list from your product selection or product configuration.

You can find the TIA Selection Tool on the Internet.
(https://support.industry.siemens.com/cs/ww/en/view/109767888)

SIMATIC Automation Tool

You can use the SIMATIC Automation Tool to perform commissioning and maintenance activities on various SIMATIC S7 stations as bulk operations independent of TIA Portal.

The SIMATIC Automation Tool offers a wide range of functions:

- Scanning of a PROFINET/Ethernet system network and identification of all connected CPUs
- Assignment of addresses (IP, subnet, Gateway) and device name (PROFINET device) to a CPU
- Transfer of the date and the programming device/PC time converted to UTC time to the module
- Program download to CPU
- RUN/STOP mode switchover
- CPU localization through LED flashing
- Reading out of CPU error information

- Reading the CPU diagnostic buffer
- Reset to factory settings
- Firmware update of the CPU and connected modules

You can find the SIMATIC Automation Tool on the Internet.
(https://support.industry.siemens.com/cs/ww/en/view/98161300)

PRONETA

SIEMENS PRONETA (PROFINET network analysis) is a commissioning and diagnostic tool for PROFINET networks. PRONETA Basic has two core functions:

- In the network analysis, you get an overview of the PROFINET topology. Compare a real configuration with a reference installation or make simple parameter changes, e.g. to the names and IP addresses of the devices.
- The "IO test" is a simple and rapid test of the wiring and the module configuration of a plant, including documentation of the test results.

You can find SIEMENS PRONETA Basic on the Internet:
(https://support.industry.siemens.com/cs/ww/en/view/67460624)

SIEMENS PRONETA Professional is a licensed product that offers you additional functions. It offers you simple asset management in PROFINET networks and supports operators of automation systems in automatic data collection/acquisition of the components used through various functions:

- The user interface (API) offers an access point to the automation cell to automate the scan functions using MQTT or a command line.
- With PROFIenergy diagnostics, you can quickly detect the current pause mode or the readiness for operation of devices that support PROFIenergy and change these as needed.
- The data record wizard supports PROFINET developers in reading and writing acyclic PROFINET data records quickly and easily without PLC and engineering.

You can find SIEMENS PRONETA Professional on the Internet.
(https://www.siemens.com/proneta-professional)

SINETPLAN

SINETPLAN, the Siemens Network Planner, supports you in planning automation systems and networks based on PROFINET. The tool facilitates professional and predictive dimensioning of your PROFINET installation as early as in the planning stage. In addition, SINETPLAN supports you during network optimization and helps you to exploit network resources optimally and to plan reserves. This helps to prevent problems in commissioning or failures during productive operation even in advance of a planned operation. This increases the availability of the production plant and helps improve operational safety.

The advantages at a glance

- Network optimization thanks to port-specific calculation of the network load
- Increased production availability thanks to online scan and verification of existing systems
- Transparency before commissioning through importing and simulation of existing STEP 7 projects
- Efficiency through securing existing investments in the long term and the optimal use of resources

You can find SINETPLAN on the Internet (https://new.siemens.com/global/en/products/automation/industrial-communication/profinet/sinetplan.html).

1.2.3 SIMATIC Technical Documentation

Additional SIMATIC documents will complete your information. You can find these documents and their use at the following links and QR codes.

The Industry Online Support gives you the option to get information on all topics. Application examples support you in solving your automation tasks.

Overview of the SIMATIC Technical Documentation

Here you will find an overview of the SIMATIC documentation available in Siemens Industry Online Support:

Industry Online Support International (https://support.industry.siemens.com/cs/ww/en/view/109742705)

Watch this short video to find out where you can find the overview directly in Siemens Industry Online Support and how to use Siemens Industry Online Support on your mobile device:

Quick introduction to the technical documentation of automation products per video (https://support.industry.siemens.com/cs/us/en/view/109780491)

YouTube video: Siemens Automation Products - Technical Documentation at a Glance (https://youtu.be/TwLSxxRQQsA)

Retention of the documentation

Retain the documentation for later use.

For documentation provided in digital form:

1. Download the associated documentation after receiving your product and before initial installation/commissioning. Use the following download options:
   - Industry Online Support International: (https://support.industry.siemens.com)

     The article number is used to assign the documentation to the product. The article number is specified on the product and on the packaging label. Products with new, non-compatible functions are provided with a new article number and documentation.
   - ID link:

     Your product may have an ID link. The ID link is a QR code with a frame and a black frame corner at the bottom right. The ID link takes you to the digital nameplate of your product. Scan the QR code on the product or on the packaging label with a smartphone camera, barcode scanner, or reader app. Call up the ID link.
2. Retain this version of the documentation.

Updating the documentation

The documentation of the product is updated in digital form. In particular in the case of function extensions, the new performance features are provided in an updated version.

1. Download the current version as described above via the Industry Online Support or the ID link.
2. Also retain this version of the documentation.

mySupport

With "mySupport" you can get the most out of your Industry Online Support.

Registration	You must register once to use the full functionality of "mySupport". After registration, you can create filters, favorites and tabs in your personal workspace.
Support requests	Your data is already filled out in support requests, and you can get an overview of your current requests at any time.
Documentation	In the Documentation area you can build your personal library.
Favorites	You can use the "Add to mySupport favorites" to flag especially interesting or frequently needed content. Under "Favorites", you will find a list of your flagged entries.
Recently viewed articles	The most recently viewed pages in mySupport are available under "Recently viewed articles".
CAx data	The CAx data area gives you access to the latest product data for your CAx or CAe system. You configure your own download package with a few clicks: • Product images, 2D dimension drawings, 3D models, internal circuit diagrams, EPLAN macro files • Manuals, characteristics, operating manuals, certificates • Product master data

You can find "mySupport" on the Internet. (https://support.industry.siemens.com/My/ww/en)

Application examples

The application examples support you with various tools and examples for solving your automation tasks. Solutions are shown in interplay with multiple components in the system - separated from the focus on individual products.

You can find the application examples on the Internet.
(https://support.industry.siemens.com/cs/ww/en/ps/ae)

Safety instructions

2

2.1 General safety instructions

The safety instructions can be found in section "Safety instructions" in the System Manual "SIMATIC S7-1500, ET 200MP Automation System" (https://support.industry.siemens.com/cs/ww/en/view/59191792) document.

Cybersecurity-relevant information can be found in the Industrial Cybersecurity (Page 22) section.

2.2 Warnings in this document

You can find explanations of the warnings used in this document in the "Legal information" section.

Industrial cybersecurity 3

Due to the digitalization and increasing networking of machines and industrial plants, the risk of cyber attacks is also growing. Appropriate protective measures are therefore mandatory, particularly in the case of critical infrastructure facilities.

3.1 Cybersecurity information

Siemens provides products and solutions with industrial cybersecurity functions that support the secure operation of plants, systems, machines and networks.

In order to protect plants, systems, machines and networks against cyber threats, it is necessary to implement – and continuously maintain – a holistic, state-of-the-art industrial cybersecurity concept. Siemens' products and solutions constitute one element of such a concept.

Customers are responsible for preventing unauthorized access to their plants, systems, machines and networks. Such systems, machines and components should only be connected to an enterprise network or the internet if and to the extent such a connection is necessary and only when appropriate security measures (e.g. firewalls and/or network segmentation) are in place.

For additional information on industrial cybersecurity measures that may be implemented, please visit
https://www.siemens.com/cybersecurity-industry.

Siemens' products and solutions undergo continuous development to make them more secure. Siemens strongly recommends that product updates are applied as soon as they are available and that the latest product versions are used. Use of product versions that are no longer supported, and failure to apply the latest updates may increase customer's exposure to cyber threats.

To stay informed about product updates, subscribe to the Siemens Industrial Cybersecurity RSS Feed under
https://new.siemens.com/cert.

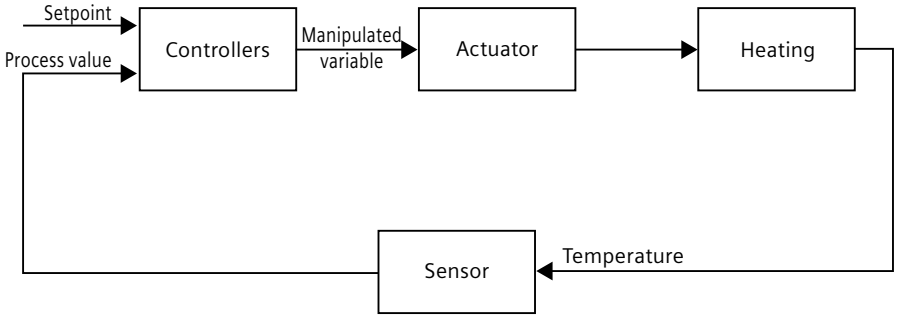
Principles for control

4

4.1 Controlled system and actuators

Controlled system

Room temperature control by means of a heating system is a simple example of a controlled system. A sensor measures the room temperature and transfers the value to a controller. The controller compares the current room temperature with a setpoint and calculates an output value (manipulated variable) for heating control.



A properly set PID controller reaches this setpoint as quickly as possible and then holds it a constant value. After a change in the output value, the process value often changes only with a time delay. The controller has to compensate for this response.

Actuators

The actuator is an element of the controlled system and is influenced by the controller. Its function modifies mass and energy flows.

The table below provides an overview of actuator applications.

Application	Actuator
Liquid and gaseous mass flow	Valve, shutter, gate valve
Solid mass flow, e.g., bulk material	Articulated baffle, conveyor, vibrator channel
Flow of electrical power	Switching contact, contactor, relay, thyristor
	Variable resistor, variable transformer, transistor

Actuators are distinguished as follows:

- Proportional actuators with constant actuating signal

  These elements set degrees of opening, angular positions or positions in proportion to the output value. The output value has an analog effect on the process within the control range.

  Actuators in this group include spring-loaded pneumatic drives, as well as motorized drives with position feedback for which a position control system is formed.

An continuous controller, such as PID_Compact, generates the output value.

- Proportional actuators with pulse-width modulated signal

  These actuators are used to generate the output of pulses with a length proportional to the output value within the sampling time intervals. The actuator - e.g. a heating resistor or cooling apparatus - is switched on in isochronous mode for durations that differ depending on the output value.

  The actuating signal can assume unipolar "On" or "Off" states, or represent bipolar states such as "open/close", "forward/backward", "accelerate/brake".

  The output value is generated by a two-step controller such as PID_Compact with pulse-width modulation.

- Actuators with integral action and three-step actuating signal

  Actuators are frequently operated by motors with an on period that is proportional to the actuator travel of the choke element. This includes elements such as valves, shutters, and gate valves. In spite of their different design, all of these actuators follow the effect of an integral action at the input of the controlled system.

  A step controller, such as PID_3Step. generates the output value.

4.2 Controlled systems

The properties of a controlled system can hardly be influenced as these are determined by the technical requirements of the process and machinery. Acceptable control results can only be achieved by selecting a suitable controller type for the specific controlled system and adapting the controller to the time response of the controlled system. Therefore, it is indispensable for the configuration of the proportional, integral and derivative actions of the controller to have precise knowledge of the type and parameters of the controlled system.

Controlled system types

Controlled systems are classified based on their time response to step changes of the output value.

We distinguish between the following controlled systems:

- Self-regulating controlled systems
  - Proportional-action controlled systems
  - PT1 controlled systems
  - PT2 controlled systems
- Non-self-regulating controlled systems
- Controlled systems with and without dead time

Self-regulating controlled systems

Proportional-action controlled systems

In proportional-action controlled systems, the process value follows the output value almost immediately. The ratio between the process value and output value is defined by the proportional Gain of the controlled system.

Examples:

- Gate valve in a piping system
- Voltage dividers
- Step-down function in hydraulic systems

PT1 controlled systems

In a PT1 controlled system, the process value initially changes in proportion to the change of the output value. The rate of change of the process value is reduced as a function of the time until the end value is reached, i.e., it is delayed.

Examples:

- Spring damping system
- Charge of RC elements
- Water container that is heated with steam.

The time constants are often identical for heating and cooling processes, or for charging and discharge characteristics. With different time constants, controlling is clearly more complex.

PT2 controlled systems

In a PT2 controlled system, the process value does not immediately follow a step change of the output value, i.e., it increases in proportion to the positive rate of rise and then approaches the setpoint at a decreasing rate of rise. The controlled system shows a proportional response characteristic with second order delay element.

Examples:

- Pressure control
- Flow rate control
- Temperature control

Non-self-regulating controlled systems

Non-self-regulating controlled systems have an integral response. The process value approaches an infinite maximum value.

Example:

- Liquid flow into a container

Controlled systems with dead time

A dead time always represents the runtime or transport time that has to expire before a change to the system input can be measured at the system output.

In controlled systems with dead time, the process value change is delayed by the amount of the dead time.

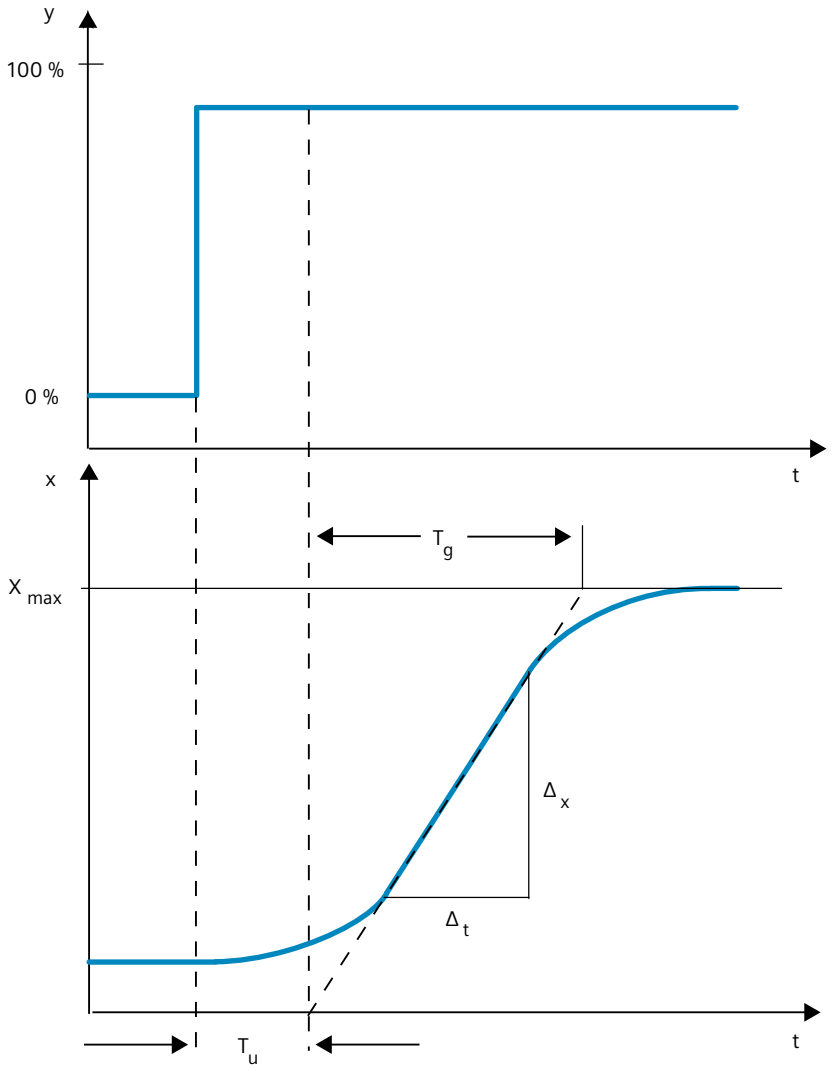
Example:

- Conveyor

4.3 Characteristic values of the control section

Determining the time response from the step response

Time response of the controlled system can be determined based on the time characteristic of process value x following a step change of output value y. Most controlled systems are self-regulating controlled systems.



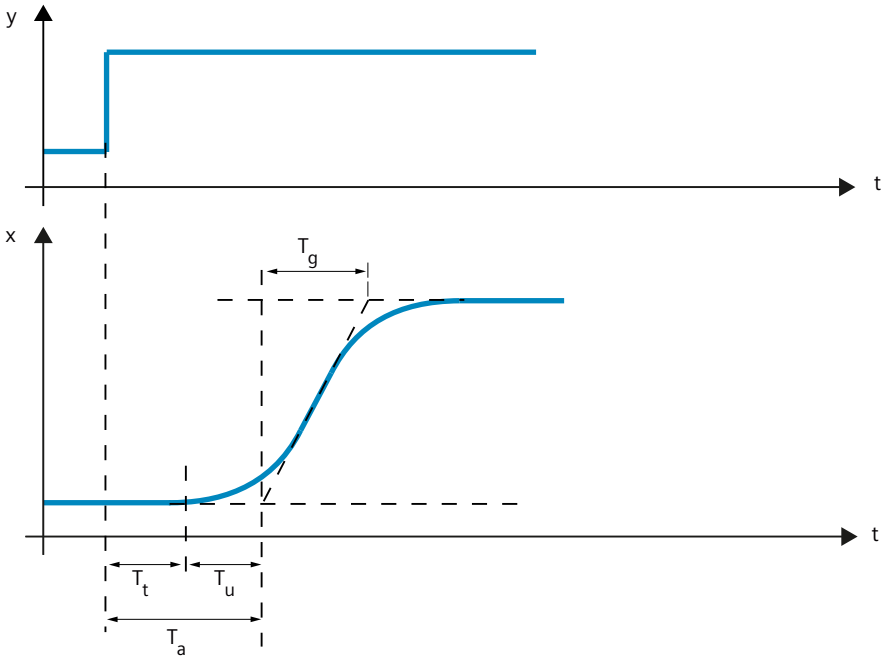
The time response can be determined by approximation using the variables Delay time T_u, Recovery time T_g and Maximum value X_{max}. The variables are determined by applying tangents to the maximum value and the inflection point of the step response. In many situations, it is not possible to record the response characteristic up to the maximum value because the process value cannot exceed specific values. In this case, the rate of rise v_{max} is used to identify the controlled system ($v_{max} = \Delta_x/\Delta_t$).

The controllability of the controlled system can be estimated based on the ratio T_u/T_g, or $T_u \times v_{max}/X_{max}$. Rule:

Process type	T_u / T_g	Suitability of the controlled system for controlling
I	< 0.1	can be controlled well
II	0.1 to 0.3	can still be controlled
III	> 0.3	difficult to control

Influence of the dead time on the controllability of a controlled system

A controlled system with dead time and recovery reacts as follows to a jump of the output value.



T_t	Dead time
T_u	Delay time
T_g	Recovery time
y	Output value
x	Process value

The controllability of a self-regulating controlled system with dead time is determined by the ratio of T_t to T_g. T_t must be small compared to T_g. Rule:

$T_t/T_g \leq 1$

Response rate of controlled systems

Controlled systems can be judged on the basis of the following values:

$T_u < 0.5$ min, $T_g < 5$ min = fast controlled system

$T_u > 0.5$ min, $T_g > 5$ min = slow controlled system

Parameters of certain controlled systems

Physical quantity	Controlled system	Delay time T_u	Recovery time T_g	Rate of rise v_{max}
Temperature	Small electrically heated furnace	0.5 to 1 min	5 to 15 min	Up to 60 K/min.
	Large electrically heated annealing furnace	1 to 5 min	10 to 20 min	Up to 20 K/min.
	Large gas-heated annealing furnace	0.2 to 5 min	3 to 60 min	1 to 30 K/min
	Distillation tower	1 to 7 min	40 to 60 min	0.1 to 0.5° C/s
	Autoclaves (2.5 m^3)	0.5 to 0.7 min	10 to 20 min	Not specified
	High-pressure autoclaves	12 to 15 min	200 to 300 min	Not specified
	Steam superheater	30 s to 2.5 min	1 to 4 min	2°C/s
	Injection molding machines	0.5 to 3 min	3 to 30 min	5 to 20 K/min
	Extruders	1 to 6 min	5 to 60 min	
	Packaging machines	0.5 to 4 min	3 to 40 min	2 to 35 K/min
	Room heating	1 to 5 min	10 to 60 min	1° C/min
Flow rate	Pipeline with gas	0 to 5 s	0.2 to 10 s	Not relevant
	Pipeline with liquid	None	None	
Pressure	Gas pipeline	None	0.1 s	Not relevant
	Drum boiler with gas or oil firing	None	150 s	Not relevant
	Drum boiler with impact grinding mills	1 to 2 min	2 to 5 min	Not relevant
Vessel level	Drum boiler	0.6 to 1 min	Not specified	0.1 to 0.3 cm/s
Speed	Small electric drive	None	0.2 to 10 s	Not relevant
	Large electric drive	None	5 to 40 s	Not relevant
	Steam turbine	None	Not specified	50 min^{-1}
Voltage	Small generators	None	1 to 5 s	Not relevant
	Large generators	None	5 to 10 s	Not relevant

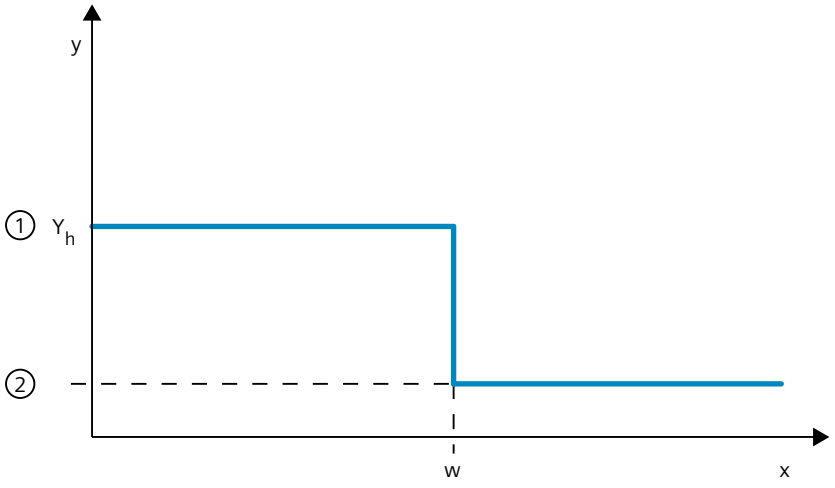
4.4 Pulse controller

Two-step controllers without feedback

Two-step controllers have the state "ON" and "OFF" as the switching function. This corresponds to 100% or 0% output. This behavior generates a sustained oscillation of process value x around setpoint w.

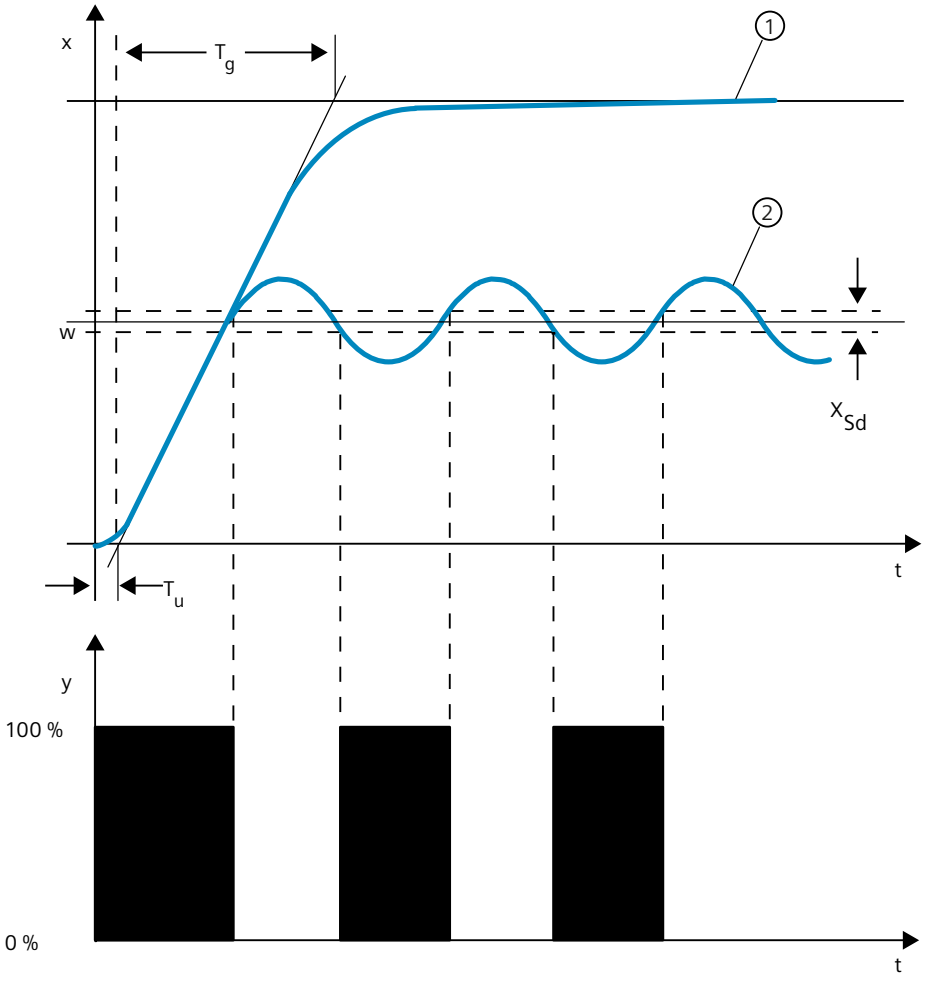
The amplitude and duration of the oscillation increase in proportion to the ratio between the delay time T_u and recovery time T_g of the controlled system. These controllers are used mainly for simple temperature control systems (such as electrically directly heated furnaces) or as limit-value signaling units.

The following diagram shows the characteristic of a two-step controller



①	ON
②	OFF
Y_h	Control range
w	Setpoint

The following diagram shows the control function of a two-step controller



①	Response characteristic without controller
②	Response characteristic with two-step controller
T_u	Delay time
T_g	Recovery time
X_{Sd}	Switching difference

Two-step controllers with feedback

The behavior of two-step controllers in the case of controlled systems with larger delay times, such as furnaces where the functional space is separated from the heating, can be improved by the use of electronic feedback.

The feedback is used to increase the switching frequency of the controller, which reduces the amplitude of the process value. In addition, the control-action results can be improved substantially in dynamic operation. The limit for the switching frequency is set by the output level. It should not exceed 1 to 5 switches per minute at mechanical actuators, such as relays and contactors. In the case of binary voltage and current outputs with downstream thyristor or Triac controllers high switching frequencies can be selected that exceed the limit frequency of the controlled system by far.

Since the switching pulses can no longer be determined at the output of the controlled system, results comparable with those of continuous controllers are obtained.

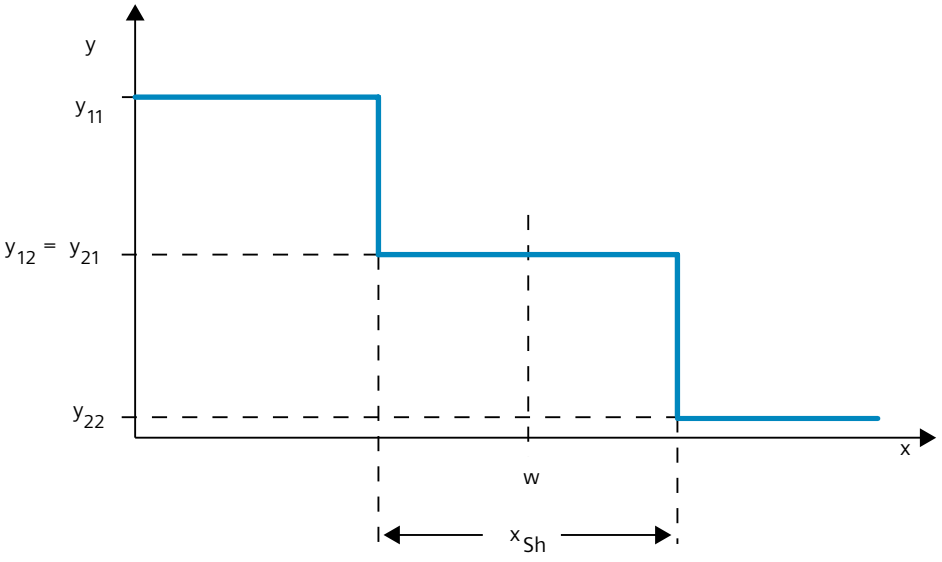
The output value is generated by pulse-width modulation of the output value of a continuous controller.

Two-step controllers with feedback are used for temperature control in furnaces, at processing machines in the plastics, textile, paper, rubber and foodstuff industries as well as for heating and cooling devices.

Three-step controllers

Three-step controllers are used for heating / cooling. These controllers have two switching points as their output. The control-action results are optimized through electronic feedback structures. Fields of applications for such controllers are heating, low-temperature, climatic chambers and tool heating units for plastic-processing machines.

The following diagram shows the characteristic of a three-step controller

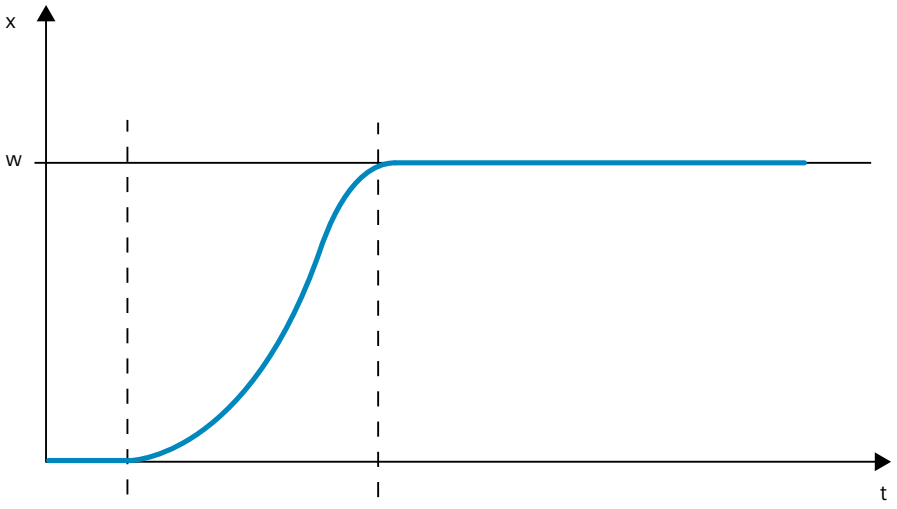


y	Output value, e.g. y11 = 100% heating y12 = 0% heating y21 = 0% cooling y22 = 100% cooling
x	Physical quantity of the process value, e.g., temperature in° C
w	Setpoint
x_{Sh}	Distance between Switching Point 1 and Switching Point 2

4.5 Response to setpoint changes and disturbances

Response to setpoint changes

The process value should follow a setpoint change as quickly as possible. The response to setpoint changes is improved by minimizing fluctuation of the process value and the time required to reach the new setpoint.

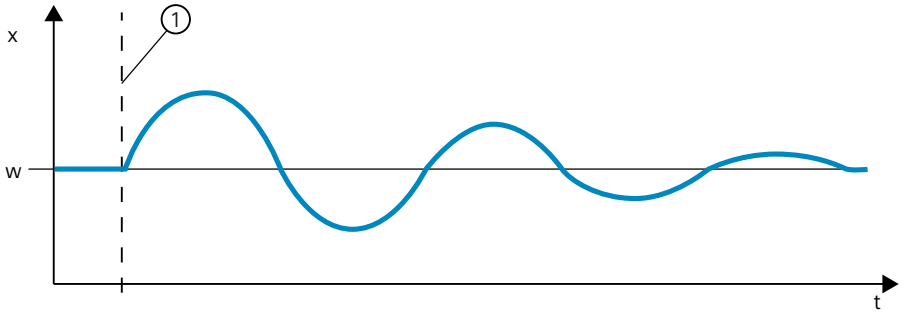


x Process value

w Setpoint

Response to disturbances

The setpoint is influenced by disturbance variables. The controller has to eliminate the resulting control deviations in the shortest time possible. The response to disturbances is improved by minimizing fluctuation of the process value and the time required to reach the new setpoint.



x Process value

w Setpoint

① Influencing a disturbance variable

Disturbance variables are corrected by a controller with integral action. A persistent disturbance variable does not reduce control quality because the control deviation is relatively constant. Dynamic disturbance variables have a more significant impact on control

quality because of control deviation fluctuation. The control deviation is eliminated again only by means of the slow acting integral action.

A measurable disturbance variable can be included in the controlled system. This inclusion would significantly accelerated the response of the controller.

4.6 Control Response at Different Feedback Structures

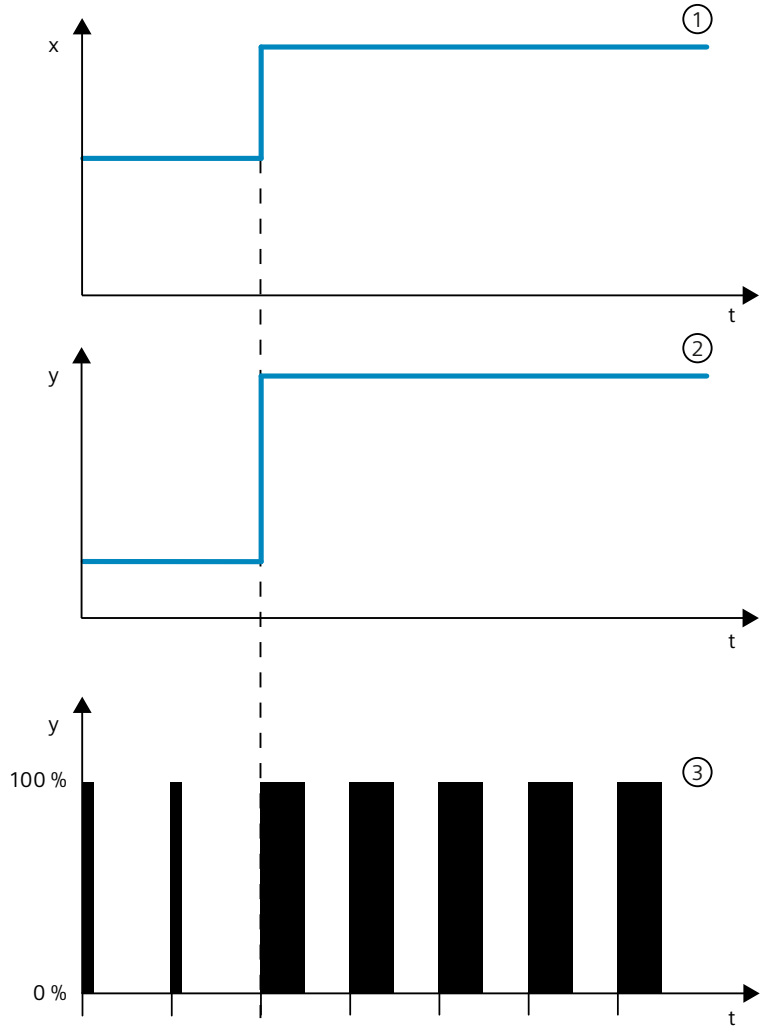
Control behavior of controllers

A precise adaptation of the controller to the time response of the controlled system is decisive for the controller's precise settling to the setpoint and optimum response to disturbance variables.

The feedback circuit can have a proportional action (P), proportional-derivative action (PD), proportional-integral action (PI), or proportional-integral-derivative action (PID).

If step functions are to be triggered by control deviations, the step responses of the controllers differ depending on their type.

Step response of a proportional action controller



① Control deviation
② Output value of a continuous controller
③ Output value of a pulse controller

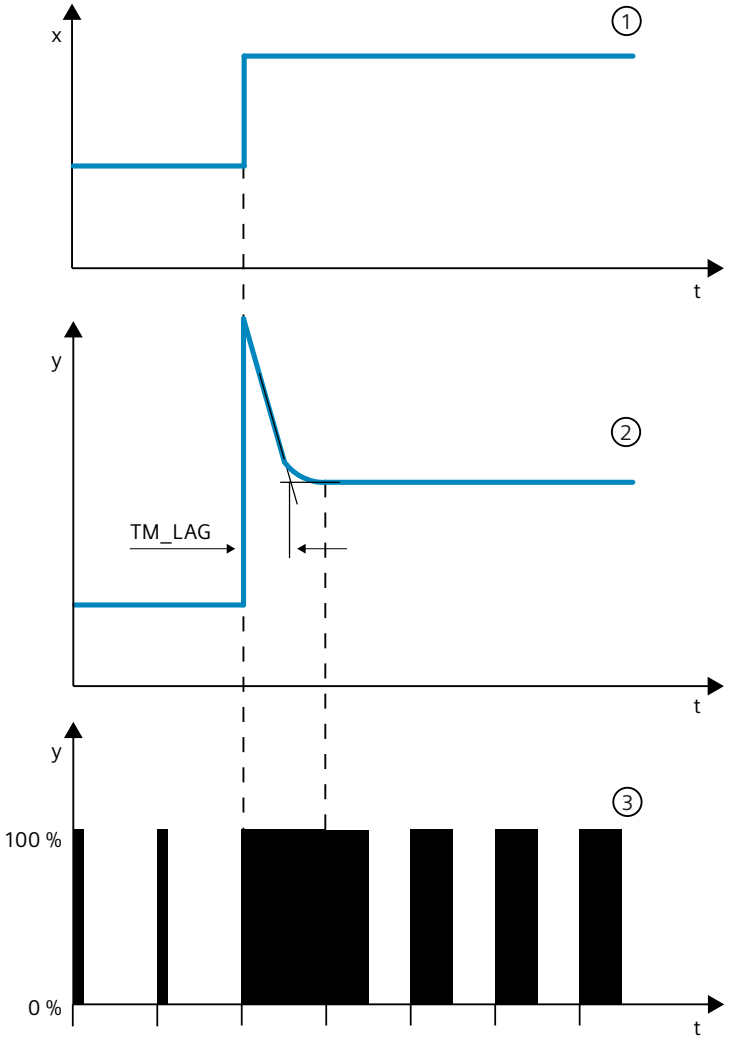
Equation for proportional action controller

Output value and control deviation are directly proportional, meaning:

Output value = proportional gain × control deviation

y = GAIN × x

Step response of a PD-action controller



①	Control deviation
②	Output value of a continuous controller
③	Output value of a pulse controller
TM_LAG	Delay of the Derivative action

Equation for PD-action controller

The following applies for the step response of the PD-action controller in the time range:

$$y = GAIN \cdot X_W \cdot \left(1 + \frac{TD}{TM_LAG} \cdot e^{\frac{-t}{TM_LAG}} \right)$$

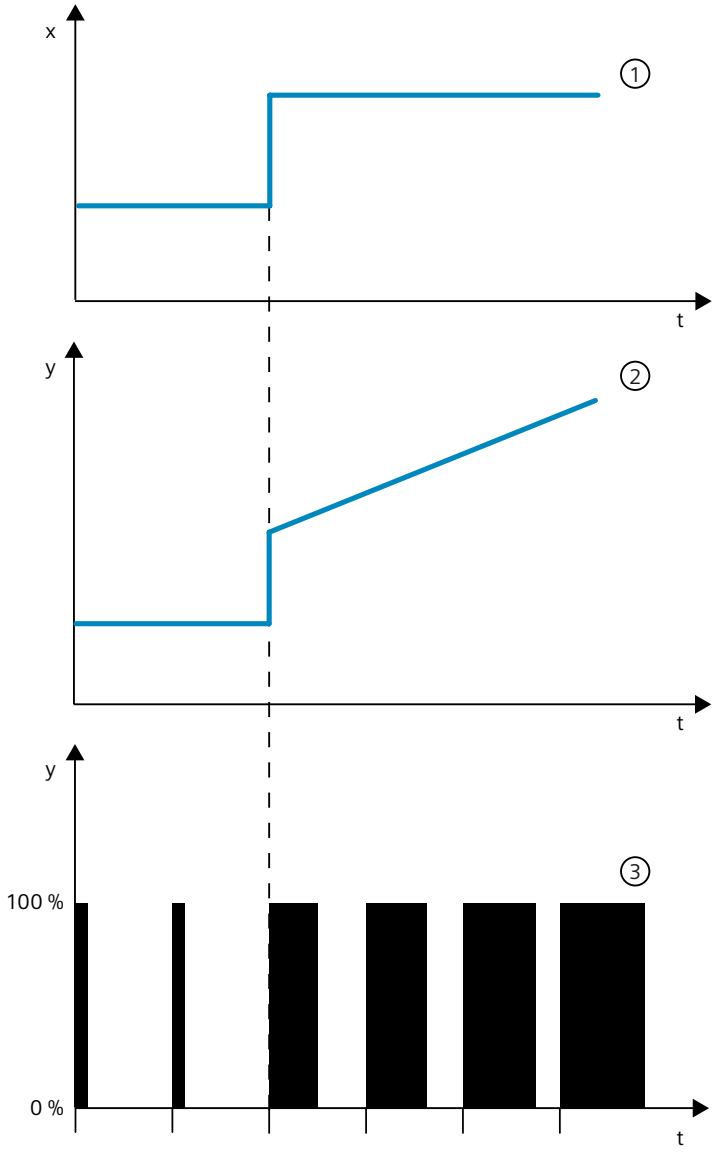
t = time interval since the step of the control deviation

The derivative action generates a output value as a function of the rate of change of the process value. A derivative action by itself is not suitable for controlling because the output value only follows a step of the process value. As long as the process value remains constant, the output value will no longer change.

The response to disturbances of the derivative action is improved in combination with a proportional action. Disturbances are not corrected completely. The good dynamic response is advantageous. A well attenuated, non-oscillating response is achieved during approach and setpoint change.

A controller with derivative action is not appropriate if a controlled system has pulsing measured quantities, for example, in the case of pressure or flow control systems.

Step response of a PI-action controller



① Control deviation
② Output value of a continuous controller
③ Output value of a pulse controller

An integral action in the controller adds the control deviation as a function of the time. This means that the controller corrects the system until the control deviation is eliminated. A sustained control deviation is generated at controllers with proportional action only. This effect can be eliminated by means of an integral action in the controller.

In practical experience, a combination of the proportional, integral and derivative actions is ideal, depending on the requirements placed on the control response. The time response of the individual components can be described by the controller parameters proportional gain GAIN, integration time TI (integral action), and derivative action time TD (derivative action).

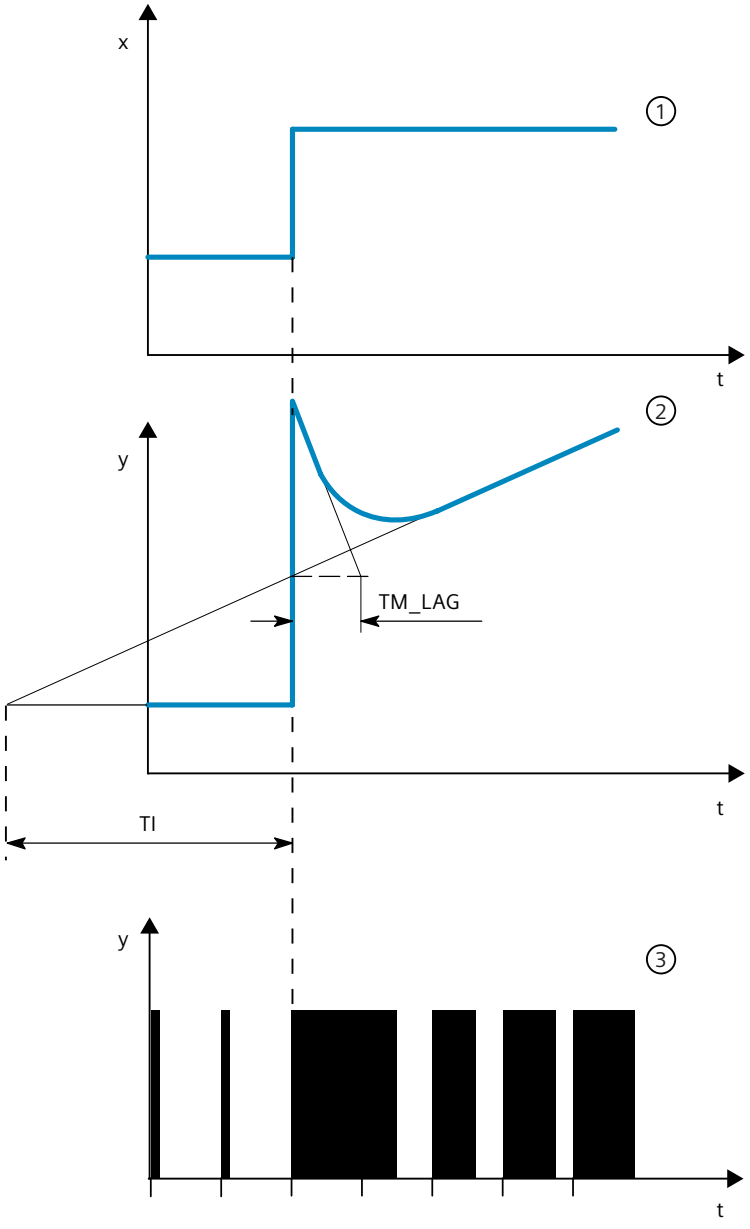
Equation for PI-action controller

The following applies for the step response of the PI-action controller in the time range:

$$y = GAIN \cdot X_W \cdot \left(1 + \frac{1}{TI \cdot t}\right)$$

t = time interval since the step of the control deviation

Step response of a PID controller



①	Control deviation
②	Output value of a continuous controller
③	Output value of a pulse controller
TM_LAG	Delay of the Derivative action
T_i	Integration time

Equation for PID controller

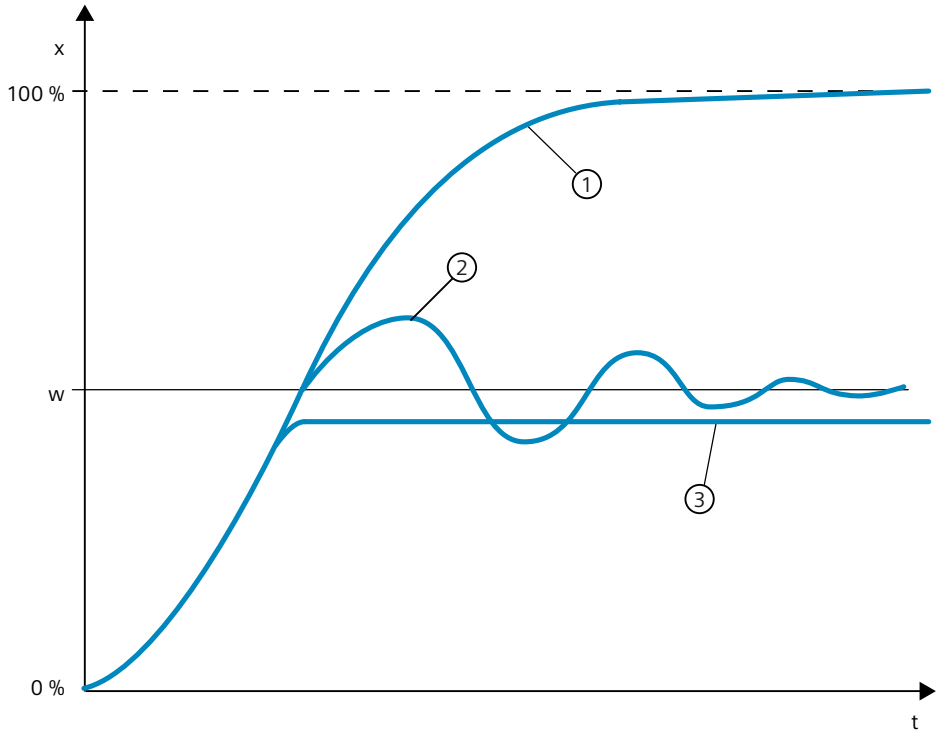
The following applies for the step response of the PID controller in the time range:

$$y = GAIN \cdot X_w \cdot \left(1 + \frac{1}{TI \cdot t} + \frac{TD}{TM_LAG} \cdot e^{\frac{-t}{TM_LAG}} \right)$$

t = time interval since the step of the control deviation

Response of a controlled system with different controller structures

Most of the controller systems occurring in process engineering can be controlled by means of a controller with PI-action response. In the case of slow controlled system with a large dead time, for example temperature control systems, the control result can be improved by means of a controller with PID action.



①	No controller
②	PID controller
③	PD-action controller
w	Setpoint
x	Process value

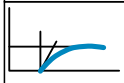
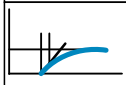
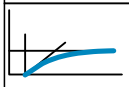
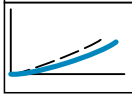
Controllers with PI and PID action have the advantage that the process value does not have any deviation from the setpoint value after settling. The process value oscillates over the setpoint during approach.

4.7 Selection of the controller structure for specified controlled systems

Selection of the Suitable Controller Structures

To achieve optimum control results, select a controller structure that is suitable for the controlled system and that you can adapt to the controlled system within specific limits.

The table below provides an overview of suitable combinations of a controller structure and controlled system.

Controlled system		Controller structure			
		P	**PD**	**PI**	**PID**
	With dead time only	Unsuitable	Unsuitable	Suitable	Unsuitable
	PT1 with dead time	Unsuitable	Unsuitable	Well suited	Well suited
	PT2 with dead time	Unsuitable	Suited conditionally	Well suited	Well suited
	Higher order	Unsuitable	Unsuitable	Suited conditionally	Well suited
	Not self-regulating	Well suited	Well suited	Well suited	Well suited

The table below provides an overview of suitable combinations of a controller structure and physical quantity.

Physical quantity	Controller structure			
	P	**PD**	**PI**	**PID**
	Sustained control deviation		**No sustained control deviation**	
Temperature	For low performance requirements and proportional action controlled systems with $T_u/Tg < 0,1$	Well suited	The most suitable controller structures for high performance requirements (except for specially adapted special controllers)	
Pressure	Suitable, if the delay time is inconsiderable	Unsuitable	The most suitable controller structures for high performance requirements (except for specially adapted special controllers)	
Flow rate	Unsuitable, because required GAIN range is usually too large	Unsuitable	Suitable, but integral action controller alone often better	Hardly required

4.8 PID parameter settings

Rule of Thumb for the Parameter Setting

Controller structure	Setting
P	GAIN ≈ $v_{max} \times T_u$ [° C]
PI	GAIN ≈ $1.2 \times v_{max} \times T_u$ [° C] TI ≈ $4 \times T_u$ [min]
PD	GAIN ≈ $0.83 \times v_{max} \times T_u$ [° C] TD ≈ $0.25 \times v_{max} \times T_u$ [min] TM_LAG ≈ 0.5 × TD[min]
PID	GAIN ≈ $0.83 \times v_{max} \times T_u$ [° C] TI ≈ $2 \times T_u$ [min] TD ≈ $0.4 \times T_u$ [min] TM_LAG ≈ 0.5 × TD[min]
PD/PID	GAIN ≈ $0.4 \times v_{max} \times T_u$ [° C] TI ≈ $2 \times T_u$ [min] TD ≈ $0.4 \times T_u$ [min] TM_LAG ≈ 0.5 × TD[min]

Instead of $v_{max} = \Delta_x / \Delta_t$, you can use X_{max} / T_g.

In the case of controllers with PID structure the setting of the integral action time and differential-action time is usually coupled with each other.

The ratio TI / TD lies between 4 and 5 and is optimal for most controlled systems.

Non-observance of the differential-action time TD is uncritical at PD controllers.

In the case of PI and PID controllers, control oscillations occur if the integral action time TI has been select by more than half too small.

An integral action time that is too large slows down the settling times of disturbances. One cannot expect that the control loops operate "optimally" after the first parameter settings. Experience shows that adjusting is always necessary, when a system exists that is "difficult to control" with $T_u / T_g > 0.3$.

Configuring a software controller

5

5.1 Overview of software controller

For the configuration of a software controller, you need an instruction with the control algorithm and a technology object. The technology object for a software controller corresponds with the instance DB of the instruction. The configuration of the controller is saved in the technology object. In contrast to the instance DBs of other instructions, technology objects are not stored for the program resources, but rather under CPU > Technology objects.

Technology objects and instructions

CPU	Library	Instruction	Technology object	Description
S7-1200	Compact PID	PID_Compact V1.x	PID_Compact V1.x	Universal PID controller with integrated tuning
S7-1200		PID_3Step V1.x	PID_3Step V1.x	PID controller with integrated tuning for valves
S7-1500 S7-1200 V4.x		PID_Compact V2.x	PID_Compact V2.x	Universal PID controller with integrated tuning
S7-1500 S7-1200 V4.x S7-1200 G2		PID_3Step V2.x	PID_3Step V2.x	PID controller with integrated tuning for valves
S7-1500 ≥ V1.7 S7-1200 ≥ V4.1 S7-1200 G2		PID_Temp V1.x	PID_Temp V1.x	Universal PID temperature controller with integrated tuning
S7-1500 ≥ V3.1 S7-1200 G2		PID_Compact V3.x	PID_Compact V3.x	Universal PID controller with integrated tuning
S7-1500 ≥ V4.1 S7-1200 G2 ≥ V4.1		PID_Temp V2.0	PID_Temp V2.0	Universal PID temperature controller with integrated tuning
S7-1500/300/400	PID basic functions	CONT_C	CONT_C	Continuous controller
S7-1500/300/400		CONT_S	CONT_S	Step controller for actuators with integrating behavior
S7-1500/300/400		PULSEGEN	-	Pulse generator for actuators with proportional behavior
S7-1500/300/400		TCONT_CP	TCONT_CP	Continuous temperature controller with pulse generator
S7-1500/300/400		TCONT_S	TCONT_S	Temperature controller for actuators with integrating behavior
S7-300/400	PID Self Tuner	TUN_EC	TUN_EC	Optimization of a continuous controller
S7-300/400		TUN_ES	TUN_ES	Optimization of a step controller
S7-300/400	Standard PID Con-	PID_CP	PID_CP	Continuous controller with pulse generator

CPU	Library	Instruction	Technology object	Description
S7-300/400	trol (PID Professional optional package)	PID_ES	PID_ES	Step controller for actuators with integrating behavior
S7-300/400		LP_SCHED	-	Distribute controller calls
S7-300/400	Modular PID Control (PID Professional optional package)	A_DEAD_B	-	Filter interfering signal from control deviation
S7-300/400		CRP_IN	-	Scale analog input signal
S7-300/400		CRP_OUT	-	Scale analog output signal
S7-300/400		DEAD_T	-	Delay output of input signal
S7-300/400		DEADBAND	-	Suppress small fluctuations to the process value
S7-300/400		DIF	-	Differentiate input signals over time
S7-300/400		ERR_MON		Monitor control deviation
S7-300/400		INTEG	-	Integrate input signals over time
S7-300/400		LAG1ST	-	First-order delay element
S7-300/400		LAG2ND	-	Second-order delay element
S7-300/400		LIMALARM	-	Report limit values
S7-300/400		LIMITER	-	Limiting the manipulated variable
S7-300/400		LMNGEN_C	-	Determine manipulated variable for continuous controller
S7-300/400		LMNGEN_S	-	Determine manipulated variable for step controller
S7-300/400		NONLIN	-	Linearize encoder signal
S7-300/400		NORM	-	Scale process value physically
S7-300/400		OVERRIDE	-	Switch manipulated variable from 2 PID controllers to 1 actuator
S7-300/400		PARA_CTL	-	Switch parameter sets
S7-300/400		PID	-	PID algorithm
S7-300/400		PUSLEGEN_M	-	Generate pulse for proportional actuators
S7-300/400		RMP_SOAK	-	Specify setpoint according to ramp / soak
S7-300/400		ROC_LIM	-	Limit rate of change
S7-300/400		SCALE_M	-	Scale process value
S7-300/400		SP_GEN	-	Specify setpoint manually
S7-300/400		SPLT_RAN	-	Split manipulated variable range
S7-300/400		SWITCH	-	Switch analog values
S7-300/400		LP_SCHED_M	-	Distribute controller calls

5.2 Steps for the configuration of a software controller

All SW-controllers are configured according to the same scheme:

Step	Description
1	Add technology object (Page 46)
2	Configure technology object (Page 47)
3	Call instruction in the user program (Page 48)
4	Download technology object to device (Page 49)
5	Commission software controller (Page 50)
6	Save optimized PID parameters in the project (Page 50)
7	Comparing values (Page 55)
8	Display instances of a technology object (Page 76)

5.3 Add technology objects

Add technology object in the project navigator

When a technology object is added, an instance DB is created for the instruction of this technology object. The configuration of the technology object is stored in this instance DB.

Requirement

A project with a CPU has been created.

Procedure

To add a technology object, proceed as follows:

1. Open the CPU folder in the project tree.
2. Open the "Technology objects" folder.
3. Double-click "Add new object".
   The "Add new object" dialog box opens.
4. Click on the "PID" button.
   All available PID controllers for this CPU are displayed.
5. Select the instruction for the technology object, for example, PID_Compact.
6. Enter an individual name for the technology object in the "Name" input field.
7. Select the "Manual" option if you want to change the suggested data block number of the instance DB.
8. Click "Further information" if you want to add own information to the technology object.
9. Confirm with "OK".

Result

The new technology object has been created and stored in the project tree in the "Technology objects" folder. The technology object is used if the instruction for this technology object is called in a cyclic interrupt OB.

NOTE

You can select the "Add new and open" check box at the bottom of the dialog box. This opens the configuration of the technology object after adding has been completed.

5.4 Configure technology objects

The properties of technology objects PID_Compact, PID_3Step and PID_Temp can be configured in two ways.

- In the Inspector window of the programming editor
- In the configuration editor

The properties of other technology objects for PID control can only be configured in the Configuration Editor.

Inspector window of the programming editor

In the Inspector window of the programming editor you can only configure the parameters required for operation.

The offline values of the parameters are also shown in online mode. You can only change the online values in the commissioning window.

To open the Inspector window of the technology object, follow these steps:

1. Open the "Program blocks" folder in the project tree.
2. Double-click the block (cyclic interrupt OB) in which you open the instruction of the SW controller.
   The block is opened in the work area.
3. Click on the instruction of the SW controller.
4. In the Inspector window, select the "Properties" and "Configuration" tabs consecutively.

Configuration window

For each technology object, there is a specific configuration window in which you can configure all properties.

To open the configuration window of the technology object, follow these steps:

1. Open the "Technology objects" folder in the project tree.
2. Open the technology object in the project tree.
3. Double-click the "Configuration" object.

Symbols

Icons in the area navigation of the configuration and in the Inspector window show additional details about the completeness of the configuration:

	**The configuration contains default values and is complete**. The configuration exclusively contains default values. With these default values the use of the technology object is possible without further changes.
	**The configuration contains user-defined or automatically adjusted values and is complete**. All input fields of the configuration contain valid values and at least one default setting was changed.
	**The configuration is incomplete or faulty**. At least one input field or a collapsible list contains no value or an invalid value. The corresponding field or the drop-down list box has a red background. When clicked, the roll-out error message indicates the cause of the error.

The properties of a technology object are described in detail in the section for the technology object.

5.5 Call instruction in the user program

The instruction of the software controller must be called in a cyclic interrupt OB. The sampling time of the software controller is determined by the interval between the calls in the cyclic interrupt OB.

Requirement

The cyclic interrupt OB is created and the cycle time of the cyclic interrupt OB is correctly configured.

Procedure

Proceed as follows to call the instruction in the user program:

1. Open the CPU folder in the project tree.
2. Open the "Program blocks" folder.
3. Double-click the cyclic interrupt OB.
   The block is opened in the work area.
4. Open the "Technology" group in the "Instructions" window and the "PID Control" folder.
   The folder contains all instructions for software controllers that can be configured on the CPU.
5. Select the instruction and drag it to your cyclic interrupt OB.
   The "Call options" dialog box opens.
6. Select a technology object or type the name for a new technology object from the "Name" list.

Result

If the technology object does not exist yet, it is added. The instruction is added in the cyclic interrupt OB. The technology object is assigned to this call of the instruction.

5.6 Downloading technology objects to device

A new or modified configuration of the technology object must be downloaded to the CPU for the online mode. The following characteristics apply when downloading retentive data:

- **Software (changes only)**
  - S7-1200, S7-1200 G2, S7-1500:
    Retentive data is retained.
  - S7-300/400:
    Retentive data is updated immediately. CPU does not change to STOP.
- **Download PLC program to device and reset**
  - S7-1200, S7-1200 G2, S7-1500:
    Retentive data is updated at the next change from STOP to RUN. The PLC program can only be downloaded completely.
  - S7-300/400:
    Retentive data is updated at the next change from STOP to RUN.

Downloading retentive data to an CPU S7-1200, S7-1200 G2 or S7-1500

NOTE

The download and reset of the PLC program during ongoing system operation can result in serious damages or injuries in the case of malfunctions or program errors.

Make sure that dangerous states cannot occur before you download and reset the PLC program.

Proceed as follows to download the retentive data:

1. Select the entry of the CPU in the project tree.
2. Select the command "Download and reset PLC program" from the "Online" menu.
   - If you have not established an online connection yet, the "Extended download" dialog opens. In this case, set all required parameters for the connection and click "Download".
   - If the online connection has been defined, the project data is compiled, if necessary, and the dialog "Load preview" opens. This dialog displays messages and recommends actions necessary for download.
3. Check the messages.

   As soon as download is possible, the "Download" button becomes active.
4. Click on "Download".

   The complete PLC program is downloaded and the "Load results" dialog opens. This dialog displays the status and the actions after the download.

5. If the modules are to restart immediately after the download, select the check box "Start all".
6. Close the dialog "Download results" with "Finish".

Result

The complete PLC program is downloaded to the device. Blocks that only exist online in the device are deleted. By downloading all affected blocks and by deleting any blocks in the device that are not required, you avoid inconsistencies between the blocks in the user program.

The messages under "Info > General" in the Inspector window indicate whether the download was successful.

5.7 Commissioning software controller

Procedure

To open the "Commissioning" work area of the technology object, follow these steps:

1. Open the "Technology objects" folder in the project tree.
2. Open the technology object in the project tree.
3. Double-click the "Commissioning" object.

The commissioning functions are specific for each controller and are described there.

5.8 Save optimized PID parameter in the project

The software controller is optimized in the CPU. Through this, the values in the instance-DB on the CPU no longer agree with those in the project.

To update the PID parameter in the project with the optimized PID parameters, proceed as follows:

Requirement

- An online connection to the CPU is established and the CPU is in "RUN" mode.
- The functions of the commissioning window have been enabled by means of the "Start" button.

Procedure

1. Open the CPU folder in the project tree.
2. Open the "Technology objects" folder.
3. Open a technology object.
4. Double click on "Commissioning".
5. Click on the  icon "Upload PID parameters".
6. Save the project.

Result

The currently active PID parameters are stored in the project data. When reloading the project data in the CPU, the optimized parameters are used.

5.9 Working with multi-instance objects

If a function block (FB) calls another FB, its instance data can also be saved in the instance DB of the calling FB. This type of block call is referred to as a multi-instance. The PID software controllers support this type of call and can be used as multi-instance.

Advantages

The use of multi-instances offers the following advantages:

- Good structuring possibility
- Lower number of instance DBs
- Individually configured FBs as template for a software controller than you can instantiate as often as you wish

Restrictions

When using multi-instances for PID software controllers, the following restrictions are in place compared to using a single instance:

- No support of Openness for PID multi-instance objects
- No comparison of PID multi-instance objects in a comparison editor. Comparison is only possible via the block containing the multi-instance objects.
- No technology object-specific Inspector window of the programming editor for calling the PID_Compact, PID_3Step and PID_Temp instructions

Configuration of multi-instance objects

The configuration and commissioning of PID multi-instance objects is not opened via the "Technology objects" folder in the project tree, as is the case with single-instance objects. For multi-instance objects, you can find configuration and commissioning in the "Technology objects" tab of the detail view.

To open the configuration of multi-instance objects, follow these steps:

1. Select the FB or instance DB with the multi-instance object in the project tree.
2. Click on the "Technology objects" tab in the detail view.
3. Navigate to the desired multi-instance object.
4. Open the configuration of the multi-instance object.

NOTE

The configuration editor does not offer online functionality for multi-instance objects in an FB. Instance DBs do not have this restriction.

Commissioning of multi-instance objects

To open the commissioning of multi-instance objects, follow these steps:

1. Select the instance DB with the multi-instance object in the project tree.
2. Click on the "Technology objects" tab in the detail view.
3. Navigate to the desired multi-instance object.
4. Open the commissioning of the multi-instance object.

This functionality is not available for PID multi-instance objects in FBs.

NOTE

If PID multi-instance objects are in an array, you can only navigate to these multi-instance objects in the detail view if the number of array elements does not exceed 100. For arrays with more than 100 elements, the individual PID multi-instance objects are not displayed and the editors for configuration and commissioning are not available.

Example for the use of PID multi-instance objects

To use PID multi-instance objects for your application, you can do the following:

1. Add a function block to your program.
2. Call one or multiple suitable PID controllers with the "Multi-instance" call option in this FB.
3. Add your own application-dependent functionality in the same FB, for example, pre-processing of the setpoint.
4. Select the FB in the project tree and then open the configuration editors of the PID multi-instance objects via the "Technology objects" tab of the detail view.
5. Perform the configuration, which should be identical for all instances of the FB, in the configuration editors.
6. Close the configuration editors.
7. Instantiate the FB as required in the user program so that instance DBs are created.
8. Select one of these instance DBs in the project tree and then open the configuration editors of the PID multi-instance objects via the "Technology objects" tab of the detail view.
9. Perform the configuration, which is individual for this instance DB, in the configuration editors.
10. Close the configuration editors.
11. Repeat steps 8 to 10 for the other instance DBs with PID multi-instance objects.
12. Compile the program, load it into the device and set up an online connection.
13. Select an instance DB that contains PID multi-instance objects in the project tree and then open the commissioning editors of the PID multi-instance objects via the "Technology objects" tab of the detail view.
14. Commission the PID multi-instance objects.
15. Close the commissioning editors.
16. Repeat steps 13 to 15 for the other instance DBs with PID multi-instance objects.

5.10 Comparing values

5.10.1 Comparison display and boundary conditions

The "Compare values" function provides the following options:

- Comparison of configured start values of the project with the start values in the CPU and the actual values
- Direct editing of actual values and the start values of the project
- Immediate detection and display of input errors with suggested corrections
- Backup of actual values in the project
- Transfer of start values of the project to the CPU as actual values

Icons and operator controls

The following icons and operator controls are available:

Icon	Function
	Start value in CPU is equal to the configured Start value in project
	Start value in CPU is not equal to the configured Start value in project
	The comparison of the Start value in CPU with the configured Start value in project cannot be performed
	At least one of the two comparison values has a process-related or syntax error.
	Create snapshot of monitor values and accept setpoints of this snapshot as start values
	Load start values of setpoints as actual values (initialize setpoints)
	Opens the "Compare values" dialog

Boundary conditions

The "Compare values" function is available for S7-1200, S7-1200 G2 and S7-1500 without limitations.

The following limitation applies to S7-300 and S7-400:

In monitoring mode, an S7-300/S7-400 cannot transfer the start values to the CPU. These values cannot be displayed online with "Compare values".

The actual values of the technology object are displayed and can be changed directly.

5.10.2 Comparing values

The procedure is shown in the following using "PID Parameters" as an example.

Requirements

- A project with a software controller is configured.
- The project is downloaded to the CPU.
- The configuration dialog is open in the project navigator.

Procedure

1. Open a software controller in the project navigation.
2. Double-click the "Configuration" object.
3. Navigate within the configuration window to the "PID Parameters" dialog.
4. Click the  icon to activate monitoring mode.

   The icons and operator controls (Page 54) of the "Compare values" function are shown behind the parameters.
5. To change values in the "PID parameters" dialog, select the "Enable manual input" check box.
6. Click in the input field of a parameter and enter the new parameter value.

   If the background of the input field is gray, you can only read the values, not change them.
7. Click the  icon to open the dialog for the start values.

   This dialog indicates two values of the parameter:

   – Start value in CPU: The start value in the CPU is shown in the top part.
   – Start value in the project: The configured start value in the project is shown in the bottom part.
8. Enter the desired value in the input box for the project.

Error detection

The input of incorrect values is detected. Corrections are suggested in this case.

If you enter a value with incorrect syntax, a rollout containing the corresponding error message opens below the parameter. The incorrect value is not applied.

If you enter a value that is incorrect for the process, a dialog opens containing the error message and a suggested correction:

- Click "No" to accept this suggested correction and correct your input.
- Click "OK" to apply the incorrect value.

NOTICE
Malfunction of the controller Values incorrect for the process can result in controller malfunctions.

Backing up actual values

Click the  icon to transfer the actual controller values to the start values of your configured project.

Transferring project values to the CPU

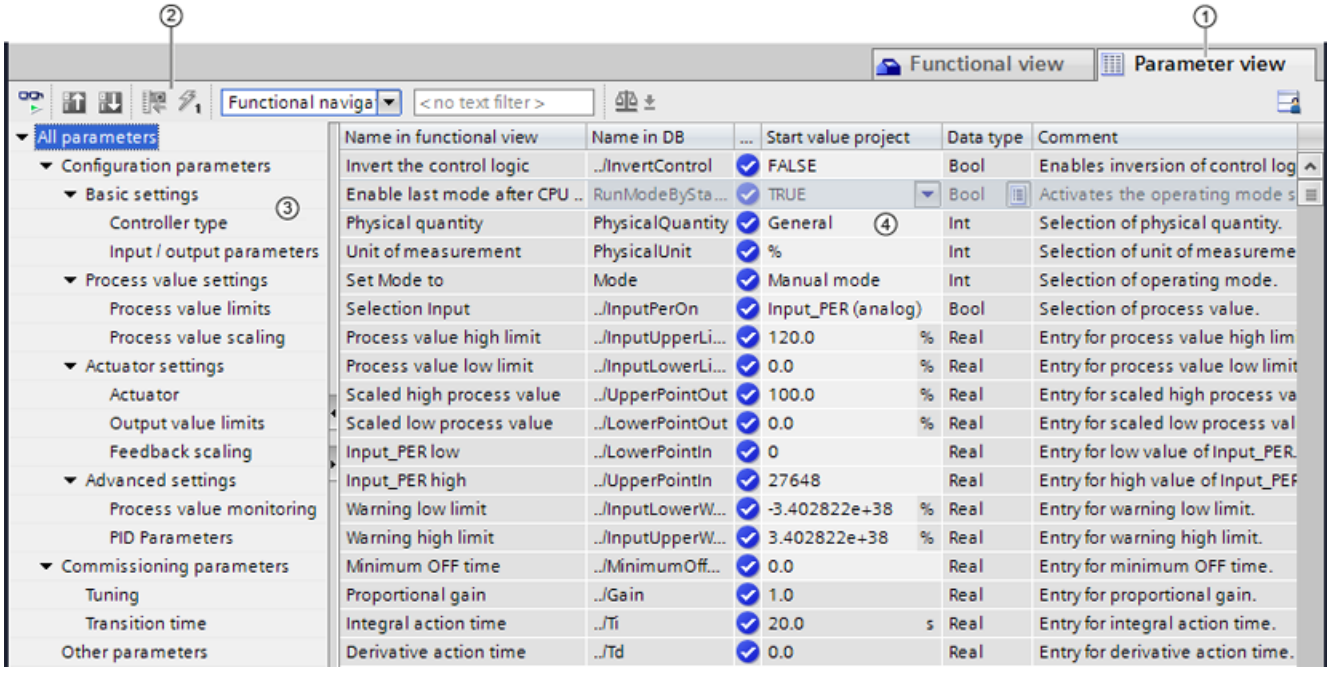
Click the  icon to transfer the configured values of your project to the CPU.

⚠ CAUTION
Prevent personal injury and property damage! Downloading and resetting of the user program while the plant is operating may result in significant property damage and severe personal injuries in the event of malfunctions or program errors. Make sure that dangerous states cannot occur before you download and reset the user program.

5.11 Parameter view

5.11.1 Introduction to the parameter view

The Parameter view provides you with a general overview of all relevant parameters of a technology object. You obtain an overview of the parameter settings and can easily change them in offline and online mode.



① "Parameter view" tab

② Toolbar (Page 59)

③ Navigation (Page 59)

④ Parameter table (Page 60)

Function scope

The following functions are available for analyzing the parameters of the technology objects and for enabling targeted monitoring and modification.

Display functions:

- Display of parameter values in offline and online mode
- Display of status information of the parameters
- Display of value deviations and option for direct correction
- Display of configuration errors
- Display of value changes as a result of parameter dependencies
- Display of all memory values of a parameter: Start value PLC, Start value project, Monitor value
- Display of the parameter comparison of the memory values of a parameter

Operator control functions:

- Navigation for quickly changing between the parameters and parameter structures.
- Text filter for faster searches for particular parameters.
- Sorting function for customizing the order of parameters and parameter groups to requirements.
- Memory function for backing up structural settings of the Parameter view.
- Monitoring and modifying of parameter values online.
- Change display format of value.
- Function for saving a snapshot of parameter values of the CPU in order to capture momentary situations and to respond to them.
- Function for applying a snapshot of parameter values as start values.
- Download of modified start values to the CPU.
- Comparison functions for comparing parameter values with one another.

Validity

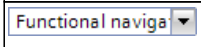
The Parameter view described here is available for the following technology objects:

- Motion Control
  - TO_Positioning_Axis_PTO (S7-1200 G2 Motion Control)
  - TO_CommandTable_PTO (S7-1200 G2 Motion Control)
  - TO_Positioning_Axis (S7-1200 Motion Control)
  - TO_CommandTable (S7-1200 Motion Control)
  - TO_Axis_PTO (S7-1200 Motion Control)
  - TO_CommandTable_PTO (S7-1200 Motion Control)
- PID
  - PID_Compact
  - PID_3Step
  - PID_Temp
  - CONT_C (S7-1500 only)
  - CONT_S (S7-1500 only)
  - TCONT_CP (S7-1500 only)
  - TCONT_S (S7-1500 only)

5.11.2 Structure of the parameter view

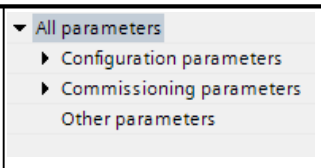
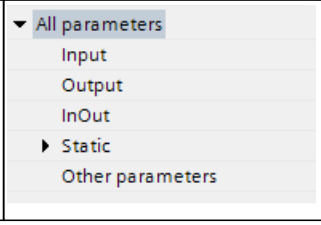
5.11.2.1 Toolbar

The following functions can be selected in the toolbar of the parameter view.

Icon	Function	Explanation
	Monitor all	Starts the monitoring of visible parameters in the active Parameter view (online mode).
	Create snapshot of monitor values and accept setpoints of this snapshot as start values	Applies the current monitor values to the “Snapshot” column and updates the start values in the project. Only in online mode for PID_Compact, PID_3Step and PID_Temp.
	Load start values of setpoints as actual values (initialize setpoints)	Transfers the start values updated in the project to the CPU. Only in online mode for PID_Compact, PID_3Step and PID_Temp.
	Create snapshot of monitor values	Applies the current monitor values to the “Snapshot” column. Only in online mode.
	Modify all selected parameters immediately and once	This command is executed once and as quickly as possible without reference to any particular point in the user program. Only in online mode.
	Select navigation structure	Toggles between functional navigation and data navigation.
	Text filter...	After entry of a character string: Display of all parameters containing the specified string in one of the currently visible columns.
	Selection of compare values	Selection of parameter values that are to be compared with one another in online mode (Start value in project, Start value in PLC, Snapshot) Only in online mode.
	Save window settings	Saves your display settings for the Parameter view (e.g., selected navigation structure, activated table columns, etc.)

5.11.2.2 Navigation

Within the "Parameter view" tab, the following alternative navigation structures can be selected.

Navigation		Explanation
Functional navigation		In the functional navigation, the structure of the parameters is based on the structure in the configuration dialog ("Functional view" tab), commissioning dialog, and diagnostics dialog. The last group "Other parameters" contains all other parameters of the technology object.
Data navigation		In the data navigation, the structure of the parameters is based on the structure in the instance DB / technology DB. The last group "Other parameters" contains the parameters that are not contained in the instance DB / technology DB.

You can use the "Select navigation structure" drop-down list to toggle the navigation structure.

5.11.2.3 Parameter table

The table below shows the meaning of the individual columns of the parameter table. You can show or hide the columns as required.

- Column "Offline" = X: Column is visible in offline mode.
- Column "Online" = X: Column is visible in online mode (online connection to the CPU).

Column	Explanation	Offline	Online
Name in functional view	Name of the parameter in the functional view. The display field is empty for parameters that are not configured via the technology object.	X	X
Full name in DB	Complete path of the parameter in the instance DB / technology DB. The display field is empty for parameters that are not contained in the instance DB / technology DB.	X	X
Name in DB	Name of the parameter in the instance DB / technology DB. If the parameter is part of a structure or UDT, the prefix ". ./" is added. The display field is empty for parameters that are not contained in the instance DB / technology DB.	X	X
Status of configuration	Display of the completeness of the configuration using status symbols. see Status of configuration (offline) (Page 68)	X	
Compare result	Result of the "Compare values" function. This column is shown if there is an online connection and the "Monitor all" button is selected.		X
Start value project	Configured start value in the project. Error indication if entered values have a syntax or process-related error.	X	X
Default value	Value that is pre-assigned to the parameter. The display field is empty for parameters that are not contained in the instance DB / technology DB.	X	X
Snapshot	Snapshot of the current values in the CPU (monitor values). Error indication if values have a process-related error.	X	X
Start value PLC	Start value in the CPU. This column is shown if there is an online connection and the "Monitor all" button is selected. Error indication if values have a process-related error.		X
Monitor value	Current value in the CPU. This column is shown if there is an online connection and the "Monitor all" button is selected. Error indication if values have a process-related error.		X
Modify value	Value that is to be used to change the monitor valuet. This column is shown if there is an online connection and the "Monitor all" button is selected. Error indication if entered values have a syntax or process-related error.		X

Column	Explanation	Offline	Online
Selection for transmission 	Selection of the Modify values that are to be transmitted using the "Modify all selected parameters immediately and once" button. This column is displayed together with the "Modify value" column.		X
Minimum value	Minimum process-related value of the parameter. If the minimum value is dependent on other parameters, it is defined: • Offline: By the Start value project. • Online: By the Monitor values.	X	X
Maximum value	Maximum process-related value of the parameter. If the maximum value is dependent on other parameters, it is defined: • Offline: By the Start value project. • Online: By the Monitor values.	X	X
Setpoint	Designates the parameter as a setpoint. These parameters can be initialized online.	X	X
Data type	Data type of the parameter. The display field is empty for parameters that are not contained in the instance DB / technology DB.	X	X
Retain	Designates the value as a retentive value. The values of retentive parameters are retained even after the voltage supply is switched off.	X	X
Accessible from HMI	Indicates whether the HMI can access this parameter during runtime.	X	X
Visible in HMI	Indicates whether the parameter is visible in the selection list of the HMI by default.	X	X
Comment	Brief description of the parameter.	X	X

See also

Comparing values (Page 54)

5.11.3 Opening the parameter view

Requirement

The technology object has been added in the project tree, i.e., the associated instance DB / technology DB of the instruction has been created.

Procedure

1. Open the "Technology objects" folder in the project tree.
2. Open the technology object in the project tree.
3. Double-click the "Configuration" object.
4. Select the "Parameter view" tab in the top right corner.

Result

The Parameter view opens. Each displayed parameter is represented by one row in the parameter table.

The displayable parameter properties (table columns) vary depending on whether you are working with the Parameter view in offline or online mode.

In addition, you can selectively display and hide individual table columns.

See also

Default setting of the parameter view (Page 62)

5.11.4 Default setting of the parameter view

Default settings

To enable you to work efficiently with the Parameter view, you can customize the parameter display and save your settings.

The following customizations are possible and can be saved:

- Show and hide columns
- Change column width
- Change order of the columns
- Toggle navigation
- Select parameter group in the navigation
- Selection of compare values

Show and hide columns

To show or hide columns in the parameter table, follow these steps:

1. Position the cursor in the header of the parameter table.
2. Select the "Show/Hide" command in the shortcut menu.
   The selection of available columns is displayed.
3. To show a column, select the check box for the column.
4. To hide a column, clear the check box for the column.

or

1. Position the cursor in the header of the parameter table.
2. Select the "Show all columns" command in the shortcut menu if all columns of the offline or online mode are to be displayed.

Some columns can only be displayed in online mode: see Parameter table (Page 60).

Change column width

To customize the width of a column so that all texts in the rows can be read, follow these steps:

1. Position the cursor in the header of the parameter table to the right of the column to be customized until the shape of the cursor changes to a cross.
2. Then double-click this location.

or

1. Open the shortcut menu on the header of the parameter table.
2. Click
   - "Optimize column width" or
   - "Optimize width of all columns".

If the column width setting is too narrow, the complete content of individual fields are shown if you hover the cursor briefly over the relevant field.

Change order of the columns

The columns of the parameter table can be arranged in any way.

To change the order of the columns, follow these steps:

1. Click on the column header and use a drag-and-drop operation to move it to the desired location.

   When you release the mouse button, the column is anchored to the new position.

Toggle navigation

To toggle the display form of the parameters, follow these steps:

1. Select the desired navigation in the “Select navigation structure” drop-down list.
   - Data navigation
   - Functional navigation

See also Navigation (Page 59).

Select parameter group in the navigation

Within the selected navigation, you choose between the “All parameters” display or the display of a subordinate parameter group of your choice.

1. Click the desired parameter group in the navigation.

   The parameter table only displays the parameters of the parameter group.

Selection of compare values (online)

To set the compare values for the “Compare values” function, follow these steps:

1. Select the desired compare values in the “Selection of compare values” drop-down list.
   - Start value project / Start value PLC
   - Start value project / Snapshot
   - Start value PLC / Snapshot

The “Start value project / Start value PLC” option is set by default.

Saving the default setting of the Parameter view

To save the above customizations of the Parameter view, follow these steps:

1. Customize the Parameter view according to your requirements.
2. Click the “Save window settings” button  at the top right of the Parameter view.

5.11.5 Working with the parameter view

5.11.5.1 Overview

The following table provides an overview of the functions of the Parameter view in online and offline mode described in the following.

- Column "Offline" = X: This function is possible in offline mode.
- Column "Online" = X: This function is possible in online mode.

Function/action	Offline	Online
Filtering the parameter table (Page 65)	X	X
Sorting the parameter table (Page 65)	X	X
Transferring parameter data to other editors (Page 66)	X	X
Indicating errors (Page 66)	X	X
Editing start values in the project (Page 67)	X	X
Status of configuration (offline) (Page 68)	X	
Monitoring values online in the parameter view (Page 69)		X
Create snapshot of monitor values (Page 71)		X
Modifying values (Page 71)		X
Comparing values (Page 73)		X
Applying values from the online program as start values (Page 74)		X
Initializing setpoints in the online program (Page 75)		X

5.11.5.2 Filtering the parameter table

You can filter the parameters in the parameter table in the following ways:

- With the text filter
- With the subgroups of the navigation

Both filter methods can be used simultaneously.

With the text filter

Texts that are visible in the parameter table can be filtered. This means only texts in displayed parameter rows and columns can be filtered.

1. Enter the desired character string for filtering in the “Text filter...” input box.

   The parameter table displays only the parameters containing the character string.

The text filtering is reset.

- When another parameter group is selected in the navigation.
- When navigation is changed from data navigation to functional navigation, or vice versa.

With the subgroups of the navigation

1. Click the desired parameter group in the navigation, e.g., "Static".

   The parameter table only shows the static parameters. You can select further subgroups for some groups of the navigation.
2. Click “All parameters” in the navigation if all parameters are to be shown again.

5.11.5.3 Sorting the parameter table

The values of the parameters are arranged in rows. The parameter table can be sorted by any displayed column.

- In columns containing numerical values, sorting is based on the magnitude of the numerical value.
- In text columns, sorting is alphabetical.

Sorting by column

1. Position the cursor in the header cell of the desired column.

   The background of this cell turns blue.
2. Click the column header.

Result

The entire parameter table is sorted by the selected column. A triangle with tip facing up appears in the column header.

Clicking the column header again changes the sorting as follows:

- Symbol "▲": Parameter table is sorted in ascending order.
- Symbol "▼": Parameter table is sorted in descending order.
- No symbol: The sorting is removed again. The parameter table assumes the default display.

The "../" prefix in the "Name in DB" column is ignored when sorting.

5.11.5.4 Transferring parameter data to other editors

After selecting an entire parameter row of the parameter table, you can use the following:

- Drag-and-drop
- <Ctrl+C>/<Ctrl+V>
- Copy/Paste via shortcut menu

Transfer parameters to the following editors of the TIA Portal:

- Program editor
- Watch table
- Signal table for trace function

The parameter is inserted with its full name: See information in "Full name in DB" column.

5.11.5.5 Indicating errors

Error indication

Parameter assignment errors that result in compilation errors (e.g. limit violation) are indicated in the Parameter view.

Every time a value is input in the Parameter view, a check is made for process-related and syntax errors and the result is indicated.

Bad values are indicated by:

- Red error symbol in the "Status of configuration" (offline mode) or "Compare result" (online mode, depending on the selected comparison type) columns

and/or

- Table field with red background

  If you click the bad field, a roll-out error message appears with information of the permissible value range or the required syntax (format)

Compilation error

From the error message of the compiler, you can directly open the Parameter view (functional navigation) containing the parameter causing the error in situations where the parameter is not displayed in the configuration dialog.

5.11.5.6 Editing start values in the project

With the Parameter view, you can edit the start values in the project in offline mode and online mode.

- You make value changes in the “Start value project” column of the parameter table.
- In the “Status of configuration” column of the parameter table, the progress of the configuration is indicated by the familiar status symbols from the configuration dialog of the technology object.

Boundary conditions

- If other parameters depend on the parameter whose start value was changed, the start value of the dependent parameters are also adapted.
- If a parameter of a technology object is not editable, it is also not editable in the parameter view. The ability to edit a parameter can also depend on the values of other parameters.

Defining new start values

To define start values for parameters in the Parameter view, follow these steps:

1. Open the Parameter view of the technology object.
2. Enter the desired start values in the "Start value project" column. The value must match the data type of the parameter and must not exceed the value range of the parameter. The limits of the value range can be seen in the “Maximum value” and “Minimum value” columns.

The "Status of configuration" column indicates the progress of the configuration with colored symbols.

See also Status of configuration (offline) (Page 68)

Following adaptation of the start values and downloading of the technology object to the CPU, the parameters take the defined value at startup if they are not declared as retentive (“Retain” column).

Error indication

When a start value is input, a check is made for process-related and syntax errors and the result is indicated.

Bad start values are indicated by:

- Red error symbol in the "Status of configuration" (offline mode) or "Compare result" (online mode, depending on the selected comparison type) columns

and/or

- Red background in the “Start value project” field
  If you click on the bad field, a roll-out error message appears with information of the permissible value range or the necessary syntax (format)

Correcting bad start values

1. Correct bad start values using information from the roll-out error message.

   Red error symbol, red field background, and roll-out error message are no longer displayed.

The project cannot be successfully compiled unless the start values are error-free.

5.11.5.7 Status of configuration (offline)

The status of the configuration is indicated by icons:

- In the “Status of configuration” column in the parameter table
- In the navigation structure of the functional navigation and data navigation

Symbol in “Status of configuration” column

Symbol	Meaning
	The start value of the parameter corresponds to the default value and is valid. A start value has not yet been defined by the user.
	The start value of the parameter contains a value defined by the user or an automatically adjusted value. The start value is different than the default value. The start value is error-free and valid.
	The start value of the parameter is invalid (syntax or process-related error). The input box has a red background. When clicked, the roll-out error message indicates the cause of the error.
	Only for S7-1200 Motion Control: The start value of the parameter is valid but contains warnings. The input box has a yellow background.
	The parameter is not relevant in the current configuration.

Symbol in the navigation

The symbols in the navigation indicate the progress of the configuration in the same way as in the configuration dialog of the technology object.

See also

Configure technology objects (Page 47)

5.11.5.8 Monitoring values online in the parameter view

You can monitor the values currently taken by the parameters of the technology object in the CPU (monitor values) directly in the Parameter view.

Requirements

- There is an online connection.
- The technology object is downloaded to the CPU.
- The program execution is active (CPU in "RUN").
- The Parameter view of the technology object is open.

Procedure

1. Start the monitoring by clicking .

   As soon as the Parameter view is online, the following columns are additionally displayed:

   – Compare result
   – Start value PLC
   – Monitor value
   – Modify value
   – Selection for transmission

   The "Monitor value" column shows the current parameter values on the CPU.

   Meaning of the additional columns: see Parameter table (Page 60)
2. Stop the monitoring by clicking  again.

Display

All columns that are only available online have an orange background:

- Values in light-orange cells can be changed.
- Values in cells with a dark orange background cannot be changed.

5.11.5.9 Change display format of value

The display format of the value can be selected via the shortcut menu of a table row in the Parameter view of the technology object.

The display format of the following values can be changed both in online mode and in offline mode:

- Start value project
- Start value PLC
- Maximum value
- Minimum value
- Snapshot
- Monitor value
- Default value
- Modify value

The set display format applies to all values of the table row.

The following display formats of the value can be changed:

- Default
- Hex
- Octal
- Bin
- Dec (+/-)
- DEC

Depending on the parameter selected in the parameter view, only the supported display formats can be selected.

Requirements

- The Parameter view of the technology object is open.

Procedure

To change the display format of the value, proceed as follows:

1. Select one or more table rows in which you want to change the display format.
2. Select the "Display format" command in the shortcut menu.
3. Select the desired display format.

NOTE

To change the display format of a certain data type in multiple table rows, sort the Parameter view by this data type. Then select the first and last table row with this data type while keeping the <Shift> key pressed and change the display format for the selected table rows.

5.11.5.10 Create snapshot of monitor values

You can back up the current values of the technology object on the CPU (monitor values) and display them in the Parameter view.

Requirements

- There is an online connection.
- The technology object is downloaded to the CPU.
- The program execution is active (CPU in "RUN").
- The Parameter view of the technology object is open.
- The “Monitor all” button is selected.

Procedure

To show the current parameter values, follow these steps:

1. In the Parameter view, click the “Create snapshot of monitor values" icon.

Result

The current monitor values are transferred once to the "Snapshot" column of the parameter table.

You can analyze the values "frozen" in this way while the monitor values continue to be updated in the "Monitor values" column.

5.11.5.11 Modifying values

With the Parameter view, you can modify values of the technology object in the CPU.

You can assign values to the parameter once (Modify value) and modify them immediately. The modify request is executed as quickly as possible without reference to any particular point in the user program.

DANGER
Danger when modifying: Changing the parameter values while the plant is operating may result in severe damage to property and personal injury in the event of malfunctions or program errors. Make sure that dangerous states cannot occur before you use the "Modify" function.

Requirements

- There is an online connection.
- The technology object is downloaded to the CPU.
- The program execution is active (CPU in "RUN").
- The Parameter view of the technology object is open.
- The “Monitor all” button is selected.
- The parameter can be modified (associated field in the "Modify value" column has a light-orange background).

Procedure

To modify parameters immediately, follow these steps:

1. Enter the desired modify values in the “Modify values” column of the parameter table.
2. Check whether the check box for modifying is selected in the "Select for transmission" column.

   The modify values and associated check boxes of dependent parameters are automatically adapted at the same time.
3. Click the “Modify all selected parameters immediately and once” icon .

The selected parameters are modified once and immediately with the specified values and can be monitored in the "Monitor values" column. The check boxes for modifying in the "Selection for transmission" column are automatically cleared after the modify request is complete.

Error indication

When a start value is input, a check is made immediately for process-related and syntax errors and the result is indicated.

Bad start values are indicated by:

- Red background in the “Modify value” field

and

- If you click the bad field, a roll-out error message appears with information of the permissible value range or the necessary syntax (format)

Bad modify values

- Modify values with process-related errors can be transmitted.
- Modify values with syntax errors **cannot** be transmitted.

5.11.5.12 Comparing values

You can use comparison functions to compare the following memory values of a parameter:

- Start value project
- Start value PLC
- Snapshot

Requirements

- There is an online connection.
- The technology object is downloaded to the CPU.
- The program execution is active (CPU in "RUN").
- The Parameter view of the technology object is open.
- The “Monitor all” button is selected.

Procedure

To compare the start values on the various target systems, follow these steps:

1. Click the "Selection of comparison values" icon .

   A selection list containing the comparison options opens:

   – Start value project - Start value PLC (default setting)
   – Start value project - Snapshot
   – Start value PLC - Snapshot

2. Select the desired comparison option.

   The selected comparison option is executed as follows:

   – A scales symbol appears in the header cells of the two columns selected for comparison.
   – Symbols are used in the "Compare result" column to indicate the result of the comparison of the selected columns.

Symbol in "Compare result" column

Symbol	Meaning
	The compare values are equal and error-free.
	The compare values are not equal and error-free.
	At least one of the two compare values has a process-related or syntax error.
	The comparison cannot be performed. At least one of the two comparison values is not available (e.g. snapshot).
	Comparison of the value is inappropriate since it is not relevant in one of the configurations.

Symbol in the navigation

The symbols are shown in the same way in the navigation if the comparison result applies to at least one of the parameters below the displayed navigation structure.

5.11.5.13 Applying values from the online program as start values

In order to apply optimized values from the CPU to the project as start values, you create a snapshot of the monitor values. Values of the snapshot marked as a "Setpoint" are then applied to the project as start values.

Requirements

- The technology object is of the type "PID_Compact", "PID_3Step" or "PID_Temp".
- There is an online connection.
- The technology object is downloaded to the CPU.
- The program execution is active (CPU in "RUN").
- The Parameter view of the technology object is open.
- The “Monitor all” button  is selected.

Procedure

To apply optimized values from the CPU, follow these steps:

1. Click the "Create snapshot of monitor values and accept setpoints of this snapshot as start values" icon .

Result

The current monitor values are applied to the "Snapshot" column and their setpoints are copied to the "Start value in project" column as new start values.

NOTE
Applying values of individual parameters
You can also apply the values of individual parameters that are not marked as a setpoint from the "Snapshot" column to the "Start values project" column. To do so, copy the values and insert them into the "Start value in project" column using the "Copy" and "Paste" commands in the shortcut menu.

5.11.5.14 Initializing setpoints in the online program

You can initialize all parameters that are marked as a "Setpoint" in the Parameter view with new values in the CPU in one step. In so doing, the start values are downloaded from the project to the CPU. The CPU remains in "RUN" mode.

To avoid data loss on the CPU during a cold restart or warm restart, you must also download the technology object to the CPU.

⚠ DANGER
Danger when changing parameter values
Changing the parameter values while the plant is operating may result in severe damage to property and personal injury in the event of malfunctions or program errors.
Make sure that dangerous states cannot occur before you reinitialize the setpoints.

Requirements

- The technology object is of the type "PID_Compact", "PID_3Step" or "PID_Temp".
- There is an online connection.
- The technology object is downloaded to the CPU.
- The program execution is active (CPU in "RUN").
- The Parameter view of the technology object is open.
- The “Monitor all” button is selected.
- The parameters marked as " have a "Start value in project" that is free of process-related and syntax errors.

Procedure

To initialize all setpoints, follow these steps:

1. Enter the desired values in the "Start value in project" column.
   Ensure that the start values are free of process-related and syntax errors.
2. Click the icon "Load start values of setpoints as actual values".

Result

The setpoints in the CPU are initialized with the start values from the project.

5.12 Display instance DB of a technology object.

An instance DB, in which the parameter and static variables are saved, is created for each technology object.

Procedure

To display the instance DB of a technology object, proceed as follows:

1. Open the CPU folder in the project tree.
2. Open the "Technology objects" folder.
3. Highlight a technology object.
4. Select the command "Open DB editor" in the shortcut menu.

Using PID_Compact

6

6.1 Technology object PID_Compact

The technology object PID_Compact provides a continuous PID controller with integrated optimization. You can alternatively configure a pulse controller. Both manual and automatic mode are possible.

PID-Compact continuously acquires the measured process value within a control loop and compares it with the required setpoint. From the resulting control deviation, the instruction PID_Compact calculates an output value by which the process value is adapted as quickly and stable as possible to the setpoint. The output value for the PID controller consists of three actions:

- **Proportional** action

  The proportional action of the output value increases in proportion to the control deviation.

- **I** action

  The integral action of the output value increases until the control deviation has been balanced.

- **D** action

  The derivative action increases with the rate of change of control deviation. The process value is corrected to the setpoint as quickly as possible. The derivative action will be reduced again if the rate of change of control deviation drops.

The instruction PID_Compact calculates the proportional, integral and derivative parameters for your controlled system during pretuning. Fine tuning can be used to tune the parameters further. You do not need to manually determine the parameters.

Additional information

- Overview of software controller (Page 44)
- Add technology objects (Page 46)
- Configure technology objects (Page 47)
- Configuring PID_Compact as of V2 (Page 78)
- Configuring PID_Compact V1 (Page 105)

FAQ

For more information, see the following FAQs in the Siemens Industry Online Support:

- Entry ID 79047707 (https://support.industry.siemens.com/cs/ww/en/view/79047707)

6.2 PID_Compact as of V2

6.2.1 Configuring PID_Compact as of V2

6.2.1.1 Basic settings as of V2

Introduction as of V2

Configure the following properties of the "PID_Compact" technology object under "Basic settings" in the Inspector window or in the configuration window:

- Physical quantity
- Control logic
- Start-up behavior after reset
- Setpoint (only in the Inspector window)
- Process value (only in the Inspector window)
- Output value (only in the Inspector window)

Setpoint, process value and output value

You can only configure the setpoint, process value and output value in the Inspector window of the programming editor. Select the source for each value:

- Instance DB

  The value saved in the instance DB is used.

  Value must be updated in the instance DB by the user program.

  There should be no value at the instruction.

  Can be changed using HMI.

- Instruction

  The value connected to the instruction is used.
  The value is written to the instance DB each time the instruction is called.

  Cannot be changed using HMI.

Control mode as of V2

Physical quantity

Select the unit of measurement and physical quantity for the setpoint and the process value in the "Controller type" group. The setpoint and the process value are displayed in this unit.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic.

PID_Compact does not work with negative proportional gain. Select the check box "Invert control logic" to reduce the process value with a higher output value.

Examples

- Opening the drain valve will reduce the level of a container's contents.
- Increasing cooling will reduce the temperature.

Startup characteristics

1. To switch to "Inactive" mode after CPU restart, clear the "Activate Mode after CPU restart" check box.

   To switch to the operating mode saved in the Mode parameter after CPU restart, select the "Activate Mode after CPU restart" check box.

2. In the "Set Mode to" drop-down list, select the mode that is to be enabled after a complete download to the device.

   After a complete download to the device, PID_Compact starts in the selected operating mode. With each additional restart, PID_Compact starts in the mode that was last saved in Mode.

Example

You have selected the "Activate Mode after CPU restart" check box and the entry "Pretuning" in the "Set Mode to" list. After a complete download to the device, PID_Compact starts in the "Pretuning" mode. If pretuning is still active, PID_Compact starts in "Pretuning" mode again after restart of the CPU. If pretuning was successfully completed and automatic mode is active, PID_Compact starts in "Automatic mode" after restart of the CPU.

Setpoint as of V2

Procedure

Proceed as follows to define a fixed setpoint:

1. Select "Instance DB".
2. Enter a setpoint, e.g. 80° C.
3. Delete any entry in the instruction.

Proceed as follows to define a variable setpoint:

1. Select "Instruction".
2. Enter the name of the REAL variable in which the setpoint is saved.

   Program-controlled assignment of various values to the REAL variable is possible, for example for the time controlled change of the setpoint.

Process value as of V2

PID_Compact will scale the value of the analog input to the physical quantity if you use the analog input value directly.

You will need to write a program for processing if you wish first to process the analog input value. The process value is, for example, not directly proportional to the value at the analog input. The processed process value must be in floating point format.

Procedure

Proceed as follows to use the analog input value without processing:

1. Select the entry "Input_PER" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the address of the analog input.

Proceed as follows to use the processed process value in floating point format:

1. Select the entry "Input" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the name of the variable in which the processed process value is saved.

Output value as of V2

PID_Compact offers three output values. Your actuator will determine which output value you use.

- Output_PER

  The actuator is triggered via an analog output and controlled with a continuous signal, e.g. 0...10V, 4...20mA.

- Output

  The output value needs to be processed by the user program, for example because of non-linear actuator response.

- Output_PWM

  The actuator is controlled via a digital output. Pulse width modulation creates minimum ON and minimum OFF times.

Procedure

Proceed as follows to use the analog output value:

1. Select the entry "Output_PER (analog)" in the drop-down list "Output".
2. Select "Instruction".
3. Enter the address of the analog output.

Proceed as follows to process the output value using the user program:

1. Select the entry "Output" in the drop-down list "Output".
2. Select "Instance DB".

   The calculated output value is saved in the instance data block.
3. For the preparation of the output value, use the output parameter Output.
4. Transfer the processed output value to the actuator via a digital or analog CPU output.

Proceed as follows to use the digital output value:

1. Select the entry "Output_PWM" in the drop-down list "Output".
2. Select "Instruction".
3. Enter the address of the digital output.

6.2.1.2 Process value settings as of V2

Scaling process value as of V2

If you have configured the use of Input_PER in the basic setting, you must convert the value of the analog input to the physical quantity of the process value. The current configuration is displayed in the Input_PER display.

Input_PER will be scaled using a low and high value pair if the process value is directly proportional to the value of the analog input.

Procedure

To scale the process value, follow these steps:

1. Enter the low pair of values in the "Scaled low process value" and "Low" input fields.
2. Enter the high pair of values in the "Scaled high process value" and "High" input boxes.

Default settings for the value pairs are stored in the hardware configuration. To use the value pairs from the hardware configuration, follow these steps:

1. Select the PID_Compact instruction in the programming editor.
2. Interconnect Input_PER with an analog input in the basic settings.
3. Click the "Automatic setting" button in the process value settings.

The existing values will be overwritten with the values from the hardware configuration.

Process value limits as of V2

You must specify an appropriate absolute high limit and low limit for the process value as limit values for your controlled system. As soon as the process value violates these limits, an error occurs (ErrorBits = 0001h). Tuning is canceled when the process value limits are violated. You can configure how PID_Compact reacts to an error in automatic mode in the output value settings.

6.2.1.3 Advanced settings as of V2

Process value monitoring as of V2

Configure a warning high and low limit for the process value in the "Process value monitoring" configuration window. If one of the warning limits is exceeded or undershot during operation, a warning will be displayed at the PID_Compact instruction:

- At the InputWarning_H output parameter if the warning high limit has been exceeded
- At the InputWarning_L output parameter if the warning low limit has been undershot

The warning limits must be within the process value high and low limits.

The process value high and low limits will be used if you do not enter values.

Example

Process value high limit = 98 °C; warning high limit = 90 °C

Warning low limit = 10 °C; process value low limit = 0 °C

PID_Compact will respond as follows:

Process value	InputWarning_H	InputWarning_L	ErrorBits	Operating mode
> 98 °C	TRUE	FALSE	0001h	Inactive or Substitute output value with error monitoring
≤ 98 °C and > 90 °C	TRUE	FALSE	0000h	Automatic mode
≤ 90 °C and ≥ 10 °C	FALSE	FALSE	0000h	Automatic mode
< 10 °C and ≥ 0 °C	FALSE	TRUE	0000h	Automatic mode
< 0 °C	FALSE	TRUE	0001h	Inactive or Substitute output value with error monitoring

In the output value settings, you can specify the reaction of PID_Compact when the process value high limit or low limit is violated.

See also

State and Mode as of V2 parameters (Page 274)

PWM limits as of V2

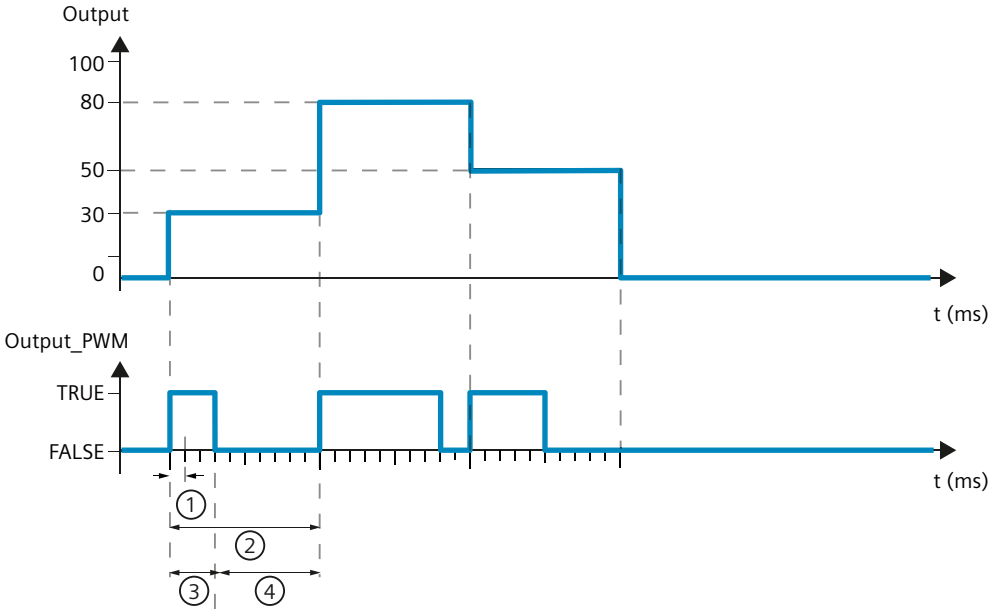
Via pulse width modulation, the value at the output parameter Output is transformed into a pulse sequence that is output at output parameter Output_PWM.

Output is calculated in the PID algorithm sampling time. The sampling time is used as time period of the pulse width modulation.

The PID algorithm sampling time is determined during pretuning or fine tuning. If manually setting the PID parameters, you will also need to configure the PID algorithm sampling time.

Output_PWM is output in the PID_Compact sampling time. The PID_Compact sampling time is equivalent to the cycle time of the calling OB.

The pulse duration is proportional to the value at Output and is always an integer multiple of the PID_Compact sampling time.



① PID_Compact sampling time

② PID algorithm sampling time

③ Pulse duration

④ Break time

The "Minimum ON time" and the "Minimum OFF time" are rounded to an integer multiple of the PID_Compact sampling time.

A pulse or a break is never shorter than the minimum ON or OFF time. The inaccuracies this causes are added up and compensated in the next cycle.

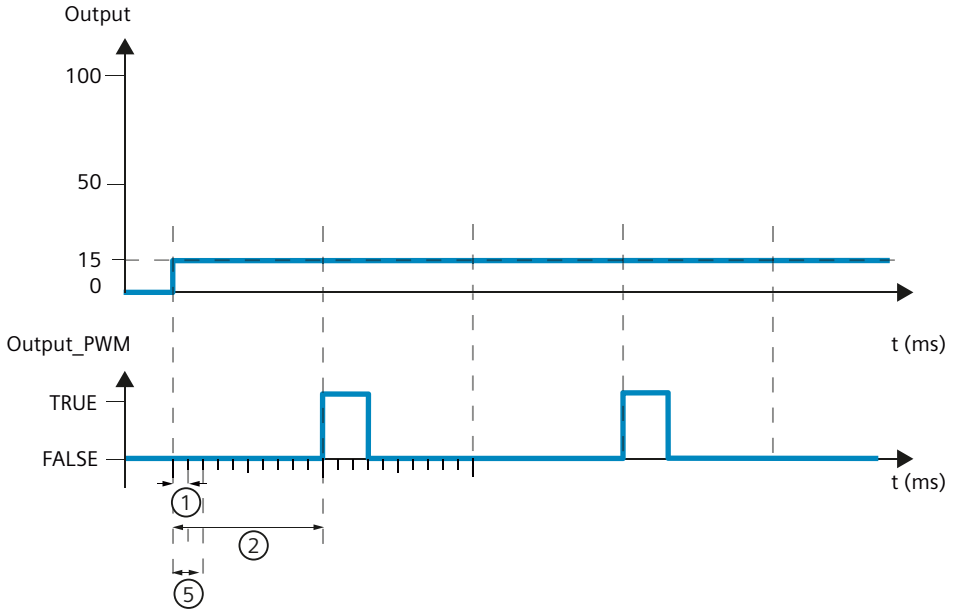
Example

PID_Compact sampling time (equivalent to the cycle time of the calling OB) = 100 ms

PID algorithm sampling time (equivalent to the time period)= 1000 ms

Minimum ON time = 200 ms

Output is a constant 15%. The smallest pulse that PID_Compact can output is 20%. In the first cycle, no pulse is output. In the second cycle, the pulse not output in the first cycle is added to the pulse of the second cycle.



① PID_Compact sampling time

② PID algorithm sampling time

⑤ Minimum ON time

In order to minimize operation frequency and conserve the actuator, extend the minimum ON and OFF times.

If you are using "Output" or "Output_PER", you must configure the value 0.0 for the minimum ON and OFF times.

NOTE

The minimum ON and OFF times only affect the output parameter Output_PWM and are not used for any pulse generators integrated in the CPU.

Output value as of V2

Output value limits

In the "Output value limits" configuration window, configure the absolute limits of your output value in percent. Absolute output value limits are not violated in neither manual mode nor automatic mode. If an output value outside the limits is specified in manual mode, the effective value is limited in the CPU to the configured limits.

The output value limits must match the control logic.

The valid output value limit values depend on the Output used.

Output	-100.0 to 100.0%
Output_PER	-100.0 to 100.0%
Output_PWM	0.0 to 100.0%

Reaction to error

NOTICE
Your system may be damaged. If you output "Current value while error pending " or "Substitute output value while error pending" in the event of an error, PID_Compact remains in automatic mode. This may cause a violation of the process value limits and damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

PID_Compact is preset so that the controller stays active in most cases in the event of an error. If errors occur frequently in controller mode, this default reaction has a negative effect on the control response. In this case, check the Errorbits parameter and eliminate the cause of the error.

PID_Compact generates a programmable output value in response to an error:

- Zero (inactive)

  PID_Compact outputs 0.0 as output value for all errors and switches to "Inactive" mode. The controller is only reactivated by a falling edge at Reset or a rising edge at ModeActivate.

- Current value while error is pending

  If the following errors occur in **automatic mode**, PID_Compact returns to automatic mode as soon as the errors are no longer pending.

  If one or more of the following errors occur, PID_Compact stays in automatic mode:

  – 0001h: The "Input" parameter is outside the process value limits.

  – 0800h: Sampling time error

  – 40000h: Invalid value at Disturbance parameter.

If one or more of the following errors occur in **automatic mode**, PID_Compact switches to "Substitute output value with error monitoring" mode and outputs the last valid output value:

- 0002h: Invalid value at Input_PER parameter.
- 0200h: Invalid value at Input parameter.
- 0400h: Calculation of output value failed.
- 1000h: Invalid value at Setpoint parameter.

If an error occurs in **manual mode**, PID_Compact continues using the manual value as the output value. If the manual value is invalid, the substitute output value is used. If the manual value and substitute output value are invalid, the output value low limit is used.

If the following error occurs during a **pretuning or fine tuning**, PID_Compact remains in active mode:

- 0020h: Pretuning is not permitted during fine tuning.

When any other error occurs, PID_Compact cancels the tuning and switches to the mode from which tuning was started.

As soon as no errors are pending, PID_Compact returns to automatic mode.

- Substitute output value while error is pending

  PID_Compact outputs the substitute output value.

  If the following error occurs, PID_Compact stays in "Substitute output value with error monitoring" mode and outputs the output value low limit:

  - 20000h: Invalid value at SubstituteOutput tag.

  For all other errors, PID_Compact reacts as described for "Current value while error is pending".

See also

State and Mode as of V2 parameters (Page 274)

PID parameters V2

The PID parameters are displayed in the "PID Parameters" configuration window. The PID parameters will be adapted to your controlled system during controller tuning. You do not need to enter the PID parameters manually.

NOTE

The currently active PID parameters are located for PID_Compact V1 in the sRet structure and as of PID_Compact V2 in the Retain.CtrlParams structure.

Change the currently active PID parameters only in "Inactive" mode online to prevent malfunction of the PID controller.

If you want to change the PID parameters in "Automatic mode" or "Manual mode" online, change the PID parameters as follows:

- PID_Compact V1: Change the PID parameters in the sBackUp structure and apply these changes with sPid_Cmpt.b_LoadBackUp = TRUE to the sRet structure.
- PID_Compact as of V2: Change the PID parameters in the CtrlParamsBackUp structure and apply these changes with LoadBackUp = TRUE to the Retain.CtrlParams structure.

Online changes to the PID parameters in "Automatic mode" can result in jumps at the output value.

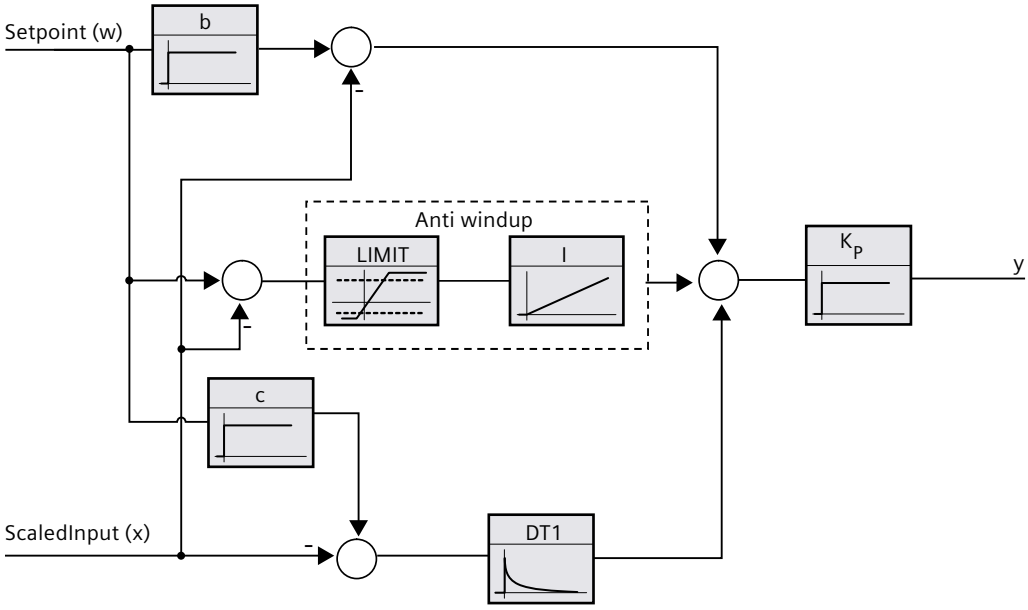
The PID algorithm operates according to the following transfer function:

$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
y	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (derivative delay T1 = a × T_D)
c	Derivative action weighting

The diagram below illustrates the integration of the parameters into the PID algorithm:



All PID parameters are retentive. If you enter the PID parameters manually, you must completely download PID_Compact.

Downloading technology objects to device (Page 49)

Proportional gain

The value specifies the proportional gain of the controller. PID_Compact does not work with a negative proportional gain. Control logic is inverted under Basic settings > Controller type.

Integration time

The integration time determines the time response of the integral action. The integral action is deactivated with integration time = 0.0. When the integration time is changed from a different value to 0.0 online in "Automatic mode", the previous integral action is deleted and the output value jumps.

Derivative action time

The derivative action time determines the time response of the derivative action. Derivative action is deactivated with derivative action time = 0.0.

Derivative delay coefficient

The derivative delay coefficient delays the effect of the derivative action.

Derivative delay = derivative action time × derivative delay coefficient

- 0.0: Derivative action is effective for one cycle only and therefore almost not effective.
- 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant.
- > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed.

Proportional action weighting

The proportional action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Proportional action for setpoint change is fully effective
- 0.0: Proportional action for setpoint change is not effective

The proportional action is always fully effective when the process value is changed.

Derivative action weighting

The derivative action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Derivative action is fully effective upon setpoint change
- 0.0: Derivative action is not effective upon setpoint change

The derivative action is always fully effective when the process value is changed.

PID algorithm sampling time

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_Compact are executed at every call.

If you use Output_PWM, the sampling time of the PID algorithm is used as the period duration of the pulse width modulation. The accuracy of the output signal is determined by the ratio of the PID algorithm sampling time to the cycle time of the OB. It is therefore recommended that the cycle time is a maximum of one tenth of the PID algorithm sampling time.

Rule for tuning

Select whether PI or PID parameters are to be calculated in the "Controller structure" drop-down list.

- **PID**

  Calculates PID parameters during pretuning and fine tuning.

- **PI**

  Calculates PI parameters during pretuning and fine tuning.

- **User-defined**

  The drop-down list displays "User-defined" if you have configured different controller structures for pretuning and fine tuning via a user program.

PID parameters V3

The PID parameters are displayed in the "PID Parameters" configuration window. During tuning, the PID parameters are adapted to the controlled system with the exception of the dead zone width that has to be configured manually.

NOTE

The currently active PID parameters are located in the Retain.CtrlParams structure.

Change the currently active PID parameters only in "Inactive" mode online to prevent malfunction of the PID controller.

If you want to change the PID parameters in "Automatic mode" or "Manual mode" online, change the PID parameters in the CtrlParamsBackUp structure and apply these changes with LoadBackUp = TRUE to the Retain.CtrlParams structure.

Online changes to the PID parameters in "Automatic mode" can result in jumps at the output value.

PID_Compact is a PIDT1 controller with Anti-Windup and weighting of the proportional and derivative actions.

The PID algorithm operates according to the following equation (dead zone deactivated):

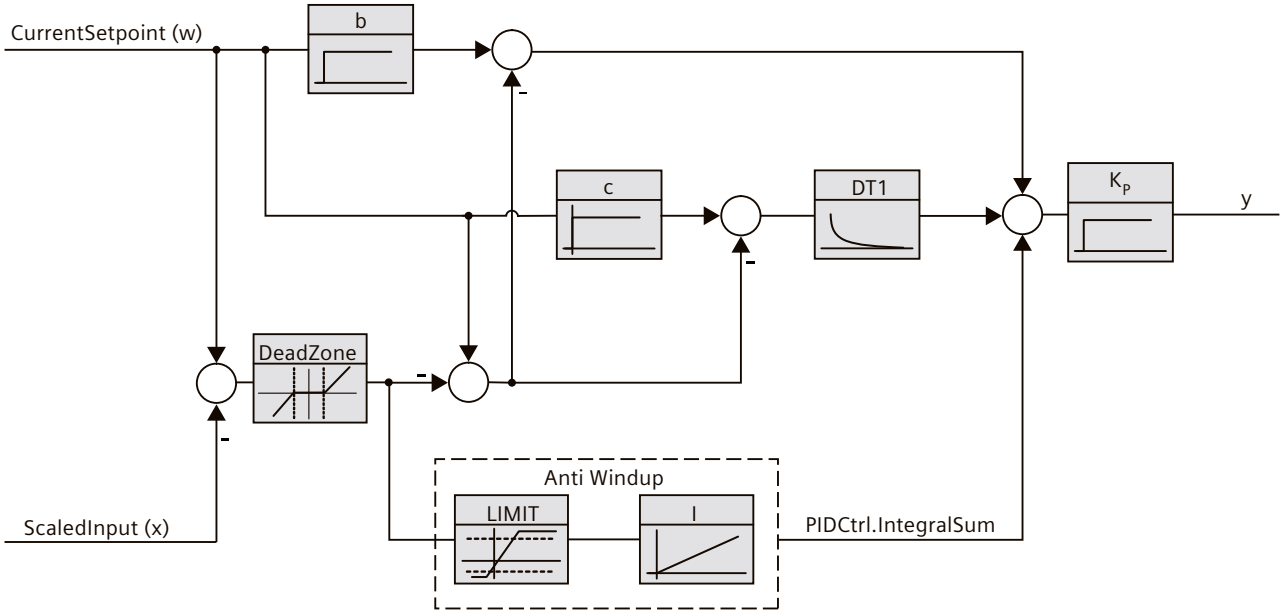
$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description	Associated parameters of the PID_Compact instruction
y	Output value of the PID algorithm	-
K_p	Proportional gain	Retain.CtrlParams.Gain
s	Laplace operator	-
b	Proportional action weighting	Retain.CtrlParams.PWeighting
w	Setpoint	CurrentSetpoint
x	Process value	ScaledInput

Icon	Description	Associated parameters of the PID_Compact instruction
T_I	Integration time	Retain.CtrlParams.Ti
T_D	Derivative action time	Retain.CtrlParams.Td
a	Derivative delay coefficient (derivative delay T1 = a × T_D)	Retain.CtrlParams.TdFiltRatio
c	Derivative action weighting	Retain.CtrlParams.DWeighting
DeadZone	Dead zone width	Retain.CtrlParams.DeadZone

The diagram below illustrates the integration of the parameters into the PID algorithm:



All PID parameters are retentive. If you enter the PID parameters manually, you must completely download PID_Compact.

Download technology objects to device

Proportional gain

The value specifies the proportional gain of the controller. PID_Compact does not work with a negative proportional gain. Control logic is inverted under Basic settings > Controller type.

Integration time

The integration time determines the time response of the integral action. The integral action is deactivated with integration time = 0.0. When the integration time is changed from a different value to 0.0 online in "Automatic mode", the previous integral action is deleted and the output value jumps.

If the output value reaches an output value limit in automatic mode, the integral action is stopped depending on the direction (Anti-Windup). As of PID_Compact Version 3.0, the integral component is also actively limited in order to prevent delayed control behavior, e.g. when the output value limits change. Changes to the following tags can lead to an adjustment of the integral component in automatic mode:

- Output value limits (Config.OutputLowerLimit and Config.OutputUpperLimit tags)
- Setpoint (Setpoint tag)
- Proportional gain (Retain.CtrlParams.Gain tag)
- Proportional action weighting (Retain.CtrlParams.PWeighting tag)
- Disturbance variable (Disturbance variable)

Derivative action time

The derivative action time determines the time response of the derivative action. Derivative action is deactivated with derivative action time = 0.0.

Derivative delay coefficient

The derivative delay coefficient delays the effect of the derivative action.

Derivative delay = derivative action time × derivative delay coefficient

- 0.0: Derivative action is effective for one cycle only and therefore almost not effective.
- 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant.
- > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed.

Proportional action weighting

The proportional action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Proportional action for setpoint change is fully effective
- 0.0: Proportional action for setpoint change is not effective

The proportional action is always fully effective when the process value is changed.

Derivative action weighting

The derivative action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Derivative action is fully effective upon setpoint change
- 0.0: Derivative action is not effective upon setpoint change

The derivative action is always fully effective when the process value is changed.

PID algorithm sampling time

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_Compact are executed at every call.

If you use Output_PWM, the sampling time of the PID algorithm is used as the period duration of the pulse width modulation. The accuracy of the output signal is determined by the ratio of the PID algorithm sampling time to the cycle time of the OB. It is therefore recommended that the cycle time is a maximum of one tenth of the PID algorithm sampling time.

Dead zone width

If the process value is affected by noise, the noise can also have an effect on the output value. The output value may fluctuate considerably when the controller gain is high and the derivative action is activated. If the process value lies within the dead zone around the setpoint, the control deviation is suppressed so that the PID algorithm does not react and unnecessary fluctuations of the output value are reduced.

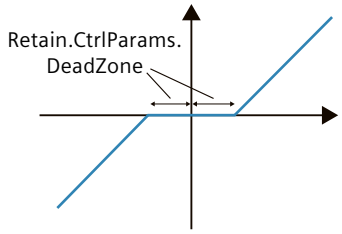
The dead zone width is not set automatically during tuning. You must correctly configure the dead zone width manually. The dead zone is deactivated by setting the dead zone width = 0.0.

When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning.

If values other than 1.0 are configured for the proportional action weighting or the derivative action weighting, setpoint changes even within the dead zone affect the output value.

Process value changes within the dead zone do not affect the output value, regardless of the weighting.

The diagram below illustrates the effect of the dead zone: The X / horizontal axis shows the control deviation = Setpoint - Process value. The Y / vertical axis shows the output signal of the dead zone that is passed to the PID algorithm.



Rule for tuning

Select whether PI or PID parameters are to be calculated in the "Controller structure" drop-down list.

- **PID**

  Calculates PID parameters during pretuning and fine tuning.

- **PI**

  Calculates PI parameters during pretuning and fine tuning.

- **User-defined**

  The drop-down list displays "User-defined" if you have configured different controller structures for pretuning and fine tuning via a user program.

See also

Selection of the controller structure for specified controlled systems (Page 42)

6.2.2 Commissioning PID_Compact as of V2

6.2.2.1 Pretuning as of V2

The pretuning determines the process response to a jump change of the output value and searches for the point of inflection. The PID parameters are calculated from the maximum rate of rise and dead time of the controlled system. You obtain the best PID parameters when you perform pretuning and fine tuning.

The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. This is most likely the case in operating modes "Inactive" and "manual mode". The PID parameters are backed up before being recalculated.

Requirement

- The "PID_Compact" instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- PID_Compact is in one of the following modes: "Inactive", "Manual mode", or "Automatic mode".
- The setpoint and the process value lie within the configured limits (see "Process value monitoring" configuration).
- The difference between setpoint and process value is greater than 30% of the difference between process value high limit and process value low limit.
- The distance between the setpoint and the process value is > 50% of the setpoint.

Procedure

To perform pretuning, follow these steps:

1. Double-click the "PID_Compact > Commissioning" entry in the project tree.
2. Select the entry "Pretuning" in the "Tuning mode" drop-down list.
3. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - Pretuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon when the progress bar has reached 100% and it can be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If pretuning was performed without an error message, the PID parameters have been tuned. PID_Compact switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If pretuning is not possible, PID_Compact responds with the configured reaction to errors.

See also

State and Mode as of V2 parameters (Page 274)

6.2.2.2 Fine tuning as of V2

Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are tuned for the operating point from the amplitude and frequency of this oscillation. All PID parameters are recalculated from the results. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. You obtain the best PID parameters when you perform pretuning and fine tuning.

PID_Compact automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The PID parameters are backed up before being recalculated.

Requirement

- The PID_Compact instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- The setpoint and the process value lie within the configured limits.
- The control loop has stabilized at the operating point. The operating point is reached when the process value corresponds to the setpoint.
- No disturbances are expected.
- PID_Compact is in inactive mode, automatic mode or manual mode.

Process depends on initial situation

Fine tuning can be started from the following operating modes: "Inactive", "automatic mode", or "manual mode". Fine tuning proceeds as follows when started from:

- Automatic mode

  Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning.

  PID_Compact controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

- Inactive or manual mode

  If the requirements for pretuning are met, pretuning is started. The determined PID parameters will be used for control until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. If pretuning is not possible, PID_Compact responds with the configured responses in the event of an error.

  An attempt is made to reach the setpoint with the minimum or maximum output value if the process value for pretuning is already too near the setpoint. This can produce increased overshoot.

Procedure

To perform fine tuning, follow these steps:

1. Select the entry "Fine tuning" in the "Tuning mode" drop-down list.
2. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - The process of fine tuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon in the "Tuning mode" group when the progress bar has reached 100% and it is to be assumed that tuning is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If fine tuning was performed without errors, the PID parameters have been tuned. PID_Compact switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If errors occurred during "fine tuning", PID_Compact responds with the configured response to errors.

See also

State and Mode as of V2 parameters (Page 274)

6.2.2.3 "Manual" mode as of V2

The following section describes how you can use the "manual mode" operating mode in the commissioning window of the "PID_Compact" technology object. Manual mode is also possible when an error is pending.

Requirement

- The "PID_Compact" instruction is called in a cyclic interrupt OB.
- An online connection to the CPU has been established and the CPU is in "RUN" mode.

Procedure

Use "Manual mode" in the commissioning window if you want to test the controlled system by specifying a manual value. To define a manual value, proceed as follows:

1. Click the "Start" icon.
2. Select the "Manual mode" check box in the "Online status of controller" area.

   PID_Compact operates in manual mode. The most recent current output value remains in effect.
3. Enter the manual value in the "Output" field as a % value.
4. Click the  icon.

Result

The manual value is written to the CPU and immediately goes into effect.

Clear the "Manual mode" check box if the output value is to be specified again by the PID controller. The switchover to automatic mode is bumpless.

See also

State and Mode as of V2 parameters (Page 274)

6.2.3 Override control with PID_Compact as of V2

Override control

In case of override control, two or more controllers share one actuator. Only one controller has access to the actuator at any time and influences the process.

A logic operation decides which controller has access to the actuator. This decision is often made based on a comparison of the output values of all controllers, for example, in case of a maximum selection, the controller with the largest output value gets access to the actuator.

The selection based on the output value requires that all controllers operate in automatic mode. The controllers that do not have an effect on the actuator are updated. This is necessary to prevent windup effects and their negative impacts on the control response and the switchover between the controllers.

PID_Compact supports override controls as of version 2.3 by offering a simple process for updating the controllers that are not active:

- By using the OverwriteInitialOutputValue and PIDCtrl.PIDInit tags, you can preassign the integral action of the controller in automatic mode as though the PID algorithm had calculated Output = OverwriteInititalOutputValue for the output value in the last cycle.
- To do this, OverwriteInitialOutputValue is interconnected with the output value of the controller that currently has access to the actuator.
- By setting the bit PIDCtrl.PIDInit, you trigger the preassignment of the integral action as well as the restart of the controller cycle and the PWM period.
- The subsequent calculation of the output value in the current cycle takes place based on the preassigned (and synchronized for all controllers) integral action as well as the proportional action and integral action from the current control deviation.
- The derivative action is not active during the call with PIDCtrl.PIDInit = TRUE and therefore does not contribute to the output value.

This procedure ensures that the calculation of the current output value and thus the decision on which controller is to have access to the actuator is only based on the current process state and the PI parameters. Windup effects for controllers that are not active and thus incorrect decisions of the switchover logic are prevented.

Requirements

- PIDCtrl.PIDInit only takes effect if the integral action is activated (Retain.CtrlParams.Ti tag > 0.0).
- You must assign PIDCtrl.PIDInit and OverwriteInitialOutputValue in your user program yourself (see example below). PID_Compact does not automatically change these tags.
- PIDCtrl.PIDInit only takes effect when PID_Compact is in automatic mode (parameter State = 3)
- If possible, select the sampling time of the PID algorithm (Retain.CtrlParams.Cycle tag) in such a way that it is identical for all controllers, and call all controllers in the same cyclic interrupt OB. In this way, you ensure that the switchover does not take place within a controller cycle or a PWM period.

NOTE

Constant adaptation of the output value limits

Instead of the active updating of the controllers without access to the actuator described here, this is implemented alternatively by constant adaptation of the output value limits in other controller systems.

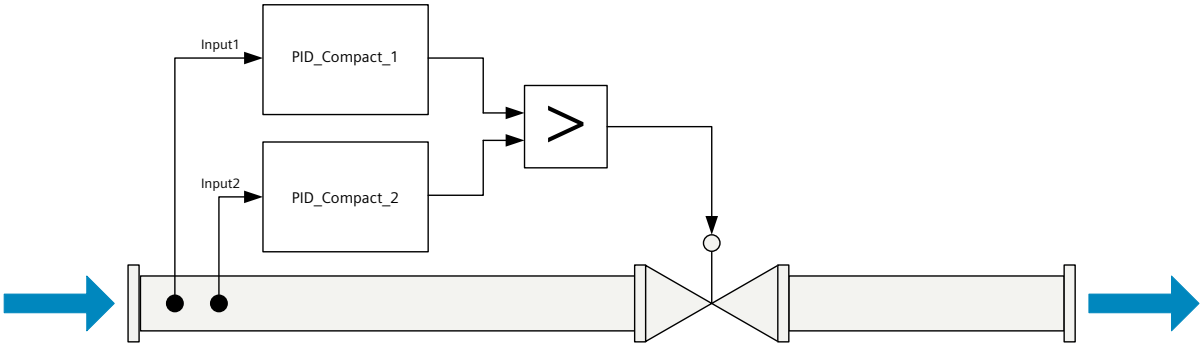
This is not possible with PID_Compact, because a change of the output value limits is not supported in automatic mode.

Example: Control of a gas pipeline

PID_Compact is used for control of a gas pipeline.

The main goal is to control the flow rate Input1. The controller PID_Compact_1 is used for this purpose. In addition, the pressure Input2 (measured in flow direction in front of the valve) is to be kept below the high limit with the limiting controller PID_Compact_2.

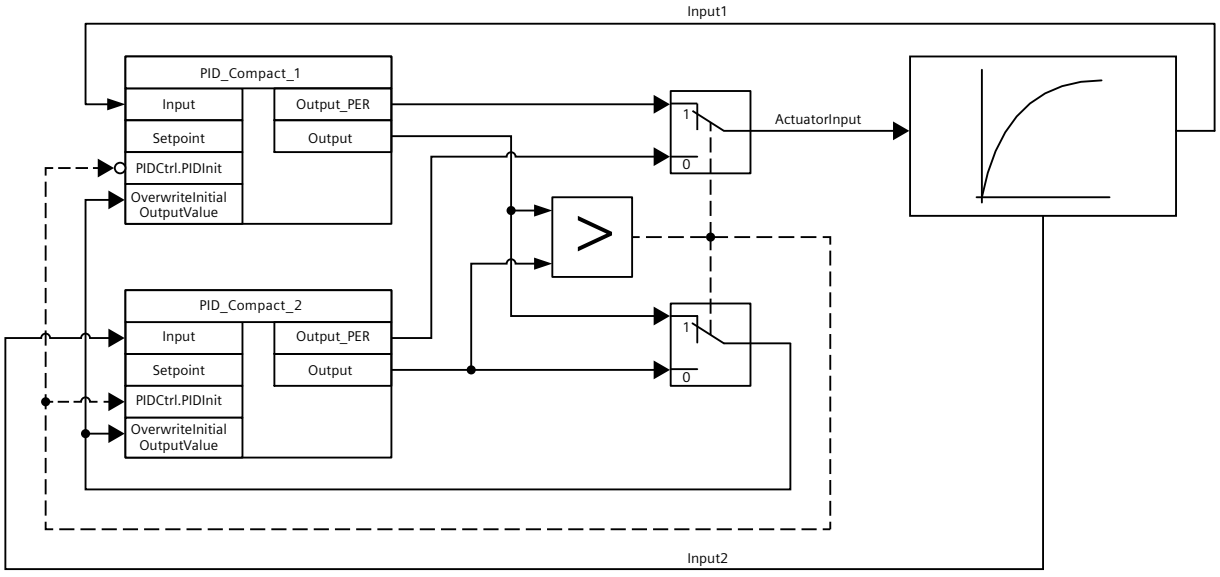
Flow rate and pressure are controlled by a single solenoid valve. The output value of the controller corresponds to the valve opening: The valve is opened when the output value increases. This means the flow rate increases (normal control logic) while the pressure drops (inverted control logic).



The valve is controlled with the output value of PID_Compact in I/O format (parameter Output_PER) by writing the program tag ActuatorInput.

The setpoint for the flow rate is specified at the parameter PID_Compact_1.Setpoint.

The pressure high limit is specified as setpoint at the parameter PID_Compact_2.Setpoint.



Both controllers must share one valve as shared actuator. The logic that decides which controller gets access to the actuator is implemented by a maximum selection of the output value (in Real format, parameter Output) in this case. Because the output value corresponds to the opening of the valve, the controller that requires the larger valve opening gets the control.

NOTE

Activate inversion of the control logic

Because a decrease of the process value (pressure) is to be achieved with the pressure regulator PID_Compact_2 when the output value increases (valve opening), the inversion of the control logic must be activated: PID_Compact_2.Config.InvertControl = TRUE.

In normal operation of the plant, the process value of the flow rate corresponds to the setpoint. The flow controller PID_Compact_1 has settled on a stationary output value PID_Compact_1.Output. The process value of the pressure in normal operation is significantly below the high limit that is specified as setpoint for PID_Compact_2. The pressure regulator therefore wants to close the valve even further to increase the pressure, which means it will calculate an output value PID_Compact_2.Output that is less than the output value of the flow controller PID_Compact_1.Output. The maximum selection of the switchover logic therefore gives the flow controller PID_Compact_1 continued access to the actuator. In addition, it is ensured that PID_Compact_2 is updated by means of the assignments PID_Compact_2.OverwriteInitialOutputValue = PID_Compact_1.Output and PID_Compact_2.PIDCtrl.PIDInit = TRUE.

If the pressure now approaches the high limit or exceeds it, for example due to a fault, the pressure regulator PID_Compact_2 calculates a higher output value to open the valve even further and thus reduce the pressure. If PID_Compact_2.Output is greater than PID_Compact_1.Output, the pressure regulator PID_Compact_2 receives access to the actuator through the maximum selection and opens it. It is ensured that PID_Compact_1 is updated by means of the assignments PID_Compact_1.OverwriteInitialOutputValue = PID_Compact_2.Output and PID_Compact_1.PIDCtrl.PIDInit = TRUE.

The pressure is reduced while the flow rate increases and can no longer be kept at the setpoint.

Once the fault has been remedied, the pressure will continue to drop and the opening of the valve is reduced by the pressure regulator. If the flow controller calculates a larger opening as output value, the plant returns to normal operation so that the flow controller PID_Compact_1 once again has access to the actuator.

This example can be implemented with the following SCL program code:

```
"PID_Compact_1"(Input := "Input1");
"PID_Compact_2"(Input := "Input2");
IF "PID_Compact_1".Output >= "PID_Compact_2".Output THEN
  "ActuatorInput" := "PID_Compact_1".Output_PER;
  "PID_Compact_1".PIDCtrl.PIDInit := FALSE;
  "PID_Compact_2".PIDCtrl.PIDInit := TRUE;
  "PID_Compact_2".OverwriteInitialOutputValue :=
  "PID_Compact_1".Output;
ELSE
  "ActuatorInput" := "PID_Compact_2".Output_PER;
  "PID_Compact_1".PIDCtrl.PIDInit := TRUE;
  "PID_Compact_2".PIDCtrl.PIDInit := FALSE;
  "PID_Compact_1".OverwriteInitialOutputValue :=
  "PID_Compact_2".Output;
END_IF;
```

6.2.4 Simulating PID_Compact as of V2 with PLCSIM

NOTE

Simulation with PLCSIM

The simulation of PID_Compact V2.x with PLCSIM for CPU S7-1200 is not supported.

PID_Compact as of V2 can be simulated only for CPU S7-1500 and CPU S7-1200 G2 with PLCSIM.

For the simulation with PLCSIM, the time behavior of the simulated PLC is not exactly identical to that of a "real" PLC. The actual cycle clock of a cyclic interrupt OB can have larger fluctuations with a simulated PLC than with "real" PLCs.

In the standard configuration, PID_Compact determines the time between calls automatically and monitors them for fluctuations.

For the simulation of PID_Compact with PLCSIM, for example, a sampling time error (ErrorBits = DW#16#00000800) can therefore be detected.

This results in ongoing tuning being aborted.

The response in automatic mode depends on the value of the ActivateRecoverMode tag.

To prevent this from happening, you should configure PID_Compact for simulation with PLCSIM as follows:

- CycleTime.EnEstimation = FALSE
- CycleTime.EnMonitoring = FALSE
- CycleTime.Value: Assign the cycle clock of the calling cyclic interrupt OB in seconds to this tag.

6.3 PID_Compact V1

6.3.1 Configuring PID_Compact V1

6.3.1.1 Basic settings V1

Introduction V1

Configure the following properties of the "PID_Compact" technology object under "Basic settings" in the Inspector window or in the configuration window:

- Physical quantity
- Control logic
- Start-up behavior after reset
- Setpoint (only in the Inspector window)
- Process value (only in the Inspector window)
- Output value (only in the Inspector window)

Setpoint, process value and output value

You can only configure the setpoint, process value and output value in the Inspector window of the programming editor. Select the source for each value:

- Instance DB

  The value saved in the instance DB is used.

  Value must be updated in the instance DB by the user program.

  There should be no value at the instruction.

  Change via HMI possible.

- Instruction

  The value connected to the instruction is used.
  The value is written to the instance DB each time the instruction is called.

  No change via HMI possible.

Control mode V1

Physical quantity

Select the unit of measurement and physical quantity for the setpoint and process value in the "Controller type" group. The setpoint and process value will be displayed in this unit.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic.

PID_Compact does not work with negative proportional gain. Select the check box "Invert control logic" to reduce the process value with a higher output value.

Examples

- Opening the drain valve will reduce the level of a container's contents.
- Increasing cooling will reduce the temperature.

Start-up behavior after reset

To change straight to the last active operating mode after restarting the CPU, select the "Enable last mode after CPU restart" check box.

PID_Compact will remain in "Inactive" mode if the check box is cleared.

Setpoint V1

Procedure

Proceed as follows to define a fixed setpoint:

1. Select "Instance DB".
2. Enter a setpoint, e.g. 80° C.
3. Delete any entry in the instruction.

Proceed as follows to define a variable setpoint:

1. Select "Instruction".
2. Enter the name of the REAL variable in which the setpoint is saved.

   Program-controlled assignment of various values to the REAL variable is possible, for example for the time controlled change of the setpoint.

Process value V1

PID_Compact will scale the value of the analog input to the physical quantity if you use the analog input value directly.

You will need to write a program for processing if you wish first to process the analog input value. The process value is, for example, not directly proportional to the value at the analog input. The processed process value must be in floating point format.

Procedure

Proceed as follows to use the analog input value without processing:

1. Select the entry "Input_PER" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the address of the analog input.

Proceed as follows to use the processed process value in floating point format:

1. Select the entry "Input" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the name of the variable in which the processed process value is saved.

Output value V1

PID_Compact offers three output values. Your actuator will determine which output value you use.

- Output_PER

  The actuator is triggered via an analog output and controlled with a continuous signal, e.g. 0...10V, 4...20mA.

- Output

  The output value needs to be processed by the user program, for example because of non-linear actuator response.

- Output_PWM

  The actuator is controlled via a digital output. Pulse width modulation creates minimum ON and minimum OFF times.

Procedure

Proceed as follows to use the analog output value:

1. Select the entry "Output_PER (analog)" in the drop-down list "Output".
2. Select "Instruction".
3. Enter the address of the analog output.

Proceed as follows to process the output value using the user program:

1. Select the entry "Output" in the drop-down list "Output".
2. Select "Instance DB".
   The calculated output value is saved in the instance data block.
3. For the preparation of the output value, use the output parameter Output.
4. Transfer the processed output value to the actuator via a digital or analog CPU output.

Proceed as follows to use the digital output value:

1. Select the entry "Output_PWM" in the drop-down list "Output".
2. Select "Instruction".
3. Enter the address of the digital output.

6.3.1.2 Process value settings V1

Configure the scaling of your process value and specify the process value absolute limits In the "Process value settings" configuration window.

Scaling the process value

If you have configured the use of Input_PER in the basic settings, you will need to convert the value of the analog input into the physical quantity of the process value. The current configuration will be displayed in the Input_PER display.

Input_PER will be scaled using a low and high value pair if the process value is directly proportional to the value of the analog input.

1. Enter the low pair of values in the "Scaled low process value" and "Low" input fields.
2. Enter the high pair of values in the "Scaled high process value" and "High" input boxes.

Default settings for the value pairs are saved in the hardware configuration. Proceed as follows to use the value pairs from the hardware configuration:

1. Select the instruction PID_Compact in the programming editor.
2. Connect Input_PER with an analog input in the basic settings.
3. Click on the "Automatic setting" button in the process value settings.

The existing values will be overwritten with the values from the hardware configuration.

Monitoring process value

Specify the absolute high and low limit of the process value. As soon as these limits are violated during operation, the controller switches off and the output value is set to 0%. You must enter reasonable limits for your controlled system. Reasonable limits are important during optimization to obtain optimal PID parameters.

The default for the "High limit process value" is 120 %. At the I/O input, the process value can be a maximum of 18% higher than the standard range (overrange). An error is no longer reported for a violation of the "High limit process value". Only a wire-break and a short-circuit are recognized and the PID_Compact switches to "Inactive" mode.

WARNING
If you set very high process value limits (for example -3.4*10^{38}...+3.4*10^{38}), process value monitoring will be disabled. Your system may then be damaged if an error occurs.

See also

Process value monitoring V1 (Page 109)
PWM limits V1 (Page 110)
Output value limits V1 (Page 112)
PID parameters V1 (Page 112)

6.3.1.3 Advanced settings V1

Process value monitoring V1

Configure a warning high and low limit for the process value in the "Process value monitoring" configuration window. If one of the warning limits is exceeded or undershot during operation, a warning will be displayed at the PID_Compact instruction:

- At the InputWarning_H output parameter if the warning high limit has been exceeded
- At the InputWarning_L output parameter if the warning low limit has been undershot

The warning limits must be within the process value high and low limits.

The process value high and low limits will be used if you do not enter values.

Example

Process value high limit = 98° C; warning high limit = 90° C

Warning low limit = 10° C; process value low limit = 0° C

PID_Compact will respond as follows:

Process value	InputWarning_H	InputWarning_L	Operating mode
> 98° C	TRUE	FALSE	Inactive
≤ 98° C and > 90° C	TRUE	FALSE	Automatic mode
≤ 90° C and ≥ 10° C	FALSE	FALSE	Automatic mode
< 10° C and ≥ 0° C	FALSE	TRUE	Automatic mode
< 0° C	FALSE	TRUE	Inactive

See also

Process value settings V1 (Page 108)
PWM limits V1 (Page 110)
Output value limits V1 (Page 112)
PID parameters V1 (Page 112)

PWM limits V1

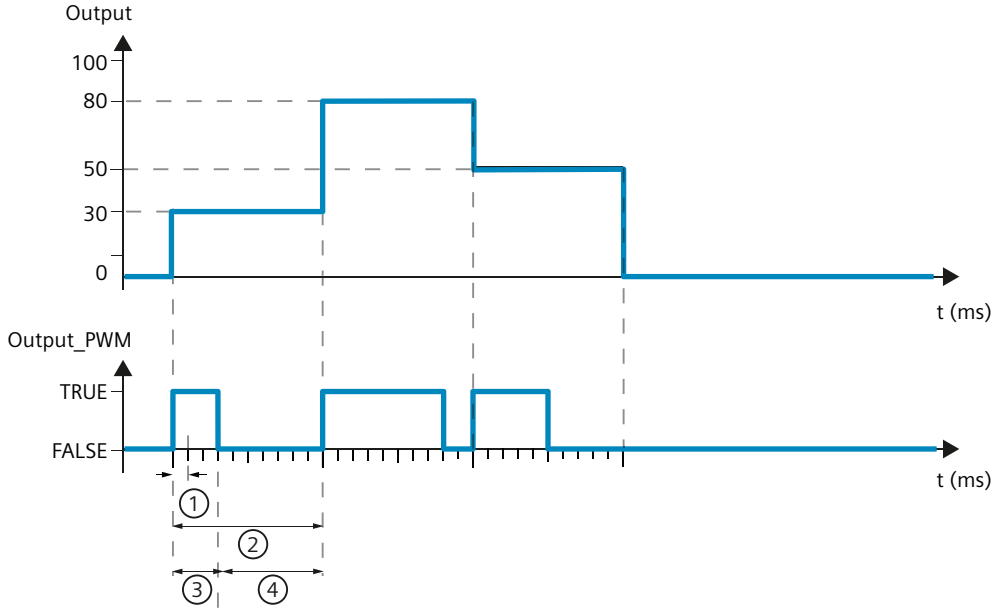
Via pulse width modulation, the value at the output parameter Output is transformed into a pulse sequence that is output at output parameter Output_PWM.

Output is calculated in the PID algorithm sampling time. The sampling time is used as time period of the pulse width modulation.

The PID algorithm sampling time is determined during pretuning or fine tuning. If manually setting the PID parameters, you will also need to configure the PID algorithm sampling time.

Output_PWM is output in the PID_Compact sampling time. The PID_Compact sampling time is equivalent to the cycle time of the calling OB.

The pulse duration is proportional to the value at Output and is always an integer multiple of the PID_Compact sampling time.



① PID_Compact sampling time
② PID algorithm sampling time
③ Pulse duration
④ Break time

The "Minimum ON time" and the "Minimum OFF time" are rounded to an integer multiple of the PID_Compact sampling time.

A pulse or a break is never shorter than the minimum ON or OFF time. The inaccuracies this causes are added up and compensated in the next cycle.

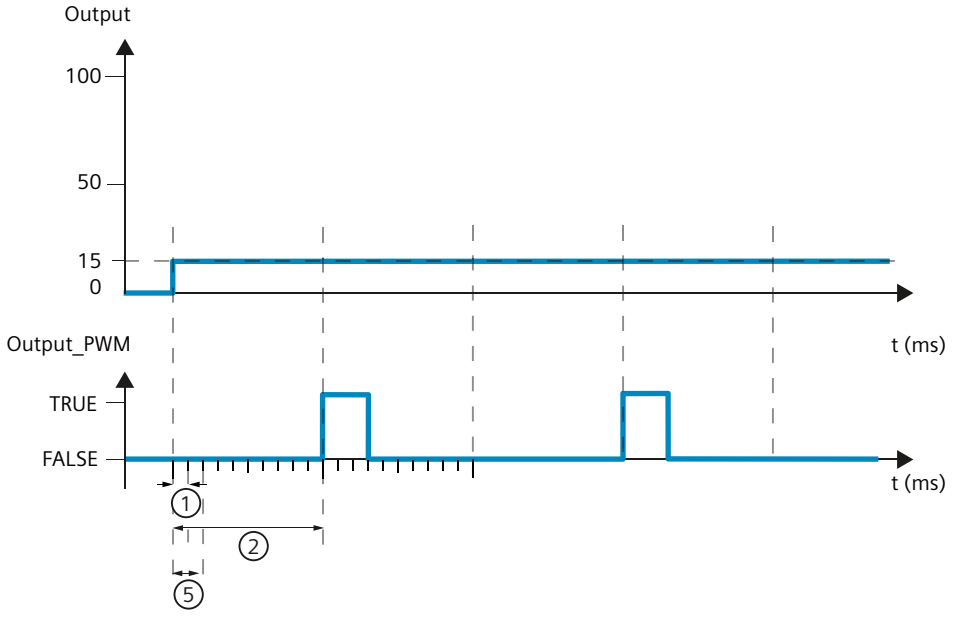
Example

PID_Compact sampling time (equivalent to the cycle time of the calling OB) = 100 ms

PID algorithm sampling time (equivalent to the time period)= 1000 ms

Minimum ON time = 200 ms

Output is a constant 15%. The smallest pulse that PID_Compact can output is 20%. In the first cycle, no pulse is output. In the second cycle, the pulse not output in the first cycle is added to the pulse of the second cycle.



① PID_Compact sampling time

② PID algorithm sampling time

⑤ Minimum ON time

In order to minimize operation frequency and conserve the actuator, extend the minimum ON and OFF times.

If you are using "Output" or "Output_PER", you must configure the value 0.0 for the minimum ON and OFF times.

NOTE

The minimum ON and OFF times only affect the output parameter Output_PWM and are not used for any pulse generators integrated in the CPU.

See also

Process value settings V1 (Page 108)

Process value monitoring V1 (Page 109)

Output value limits V1 (Page 112)

PID parameters V1 (Page 112)

Output value limits V1

In the "Output value limits" configuration window, configure the absolute limits of your output value in percent. Absolute output value limits are not violated in neither manual mode nor in automatic mode. If a output value outside the limits is specified in manual mode, the effective value is limited in the CPU to the configured limits.

The valid output value limit values depend on the Output used.

Output	-100.0 to 100.0
Output_PER	-100.0 to 100.0
Output_PWM	0.0 to 100.0

PID_Compact sets the output value to 0.0 if an error occurs. 0.0 must therefore always be within the output value limits. You will need to add an offset to Output and Output_PER in the user program if you want an output value low limit of greater than 0.0.

See also

Process value settings V1 (Page 108)
Process value monitoring V1 (Page 109)
PWM limits V1 (Page 110)
PID parameters V1 (Page 112)

PID parameters V1

The PID parameters are displayed in the "PID Parameters" configuration window. The PID parameters will be adapted to your controlled system during controller tuning. You do not need to enter the PID parameters manually.

NOTE

The currently active PID parameters are located for PID_Compact V1 in the sRet structure and as of PID_Compact V2 in the Retain.CtrlParams structure.

Change the currently active PID parameters only in "Inactive" mode online to prevent malfunction of the PID controller.

If you want to change the PID parameters in "Automatic mode" or "Manual mode" online, change the PID parameters as follows:

- PID_Compact V1: Change the PID parameters in the sBackUp structure and apply these changes with sPid_Cmpt.b_LoadBackUp = TRUE to the sRet structure.
- PID_Compact as of V2: Change the PID parameters in the CtrlParamsBackUp structure and apply these changes with LoadBackUp = TRUE to the Retain.CtrlParams structure.

Online changes to the PID parameters in "Automatic mode" can result in jumps at the output value.

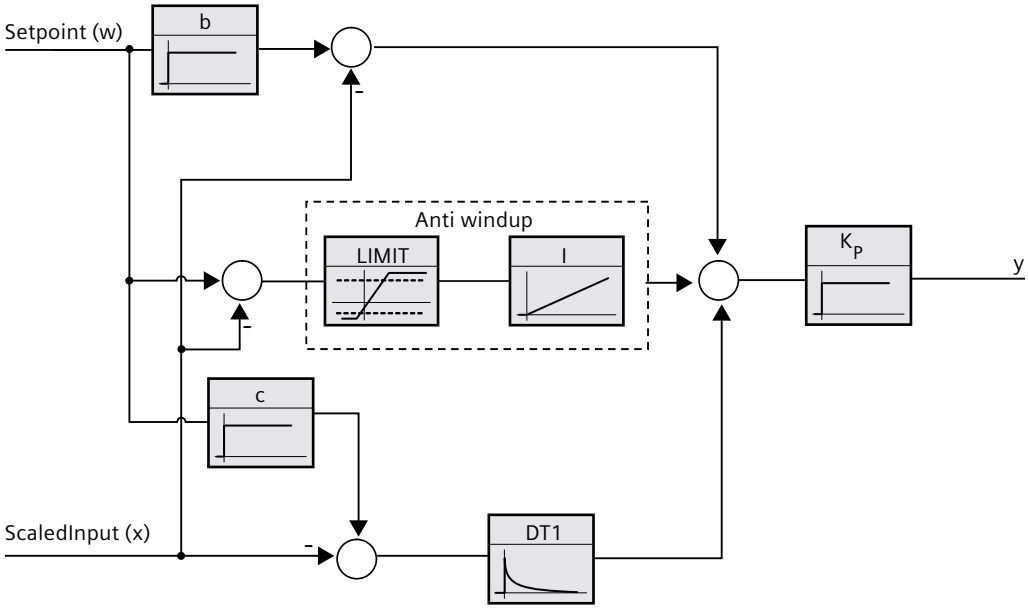
The PID algorithm operates according to the following transfer function:

$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
y	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (derivative delay T1 = a × T_D)
c	Derivative action weighting

The diagram below illustrates the integration of the parameters into the PID algorithm:



All PID parameters are retentive. If you enter the PID parameters manually, you must completely download PID_Compact.

Downloading technology objects to device (Page 49)

Proportional gain

The value specifies the proportional gain of the controller. PID_Compact does not work with a negative proportional gain. Control logic is inverted under Basic settings > Controller type.

Integration time

The integration time determines the time response of the integral action. The integral action is deactivated with integration time = 0.0. When the integration time is changed from a different value to 0.0 online in "Automatic mode", the previous integral action is deleted and the output value jumps.

Derivative action time

The derivative action time determines the time response of the derivative action. Derivative action is deactivated with derivative action time = 0.0.

Derivative delay coefficient

The derivative delay coefficient delays the effect of the derivative action.

Derivative delay = derivative action time × derivative delay coefficient

- 0.0: Derivative action is effective for one cycle only and therefore almost not effective.
- 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant.
- > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed.

Proportional action weighting

The proportional action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Proportional action for setpoint change is fully effective
- 0.0: Proportional action for setpoint change is not effective

The proportional action is always fully effective when the process value is changed.

Derivative action weighting

The derivative action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Derivative action is fully effective upon setpoint change
- 0.0: Derivative action is not effective upon setpoint change

The derivative action is always fully effective when the process value is changed.

PID algorithm sampling time

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_Compact are executed at every call.

If you use Output_PWM, the sampling time of the PID algorithm is used as the period duration of the pulse width modulation. The accuracy of the output signal is determined by the ratio of the PID algorithm sampling time to the cycle time of the OB. It is therefore recommended that the cycle time is a maximum of one tenth of the PID algorithm sampling time.

Rule for tuning

Select whether PI or PID parameters are to be calculated in the "Controller structure" drop-down list.

- **PID**

  Calculates PID parameters during pretuning and fine tuning.
- **PI**

  Calculates PI parameters during pretuning and fine tuning.
- **User-defined**

  The drop-down list displays "User-defined" if you have configured different controller structures for pretuning and fine tuning via a user program.

6.3.2 Commissioning PID_Compact V1

6.3.2.1 Commissioning V1

The commissioning window helps you commission the PID controller. You can monitor the values for the setpoint, process value and output value along the time axis in the trend view. The following functions are supported in the commissioning window:

- Controller pretuning
- Controller fine tuning

  Use fine tuning for fine adjustments to the PID parameters.
- Monitoring the current closed-loop control in the trend view
- Testing the controlled system by specifying a manual output value

All functions require an online connection to the CPU to have been established.

Basic handling

- Select the desired sampling time in the "Sampling time" drop-down list.

  All values in the commissioning window are updated in the selected update time.
- Click the "Start" icon in the measuring group if you want to use the commissioning functions.

  Value recording is started. The current values for the setpoint, process value and output value are entered in the trend view. Operation of the commissioning window is enabled.
- Click the "Stop" icon if you want to end the commissioning functions.

  The values recorded in the trend view can continue to be analyzed.

Closing the commissioning window will terminate recording in the trend view and delete the recorded values.

See also

Pretuning V1 (Page 116)
Fine tuning V1 (Page 118)
"Manual" mode V1 (Page 120)

6.3.2.2 Pretuning V1

The pretuning determines the process response to a jump change of the output value and searches for the point of inflection. The tuned PID parameters are calculated as a function of the maximum slope and dead time of the controlled system.

The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. The PID parameters are backed up before being recalculated.

Requirement

- The "PID_Compact" instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- PID_Compact is in "inactive" or "manual" mode.
- The setpoint may not be changed during controller tuning. PID_Compact will otherwise be deactivated.
- The setpoint and the process value lie within the configured limits (see "Process value monitoring" configuration).
- The difference between setpoint and process value is greater than 30% of the difference between process value high limit and process value low limit.
- The distance between the setpoint and the process value is > 50% of the setpoint.

Procedure

To perform pretuning, follow these steps:

1. Double-click the "PID_Compact > Commissioning" entry in the project tree.
2. Select the entry "Pretuning" in the "Tuning mode" drop-down list.
3. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - Pretuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon when the progress bar has reached 100% and it is to be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If pretuning was performed without an error message, the PID parameters have been tuned. PID_Compact switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If pretuning is not possible, PID_Compact will change to "Inactive" mode.

See also

Parameters State and sRet.i_Mode V1 (Page 299)
Commissioning V1 (Page 115)
Fine tuning V1 (Page 118)
"Manual" mode V1 (Page 120)

6.3.2.3 Fine tuning V1

Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are optimized for the operating point from the amplitude and frequency of this oscillation. All PID parameters are recalculated on the basis of the findings. PID parameters from fine tuning usually have better master control and disturbance behavior than PID parameters from pretuning.

PID_Compact automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The PID parameters are backed up before being recalculated.

Requirement

- The PID_Compact instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- The setpoint and the process value lie within the configured limits (see "Process value monitoring" configuration).
- The control loop has stabilized at the operating point. The operating point is reached when the process value corresponds to the setpoint.
- No disturbances are expected.
- The setpoint may not be changed during controller tuning.
- PID_Compact is in inactive mode, automatic mode or manual mode.

Process depends on initial situation

Fine tuning can be started in "inactive", "automatic" or "manual" mode. Fine tuning proceeds as follows when started in:

- Automatic mode

  Start fine tuning in automatic mode if you wish to improve the existing PID parameters using controller tuning.

  PID_Comact will regulate using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

- Inactive or manual mode

  If the requirements for pretuning are met, pretuning is started. The PID parameters established will be used for adjustment until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. If pretuning is not possible, PID_Compact will change to "Inactive" mode.

  An attempt is made to reach the setpoint with a minimum or maximum output value if the process value for pretuning is already too near the setpoint. This can produce increased overshoot.

Procedure

Proceed as follows to carry out "fine tuning":

1. Select the entry "Fine tuning" in the "Tuning mode" drop-down list.
2. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - The process of fine tuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon in the "Tuning mode" group when the progress bar has reached 100% and it is to be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

The PID parameters will have been optimized if fine tuning has been executed without errors. PID_Compact changes to automatic mode and uses the optimized parameters. The optimized PID parameters will be retained during power OFF and a restart of the CPU.

If errors occurred during "fine tuning", PID_Compact will change to "inactive" mode.

See also

Parameters State and sRet.i_Mode V1 (Page 299)

Commissioning V1 (Page 115)

Pretuning V1 (Page 116)

"Manual" mode V1 (Page 120)

6.3.2.4 "Manual" mode V1

The following section describes how you can use the "Manual" operating mode in the commissioning window of the "PID Compact" technology object.

Requirement

- The "PID_Compact" instruction is called in a cyclic interrupt OB.
- An online connection to the CPU has been established and the CPU is in the "RUN" mode.
- The functions of the commissioning window have been enabled via the "Start" icon.

Procedure

Use "Manual mode" in the commissioning window if you want to test the controlled system by specifying a manual value. To define a manual value, proceed as follows:

1. Select the "Manual mode" check box in the "Online status of controller" area.

   PID_Compact operates in manual mode. The most recent current output value remains in effect.
2. Enter the manual value in the "Output" field as a % value.
3. Click the control icon .

Result

The manual value is written to the CPU and immediately goes into effect.

NOTE

PID_Compact continues to monitor the process value. If the process value limits are exceeded, PID_Compact is deactivated.

Clear the "Manual mode" check box if the output value is to be specified again by the PID controller. The switchover to automatic mode is bumpless.

See also

Parameters State and sRet.i_Mode V1 (Page 299)
Commissioning V1 (Page 115)
Pretuning V1 (Page 116)
Fine tuning V1 (Page 118)

6.3.3 Simulating PID_Compact V1 with PLCSIM

NOTE

Simulation with PLCSIM

For the simulation with PLCSIM, the time behavior of the simulated PLC is not exactly identical to that of a "real" PLC. The actual cycle clock of a cyclic interrupt OB can have larger fluctuations with a simulated PLC than with "real" PLCs.

In the standard configuration, PID_Compact determines the time between calls automatically and monitors them for fluctuations.

For a simulation of PID_Compact with PLCSIM, for example, a sampling time error (ErrorBits = DW#16#00000800) can therefore be detected.

PID_Compact switches to "Inactive" mode (State = 0) in this case.

To prevent this from happening, you should configure PID_Compact for simulation with PLCSIM as follows:

- sb_EnCyclEstimation = FALSE
- sb_EnCyclMonitoring = FALSE
- sPid_Calc.r_Cycle: Assign the cycle clock of the calling cyclic interrupt OB in seconds to this tag.

Using PID_3Step

7

7.1 Technology object PID_3Step

The technology object PID_3Step provides a PID controller with tuning for valves or actuators with integral response.

You can configure the following controllers:

- Three-point step controller with position feedback
- Three-point step controller without position feedback
- Valve controller with analog output value

PID_3Step continuously acquires the measured process value within a control loop and compares it with the setpoint. From the resulting control deviation, PID_3Step calculates an output value through which the process value reaches the setpoint as quickly and steadily as possible. The output value for the PID controller consists of three actions:

- **Proportional** action

  The proportional action of the output value increases in proportion to the control deviation.

- **I** action

  The integral action of the output value increases until the control deviation has been balanced.

- **D** action

  The derivative action increases with the rate of change of control deviation. The process value is corrected to the setpoint as quickly as possible. The derivative action will be reduced again if the rate of change of control deviation drops.

The instruction PID_3Step calculates the proportional, integral and derivative parameters for your controlled system during pretuning. Fine tuning can be used to tune the parameters further. You do not need to manually determine the parameters.

Additional information

- Overview of software controller (Page 44)
- Add technology objects (Page 46)
- Configure technology objects (Page 47)
- Configuring PID_3Step V2 (Page 123)
- Configuring PID_3Step V1 (Page 142)

Principle

For more information, see the following FAQs in the Siemens Industry Online Support:

- Entry ID 68011827 (https://support.industry.siemens.com/cs/ww/en/view/68011827)

7.2 PID_3Step V2

7.2.1 Configuring PID_3Step V2

7.2.1.1 Basic settings V2

Introduction V2

Configure the following properties of the "PID_3Step" technology object under "Basic settings" in the Inspector window or in the configuration window:

- Physical quantity
- Control logic
- Start-up behavior after reset
- Setpoint (only in the Inspector window)
- Process value (only in the Inspector window)
- Output value (only in the Inspector window)
- Position feedback (only in the Inspector window)

Setpoint, process value, output value and position feedback

You can only configure the setpoint, process value, output value and position feedback in the Inspector window of the programming editor. Select the source for each value:

- Instance DB

  The value saved in the instance DB is used.

  Value must be updated in the instance DB by the user program.

  There should be no value at the instruction.

  Change via HMI possible.

- Instruction

  The value connected to the instruction is used.
  The value is written to the instance DB each time the instruction is called.

  No change via HMI possible.

Control mode V2

Physical quantity

Select the unit of measurement and physical quantity for the setpoint and the process value in the "Controller type" group. The setpoint and the process value are displayed in this unit.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic.

PID_3Step does not work with negative proportional gain. Select the check box "Invert control logic" to reduce the process value with a higher output value.

Examples

- Opening the drain valve will reduce the level of a container's contents.
- Increasing cooling will reduce the temperature.

Startup characteristics

1. To switch to "Inactive" mode after CPU restart, clear the "Activate Mode after CPU restart" check box.

   To switch to the operating mode saved in the Mode parameter after CPU restart, select the "Activate Mode after CPU restart" check box.

2. In the "Set Mode to" drop-down list, select the mode that is to be enabled after a complete download to the device.

   After a complete download to the device, PID_3Step starts in the selected operating mode. With each additional restart, PID_3Step starts in the mode that was last saved in Mode.

Example

You have selected the "Activate Mode after CPU restart" check box and the entry "Pretuning" in the "Set Mode to" list. After a complete download to the device, PID_3Step starts in the "Pretuning" mode. If pretuning is still active, PID_3Step starts in "Pretuning" mode again after restart of the CPU. If pretuning was successfully completed and automatic mode is active, PID_3Step starts in "Automatic mode" after restart of the CPU.

Setpoint V2

Procedure

Proceed as follows to define a fixed setpoint:

1. Select "Instance DB".
2. Enter a setpoint, e.g. 80° C.
3. Delete any entry in the instruction.

Proceed as follows to define a variable setpoint:

1. Select "Instruction".
2. Enter the name of the REAL variable in which the setpoint is saved.

   Program-controlled assignment of various values to the REAL variable is possible, for example for the time controlled change of the setpoint.

Process value V2

PID_3Step will scale the value of the analog input to the physical quantity if you use the analog input value directly.

You will need to write a program for processing if you wish first to process the analog input value. The process value is, for example, not directly proportional to the value at the analog input. The processed process value must be in floating point format.

Procedure

Proceed as follows to use the analog input value without processing:

1. Select the entry "Input_PER" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the address of the analog input.

Proceed as follows to use the processed process value in floating point format:

1. Select the entry "Input" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the name of the variable in which the processed process value is saved.

Position feedback V2

Position feedback configuration depends upon the actuator used.

- Actuator without position feedback
- Actuator with digital endstop signals
- Actuator with analog position feedback
- Actuator with analog position feedback and endstop signals

Actuator without position feedback

Proceed as follows to configure PID_3Step for an actuator without position feedback:

1. Select the entry "No Feedback" in the drop-down list "Feedback".

Actuator with digital endstop signals

Proceed as follows to configure PID_3Step for an actuator with endstop signals:

1. Select the entry "No Feedback" in the drop-down list "Feedback".
2. Activate the "Actuator endstop signals" check box.
3. Select "Instruction" as source for Actuator_H and Actuator_L.
4. Enter the addresses of the digital inputs for Actuator_H and Actuator_L.

Actuator with analog position feedback

Proceed as follows to configure PID_3Step for an actuator with analog position feedback:

1. Select the entry "Feedback" or "Feedback_PER" in the drop-down list "Feedback".
   - Use the analog input value for Feedback_PER. Configure Feedback_PER scaling in the actuator settings.
   - Process the analog input value for Feedback using your user program.
2. Select "Instruction" as source.
3. Enter the address of the analog input or the variable of your user program.

Actuator with analog position feedback and endstop signals

Proceed as follows to configure PID_3Step for an actuator with analog position feedback and endstop signals:

1. Select the entry "Feedback" or "Feedback_PER" in the drop-down list "Feedback".
2. Select "Instruction" as source.
3. Enter the address of the analog input or the variable of your user program.
4. Activate the "Actuator endstop signals" check box.
5. Select "Instruction" as source for Actuator_H and Actuator_L.
6. Enter the addresses of the digital inputs for Actuator_H and Actuator_L.

Output value V2

PID_3Step offers an analog output value (Output_PER) and digital output values (Output_UP, Output_DN). Your actuator will determine which output value you use.

- Output_PER

  The actuator has a relevant motor transition time and is triggered via an analog output and controlled with a continuous signal, e.g. 0...10 V or 4...20 mA. The value at Output_PER corresponds to the target position of the valve, e.g. Output_PER = 13824, when the valve is to be opened by 50%.

  For auto-tuning and anti windup behavior, for example, PID_3Step takes into consideration that the analog output value has a delayed effect on the process due to the motor transition time. If no relevant motor transition time is in effect in your process (e.g. with solenoid valves), so that the output value has a direct and full effect on the process, use PID_Compact instead.

- Output_UP, Output_DN

  The actuator has a relevant motor transition time and is controlled by two digital outputs. Output_UP moves the valve in the open state direction.
  Output_DN moves the valve in the closed state direction.

The motor transition time is taken into consideration in the calculation of the analog output value as well as in the calculation of the digital output values. It is mainly required for correct operation during auto-tuning and the anti-windup behavior. You should therefore configure the motor transition time under "Actuator settings" with the value that the motor requires to move the actuator from the closed to the opened state.

Procedure

Proceed as follows to use the analog output value:

1. Select the entry "Output (analog)" in the drop-down list "Output".
2. Select "Instruction".
3. Enter the address of the analog output.

Proceed as follows to use the digital output value:

1. Select the entry "Output (digital)" in the drop-down list "Output".
2. Select "Instruction" for Output_UP and Output_DN.
3. Enter the addresses of the digital outputs.

Proceed as follows to process the output value using the user program:

1. Select the entry corresponding to the actuator in the drop-down list "Output".
2. Select "Instruction".
3. Enter the name of the tag you are using to process the output value.
4. Transfer the processed output value to the actuator by means of an analog or digital CPU output.

7.2.1.2 Process value settings V2

Process value scaling V2

If you have configured the use of Input_PER in the basic setting, you must convert the value of the analog input to the physical quantity of the process value. The current configuration is displayed in the Input_PER display.

Input_PER will be scaled using a low and high value pair if the process value is directly proportional to the value of the analog input.

Procedure

To scale the process value, follow these steps:

1. Enter the low pair of values in the "Scaled low process value" and "Low" text boxs.
2. Enter the high pair of values in the "Scaled high process value" and "High" input boxes.

Default settings for the value pairs are stored in the hardware configuration. To use the value pairs from the hardware configuration, follow these steps:

1. Select the PID_3Step instruction in the programming editor.
2. Interconnect Input_PER with an analog input in the basic settings.
3. Click the "Automatic setting" button in the process value settings.

The existing values will be overwritten with the values from the hardware configuration.

Process value limits V2

You must specify an appropriate absolute high limit and low limit for the process value as limit values for your controlled system. As soon as the process value violates these limits, an error occurs (ErrorBits = 0001h). Tuning is canceled when the process value limits are violated. You can specify how PID_3Step responds to errors in automatic mode in the actuator settings.

7.2.1.3 Actuator settings V2

Actuator V2

Actuator-specific times

Configure the motor transition time and the minimum ON and OFF times to prevent damage to the actuator. You can find the specifications in the actuator data sheet.

The motor transition time is the time in seconds the motor requires to move the actuator from the closed to the opened state. You can measure the motor transition time during commissioning.

The motor transition time is taken into consideration in the calculation of the analog output value as well as in the calculation of the digital output values. It is mainly required for correct operation during auto-tuning and the anti-windup behavior.

If no relevant motor transition time is in effect in your process (e.g. with solenoid valves), so that the output value has a direct and full effect on the process, use PID_Compact instead.

The motor transition time is retentive. If you enter the motor transition time manually, you must completely download PID_3Step.

Downloading technology objects to device (Page 49)

If you are using "Output_UP" or "Output_DN", you can reduce the switching frequency with the minimum on and minimum OFF time.

The on or off times calculated are totaled in automatic mode and only take effect when the sum is greater than or equal to the minimum on or OFF time.

Manual_UP = TRUE or Manual_DN = TRUE in manual mode operates the actuator for at least the minimum ON or OFF time.

If you have selected the analog output value Output_PER in the basic settings, the minimum ON time and the minimum OFF time are not evaluated and cannot be changed.

Response to errors

PID_3Step is preset so that the controller stays active in most cases in the event of an error. If errors occur frequently in controller mode, this default reaction has a negative effect on the control response. In this case, check the Errorbits parameter and eliminate the cause of the error.

NOTICE
Your system may be damaged. If you output "Current value while error pending" or "Substitute output value while error pending" in the event of an error, PID_3Step remains in automatic mode even if the process value limits are violated. This may damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

PID_3Step generates a programmable output value in response to an error:

- Current value

  PID_3Step is switched off and no longer modifies the actuator position.

- Current value while error is pending

  The controller functions of PID_3Step are switched off and the position of the actuator is no longer changed.

  If the following errors occur in automatic mode, PID_3Step returns to automatic mode as soon as the errors are no longer pending.

  – 0002h: Invalid value at Input_PER parameter.
  – 0200h: Invalid value at Input parameter.
  – 0400h: Calculation of output value failed.
  – 1000h: Invalid value at Setpoint parameter.
  – 2000h: Invalid value at Feedback_PER parameter.
  – 4000h: Invalid value at Feedback parameter.
  – 8000h: Error during digital position feedback.
  – 20000h: Invalid value at SavePosition tag.

  If one or more of the following errors occur, PID_3Step stays in automatic mode:

  – 0001h: The Input parameter is outside the process value limits.
  – 0800h: Sampling time error
  – 40000h: Invalid value at Disturbance parameter.

  PID_3Step remains in manual mode if an error occurs in manual mode.

  If an error occurs during tuning or transition time measurement, PID_3Step switches to the mode in which tuning or transition time measurement was started. Only in the event of the following error is tuning not aborted:

  – 0020h: Pretuning is not permitted during fine tuning.

- Substitute output value

  PID_3Step moves the actuator to the substitute output value and then switches off.

- Substitute output value while error is pending

  PID_3Step moves the actuator to the substitute output value. When the substitute output value is reached, PID_3Step reacts as it does with "Current value for while error is pending".

Enter the substitute output value in "%".

Only substitute output values 0% and 100% can be configured when using Output_UP and Output_DN without analog position feedback (Config.OutputPerOn = FALSE and Config.FeedbackOn = FALSE). To reach the high or low endstop, the actuator is moved in the corresponding direction. If endstops are available (Config.ActuatorEndStopOn = TRUE), Output_UP and Output_DN are reset with Actuator_H = TRUE or Actuator_L = TRUE. If no endstop signals are available (Config.ActuatorEndStopOn = FALSE), Output_UP and Output_DN are reset after a travel time of Config.VirtualActuatorLimit * Retain.TransitTime/100.

Any substitute output values within the output value limits can be configured when using Output_PER or analog position feedback (Config.OutputPerOn = TRUE or Config.FeedbackOn = TRUE).

Feedback scaling V2

Scaling position feedback

If you have configured the use of Feedback_PER in the basic settings, you will need to convert the value of the analog input into %. The current configuration will be displayed in the "Feedback" display.

Feedback_PER is scaled using a low and high value pair.

1. Enter the low pair of values in the "Low endstop" and "Low" input boxes.
2. Enter the high pair of values in the "High endstop" and "High" input boxes.

"Low endstop" must be less than "High endstop"; "Low" must be less than "High".

The valid values for "High endstop" and "Low endstop" depend upon:

- No Feedback, Feedback, Feedback_PER
- Output (analog), Output (digital)

Output	Feedback	Low endstop	High endstop
Output (digital)	No Feedback	Cannot be set (0.0%)	Cannot be set (100.0%)
Output (digital)	Feedback	-100.0% or 0.0%	0.0% or +100.0%
Output (digital)	Feedback_PER	-100.0% or 0.0%	0.0% or +100.0%
Output (analog)	No Feedback	Cannot be set (0.0%)	Cannot be set (100.0%)
Output (analog)	Feedback	-100.0% or 0.0%	0.0% or +100.0%
Output (analog)	Feedback_PER	-100.0% or 0.0%	0.0% or +100.0%

Output value limits V2

Limiting the output value

You can exceed or undershoot the output value limits during the transition time measurement and with mode = 10. The output value is limited to these values in all other modes.

Enter the absolute output value limits in the "Output value high limit" and "Output value low limit" input boxes. The output value limits must be within "Low endstop" and "High endstop".

If no Feedback is available and Output (digital) is set, you cannot limit the output value. Output_UP and Output_DN are then reset upon Actuator_H = TRUE or Actuator_L = TRUE. If no endstop signals are available, Output_UP and Output_DN are reset after a travel time of 150% of the motor actuating time.

The default value of 150% can be adjusted using the tagConfig.VirtualActuatorLimit. As of PID_3Step Version 2.3 the monitoring and limiting of the travel time can be deactivated with Config.VirtualActuatorLimit = 0.0.

7.2.1.4 Advanced settings V2

Process value monitoring V2

Configure a warning high and low limit for the process value in the "Process value monitoring" configuration window. If one of the warning limits is exceeded or undershot during operation, a warning will be displayed at the PID_3Step instruction:

- At the InputWarning_H output parameter if the warning high limit has been exceeded
- At the InputWarning_L output parameter if the warning low limit has been undershot

The warning limits must be within the process value high and low limits.

The process value high and low limits will be used if you do not enter values.

Example

Process value high limit = 98° C; warning high limit = 90° C

Warning low limit = 10° C; process value low limit = 0° C

PID_3Step will respond as follows:

Process value	InputWarning_H	InputWarning_L	ErrorBits	Operating mode
> 98° C	TRUE	FALSE	0001h	As configured
≤ 98° C and > 90° C	TRUE	FALSE	0000h	Automatic mode
≤ 90° C and ≥ 10° C	FALSE	FALSE	0000h	Automatic mode
< 10° C and ≥ 0° C	FALSE	TRUE	0000h	Automatic mode
< 0° C	FALSE	TRUE	0001h	As configured

In the actuator settings, you can configure the response of PID_3Step when the process value high limit or low limit is violated.

PID parameters V2

The PID parameters are displayed in the "PID Parameters" configuration window. The PID parameters will be adapted to your controlled system during controller tuning. You do not need to enter the PID parameters manually.

NOTE

The currently active PID parameters are located in the Retain.CtrlParams structure.

Change the currently active PID parameters only in "Inactive" mode online to prevent malfunction of the PID controller.

If you want to change the PID parameters in "Automatic mode" or "Manual mode" online, change the PID parameters in the CtrlParamsBackUp structure and apply these changes to the Retain.CtrlParams structure as follows:

- PID_3Step V1: Apply the changes with Config.LoadBackUp = TRUE
- PID_3Step V2: Apply the changes with LoadBackUp = TRUE

Online changes to the PID parameters in "Automatic mode" can result in jumps at the output value.

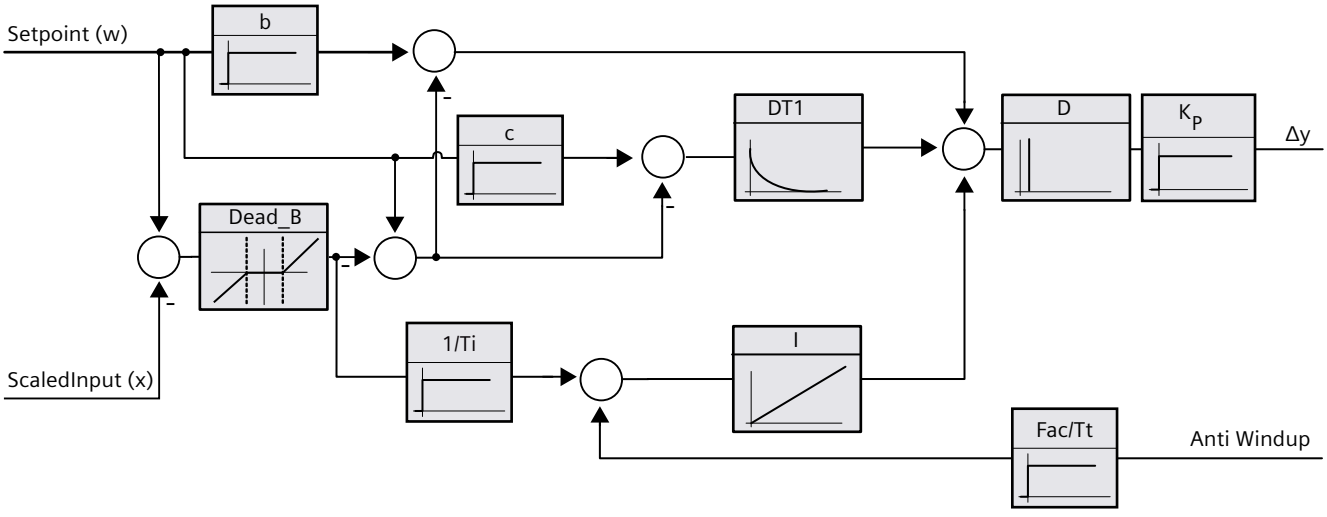
The PID algorithm operates according to the following transfer function:

$$\Delta y = K_p \cdot s \cdot \left[(b \cdot w - x) + \frac{1}{T_I \cdot s}(w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1}(c \cdot w - x)\right]$$

The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
Δy	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (derivative delay T1 = a × T_D)
c	Derivative action weighting

The diagram below illustrates the integration of the parameters into the PID algorithm:



All PID parameters are retentive. If you enter the PID parameters manually, you must completely download PID_3Step.

Downloading technology objects to device (Page 49)

Proportional gain

The value specifies the proportional gain of the controller. PID_3Step does not work with a negative proportional gain. Control logic is inverted under Basic settings > Controller type.

Integration time

The integration time determines the time response of the integral action. The integral action is deactivated with integration time = 0.0. When the integration time is changed from a different value to 0.0 online in "Automatic mode", the previous integral action is deleted and the output value jumps.

Derivative action time

The derivative action time determines the time response of the derivative action. Derivative action is deactivated with derivative action time = 0.0.

Derivative delay coefficient

The derivative delay coefficient delays the effect of the derivative action.

Derivative delay = derivative action time × derivative delay coefficient

- 0.0: Derivative action is effective for one cycle only and therefore almost not effective.
- 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant.
- > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed.

Proportional action weighting

The proportional action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Proportional action for setpoint change is fully effective
- 0.0: Proportional action for setpoint change is not effective

The proportional action is always fully effective when the process value is changed.

Derivative action weighting

The derivative action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Derivative action is fully effective upon setpoint change
- 0.0: Derivative action is not effective upon setpoint change

The derivative action is always fully effective when the process value is changed.

PID algorithm sampling time

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the PID_3Step sampling time. All other functions of PID_3Step are executed at every call.

Dead zone width

The dead zone suppresses the noise component in the steady controller state. The dead zone width specifies the size of the dead zone. The dead zone is off if the dead zone width is 0.0.

If values not equal to 1.0 are configured for the proportional action weighting or the derivative action weighting, setpoint changes even within the dead zone affect the output value.
Process value changes within the dead zone do not affect the output value, regardless of the weighting.

7.2.2 Commissioning PID_3Step V2

7.2.2.1 Pretuning V2

The pretuning determines the process response to a pulse of the output value and searches for the point of inflection. The tuned PID parameters are calculated as a function of the maximum slope and dead time of the controlled system. You obtain the best PID parameters when you perform pretuning and fine tuning.

The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. This is most likely the case in operating modes "Inactive" and "manual mode". The PID parameters are backed up before being recalculated.

The setpoint is frozen during pretuning.

Requirement

- The PID_3Step instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- The motor transition time has been configured or measured.
- PID_3Step is in one of the following modes: "Inactive", "Manual mode", or "Automatic mode".
- The setpoint and the process value lie within the configured limits (see "Process value settings" configuration).

Procedure

To perform pretuning, follow these steps:

1. Double-click the "PID_3Step > Commissioning" entry in the project tree.
2. Select the entry "Pretuning" in the "Tuning mode" drop-down list in the working area "Tuning".
3. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - Pretuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon when the progress bar has reached 100% and it is to be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If pretuning was performed without an error message, the PID parameters have been tuned. PID_3Step switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If pretuning is not possible, PID_3Step responds with the configured reaction to errors.

7.2.2.2 Fine tuning V2

Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are tuned for the operating point from the amplitude and frequency of this oscillation. All PID parameters are recalculated from the results. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. You obtain the best PID parameters when you perform pretuning and fine tuning.

PID_3Step automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The PID parameters are backed up before being recalculated.

The setpoint is frozen during fine tuning.

Requirement

- The PID_3Step instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- The motor transition time has been configured or measured.
- The setpoint and the process value lie within the configured limits (see "Process value settings" configuration).
- The control loop has stabilized at the operating point. The operating point is reached when the process value corresponds to the setpoint.
- No disturbances are expected.
- PID_3Step is in inactive mode, automatic mode or manual mode.

Process depends on initial situation

Fine tuning proceeds as follows when started from:

- Automatic mode

  Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning.

  PID_3Step controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

- Inactive or manual mode

  Pretuning is always started first. The determined PID parameters will be used for control until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

Procedure

To perform fine tuning, follow these steps:

1. Select the entry "Fine tuning" in the "Tuning mode" drop-down list.
2. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - The process of fine tuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon in the "Tuning mode" group when the progress bar has reached 100% and it is to be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If no errors occurred during fine tuning, the PID parameters have been tuned. PID_3Step switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If errors occurred during fine tuning, PID_3Step responds with the configured response to errors.

7.2.2.3 Commissioning with manual PID parameters V2

Requirement

- The PID_3Step instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- The motor transition time has been configured or measured.
- PID_3Step is in "inactive" mode.
- The setpoint and the process value lie within the configured limits (see "Process value settings" configuration).

Procedure

Proceed as follows to commission PID_3Step with manual PID parameters:

1. Double-click on "PID_3Step > Configuration" in the project tree.
2. Click on "Advanced settings > PID Parameters" in the configuration window.
3. Select the check box "Enable direct input".
4. Enter the PID parameters.
5. Double-click the "PID_3Step > Commissioning" entry in the project tree.
6. Establish an online connection to the CPU.
7. Load the PID parameters to the CPU.
8. Click the "Start PID_3Step" icon.

Result

PID_3Step changes to automatic mode and controls using the current PID parameters.

See also

PID parameters V2 (Page 132)

7.2.2.4 Measuring the motor transition time V2

Introduction

PID_3Step requires the motor transition time to be as accurate as possible for good controller results. The data in the actuator documentation contains average values for this type of actuator. The value for the specific actuator used may differ.

You can measure the motor transition time during commissioning if you are using actuators with position feedback or endstop signals. The output value limits are not taken into consideration during the motor transition time measurement. The actuator can travel to the high or the low endstop.

The motor transition time cannot be measured if neither position feedback nor endstop signals are available.

Actuators with analog position feedback

Proceed as follows to measure motor transition time with position feedback:

Requirement

- Feedback or Feedback_PER has been selected in the basic settings and the signal has been connected.
- An online connection to the CPU has been established.

1. Select the "Use position feedback" check box.
2. Enter the position to which the actuator is to be moved in the "Target position" input field.

   The current position feedback (starting position) will be displayed. The difference between "Target position" and "Position feedback" must be at least 50% of the valid output value range.
3. Click the "Start" icon.

Result

The actuator is moved from the starting position to the target position. Time measurement starts immediately and ends when the actuator reaches the target position. The motor transition time is calculated according to the following equation:

Motor transition time = (output value high limit – output value low limit) × Measuring time / AMOUNT (target position – starting position).

The progress and status of transition time measurement are displayed. The transition time measured is saved in the instance data block on the CPU and displayed in the "Measured transition time" field. When the transition time measurement is ended and ActivateRecoverMode = TRUE, PID_3Step switches to the operating mode from which the transition time measurement was started. If the transition time measurement is ended and ActivateRecoverMode = FALSE, PID_3Step changes to "Inactive" mode.

NOTE

Click on the icon "Upload measured transition time" to load the motor transition time measured to the project.

Actuators with endstop signals

Proceed as follows to measure the transition time of actuators with endstop signals:

Requirement

- The "Endstop signals" check box in the basic settings has been selected and Actuator_H and Actuator_L are connected.
- An online connection to the CPU has been established.

Proceed as follows to measure motor transition time with endstop signals:

1. Select the "Use actuator endstop signals" check box.
2. Select the direction in which the actuator is to be moved.
   - Open - Close - Open

     The actuator is moved first to the high endstop, then to the low endstop and then back to the high endstop.
   - Close - Open - Close

     The actuator is moved first to the low endstop, then to the high endstop and then back to the low endstop.
3. Click the "Start" icon.

Result

The actuator is moved in the selected direction. Time measurement will start once the actuator has reached the first endstop and will end when the actuator reaches this endstop for the second time. The motor transition time is equal to the time measured divided by two.

The progress and status of transition time measurement are displayed. The transition time measured is saved in the instance data block on the CPU and displayed in the "Measured transition time" field. When the transition time measurement is ended and ActivateRecoverMode = TRUE, PID_3Step switches to the operating mode from which the transition time measurement was started. If the transition time measurement is ended and ActivateRecoverMode = FALSE, PID_3Step changes to "Inactive" mode.

Cancelling transition time measurement

PID_3Step switches to "Inactive" mode if you cancel transition time measurement by pressing the Stop button.

7.2.3 Simulating PID_3Step V2 with PLCSIM

NOTE

Simulation with PLCSIM

The simulation of PID_3Step V2.x with PLCSIM for CPU S7-1200 is not supported.

PID_3Step V2.x can only be simulated for CPU S7-1500 and CPU S7-1200 G2 with PLCSIM.

For the simulation with PLCSIM, the time behavior of the simulated PLC is not exactly identical to that of a "real" PLC. The actual cycle clock of a cyclic interrupt OB can have larger fluctuations with a simulated PLC than with "real" PLCs.

In the standard configuration, PID_3Step determines the time between calls automatically and monitors them for fluctuations.

For a simulation of PID_3Step with PLCSIM, for example, a sampling time error ((ErrorBits = DW#16#00000800) can therefore be detected.

This results in ongoing tuning being aborted.

The response in automatic mode depends on the value of the ActivateRecoverMode tag.

To prevent this from happening, you should configure PID_3Step for simulation with PLCSIM as follows:

- CycleTime.EnEstimation = FALSE
- CycleTime.EnMonitoring = FALSE
- CycleTime.Value: Assign the cycle clock of the calling cyclic interrupt OB in seconds to this tag.

7.3 PID_3Step V1

7.3.1 Configuring PID_3Step V1

7.3.1.1 Basic settings V1

Introduction V1

Configure the following properties of the "PID_3Step" technology object under "Basic settings" in the Inspector window or in the configuration window:

- Physical quantity
- Control logic
- Start-up behavior after reset
- Setpoint (only in the Inspector window)
- Process value (only in the Inspector window)
- Output value (only in the Inspector window)
- Position feedback (only in the Inspector window)

Setpoint, process value, output value and position feedback

You can only configure the setpoint, process value, output value and position feedback in the Inspector window of the programming editor. Select the source for each value:

- Instance DB

  The value saved in the instance DB is used.

  Value must be updated in the instance DB by the user program.

  There should be no value at the instruction.

  Change via HMI possible.

- Instruction

  The value connected to the instruction is used.
  The value is written to the instance DB each time the instruction is called.

  No change via HMI possible.

Control mode V1

Physical quantity

Select the unit of measurement and physical quantity for the setpoint and process value in the "Controller type" group. The setpoint and process value will be displayed in this unit.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic.

PID_3Step does not work with negative proportional gain. Select the check box "Invert control logic" to reduce the process value with a higher output value.

Examples

- Opening the drain valve will reduce the level of a container's contents.
- Increasing cooling will reduce the temperature.

Start-up behavior after reset

To change straight to the last active mode after restarting the CPU, select the "Enable last mode after CPU restart" check box.

PID_3Step will remain in "Inactive" mode if the check box is cleared.

Setpoint V1

Procedure

Proceed as follows to define a fixed setpoint:

1. Select "Instance DB".
2. Enter a setpoint, e.g. 80° C.
3. Delete any entry in the instruction.

Proceed as follows to define a variable setpoint:

1. Select "Instruction".
2. Enter the name of the REAL variable in which the setpoint is saved.

   Program-controlled assignment of various values to the REAL variable is possible, for example for the time controlled change of the setpoint.

Process value V1

PID_3Step will scale the value of the analog input to the physical quantity if you use the analog input value directly.

You will need to write a program for processing if you wish first to process the analog input value. The process value is, for example, not directly proportional to the value at the analog input. The processed process value must be in floating point format.

Procedure

Proceed as follows to use the analog input value without processing:

1. Select the entry "Input_PER" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the address of the analog input.

Proceed as follows to use the processed process value in floating point format:

1. Select the entry "Input" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the name of the variable in which the processed process value is saved.

Position feedback V1

Position feedback configuration depends upon the actuator used.

- Actuator without position feedback
- Actuator with digital endstop signals
- Actuator with analog position feedback
- Actuator with analog position feedback and endstop signals

Actuator without position feedback

Proceed as follows to configure PID_3Step for an actuator without position feedback:

1. Select the entry "No Feedback" in the drop-down list "Feedback".

Actuator with digital endstop signals

Proceed as follows to configure PID_3Step for an actuator with endstop signals:

1. Select the entry "No Feedback" in the drop-down list "Feedback".
2. Activate the "Actuator endstop signals" check box.
3. Select "Instruction" as source for Actuator_H and Actuator_L.
4. Enter the addresses of the digital inputs for Actuator_H and Actuator_L.

Actuator with analog position feedback

Proceed as follows to configure PID_3Step for an actuator with analog position feedback:

1. Select the entry "Feedback" or "Feedback_PER" in the drop-down list "Feedback".
   - Use the analog input value for Feedback_PER. Configure Feedback_PER scaling in the actuator settings.
   - Process the analog input value for Feedback using your user program.
2. Select "Instruction" as source.
3. Enter the address of the analog input or the variable of your user program.

Actuator with analog position feedback and endstop signals

Proceed as follows to configure PID_3Step for an actuator with analog position feedback and endstop signals:

1. Select the entry "Feedback" or "Feedback_PER" in the drop-down list "Feedback".
2. Select "Instruction" as source.
3. Enter the address of the analog input or the variable of your user program.
4. Activate the "Actuator endstop signals" check box.
5. Select "Instruction" as source for Actuator_H and Actuator_L.
6. Enter the addresses of the digital inputs for Actuator_H and Actuator_L.

Output value V1

PID_3Step offers an analog output value (Output_PER) and digital output values (Output_UP, Output_DN). Your actuator will determine which output value you use.

- Output_PER

  The actuator has a relevant motor transition time and is triggered via an analog output and controlled with a continuous signal, e.g. 0...10 V or 4...20 mA. The value at Output_PER corresponds to the target position of the valve, e.g. Output_PER = 13824, when the valve is to be opened by 50%.

  For auto-tuning and anti windup behavior, for example, PID_3Step takes into consideration that the analog output value has a delayed effect on the process due to the motor transition time. If no relevant motor transition time is in effect in your process (e.g. with solenoid valves), so that the output value has a direct and full effect on the process, use PID_Compact instead.

- Output_UP, Output_DN

  The actuator has a relevant motor transition time and is controlled by two digital outputs. Output_UP moves the valve in the open state direction.
  Output_DN moves the valve in the closed state direction.

The motor transition time is taken into consideration in the calculation of the analog output value as well as in the calculation of the digital output values. It is mainly required for correct operation during auto-tuning and the anti-windup behavior. You should therefore configure the motor transition time under "Actuator settings" with the value that the motor requires to move the actuator from the closed to the opened state.

Procedure

Proceed as follows to use the analog output value:

1. Select the entry "Output (analog)" in the drop-down list "Output".
2. Select "Instruction".
3. Enter the address of the analog output.

Proceed as follows to use the digital output value:

1. Select the entry "Output (digital)" in the drop-down list "Output".
2. Select "Instruction" for Output_UP and Output_DN.
3. Enter the addresses of the digital outputs.

Proceed as follows to process the output value using the user program:

1. Select the entry corresponding to the actuator in the drop-down list "Output".
2. Select "Instruction".
3. Enter the name of the tag you are using to process the output value.
4. Transfer the processed output value to the actuator by means of an analog or digital CPU output.

7.3.1.2 Process value settings V1

Configure the scaling of your process value and specify the process value absolute limits In the "Process value settings" configuration window.

Scaling the process value

If you have configured the use of Input_PER in the basic settings, you will need to convert the value of the analog input into the physical quantity of the process value. The current configuration will be displayed in the Input_PER display.

Input_PER will be scaled using a low and high value pair if the process value is directly proportional to the value of the analog input.

1. Enter the low pair of values in the "Scaled low process value" and "Low" input fields.
2. Enter the high pair of values in the "Scaled high process value" and "High" input boxes.

Default settings for the value pairs are saved in the hardware configuration. Proceed as follows to use the value pairs from the hardware configuration:

1. Select the instruction PID_3Step in the programming editor.
2. Connect Input_PER to an analog input in the basic settings.
3. Click on the "Automatic setting" button in the process value settings.

   The existing values will be overwritten with the values from the hardware configuration.

Monitoring process value

Specify the absolute high and low limit of the process value. You must enter reasonable limits for your controlled system. Reasonable limits are important during optimization to obtain optimal PID parameters. The default for the "High limit process value" is 120 %. At the I/O input, the process value can be a maximum of 18% higher than the standard range (overrange). This setting ensures that an error is no longer signaled due to a violation of the "Process value high limit". Only a wire-break and a short-circuit are recognized and PID_3Step reacts according to the configured reaction to error.

NOTICE
Your system may be damaged. If you set very high process value limits (for example $-3.4*10^{38}$...$+3.4*10^{38}$), process value monitoring will be disabled. Your system may then be damaged if an error occurs. You need to configure useful process value limits for your controlled system.

7.3.1.3 Actuator settings V1

Actuator-specific times

Configure the motor transition time and the minimum ON and OFF times to prevent damage to the actuator. You can find the specifications in the actuator data sheet.

The motor transition time is the time in seconds the motor requires to move the actuator from the closed to the opened state. The maximum time that the actuator is moved in one direction is 110% of the motor transition time. You can measure the motor transition time during commissioning.

The motor transition time is taken into consideration in the calculation of the analog output value as well as in the calculation of the digital output values. It is mainly required for correct operation during auto-tuning and the anti-windup behavior.

If no relevant motor transition time is in effect in your process (e.g. with solenoid valves), so that the output value has a direct and full effect on the process, use PID_Compact instead.

If you are using "Output_UP" or "Output_DN", you can reduce the switching frequency with the minimum on and minimum OFF time.

The on or off times calculated are totaled in automatic mode and only take effect when the sum is greater than or equal to the minimum on or OFF time.

A rising edge at Manual_UP or Manual_DN in manual mode will operate the actuator for at least the minimum on or OFF time.

If you have selected the analog output value Output_PER in the basic settings, the minimum ON time and the minimum OFF time are not evaluated and cannot be changed.

Response to errors

PID_3Step is preset so that the controller stays active in most cases in the event of an error. If errors occur frequently in controller mode, this default reaction has a negative effect on the control response. In this case, check the Errorbits parameter and eliminate the cause of the error.

PID_3Step outputs a programmable output value in response to an error:

- Current value

  PID_3Step is switched off and no longer modifies the actuator position.

- Current value while error is pending

  The controller functions of PID_3Step are switched off and the position of the actuator is no longer changed.

  If the following errors occur in automatic mode, PID_3Step returns to automatic mode as soon as the errors are no longer pending.

  - 0002h: Invalid value at Input_PER parameter.
  - 0200h: Invalid value at Input parameter.
  - 0800h: Sampling time error
  - 1000h: Invalid value at Setpoint parameter.
  - 2000h: Invalid value at Feedback_PER parameter.
  - 4000h: Invalid value at Feedback parameter.
  - 8000h: Error during digital position feedback.

  If one of these error occurs in manual mode, PID_3Step remains in manual mode.

  If an error occurs during the tuning or transition time measurement, PID_3Step is switched off.

- Substitute output value

  PID_3Step moves the actuator to the substitute output value and then switches off.

- Substitute output value while error is pending

  PID_3Step moves the actuator to the substitute output value. When the substitute output value is reached, PID_3Step reacts as it does with "Current value for while error is pending".

Enter the substitute output value in "%".

Only substitute output values 0% and 100% can be configured when using Output_UP and Output_DN without analog position feedback (Config.OutputPerOn = FALSE and Config.FeedbackOn = FALSE). The actuator is moved in one direction at 110% of the motor transition time to ensure the high or low endstop is reached. There endstop signals take priority.

Any substitute output values within the output value limits can be configured when using Output_PER or analog position feedback (Config.OutputPerOn = TRUE or Config.FeedbackOn = TRUE).

Feedback scaling

If you have configured the use of Feedback_PER in the basic settings, you will need to convert the value of the analog input into %. The current configuration will be displayed in the "Feedback" display.

Feedback_PER is scaled using a low and high value pair.

1. Enter the low pair of values in the "Low endstop" and "Low" input boxes.
2. Enter the high pair of values in the "High endstop" and "High" input boxes.

"Low endstop" must be less than "High endstop"; "Low" must be less than "High".

The valid values for "High endstop" and "Low endstop" depend upon:

- No Feedback, Feedback, Feedback_PER
- Output (analog), Output (digital)

Output	Feedback	Low endstop	High endstop
Output (digital)	No Feedback	Cannot be set (0.0%)	Cannot be set (100.0%)
Output (digital)	Feedback	-100.0% or 0.0%	0.0% or +100.0%
Output (digital)	Feedback_PER	-100.0% or 0.0%	0.0% or +100.0%
Output (analog)	No Feedback	Cannot be set (0.0%)	Cannot be set (100.0%)
Output (analog)	Feedback	-100.0% or 0.0%	0.0% or +100.0%
Output (analog)	Feedback_PER	-100.0% or 0.0%	0.0% or +100.0%

Limiting the output value

You can only exceed or undershoot the output value limits during the transition time measurement. The output value is limited to these values in all other modes.

Enter the absolute output value limits in the "Output value high limit" and "Output value low limit" input boxes. The output value limits must be within "Low endstop" and "High endstop".

If no Feedback is available and Output (digital) is set, you cannot limit the output value. The digital outputs are reset with Actuator_H = TRUE or Actuator_L = TRUE, or after a travel time amounting to 110% of the motor transition time.

7.3.1.4 Advanced settings V1

Process value monitoring V1

Configure a warning high and low limit for the process value in the "Process value monitoring" configuration window. If one of the warning limits is exceeded or undershot during operation, a warning will be displayed at the PID_3Step instruction:

- At the InputWarning_H output parameter if the warning high limit has been exceeded
- At the InputWarning_L output parameter if the warning low limit has been undershot

The warning limits must be within the process value high and low limits.

The process value high and low limits will be used if you do not enter values.

Example

Process value high limit = 98° C; warning high limit = 90° C

Warning low limit = 10° C; process value low limit = 0° C

PID_3Step will respond as follows:

Process value	InputWarning_H	InputWarning_L	Operating mode
> 98° C	TRUE	FALSE	Inactive
≤ 98° C and > 90° C	TRUE	FALSE	Automatic mode
≤ 90° C and ≥ 10° C	FALSE	FALSE	Automatic mode
< 10° C and ≥ 0° C	FALSE	TRUE	Automatic mode
< 0° C	FALSE	TRUE	Inactive

PID parameters V1

The PID parameters are displayed in the "PID Parameters" configuration window. The PID parameters will be adapted to your controlled system during controller tuning. You do not need to enter the PID parameters manually.

NOTE

The currently active PID parameters are located in the Retain.CtrlParams structure.

Change the currently active PID parameters only in "Inactive" mode online to prevent malfunction of the PID controller.

If you want to change the PID parameters in "Automatic mode" or "Manual mode" online, change the PID parameters in the CtrlParamsBackUp structure and apply these changes to the Retain.CtrlParams structure as follows:

- PID_3Step V1: Apply the changes with Config.LoadBackUp = TRUE
- PID_3Step V2: Apply the changes with LoadBackUp = TRUE

Online changes to the PID parameters in "Automatic mode" can result in jumps at the output value.

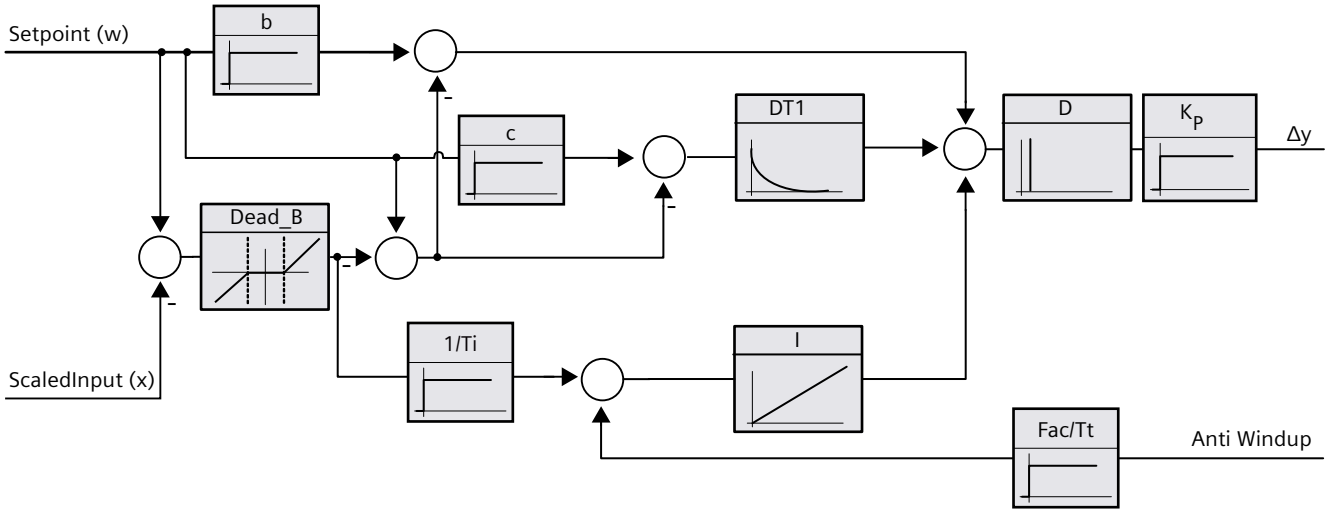
The PID algorithm operates according to the following transfer function:

$$\Delta y = K_p \cdot s \cdot \left[(b \cdot w - x) + \frac{1}{T_I \cdot s}(w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1}(c \cdot w - x)\right]$$

The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
Δy	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (derivative delay T1 = a × T_D)
c	Derivative action weighting

The diagram below illustrates the integration of the parameters into the PID algorithm:



All PID parameters are retentive. If you enter the PID parameters manually, you must completely download PID_3Step.

Downloading technology objects to device (Page 49)

Proportional gain

The value specifies the proportional gain of the controller. PID_3Step does not work with a negative proportional gain. Control logic is inverted under Basic settings > Controller type.

Integration time

The integration time determines the time response of the integral action. The integral action is deactivated with integration time = 0.0. When the integration time is changed from a different value to 0.0 online in "Automatic mode", the previous integral action is deleted and the output value jumps.

Derivative action time

The derivative action time determines the time response of the derivative action. Derivative action is deactivated with derivative action time = 0.0.

Derivative delay coefficient

The derivative delay coefficient delays the effect of the derivative action.

Derivative delay = derivative action time × derivative delay coefficient

- 0.0: Derivative action is effective for one cycle only and therefore almost not effective.
- 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant.
- > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed.

Proportional action weighting

The proportional action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Proportional action for setpoint change is fully effective
- 0.0: Proportional action for setpoint change is not effective

The proportional action is always fully effective when the process value is changed.

Derivative action weighting

The derivative action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Derivative action is fully effective upon setpoint change
- 0.0: Derivative action is not effective upon setpoint change

The derivative action is always fully effective when the process value is changed.

PID algorithm sampling time

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the PID_3Step sampling time. All other functions of PID_3Step are executed at every call.

Dead zone width

The dead zone suppresses the noise component in the steady controller state. The dead zone width specifies the size of the dead zone. The dead zone is off if the dead zone width is 0.0.

If values not equal to 1.0 are configured for the proportional action weighting or the derivative action weighting, setpoint changes even within the dead zone affect the output value.
Process value changes within the dead zone do not affect the output value, regardless of the weighting.

7.3.2 Commissioning PID_3Step V1

7.3.2.1 Commissioning V1

You can monitor the setpoint, process value and output value over time in the "Tuning" working area. The following commissioning functions are supported in the curve plotter:

- Controller pretuning
- Controller fine tuning
- Monitoring the current closed-loop control in the trend view

All functions require an online connection to the CPU to have been established.

Basic handling

- Select the desired sampling time in the "Sampling time" drop-down list.

  All values in the tuning working area are updated in the selected update time.
- Click the "Start" icon in the measuring group if you want to use the commissioning functions.

  Value recording is started. The current values for the setpoint, process value and output value are entered in the trend view. Operation of the commissioning window is enabled.
- Click the "Stop" icon if you want to end the commissioning functions.

  The values recorded in the trend view can continue to be analyzed.
- Closing the commissioning window will terminate recording in the trend view and delete the recorded values.

7.3.2.2 Pretuning V1

The pretuning determines the process response to a pulse of the output value and searches for the point of inflection. The tuned PID parameters are calculated as a function of the maximum slope and dead time of the controlled system.

The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. The PID parameters are backed up before being recalculated.

The setpoint is frozen during pretuning.

Requirement

- The PID_3Step instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- PID_3Step is in "inactive" or "manual" mode.
- The setpoint and the process value lie within the configured limits (see "Process value settings" configuration).

Procedure

To perform pretuning, follow these steps:

1. Double-click the "PID_3Step > Commissioning" entry in the project tree.
2. Select the entry "Pretuning" in the "Tuning mode" drop-down list in the working area "Tuning".
3. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - Pretuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

   NOTE

   Click the "Stop" icon when the progress bar has reached 100% and it is to be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If pretuning was performed without an error message, the PID parameters have been tuned. PID_3Step switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If pretuning is not possible, PID_3Step changes to "Inactive" mode.

7.3.2.3 Fine tuning V1

Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are optimized for the operating point from the amplitude and frequency of this oscillation. All PID parameters are recalculated on the basis of the findings. PID parameters from fine tuning usually have better master control and disturbance behavior than PID parameters from pretuning.

PID_3Step automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The PID parameters are backed up before being recalculated.

The setpoint is frozen during fine tuning.

Requirement

- The PID_3Step instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- The motor transition time has been configured or measured.
- The setpoint and the process value lie within the configured limits (see "Process value settings" configuration).
- The control loop has stabilized at the operating point. The operating point is reached when the process value corresponds to the setpoint.
- No disturbances are expected.
- PID_3Step is in inactive mode, automatic mode or manual mode.

Process depends on initial situation

Fine tuning proceeds as follows when started in:

- Automatic mode

  Start fine tuning in automatic mode if you wish to improve the existing PID parameters using controller tuning.

  PID_3Step will regulate using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

- Inactive or manual mode

  Pretuning is always started first. The PID parameters established will be used for adjustment until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

Procedure

Proceed as follows to carry out "fine tuning":

1. Select the entry "Fine tuning" in the "Tuning mode" drop-down list.
2. Click the "Start" icon.
   - An online connection will be established.
   - Value recording is started.
   - The process of fine tuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon in the "Tuning mode" group when the progress bar has reached 100% and it is to be assumed the controller tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

The PID parameters will have been optimized if fine tuning has been executed without errors. PID_3Step changes to automatic mode and uses the optimized parameters. The optimized PID parameters will be retained during power OFF and a restart of the CPU.

If errors occurred during fine tuning, PID_3Step will change to "inactive" mode.

7.3.2.4 Commissioning with manual PID parameters V1

Procedure

Proceed as follows to commission PID_3Step with manual PID parameters:

1. Double-click on "PID_3Step > Configuration" in the project tree.
2. Click on "Advanced settings > PID Parameters" in the configuration window.
3. Select the check box "Enable direct input".
4. Enter the PID parameters.
5. Double-click on "PID_3Step > Commissioning" in the project tree.
6. Establish an online connection to the CPU.
7. Load the PID parameters to the CPU.
8. Click on the "Activate controller" icon.

Result

PID_3Step changes to automatic mode and controls using the current PID parameters.

7.3.2.5 Measuring the motor transition time V1

Introduction

PID_3Step requires the motor transition time to be as accurate as possible for good controller results. The data in the actuator documentation contains average values for this type of actuator. The value for the specific actuator used may differ.

You can measure the motor transition time during commissioning if you are using actuators with position feedback or endstop signals. The output value limits are not taken into consideration during the motor transition time measurement. The actuator can travel to the high or the low endstop.

The motor transition time cannot be measured if neither position feedback nor endstop signals are available.

Actuators with analog position feedback

Proceed as follows to measure motor transition time with position feedback:

Requirement

- Feedback or Feedback_PER has been selected in the basic settings and the signal has been connected.
- An online connection to the CPU has been established.

1. Select the "Use position feedback" check box.
2. Enter the position to which the actuator is to be moved in the "Target position" input field.

   The current position feedback (starting position) will be displayed. The difference between "Target position" and "Position feedback" must be at least 50% of the valid output value range.
3. Click the "Start transition time measurement" icon.

Result

The actuator is moved from the starting position to the target position. Time measurement starts immediately and ends when the actuator reaches the target position. The motor transition time is calculated according to the following equation:

Motor transition time = (output value high limit – output value low limit) × Measuring time / AMOUNT (target position – starting position).

The progress and status of transition time measurement are displayed. The transition time measured is saved in the instance data block on the CPU and displayed in the "Measured transition time" field. PID_3Step will change to "Inactive" mode once transition time measurement is complete.

NOTE

Click on the icon "Upload measured transition time" to load the motor transition time measured to the project.

Actuators with endstop signals

Proceed as follows to measure the transition time of actuators with endstop signals:

Requirement

- The "Endstop signals" check box in the basic settings has been selected and Actuator_H and Actuator_L are connected.
- An online connection to the CPU has been established.

Proceed as follows to measure motor transition time with endstop signals:

1. Select the "Use actuator endstop signals" check box.
2. Select the direction in which the actuator is to be moved.
   - Open - Close - Open

     The actuator is moved first to the high endstop, then to the low endstop and then back to the high endstop.
   - Close - Open - Close

     The actuator is moved first to the low endstop, then to the high endstop and then back to the low endstop.
3. Click the "Start transition time measurement" icon.

Result

The actuator is moved in the selected direction. Time measurement will start once the actuator has reached the first endstop and will end when the actuator reaches this endstop for the second time. The motor transition time is equal to the time measured divided by two.

The progress and status of transition time measurement are displayed. The transition time measured is saved in the instance data block on the CPU and displayed in the "Measured transition time" field. PID_3Step will change to "Inactive" mode once transition time measurement is complete.

Cancelling transition time measurement

PID_3Step will change to "Inactive" mode immediately if you cancel transition time measurement. The actuator will stop being moved. You can reactive PID-3Step in the curve plotter.

7.3.3 Simulating PID_3Step V1 with PLCSIM

NOTE

Simulation with PLCSIM

For the simulation with PLCSIM, the time behavior of the simulated PLC is not exactly identical to that of a "real" PLC. The actual cycle clock of a cyclic interrupt OB can have larger fluctuations with a simulated PLC than with "real" PLCs.

In the standard configuration, PID_3Step determines the time between calls automatically and monitors them for fluctuations.

For a simulation of PID_3Step with PLCSIM, for example, a sampling time error (ErrorBits = DW#16#00000800) can therefore be detected.

This results in ongoing tuning being aborted.

The response in automatic mode depends on the value of the ActivateRecoverMode tag.

To prevent this from happening, you should configure PID_3Step for simulation with PLCSIM as follows:

- CycleTime.EnEstimation = FALSE
- CycleTime.EnMonitoring = FALSE
- CycleTime.Value: Assign the cycle clock of the calling cyclic interrupt OB in seconds to this tag.

Using PID_Temp

8

8.1 Technology object PID_Temp

The technology object PID_Temp provides a continuous PID controller with integrated tuning. PID_Temp is specially designed for temperature control and is suitable for heating or heating/cooling applications. As of PID_Temp V2, the instruction can also be used for exclusive cooling applications. Two outputs are available for this purpose, one each for heating and cooling. In addition to temperature control, PID_Temp can also be used for other control tasks. PID_Temp can be cascaded and used in manual or automatic mode.

PID_Temp continuously acquires the measured process value within a control loop and compares it with the set setpoint. From the resulting control deviations, the PID_Temp instruction calculates the output values which are used to adjust the process value to the setpoint. The output values for the PID controller consist of three actions:

- Proportional action

  The proportional action of the output value increases in proportion to the control deviation.

- Integral action

  The integral action of the output value increases until the control deviation has been balanced.

- Derivative action

  The derivative action increases with the rate of change of control deviation. The process value is corrected to the setpoint as quickly as possible. The derivative action will be reduced again if the rate of change of control deviation drops.

The instruction PID_Temp calculates the proportional, integral and derivative parameters for your controlled system during "pretuning". "Fine tuning" can be used to tune the parameters further. You do not need to manually determine the parameters.

Either a fixed cooling factor or two PID parameter sets can be used for heating-and-cooling applications.

Additional information

- Overview of software controller (Page 44)
- Add technology objects (Page 46)
- Configure technology objects (Page 47)
- Configuring PID_Temp (Page 162)

8.2 Configuring PID_Temp

8.2.1 Basic settings

8.2.1.1 Introduction

Configure the following properties of the "PID_Temp" technology object under "Basic settings" in the Inspector window or in the configuration window:

- Physical quantity
- Start-up behavior after reset
- Source and input of the setpoint (only in the Inspector window)
- Selection of the process value
- Source and input of the process value (only in the Inspector window)
- Activation (from PID_Temp V2) and selection of the heating output value
- Source and input of the heating output value (only in the Inspector window)
- Activation and selection of the cooling output value
- Source and input of the cooling output value (only in the Inspector window)
- Activation of PID_Temp as master or slave of a cascade
- Number of slaves
- Selection of masters (only in the Inspector window)

Setpoint, process value, heating output value and cooling output value

You can select the source and enter values or tags for the setpoint, process value, heating output value and cooling output value in the Inspector window of the programming editor.

Select the source for each value:

- Instance DB:

  The value saved in the instance DB is used. The value must be updated by the user program in the instance DB. There should be no value at the instruction. Can be changed using HMI.

- Instruction:

  The value connected to the instruction is used. The value is written to the instance DB each time the instruction is called. Cannot be changed using HMI.

8.2.1.2 Controller type

Physical quantity

Select the unit of measurement and physical quantity for the setpoint and the process value in the "Controller type" group. The setpoint and the process value are displayed in this unit.

Startup characteristics

1. To switch to "Inactive"mode after CPU restart, clear the "Activate Mode after CPU restart"check box.

   To switch to the operating mode saved in the Mode parameter after CPU restart, select the "Activate Mode after CPU restart" check box.

2. In the "Set Mode to" drop-down list, select the mode that is to be enabled after a complete download to the device.

   After a complete "Download to device", PID_Temp starts in the selected operating mode. With each additional restart, PID_Temp starts in the mode that was last saved in Mode.

   When selecting pretuning or fine tuning, you also have to set or reset the Heat.EnableTuning and Cool.EnableTuning tags in order to choose between tuning for heating and tuning for cooling.

Example:

You have selected the "Activate Mode after CPU restart" check box and the "Pretuning" entry in the "Set Mode to" list. After a complete "Download to device", PID_Temp starts in the "Pretuning" mode. If pretuning is still active, PID_Temp starts in "Pretuning" mode again after restart of the CPU (heating/cooling depends on the tags Heat.EnableTuning and Cool.EnableCooling). If pretuning was successfully completed and automatic mode is active, PID_Temp starts in "Automatic mode" after restart of the CPU.

8.2.1.3 Setpoint

Procedure

Proceed as follows to define a fixed setpoint:

1. Select "Instance DB".
2. Enter a setpoint, e.g. 80° C.
3. Delete any entry in the instruction.

Proceed as follows to define a variable setpoint:

1. Select "Instruction".
2. Enter the name of the REAL tag in which the setpoint is saved.

   Program-controlled assignment of various values to the REAL tag is possible, for example for the time-controlled change of the setpoint.

8.2.1.4 Process value

PID_Temp will scale the value of the analog input to the physical quantity if you use the analog input value directly.

You will need to write a program for processing if you wish first to process the analog input value. The process value is, for example, not directly proportional to the value at the analog input. The processed process value must be in floating point format.

Procedure

Proceed as follows to use the analog input value without processing:

1. Select the entry "Input_PER" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the address of the analog input.

Proceed as follows to use the processed process value in floating point format:

1. Select the entry "Input" in the drop-down list "Input".
2. Select "Instruction" as source.
3. Enter the name of the variable in which the processed process value is saved.

8.2.1.5 Heating and cooling output value

The PID_Temp instruction provides a PID controller with integrated tuning for temperature processes. PID_Temp is suitable for heating or heating-and-cooling applications. As of PID_Temp V2, the instruction can also be used for exclusive cooling applications.

The activation of heating and cooling determines which outputs can be used, which PID parameter set is used and which tuning is available. With PID_Temp V1.x, the heating is always activated.

- If heating is activated and cooling is deactivated, the output value of the PID algorithm (PidOutputSum) is scaled and output at the outputs for heating. The output value is calculated using the PID parameters for heating. Only the tuning for heating is available.
- If the heating and cooling are activated, positive output values of the PID algorithm (PidOutputSum) are scaled and output at the outputs for heating. Negative output values of the PID algorithm are scaled and output at the outputs for cooling. You can choose between two methods for output value calculation at the output settings (Page 168). The selected method determines which PID parameters are used and which tuning is available.
- If heating is deactivated and cooling is activated, the output value of the PID algorithm (PidOutputSum) is scaled and output at the outputs for cooling. The output value is calculated using the PID parameters for cooling. Only the tuning for cooling is available.

  PID_Temp continues to work with normal control logic: If the setpoint value is below the process value, this results in a negative output value of the PID algorithm (PidOutputSum). This is scaled and output as a positive value at the outputs for cooling. A lower start value of the PID algorithm (PidOutputSum) or a lower manual value (ManualValue) leads to a higher value at the outputs for cooling due to the scaling.

  Example with default setting:

  ManualValue = -50.0 -> OutputCool = 50.0, ManualValue = -100.0 -> OutputCool = 100.0

PID_Temp provides the following output values. Your actuator will determine which output value you use.

- OutputHeat

  Heating output value (floating-point format): The output value for heating needs to be processed by the user program, for example, because of non-linear actuator response.

- OutputHeat_PER

  Analog heating output value: The actuator for heating is triggered via an analog output and controlled with a continuous signal, e.g. 0...10 V, 4...20 mA.

- OutputHeat_PWM

  Pulse-width modulated heating output value: The actuator for heating is controlled via a digital output. Pulse width modulation creates variable ON and OFF times.

- OutputCool

  Cooling output value (floating-point format): The output value for cooling needs to be processed by the user program, for example because of non-linear actuator response.

- OutputCool_PER

  Analog cooling output value: The actuator for cooling is triggered via an analog output and controlled with a continuous signal, e.g. 0...10 V, 4...20 mA.

- OutputCool_PWM

  Pulse-width modulated cooling output value: The actuator for cooling is controlled via a digital output. Pulse width modulation creates variable ON and OFF times.

NOTE

- The OutputHeat_PWM, OutputHeat_PER, OutputCool_PWM, OutputCool_PER outputs are only calculated if you select these correspondingly from the drop-down list.
- The output OutputHeat for PID_Temp as of V2 is calculated if the check box for heating is selected. For PID_Temp V1.x, the OutputHeat output is always calculated.
- The OutputCool output is calculated if the check box for cooling is selected.
- The "Activate heating" check box is only available if the controller is not configured as a master in a cascade or if the check box for cooling is deactivated for the master controller.
- The "Activate cooling" check box is only available if the controller is not configured as a master in a cascade or if the check box for heating is deactivated for the master controller.

Procedure

Proceed as follows to use the analog output value:

1. Select the entry "OutputHeat_PER" or "OutputCool_PER" in the drop-down list "OutputHeat" or "OutputCool".
2. Select "Instruction".
3. Enter the address of the analog output.

Proceed as follows to use the pulse-width modulated output value:

1. Select the entry "OutputHeat_PWM" or "OutputCool_PWM" in the drop-down list "OutputHeat" or "OutputCool".
2. Select "Instruction".
3. Enter the address of the digital output.

Proceed as follows to process the output value using the user program:

1. Select the entry "OutputHeat" or "OutputCool" in the drop-down list "OutputHeat" or "OutputCool".
2. Select "Instruction".
3. Enter the name of the variable you are using to process the output value.
4. Transfer the processed output value to the actuator by means of an analog or digital CPU output.

8.2.1.6 Cascade

If a PID_Temp instance receives its setpoint from a higher-level master controller and outputs its output value in turn to a subordinate slave controller, this PID_Temp instance is both a master controller and a slave controller simultaneously. Both configurations listed below then have to be carried out for such a PID_Temp instance. This is the case, for example, for the middle PID_Temp instance in a cascade control system with three concatenated measured variables and three PID_Temp instances.

Configuring a controller as master in a cascade

A master controller defines the setpoint of a slave controller with its output.

In order to use PID_Temp as master in a cascade, you have to deactivate either the heating or cooling in the basic settings. In order to configure this PID_Temp instance as a master controller in a cascade, activate the "Controller is master" check box. The selection of the output value for heating is set automatically to OutputHeat or OutputCool.

OutputHeat_PWM, OutputCool_PWM, OutputHeat_PER and OutputCool_PER cannot be used at a master in a cascade.

Subsequently specify the number of directly subordinate slave controllers that receive their setpoint from this master controller.

If no own scaling function is used when assigning the OutputHeat or OutputCool parameter of the master to the Setpoint parameter of the slave, it may be necessary to adapt the output value limits and the output scaling of the master to the setpoint / process value range of the slave. This can be done in the output settings of the master in the "OutputHeat / OutputCool" section.

Configuring a controller as a slave in a cascade

A slave controller receives its setpoint (Setpoint parameter) from the output of its master controller (OutputHeat or OutputCool parameter).

In order to configure this PID_Temp instance as a slave controller in a cascade, activate the "Controller is slave" check box in the basic settings.

Subsequently select the PID_Temp instance that is to be used as the master controller for this slave controller in the Inspector window of the programming editor. The Master and Setpoint parameters of the slave controller are interconnected with the selected master controller through this selection (the existing interconnections at these parameters are overwritten). This interconnection allows the exchange of information and the setpoint specification between master and slave. If required, the interconnection can be changed subsequently at the Setpoint parameter of the slave controller in order, for example, to insert an additional filter. The interconnection at the parameter Master may not be changed subsequently.

The "Controller is master" check box must be selected at the selected master controller, and the number of slaves must be configured correctly. The master controller must be called before the slave controller in the same cyclic interrupt OB.

Additional information

Additional information about program creation, configuration and commissioning when PID_Temp is used in cascade control systems is available under Cascade control with PID_Temp (Page 196).

8.2.2 Process value settings

8.2.2.1 Process value limits

You must specify an appropriate absolute high limit and low limit for the process value as limit values for your controlled system. As soon as the process value violates these limits, an error occurs (ErrorBits = 16#0000_0001). Tuning is canceled when the process value limits are violated. You can specify how PID_Temp responds to errors in automatic mode in the output settings.

8.2.2.2 Process value scaling

If you have configured the use of Input_PER in the basic settings, you will need to convert the value of the analog input into the physical quantity of the process value. The current configuration will be displayed in the Input_PER display.

Input_PER is scaled using a low and high value pair if the process value is directly proportional to the value of the analog input.

Procedure

To scale the process value, follow these steps:

1. Enter the low pair of values in the "Scaled low process value" and "Low" input fields.
2. Enter the high pair of values in the "Scaled high process value" and "High" input fields.

Default settings for the value pairs are stored in the HW configuration of CPU S7-1500 and CPU S7-1200 (not S7-1200 G2). Proceed as follows to use the value pairs from the hardware configuration:

1. Select the instruction PID_Temp in the programming editor.
2. Connect Input_PER to an analog input in the basic settings.
3. Click on the "Automatic setting" button in the process value settings.

The existing values are overwritten with the values from the hardware configuration.

8.2.3 Output settings

8.2.3.1 Basic settings of output

Method for heating and cooling

If heating and cooling are activated in the basic settings, the following methods are available for calculating the PID output value:

- PID parameter switching (Config.AdvancedCooling = TRUE):

  The output value calculation for cooling takes place by means of a separate PID parameter set. The PID algorithm decides on the basis of the calculated output value and the control deviation whether the PID parameters for heating or cooling are used. This method is suitable if the heating and cooling actuator have different time responses and different gains.

  Tuning for heating and cooling is available if this method is selected.

- Cooling factor (Config.AdvancedCooling = FALSE):

  Output value calculation for cooling is effected with the PID parameters for heating under consideration of the configurable cooling factor Config.CoolFactor. This method is suitable if the heating and cooling actuators have a similar time response but different gains. If this method is selected, pretuning and fine tuning for cooling as well as the PID parameter set for cooling are not available. You can only execute the tuning for heating.

Cooling factor

If the cooling factor is selected as the method for heating/cooling, this factor is used in the calculation of the output value for cooling. This allows different gains of heating and cooling actuators to be taken into account.

The cooling factor is not set automatically or adjusted during tuning. You must correctly configure the cooling factor manually with the ratio "heating actuator gain / cooling actuator gain".

Example: Cooling factor = 2.0 means that the heating actuator gain is twice as high as the cooling actuator gain.

The cooling factor only takes effect and can only be changed if "Cooling factor" is selected as the method for heating / cooling.

Response to errors

NOTICE
Your system may be damaged. If you output "Current value while error pending" or "Substitute output value while error pending" in the event of an error, PID_Temp remains in automatic or manual mode. This may cause a violation of the process value limits and damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

PID_Temp is preset so that the controller stays active in most cases in the event of an error.

If errors occur frequently in controller mode, this default reaction has a negative effect on the control response. In this case, check the ErrorBits parameter and eliminate the cause of the error.

PID_Temp generates a programmable output value in response to an error:

- Zero (inactive)

  With all errors PID_Temp, switches to the "Inactive" mode and outputs the following:

  – 0.0 as PID output value (PidOutputSum)
  – 0.0 as output value for heating (OutputHeat) and output value for cooling (OutputCool)
  – 0 as analog output value for heating (OutputHeat_PER) and analog output value for cooling (OutputCool_PER)
  – FALSE as PWM output value for heating (OutputHeat_PWM) and PWM output value for cooling (OutputCool_PWM)

  This is independent of the configured output value limits and the scaling. The controller is only reactivated by a falling edge at Reset or a rising edge at ModeActivate.

- Current value while error is pending

  The error response depends on the error occurring and the operating mode.

  If one or more of the following errors occur in automatic mode, PID_Temp stays in automatic mode:

  – 16#0000_0001: The Input parameter is outside the process value limits.
  – 16#0000_0800: Sampling time error
  – 16#0004_0000: Invalid value at Disturbance parameter.
  – 16#0800_0000: Error during the calculation of the PID parameters.

  If one or more of the following errors occur in automatic mode, PID_Temp switches to "Substitute output value with error monitoring" mode and outputs the last valid PID output value (PidOutputSum):

  – 16#0000_0002: Invalid value at Input_PER parameter.
  – 16#0000_0200: Invalid value at Input parameter.
  – 16#0000_0400: Calculation of output value failed.
  – 16#0000_1000: Invalid value at Setpoint or SubstituteSetpoint parameter.

  The values at the outputs for heating and cooling resulting from the PID output value are the result of the configured output scaling.

  As soon as the errors are no longer pending, PID_Temp switches back to automatic mode.

  If an error occurs in manual mode, PID_Temp continues using the manual value as the PID output value.

  If the manual value is invalid, the configured substitute output value is used.

  If the manual value and substitute output value are invalid, the PID output value low limit for heating (Config.Output.Heat.PidLowerLimit) is used.

  If the following error occurs during pretuning or fine tuning, PID_Temp remains in active mode:

  – 16#0000_0020: Pretuning is not permitted during fine tuning.

  When any other error occurs, PID_Temp cancels the tuning and switches to the mode from which tuning was started.

- Substitute output value while error is pending

  PID_Temp behaves as described at "Current value while error is pending", but outputs the configured substitute output value (SubstituteOutput) as a PID output value (PidOutputSum) in "Substitute output value with error monitoring" operating mode.

  The values at the outputs for heating and cooling resulting from the PID output value are the result of the configured output scaling.

  In the case of controllers with activated heating output and cooling output (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), enter:

  – A positive substitute output value to output the value at the outputs for heating.
  – A negative substitute output value to output the value at the outputs for cooling.

If the following error occurs, PID_Temp stays in "Substitute output value with error monitoring" mode and outputs the PID output value low limit for heating (Config.Output.Heat.PidLowerLimit) or the PID output value high limit for cooling (Config.Output.Cool.PidUpperLimit):

– 16#0002_0000: Invalid value at SubstituteOutput tag.

8.2.3.2 Output value limits and scaling

Depending on the operating mode, the PID output value (PidOutputSum) is calculated automatically by the PID algorithm or by the manual value (ManualValue) or the configured substitute output value (SubstituteOutput).

The PID output value is limited as defined in the configuration.

- If the heating is deactivated in the basic settings and the cooling deactivated (Config.ActivateHeating = TRUE, Config.ActivateCooling = FALSE), the value is limited to the PID output value high limit (heating) and the PID output value low limit (heating).
- If the heating and cooling are activated in the basic settings (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the value is limited to the PID output value high limit (heating) and the PID output value low limit (cooling).

  The PID output value low limit (heating) and the PID output value high limit (cooling) cannot be changed and have to be assigned the value 0.0.
- As of PID_Temp V2:

  If heating is deactivated in the basic settings and cooling is activated (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE), the value is limited to the PID output value high limit (cooling) and the PID output value low limit (cooling).

You can configure both limits at the horizontal axis of the scaling characteristic line in the "OutputHeat / OutputCool" section. These are displayed in the "OutputHeat_PWM / OutputCool_PWM" and "OutputHeat_PER / OutputCool_PER" sections, but cannot be changed.

The PID output value is scaled and output at the outputs for heating and cooling. Scaling can be specified separately for each output and is specified across 2 value pairs each, consisting of a limit value of the PID output value and a scaling value:

Output	Value pair	Parameter
OutputHeat	Value pair 1	PID output value high limit (heating) Config.Output.Heat.PidUpperLimit, Scaled high output value (heating) Config.Output.Heat.UpperScaling
	Value pair 2	PID output value low limit (heating) Config.Output.Heat.PidLowerLimit, Scaled low output value (heating) Config.Output.Heat.LowerScaling

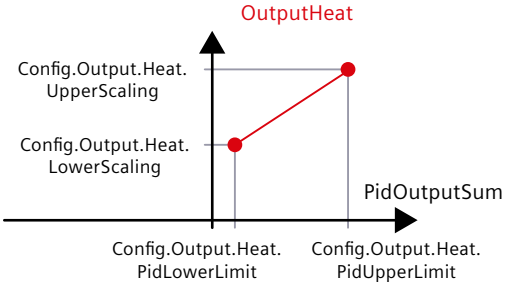
The PID output value low limit (heating) and the PID output value high limit (cooling) must have the value 0.0 if heating and cooling are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE).

Output	Value pair	Parameter
OutputHeat_PWM	Value pair 1	PID output value high limit (heating) Config.Output.Heat.PidUpperLimit, Scaled high PWM output value (heating) Config.Output.Heat.PwmUpperScaling
	Value pair 2	PID output value low limit (heating) Config.Output.Heat.PidLowerLimit, Scaled low PWM output value (heating) Config.Output.Heat.PwmLowerScaling
OutputHeat_PER	Value pair 1	PID output value high limit (heating) Config.Output.Heat.PidUpperLimit, Scaled high analog output value (heating) Config.Output.Heat.PerUpperScaling
	Value pair 2	PID output value low limit (heating) Config.Output.Heat.PidLowerLimit, Scaled low analog output value (heating) Config.Output.Heat.PerLowerScaling
OutputCool	Value pair 1	PID output value low limit (cooling) Config.Output.Cool.PidLowerLimit, Scaled high output value (cooling) Config.Output.Cool.UpperScaling
	Value pair 2	PID output value high limit (cooling) Config.Output.Cool.PidUpperLimit, Scaled low output value (cooling) Config.Output.Cool.LowerScaling
OutputCool_PWM	Value pair 1	PID output value low limit (cooling) Config.Output.Cool.PidLowerLimit, Scaled high PWM output value (cooling) Config.Output.Cool.PwmUpperScaling
	Value pair 2	PID output value high limit (cooling) Config.Output.Cool.PidUpperLimit, Scaled low PWM output value (cooling) Config.Output.Cool.PwmLowerScaling
OutputCool_PER	Value pair 1	PID output value low limit (cooling) Config.Output.Cool.PidLowerLimit, Scaled high analog output value (cooling) Config.Output.Cool.PerUpperScaling
	Value pair 2	PID output value high limit (cooling) Config.Output.Cool.PidUpperLimit, Scaled low analog output value (cooling) Config.Output.Cool.PerLowerScaling

The PID output value low limit (heating) and the PID output value high limit (cooling) must have the value 0.0 if heating and cooling are activated
(Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE).

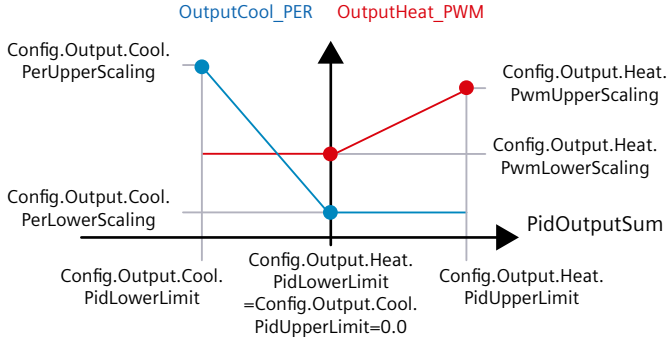
Example:

Output scaling when the OutputHeat output is used (cooling deactivated; the low limit of PID output value (heating) may be unequal to 0.0):



Example:

Output scaling when using output OutputHeat_PWM and OutputCool_PER (heating and cooling activated; the PID output value low limit (heating) and the PID output value high limit (cooling) must have the value 0.0):



With the exception of the "Inactive" operating mode, the value at an output always lies between its scaled high output value and the scaled low output value, for example for OutputHeat always between the scaled high output value (heating) and the scaled low output value (heating).

If you want to limit the value at the associated output, you therefore have to adapt these scaling values as well.

You can configure the scaling values of an output at the vertical axes of the scaling characteristic line. Each output has two separate scaling values. These can only be changed for OutputHeat_PWM, OutputCool_PWM, OutputHeat_PER and OutputCool_PER if the corresponding output is selected in the basic settings. The cooling has to be activated additionally in the basic settings at all the outputs for cooling. Heating must also be activated in the basic settings for all heating outputs.

The trend view in the commissioning dialog box only records the values of OutputHeat and OutputCool, irrespective of the selected output in the basic settings. Therefore, if necessary, adapt the scaling values for OutputHeat or OutputCool if you use OutputHeat_PWM, or OutputHeat_PER or OutputCool_PWM or OutputCool_PER and want to use the trend display in the commissioning dialog.

8.2.4 Advanced settings

8.2.4.1 Process value monitoring

Configure a warning high and low limit for the process value in the "Process value monitoring" configuration window. If one of the warning limits is exceeded or undershot during operation, a warning is displayed at the PID_Temp instruction:

- At the InputWarning_H output parameter if the warning high limit has been exceeded
- At the InputWarning_L output parameter if the warning low limit has been undershot

The warning limits must be within the process value high and low limits.

The process value high and low limits are used if you do not enter values.

Example

Process value high limit = 98° C; warning high limit = 90° C

Warning low limit = 10° C; process value low limit = 0° C

PID_Temp will respond as follows:

Process value	InputWarning_H	InputWarning_L	ErrorBits
> 98 °C	TRUE	FALSE	0001h
≤ 98° C and > 90° C	TRUE	FALSE	0000h
≤ 90° C and ≥ 10° C	FALSE	FALSE	0000h
< 10° C and ≥ 0° C	FALSE	TRUE	0000h
< 0° C	FALSE	TRUE	0001h

You can configure the response of PID_Temp when the process value high limit or low limit is violated in the output settings.

8.2.4.2 PWM limits

The PID output value PidOutputSum is scaled and transformed via a pulse width modulation into a pulse train that is output at the output parameter OutputHeat_PWM or OutputCool_PWM.

The "Sampling time of PID algorithm" represents the time between two calculations of the PID output value. The sampling time is used as time period of the pulse width modulation.

During heating, the PID output value is always calculated in the "Sampling time of PID algorithm for heating".

If heating is deactivated and cooling is activated, the PID output value is always calculated in the "Sampling time PID algorithm for cooling".

If heating and cooling are activated, the calculation of the PID output value during cooling depends on the type of cooling selected in "Basic settings of output":

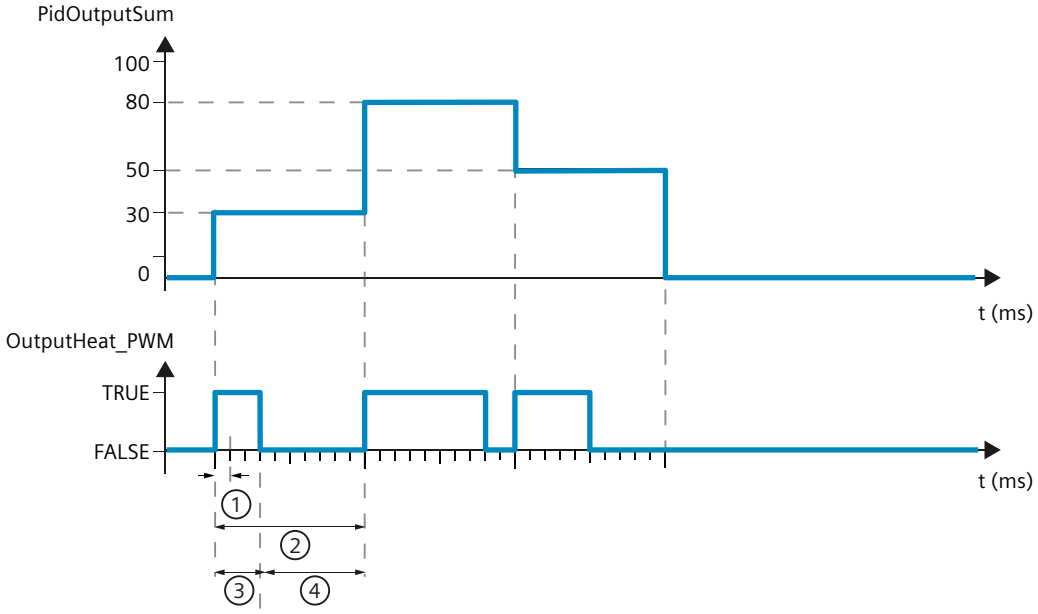
- If the cooling factor is used, the "Sampling time of PID algorithm for heating" applies.
- If the PID parameter switching is used, the "Sampling time of PID algorithm for cooling" applies.

The PID algorithm sampling time for heating or cooling is determined during pretuning or fine tuning. If you set the PID parameters manually, you will also need to configure the PID algorithm sampling time for heating or cooling.

OutputHeat_PWM and OutputCool_PWM are output in the PID_Temp sampling time. The PID_Temp sampling time is equivalent to the cycle time of the calling OB.

The pulse duration is proportional to the PID output value and is always an integer multiple of the PID_Temp sampling time.

Example for OutputHeat_PWM



① PID_Temp sampling time

② PID algorithm sampling time for heating

③ Pulse duration

④ Break time

The "Minimum ON time" and the "Minimum OFF time" can be set separately for heating and cooling, rounded to an integer multiple of the PID_Temp sampling time.

A pulse or a break is never shorter than the minimum ON or OFF time. The inaccuracies this causes are added up and compensated in the next cycle.

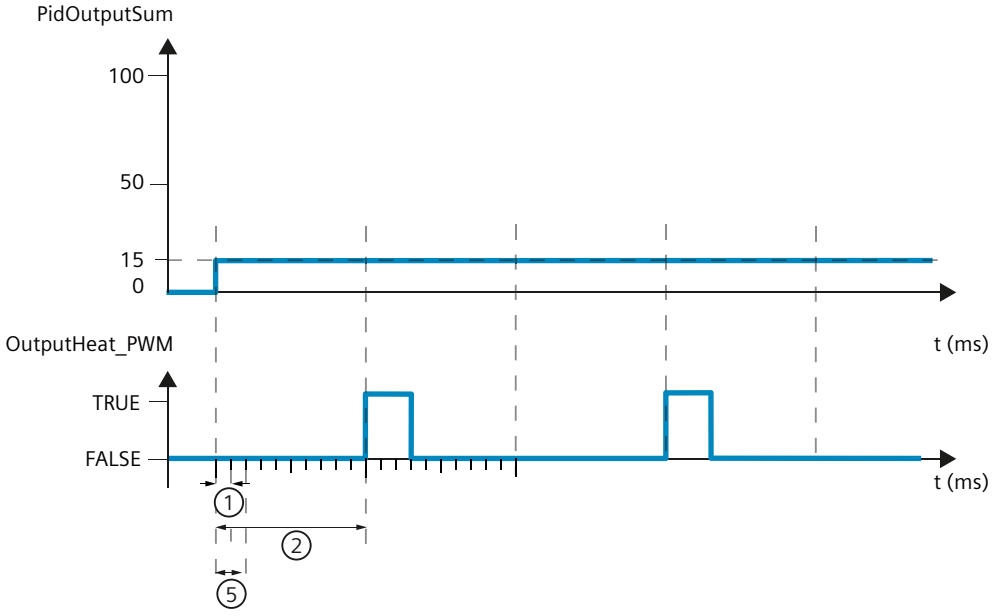
Example for OutputHeat_PWM

PID_Temp sampling time (equivalent to the cycle time of the calling OB) = 100 ms

PID algorithm sampling time (equivalent to the time period) = 1000 ms

Minimum ON time = 200 ms

The PID output value PidOutputSum amounts to a constant 15%. The smallest pulse that PID_Temp can output corresponds to 20%. In the first cycle, no pulse is output. In the second cycle, the pulse not output in the first cycle is added to the pulse of the second cycle.



① PID_Temp sampling time

② PID algorithm sampling time for heating

⑤ Minimum ON time

In order to minimize operation frequency and conserve the actuator, extend the minimum ON and OFF times.

If you have selected OutputHeat or OutputCool or OutputHeat_PER or OutputCool_PER as the output in the basic settings, the minimum ON time and the minimum OFF time are not evaluated and cannot be changed.

If the "sampling time of the PID algorithm" (Retain.CtrlParams.Heat.Cycle bzw. Retain.CtrlParams.Cool.Cycle) and thus the period duration of the pulse width modulation is very high when OutputHeat_PWM or OutputCool_PWM is used, you can specify a deviating shorter period duration with the Config.Output.Heat.PwmPeriode or Config.Output.Cool.PwmPeriode (Page 428) parameters in order to improve smoothing of the process value.

NOTE

The minimum ON and OFF times only affect the output parameters OutputHeat_PWM or OutputCool_PWM and are not used for any pulse generators integrated in the CPU.

8.2.4.3 PID parameters

The PID parameters are displayed in the "PID Parameters" configuration window.

If heating and cooling are activated in the basic settings and PID parameter switching is selected as the method for heating/cooling in the output settings, two parameter sets are available: One for heating and one for cooling. In this case, the PID algorithm decides on the basis of the calculated output value and the control deviation whether the PID parameters for heating or cooling are used.

If heating is activated and the cooling deactivated or the cooling factor is selected as the method for heating/cooling, the parameter set for heating is always used.

If heating is deactivated and cooling is activated, the parameter set for cooling is always used.

During tuning, the PID parameters are adapted to the controlled system with the exception of the dead zone width that has to be configured manually.

NOTE

The currently active PID parameters are located in the Retain.CtrlParams structure.

Change the currently active PID parameters only in "Inactive" mode online to prevent malfunction of the PID controller.

If you want to change the PID parameters in "Automatic mode" or "Manual mode" online, change the PID parameters in the CtrlParamsBackUp structure and apply these changes with LoadBackUp = TRUE to the Retain.CtrlParams structure.

Online changes to the PID parameters in "Automatic mode" can result in jumps at the output value.

PID_Temp is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions.

The PID algorithm operates according to the following transfer function (control zone and dead zone deactivated):

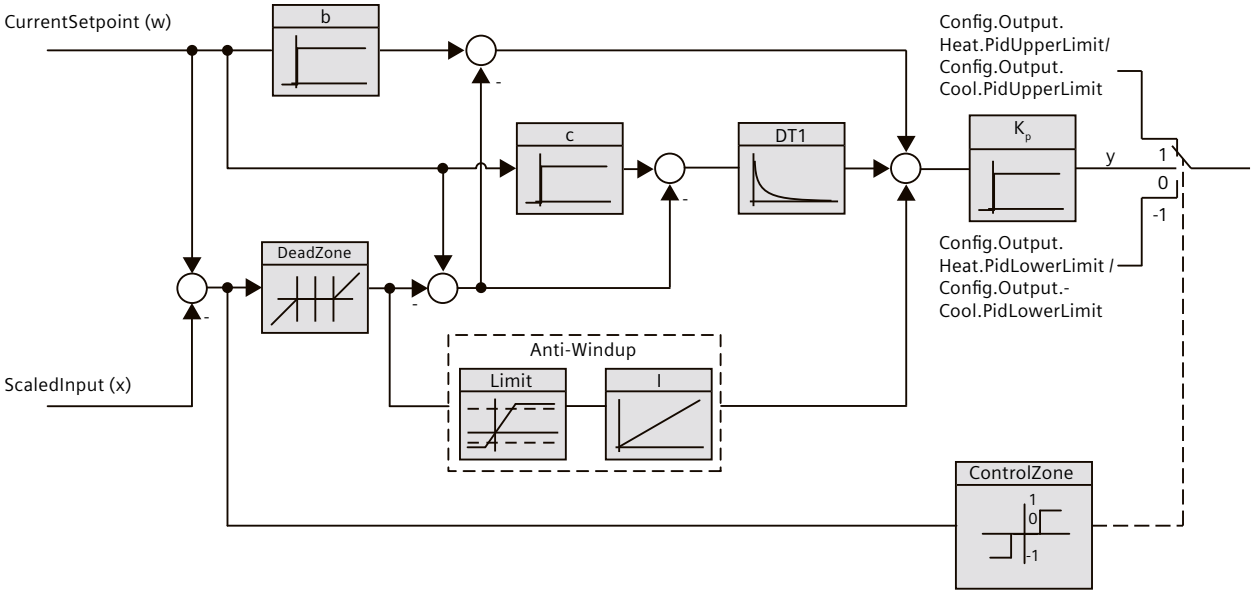
$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s}(w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1}(c \cdot w - x)\right]$$

The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Symbol	Description	Associated parameters of the PID_Temp instruction
y	Output value of the PID algorithm	-
K_p	Proportional gain	Retain.CtrlParams.Heat.Gain Retain.CtrlParams.Cool.Gain CoolFactor
s	Laplace operator	-
b	Proportional action weighting	Retain.CtrlParams.Heat.PWeighting Retain.CtrlParams.Cool.PWeighting
w	Setpoint	CurrentSetpoint
x	Process value	ScaledInput

Symbol	Description	Associated parameters of the PID_Temp instruction
T_I	Integration time	Retain.CtrlParams.Heat.Ti Retain.CtrlParams.Cool.Ti
T_D	Derivative action time	Retain.CtrlParams.Heat.Td Retain.CtrlParams.Cool.Td
a	Coefficient for derivative-action delay (Derivative delay T1 = a × T_D)	Retain.CtrlParams.Heat.TdFiltRatio Retain.CtrlParams.Cool.TdFiltRatio
c	Derivative action weighting	Retain.CtrlParams.Heat.DWeighting Retain.CtrlParams.Cool.DWeighting
DeadZone	Dead zone width	Retain.CtrlParams.Heat.DeadZone Retain.CtrlParams.Cool.DeadZone
ControlZone	Control zone width	Retain.CtrlParams.Heat.ControlZone Retain.CtrlParams.Cool.ControlZone

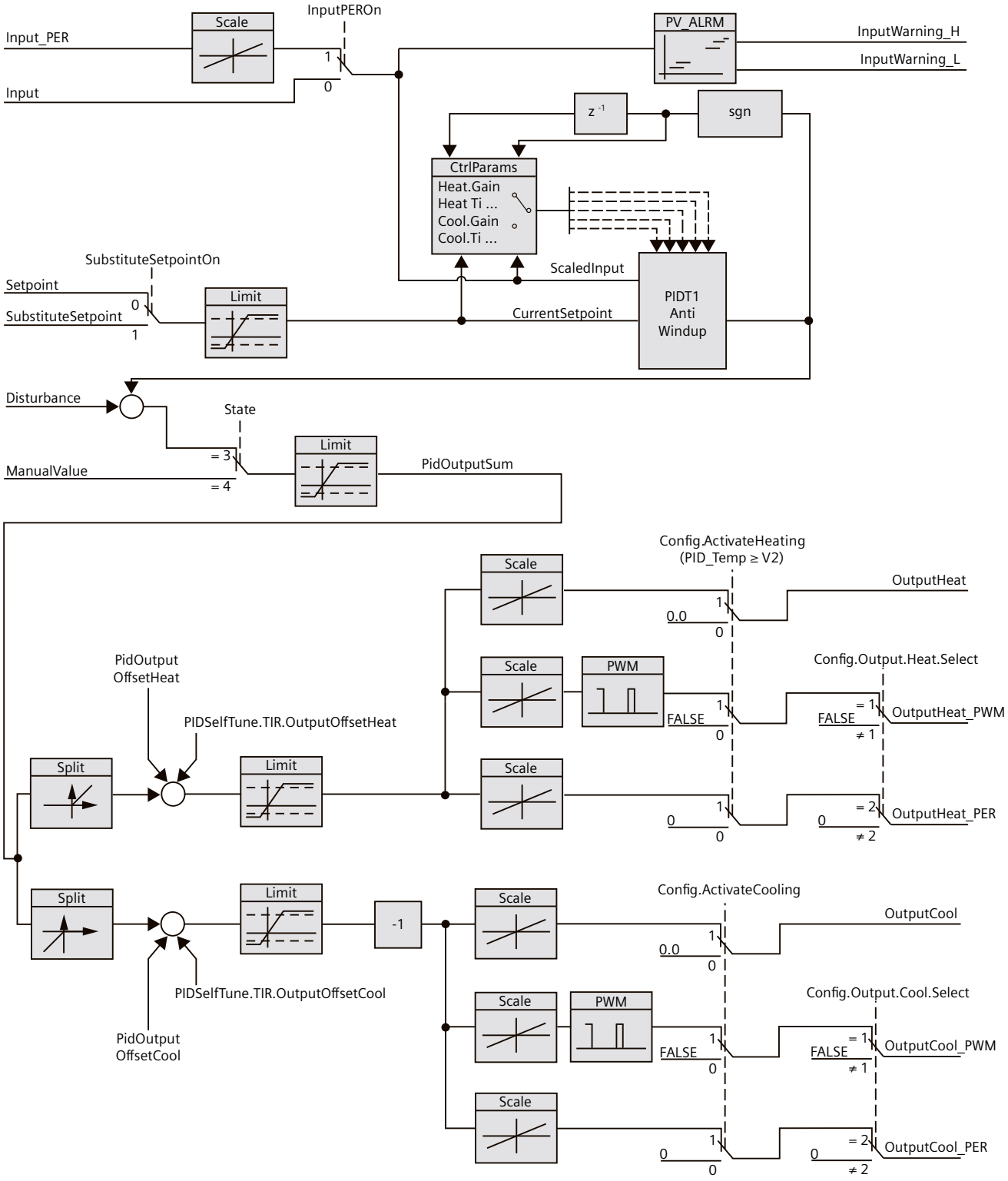
The diagram below illustrates the integration of the parameters into the PID algorithm:



All PID parameters are retentive. If you enter the PID parameters manually, you must completely download PID_Temp (Downloading technology objects to device (Page 49)).

PID_Temp block diagram

The following block diagram shows how the PID algorithm is integrated in the PID_Temp.



Proportional gain

The value specifies the proportional gain of the controller. PID_Temp does not operate with a negative proportional gain and only supports the normal control logic, meaning that an increase in the process value is achieved by an increase in the PID output value (PidOutputSum).

When cooling is activated, negative PID output values are output as positive values at the outputs for cooling due to the output scaling.

Integration time

The integration time determines the time response of the integral action. The integral action is deactivated with integration time = 0.0. When the integration time is changed from a different value to 0.0 online in "Automatic mode", the previous integral action is deleted and the output value jumps.

If the PID output value (PidOutputSum) reaches an output value limit in automatic mode, the integral action is stopped depending on the direction (anti-windup). As of PID_Temp Version 2.0, the integral component is also actively limited in order to prevent delayed control behavior, e.g. when the output value limits change. Changes to the following tags can lead to an adjustment of the integral component in automatic mode:

- Output value limits (Config.Output.Heat.PidUpperLimit, Config.Output.Heat.PidLowerLimit, Config.Output.Cool.PidUpperLimit and Config.Output.Cool.PidLowerLimit tags)
- Setpoint (Setpoint and SubstituteSetpoint tag)
- Proportional gain (Retain.CtrlParams.Heat.Gain or Retain.CtrlParams.Cool.Gain tag)
- Proportional action weighting (Retain.CtrlParams.Heat.PWeighting or Retain.CtrlParams.Cool.PWeighting tag)
- Disturbance variable (Disturbance variable)

As of PID_Temp V2, it is possible to use the static tags PIDCtrl.IntegralHoldPositive and PIDCtrl.IntegralHoldNegative to manually stop the integral action in the positive or negative direction.

Derivative action time

The derivative action time determines the time response of the derivative action. Derivative action is deactivated with derivative action time = 0.0.

Derivative delay coefficient

The derivative delay coefficient delays the effect of the derivative action.

Derivative delay = derivative action time × derivative delay coefficient

- 0.0: Derivative action is effective for one cycle only and therefore almost not effective.
- 0.5: This value has proved useful in practice for controlled systems with one dominant time constant.
- > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed.

Proportional action weighting

The proportional action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Proportional action for setpoint change is fully effective
- 0.0: Proportional action for setpoint change is not effective

The proportional action is always fully effective when the process value is changed.

Derivative action weighting

The derivative action may weaken with changes to the setpoint.

Values from 0.0 to 1.0 are applicable.

- 1.0: Derivative action is fully effective upon setpoint change
- 0.0: Derivative action is not effective upon setpoint change

The derivative action is always fully effective when the process value is changed.

PID algorithm sampling time

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The "Sampling time of PID algorithm" represents the time between two calculations of the PID output value. It is calculated during tuning and rounded to a multiple of the PID_Temp sampling time (cycle time of the cyclic interrupt OB). All other functions of PID_Temp are executed at every call.

If you use OutputHeat_PWM or OutputCool_PWM, the sampling time of the PID algorithm is additionally used as the period duration of the pulse width modulation. The accuracy of the output signal is determined by the ratio of the PID algorithm sampling time to the cycle time of the OB. The cycle time should be no more than a tenth of the PID algorithm sampling time.

The sampling time of the PID algorithm that is used as the period duration of the pulse width modulation for OutputCool_PWM depends on the method selected for heating/cooling in "Basic settings of output" when heating and cooling are activated:

- If the cooling factor is used, the "sampling time of the PID algorithm for heating" also applies to OutputCool_PWM.
- If PID parameter switching is used, the "sampling time PID algorithm for cooling" applies as the period duration for OutputCool_PWM.

If the sampling time of the PID algorithm and thus the period duration of the pulse width modulation is very high when OutputHeat_PWM or OutputCool_PWM is used, you can specify a deviating shorter period duration with the Config.Output.Heat.PwmPeriode or Config.Output.Cool.PwmPeriode (Page 428) parameters in order to improve smoothing of the process value.

Dead zone width

If the process value is affected by noise, the noise can also have an effect on the output value. The output value may fluctuate considerably when the controller gain is high and the derivative action is activated. If the process value lies within the dead zone around the setpoint, the control deviation is suppressed so that the PID algorithm does not react and unnecessary fluctuations of the output value are reduced.

The dead zone width for heating or cooling is not set automatically during tuning. You must correctly configure the dead zone width manually. The dead zone is deactivated by setting the dead zone width = 0.0.

When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning.

For controllers with activated heating output and deactivated cooling output, or controllers with activated heating output and cooling output with cooling factor, the dead zone is located symmetrically between "Setpoint - Dead zone width (heating)" and "Setpoint + Dead zone width (heating)".

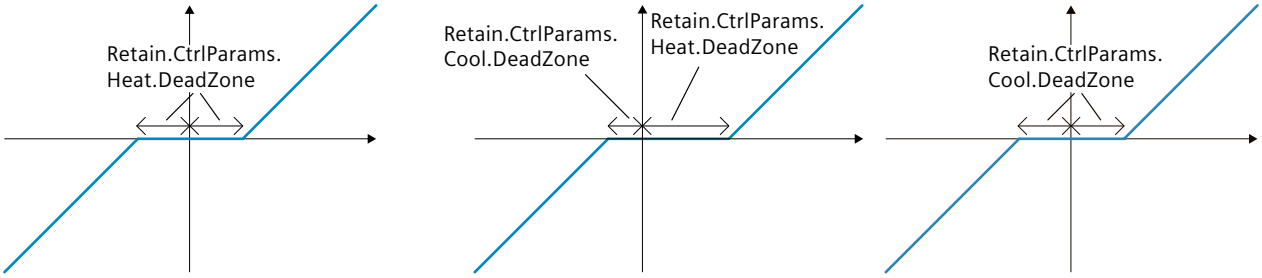
For controllers with activated heating output and cooling output with PID parameter switching, the dead zone is between "Setpoint - Dead zone width (heating)" and "Setpoint + Dead zone width (cooling)".

For controllers with deactivated heating output and activated cooling output, the dead zone is symmetrical between "Setpoint - Dead zone width (cooling)" and "Setpoint + Dead zone width (cooling)".

If values other than 1.0 are configured for the proportional action weighting or the derivative action weighting, setpoint changes even within the dead zone affect the output value.

Process value changes within the dead zone do not affect the output value, regardless of the weighting.

Dead zone depending on the configuration:



- Activated heating and deactivated cooling or activated heating and cooling with cooling factor (left)
- Activated heating and cooling with PID parameter switching (center)
- Deactivated heating and activated cooling (right)

The x / horizontal axis displays the Control deviation = Setpoint - Process value. The Y / vertical axis shows the output signal of the dead zone that is passed to the PID algorithm.

Control zone width

If the process value exits the control zone around the setpoint, the minimum or maximum output value is output. This means that the process value reaches the setpoint faster.

If the process value lies within the control zone around the setpoint, the output value is calculated by the PID algorithm.

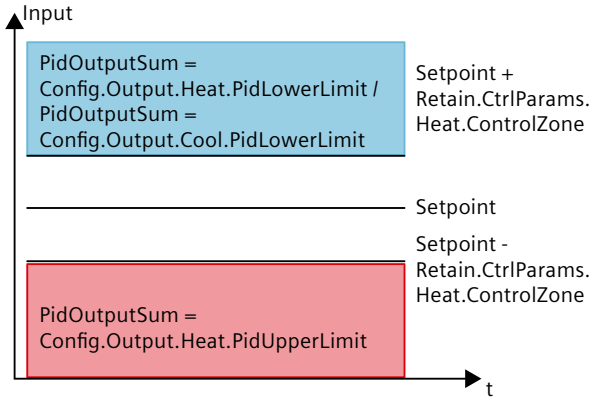
The control zone width for heating or cooling is only set automatically during the pretuning, if "PID (temperature)" is selected as the controller structure for cooling or heating (PIDSelfTune.SUT.TuneRuleHeat = 2 or PIDSelfTune.SUT.TuneRuleCool = 2).

The control zone is deactivated by setting the control zone width = 3.402822e+38.

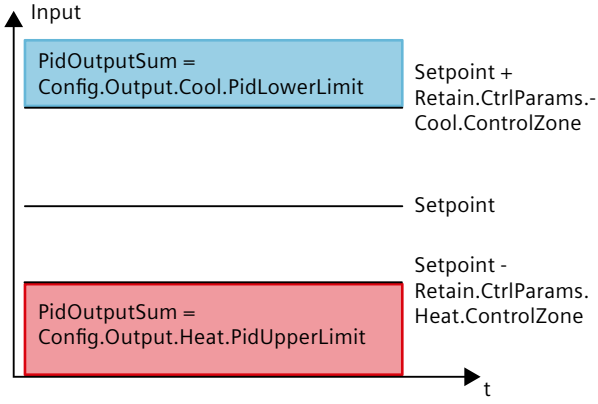
For controllers with activated heating output and deactivated cooling output or controllers with activated heating output and cooling output with cooling factor, the control zone is symmetrical between "Setpoint - Control zone width (heating)" and "Setpoint + Control zone width (heating)".

For controllers with activated heating output and cooling output with PID parameter switching, the control zone is between "Setpoint - Control zone width (heating)" and "Setpoint + Control zone width (cooling)".

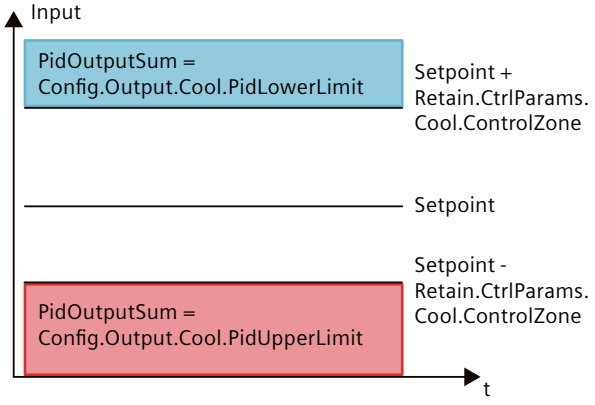
For controllers with deactivated heating output and activated cooling output, the control zone is symmetrical between "Setpoint - Control zone width (cooling)" and "Setpoint + Control zone width (cooling)".



Control zone with activated heating and deactivated cooling or activated heating and cooling with cooling factor.



Control zone with activated heating and cooling and PID parameter switching.



Control zone with deactivated heating and activated cooling.

Rule for tuning

Select whether PI or PID parameters are to be calculated in the "Controller structure" drop-down list. You can specify the rules for tuning for heating and for tuning for cooling separately.

- PID (temperature)

  Calculates PID parameters during pretuning and fine tuning.

  Pretuning is designed for temperature processes and results in a slower and rather asymptotic control response with lower overshoot than with the "PID" option. Fine tuning is identical to the "PID" option.

  The control zone width is determined automatically during pretuning only if this option is selected.

- PID

  Calculates PID parameters during pretuning and fine tuning.

- PI

  Calculates PI parameters during pretuning and fine tuning.

- User-defined

  The drop-down list displays "User-defined" if you have configured different controller structures for pretuning and fine tuning via a user program or the parameter view.

8.3 Commissioning PID_Temp

8.3.1 Commissioning

The commissioning window helps you commission the PID controller. You can monitor the values for the setpoint, process value and the output values for heating and cooling along the time axis in the trend view. The following functions are supported in the commissioning window:

- Controller pretuning
- Controller fine tuning

  Use fine tuning for fine adjustments to the PID parameters.

- Observation of the current control in the trend display
- Testing the controlled system by specifying a manual PID output value and a substitute setpoint
- Saving the actual values of the PID parameters to an offline project.

All functions require an online connection to the CPU.

The online connection to the CPU is established, if it does not exist already, and operation of the commissioning window is enabled by means of the "Monitor all" or "Start" buttons of the trend view.

Operation of the trend view

- Select the desired sampling time in the "Sampling time" drop-down list.

  All the values of the trend view are updated in the selected sampling time.
- Click the "Start" icon in the Measurement group if you want to use the trend display.

  Value recording is started. The current values for the setpoint, process value and output values for heating and cooling are entered in the trend view.
- Click the "Stop" icon if you want to close the trend display.

  The values recorded in the trend view can continue to be analyzed.

Closing the commissioning window will terminate recording in the trend view and delete the recorded values.

8.3.2 Pretuning

The pretuning determines the process response to a jump change of the output value and searches for the point of inflection. The optimized PID parameters are calculated as a function of the maximum rate of rise and dead time of the controlled system. You obtain the best PID parameters when you perform pretuning and fine tuning.

The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. This is most likely the case in operating modes "Inactive" or "Manual mode". The PID parameters are backed up before being recalculated.

PID_Temp offers different pretuning types depending on the configuration:

- Pretuning heating

  A jump is output at the output value heating, the PID parameters for heating are calculated and control to the setpoint then takes place in automatic mode.
- Pretuning heating and cooling

  A jump is output at the output value heating.

  As soon as the process value is close to the setpoint, a jump change is output at the output value cooling.

  The PID parameters for heating (Retain.CtrlParams.Heat structure) and cooling (Retain.CtrlParams.Cool structure) are calculated and then the setpoint is used as the control variable in automatic mode.
- Pretuning cooling

  A jump is output at the output value cooling.

  The PID parameters for cooling are calculated and then the setpoint is used as the control variable in automatic mode.

Depending on the configuration, the pretuning cooling can be started from two different operating states:

– After pretuning for heating and with process value close to the setpoint:

  This option is available for all versions of PID_Temp for controllers with activated heating output and cooling output with PID parameter switching.

– With distance between process value and setpoint:

  This option is also available for PID_Temp as of V2.0 for controllers with activated cooling output regardless of the activation of the heating output.

If you want to tune the PID parameters for heating and cooling, you can expect improved control response by carrying out "Pretuning heating" and subsequently "Pretuning cooling" than by carrying out "Pretuning heating and cooling". However, carrying out pretuning in two steps takes more time.

General requirements

- The PID_Temp instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- PID_Temp is in one of the following modes: "Inactive", "Manual mode", or "Automatic mode".
- The setpoint and the process value lie within the configured limits (see Process value monitoring (Page 174) configuration).
- The variables Heat.EnableTuning and Cool.EnableTuning are set automatically when the commissioning editor is used. If you are not using the commissioning editor, you must enter the appropriate values for both tags yourself.

Requirements for pretuning heating

- The heating output in the "Basic settings" is activated (Config.ActivateHeating = TRUE).
- The difference between setpoint and process value is greater than 30% of the difference between process value high limit and process value low limit.
- The distance between the setpoint and the process value is greater than 50% of the setpoint.
- The setpoint is greater than the process value.

Requirements for pretuning heating and cooling

- The heating and cooling output in the "Basic settings" are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE).
- The PID parameter switching in the "Basic settings of output" is activated (Config.AdvancedCooling = TRUE).
- The difference between setpoint and process value is greater than 30% of the difference between process value high limit and process value low limit.
- The distance between the setpoint and the process value is greater than 50% of the setpoint.
- The setpoint is greater than the process value.

Requirements for pretuning cooling with process value close to the setpoint

- The heating and cooling output in the "Basic settings" are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE).
- The PID parameter switching in the "Basic settings of output" is activated (Config.AdvancedCooling = TRUE).
- "Pretuning heating" or "Pretuning heating and cooling" has been carried out successfully if possible at the same setpoint. Successful execution is indicated by PIDSelfTune.SUT.ProcParHeatOk = TRUE .
- The difference between setpoint and process value is less than 5% of the difference between process value high limit and process value low limit.

Requirements for pretuning cooling with distance between process value and setpoint

- PID_Temp as of V2.0
- The cooling output in the "Basic settings" is activated (Config.ActivateCooling = TRUE).
- If the heating output is activated (Config.ActivateHeating = TRUE), PID parameter switching must also be activated (Config.AdvancedCooling = TRUE).
- The difference between setpoint and process value is greater than 30% of the difference between process value high limit and process value low limit.
- The distance between the setpoint and the process value is greater than 50% of the setpoint.
- The setpoint is less than the process value.

Procedure

To perform pretuning, follow these steps:

1. Double-click the "PID_Temp > Commissioning" entry in the project tree.
2. Activate the "Monitor all" button or start the trend view.

   An online connection will be established.
3. Select the desired pretuning entry from the "Tuning mode" drop-down list.
4. Click the "Start" icon.
   - Pretuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred. The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon when the progress bar ("Progress" tag) has not changed for a long period and it is to be assumed that the tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

Result

If pretuning was performed without an error message, the PID parameters have been tuned. PID_Temp switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If pretuning is not possible, PID_Temp responds with the configured reaction to errors.

8.3.3 Fine tuning

Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are tuned for the operating point from the amplitude and frequency of this oscillation. The PID parameters are recalculated from the results. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. You obtain the best PID parameters when you perform pretuning and fine tuning.

PID_Temp automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The PID parameters are backed up before being recalculated.

PID_Temp offers different fine tuning types depending on the configuration:

- Fine tuning heating:

  PID_Temp generates an oscillation of the process value with periodic changes at the output value heating and calculates the PID parameters for heating.
- Fine tuning cooling:

  PID_Temp generates an oscillation of the process value with periodic changes at the output value cooling and calculates the PID parameters for cooling.

Temporary tuning offset for heating/cooling controllers

If PID_Temp is used as a heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the PID output value (PidOutputSum) at the setpoint has to fulfill the following requirements so that process value oscillation can be generated and fine tuning can be carried out successfully:

- Positive PID output value for fine tuning heating
- Negative PID output value for fine tuning cooling

If this condition is not fulfilled, you can specify a temporary offset for fine tuning that is output at the opposing output.

- Offset for cooling output (PIDSelfTune.TIR.OutputOffsetCool) at fine tuning heating.

  Before starting tuning, enter a negative tuning offset cooling that is lower than the PID output value (PidOutputSum) at the setpoint in the stationary state.
- Offset for heating output (PIDSelfTune.TIR.OutputOffsetHeat) at fine tuning cooling

  Before starting tuning, enter a positive tuning offset heating that is higher than the PID output value (PidOutputSum) at the setpoint in the stationary state.

The defined offset is balanced by the PID algorithm so that the process value remains at the setpoint. The height of the offset allows the PID output value to be adapted correspondingly so that it fulfills the requirement mentioned above.

To avoid larger overshoots of the process value when defining the offset, it can also be increased in several steps.

If PID_Temp exits the fine tuning mode, the tuning offset is reset.

Example: Specification of an offset for fine tuning cooling

- Without offset
  - Setpoint = Process value (ScaledInput) = 80 °C
  - PID output value (PidOutputSum) = 30.0
  - Output value heating (OutputHeat) = 30.0
  - Output value cooling (OutputCool) = 0.0

    Oscillation of the process value around the setpoint cannot be generated with the cooling output alone. Fine tuning would fail here.
- With offset for heating output (PIDSelfTune.TIR.OutputOffsetHeat) = 80.0
  - Setpoint = Process value (ScaledInput) = 80 °C
  - PID output value (PidOutputSum) = -50.0
  - Output value heating (OutputHeat) = 80.0
  - Output value cooling (OutputCool) = -50.0

    Thanks to the specification of an offset for the heating output, the cooling output can now generate oscillation of the process value around the setpoint. Fine tuning can now be carried out successfully.

General requirements

- The PID_Temp instruction is called in a cyclic interrupt OB.
- ManualEnable = FALSE
- Reset = FALSE
- The setpoint and the process value lie within the configured limits (see "Process value settings" configuration).
- The control loop has stabilized at the operating point. The operating point is reached when the process value corresponds to the setpoint.

  When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning.
- No disturbances are expected.
- PID_Temp is in inactive mode, automatic mode or manual mode.
- The Heat.EnableTuning and Cool.EnableTuning tags are set automatically when the commissioning editor is used. If you are not using the commissioning editor, you must enter the appropriate values for both tags yourself.

Requirements for fine tuning heating

- The heating output is activated (Config.ActivateHeating = TRUE).
- If PID_Temp is configured as a heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the heating output has to be active at the operating point at which tuning is to be performed.

  PidOutputSum > 0.0 (see tuning offset)

Requirements for fine tuning cooling

- The cooling output is activated (Config.ActivateCooling = TRUE).
- If the heating output is activated (Config.ActivateHeating = TRUE), PID parameter switching must also be activated (Config.AdvancedCooling = TRUE).
- If PID_Temp is configured as a heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the heating output has to be active at the operating point at which tuning is to be performed.

  PidOutputSum < 0.0 (see tuning offset)

Process depends on initial situation

Fine tuning can be started from the following operating modes: "Inactive", "automatic mode", or "manual mode".

Fine tuning proceeds as follows when started from:

- Automatic mode with PIDSelfTune.TIR.RunIn = FALSE (default)

  Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning.

  PID_Temp controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start.

- Inactive, manual mode or automatic mode with PIDSelfTune.TIR.RunIn = TRUE

  An attempt is made to reach the setpoint with the minimum or maximum output value (two-point control):

  – With minimum or maximum output value heating at fine tuning heating.

  – With minimum or maximum output value cooling for fine tuning cooling.

  This can produce increased overshoot. When the setpoint is reached, fine tuning is started.

  If the setpoint cannot be reached, PID_Temp does not abort tuning automatically.

Procedure

To perform fine tuning, follow these steps:

1. Double-click the "PID_Temp > Commissioning" entry in the project tree.
2. Activate the "Monitor all" button or start the trend view.

   An online connection will be established.
3. Select the desired fine tuning entry from the "Tuning mode" drop-down list.
4. If required (see tuning offset), specify a tuning offset and wait until the stationary state is reached again.

5. Click the "Start" icon.
   - The process of fine tuning is started.
   - The "Status" field displays the current steps and any errors that may have occurred.

     The progress bar indicates the progress of the current step.

NOTE

Click the "Stop" icon in the "Tuning mode" group if the progress bar ("Progress" tag) has not changed for a long period and it is to be assumed that the tuning function is blocked. Check the configuration of the technology object and, if necessary, restart controller tuning.

In the following phases in particular, tuning is not aborted automatically if the setpoint cannot be reached.

- "Attempting to reach setpoint for heating with two-point control."
- "Attempting to reach setpoint with two-step control cooling."

Result

If fine tuning was performed without errors, the PID parameters have been tuned. PID_Temp switches to automatic mode and uses the tuned parameters. The tuned PID parameters will be retained during power OFF and a restart of the CPU.

If errors occurred during fine tuning, PID_Temp responds with the configured response to errors.

8.3.4 "Manual" mode

In manual mode, a manual PID output value is specified via the ManualValue parameter. The resulting output values for heating and cooling are determined by the configured output scaling. With the preset output scaling, specify a negative manual value to obtain a positive value at the outputs for cooling.

The following section describes how you can use the "manual mode" operating mode in the commissioning window of the "PID_Temp" technology object.

Manual mode is also possible when an error is pending.

Requirement

- The "PID_Temp" instruction is called in a cyclic interrupt OB.
- An online connection to the CPU has been established.
- The CPU is in "RUN" mode.

Procedure

Use "Manual mode" in the commissioning window if you want to test the controlled system by specifying a manual value.

To define a manual value, follow these steps:

1. Double-click the "PID_Temp > Commissioning" entry in the project tree.
2. Activate the "Monitor all" button or start the trend view.

   An online connection will be established.
3. Select the "Manual mode" check box in the "Online status of controller" area.

   PID_Temp operates in manual mode. The most recent current output value remains in effect.
4. Enter the manual value in the editable field as a % value.

   If heating and cooling are activated in the basic settings, enter the manual value as follows:

   – Enter a positive manual value to output the value at the outputs for heating.
   – Enter a negative manual value to output the value at the outputs for cooling.
5. Click the icon.

Result

The manual value is written to the CPU and immediately goes into effect.

Clear the "Manual mode" check box if the output value is to be specified again by the PID controller.

The switchover to automatic mode is bumpless.

8.3.5 Substitute setpoint

The following section describes how you can use the substitute setpoint in the commissioning window of the "PID_Temp" technology object.

Requirement

- The "PID_Temp" instruction is called in a cyclic interrupt OB.
- An online connection to the CPU has been established.
- The CPU is in "RUN" mode.

Procedure

If you want to use a different value as the setpoint than that specified at the "Setpoint" parameter (for example to tune a slave in a cascade), use the substitute setpoint in the commissioning window.

Proceed as follows to specify a substitute setpoint:

1. Double-click the "PID_Temp > Commissioning" entry in the project tree.
2. Activate the "Monitor all" button or start the trend view.

   An online connection will be established.
3. Select the "Subst.Setpoint" check box in the "Online status of controller" section.

   The substitute setpoint (SubstituteSetpoint tag) is initialized with the most recently updated setpoint and now used.
4. Enter the substitute setpoint in the editable field.
5. Click the icon.

Result

The substitute setpoint is written to the CPU and immediately goes into effect.

Clear the "Subst.Setpoint" check box if the value at the "Setpoint" parameter is to be used again as setpoint.

The switchover is not bumpless.

8.3.6 Cascade commissioning

Information about cascade commissioning with PID_Temp is available under Commissioning (Page 201).

8.4 Cascade control with PID_Temp

8.4.1 Introduction

In cascade control, several control loops are nested within each other. In the process, slaves receive their setpoint (Setpoint) from the output value (OutputHeat or OutputCool) of the respective higher-level master.

A prerequisite for establishing a cascade control system is that the controlled system can be divided into subsystems, each with its own measured variable.

Setpoint specification for the controlled variable is carried out at the outmost master.

The output value of the innermost slave is applied to the actuator and thus acts on the controlled system.

The following major advantages result from the use of a cascade control system in comparison with a single-loop control system:

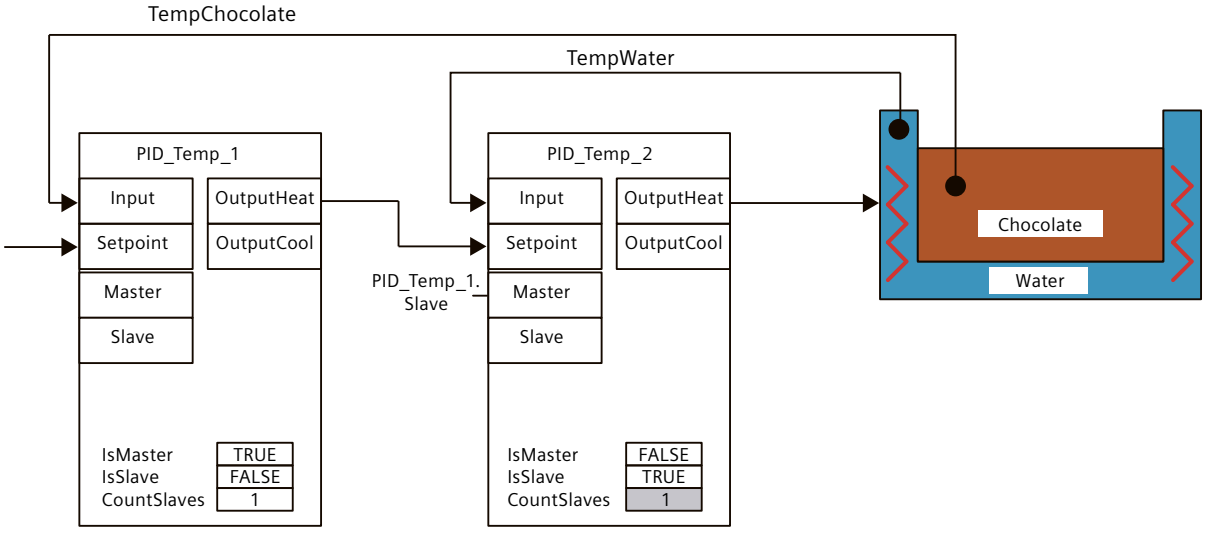
- Thanks to the additional subordinate control loops, disturbances which occur there are corrected quickly. Their influence on the controlled variable is reduced considerably. The disturbance behavior is thus improved.
- The subordinate control loops act in linearizing form. The negative effects of such non-linearities on the controlled variable are thus moderated.

PID_Temp offers the following functionality especially for use in cascade control systems:

- Specification of a substitute setpoint
- Exchange of status information between master and slave (for example, current operating mode)
- Different Anti-Windup modes (response of the master to limitation of its slave)

Example

The following block diagram shows a cascade control system with PID_Temp using the simplified example of a chocolate melting unit:



The PID_Temp_1 master compares the process value of the chocolate temperature (TempChocolate) with the setpoint specification by the user at the Setpoint parameter. Its output value OutputHeat forms the setpoint of the slave PID_Temp_2.

PID_Temp_2 attempts to regulate the process value of the water-bath temperature (TempWater) to this setpoint. The output value of PID_Temp_2 acts directly on the actuator of the controlled system (heating of the water bath) and thus influences the water-bath temperature. The water-bath temperature in turn has an effect on the chocolate temperature.

As an increasing water bath temperature causes an increasing chocolate temperature, only the heating is activated on the PID_Temp_1 master (Config.ActivateHeating = TRUE, Config.ActivateCooling = FALSE) and the output value OutputHeat is used as the setpoint for the slave.

FAQ

For more information, see the following FAQs in the Siemens Industry Online Support:

- Entry ID 103526819 (https://support.industry.siemens.com/cs/ww/en/view/103526819)

See also

Program creation (Page 198)

8.4.2 Program creation

Note the following points during program creation:

- Number of PID_Temp instances

  The number of different PID_Temp instances called up in a cyclic interrupt OB has to agree with the number of concatenated measured variables in the process.

  There are two concatenated measured variables in the example: TempChocolate and TempWater. Therefore two PID_Temp instances are required.

- Call sequence

  A master has to be called before its slaves in the same cyclic interrupt OB.

  The outermost master at which the user setpoint is specified is called first.

  The slave whose setpoint is specified by the outermost master is called next, etc.

  The innermost slave that acts on the actuator of the process with its output value is called last.

  In the example, PID_Temp_1 is called before PID_Temp_2.

- Interconnection of the measured variables

  The outermost master is interconnected with the outermost measured variable that is to be regulated to the user setpoint.

  The innermost slave is interconnected with the innermost measured variable that is influenced directly by the actuator.

  Interconnection of the measured variables with PID_Temp is carried out with the parameters Input or Input_PER.

  In the example, the outermost measured variable TempChocolate is interconnected with PID_Temp_1 and the innermost measured variable TempWater with PID_Temp_2.

- Interconnection of the output value of the master to the setpoint of the slave

  The output value (OutputHeat or OutputCool) of a master has to be assigned to the setpoint (Setpoint) of its slave. The output value that is used depends on the configuration (Page 199).

  This interconnection can be carried out in the programming editor or automatically in the Inspector window of the slave in the basic settings via the selection of the master.

  If required, you can insert your own filter or scaling functions, for example in order to adapt the output value range of the master to the setpoint / process value range of the slave.

  In the example, OutputHeat of PID_Temp_1 is assigned to Setpoint of PID_Temp_2.

- Interconnection of the interface for information exchange between master and slave

  The "Slave" parameter of a master has to be assigned to the "Master" parameter of all its directly subordinate slaves (which receive their setpoint from this master). The assignment should be carried out via the interface of the slave in order to allow the interconnection of a master with multiple slaves and the display of the interconnection in the Inspector window of the slave in the basic settings.

  This interconnection can be carried out in the programming editor or automatically in the Inspector window of the slave in the basic settings via the selection of the master.

  The Anti-Windup function and the evaluation of the slave operating modes at the master can only function correctly if this interconnection is carried out.

In the example, the "Slave" parameter of PID_Temp_1 is assigned to the "Master" parameter of PID_Temp_2.

Program code of the example using SCL (without assignment of the output value of the slave to the actuator):

```
"PID_Temp_1"(Input:="TempChocolate");
"PID_Temp_2"(Input:="TempWater", Master := "PID_Temp_1".Slave,
Setpoint := "PID_Temp_1".OutputHeat);
```

See also

PID_Temp ActivateRecoverMode tag (Page 425)

8.4.3 Configuration

You can carry out the configuration via your user program, the configuration editor or the Inspector window of the PID_Temp call.

When using PID_Temp in a cascade control system, ensure the correct configuration of the settings specified below.

If a PID_Temp instance receives its setpoint from a superior master controller and outputs its output value in turn to a subordinate slave controller, this PID_Temp instance is both a master controller and a slave controller simultaneously. Both configurations listed below have to be carried out for such a PID_Temp instance. This is the case, for example, for the middle PID_Temp instance in a cascade control system with three concatenated measured variables and three PID_Temp instances.

Configuration of a master

Setting in the configuration editor or Inspector window	DB parameter	Explanation
Basic settings → Cascade: Activate "Controller is master" check box	Config.Cascade.IsMaster = TRUE	Activates this controller as master in a cascade.
Basic settings → Cascade: Number of slaves	Config.Cascade.CountSlaves	Number of directly subordinate slaves that receive their setpoint directly from this master
Basic settings → Input/output parameters: Clear the "Activate heating" or "Activate cooling" check box	PID_Temp V1.x: Config.ActivateCooling = FALSE PID_Temp as of V2.0 Config.ActivateHeating = TRUE, Config.ActivateCooling = FALSE or: Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE	PID_Temp V1.x: The cooling has to be deactivated at a master. This allows cascade control to be realized, in which an increasing measured variable of the slave causes an increasing measured variable of the master. The output value OutputHeat is used as the setpoint for the slave. PID_Temp as of V2.0 With a master, either the cooling or the heating must be deactivated. If a rising measured variable of the slave causes a rising measured variable of the master (see example (Page 196)), activate the heating and deactivate the cooling. The output value OutputHeat is used as the setpoint for the slave. If a rising measured variable of the slave causes a falling measured variable of the master (e.g.

Setting in the configuration editor or Inspector window	DB parameter	Explanation
		rising coolant flow leads to falling temperature), deactivate the heating and activate the cooling. The output value OutputCool is used as the setpoint for the slave.
Basic settings → Input/output parameters: Selection of the output value (heating) = OutputHeat or selection of the output value (cooling) = OutputCool	Config.Output.Heat.Select = 0 or Config.Output.Cool.Select = 0	The master only uses the output parameter OutputHeat or OutputCool. OutputHeat_PWM, OutputCool_PWM, OutputHeat_PER and OutputCool_PER are deactivated.
Output settings → Output limits and scaling → OutputHeat / OutputCool: PID output value low limit (heating), PID output value high limit (heating), Scaled low output value (heating) Scaled high output value (heating) or: PID output value low limit (cooling), PID output value high limit (cooling), Scaled low output value (cooling) Scaled output high value (cooling)	Config.Output.Heat.PidLowerLimit, Config.Output.Heat.PidUpperLimit, Config.Output.Heat.LowerScaling, Config.Output.Heat.UpperScaling or: Config.Output.Cool.PidLowerLimit, Config.Output.Cool.PidUpperLimit, Config.Output.Cool.LowerScaling, Config.Output.Cool.UpperScaling	If no own scaling function is used when assigning OutputHeat or OutputCool of the master to Setpoint of the slave, it may be necessary to adapt the output value limits and the output scaling of the master to the setpoint / process value range of the slave.
This tag is not available in the Inspector window or in the functional view of the configuration editor. You can change it via the parameter view of the configuration editor.	Config.Cascade.AntiWindUpMode	The Anti-Windup mode determines how the integral action of this master is treated if directly subordinate slaves reach their output value limits. Options are: • AntiWindUpMode = 0: The Anti-Windup function is deactivated. The master does not react to the limitation of its slaves. • AntiWindUpMode = 1 (default): The integral action of the master is reduced in the ratio "Slaves in limitation/Number of slaves". This reduces the effects of the limitation on the control behavior. • AntiWindUpMode = 2: The integral action of the master is held as soon as a slave is in limitation.

Configuration of a slave

Setting in the configuration editor or Inspector window	DB parameter	Explanation
Basic settings → Cascade: Select the "Controller is slave" check box	Config.Cascade.IsSlave = TRUE	Activates this controller as slave in a cascade.

8.4.4 Commissioning

After compiling and loading of the program, you can start commissioning of the cascade control system.

Begin with the innermost slave at commissioning (implementation of tuning or change to automatic mode with existing PID parameters) and continue outwards until the outermost master has been reached.

In the example above, commissioning starts with PID_Temp_2 and is then continued with PID_Temp_1.

Tuning the slave

Tuning of PID_Temp requires a constant setpoint. Therefore, activate the substitute setpoint of a slave (SubstituteSetpoint and SubstituteSetpointOn tags) to tune the slave or set the associated master to manual mode with a corresponding manual value. This ensures that the setpoint of the slave remains constant during tuning.

Tuning the master

In order for a master to influence the process or to carry out tuning, all the downstream slaves have to be in automatic mode and their substitute setpoint has to be deactivated. A master evaluates these conditions through the interface for information exchange between master and slave (Master parameter and Slave parameter) and displays the current state at the AllSlaveAutomaticState and NoSlaveSubstituteSetpoint tags. Corresponding status messages are output in the commissioning editor.

Status message in the commissioning editor of the master	DB parameter of the master	Correction
One or more slaves are not in automatic mode.	AllSlaveAutomaticState = FALSE, NoSlaveSubstituteSetpoint = TRUE	First, carry out commissioning of all downstream slaves. Ensure that the following conditions are fulfilled before carrying out tuning or activating manual mode or automatic mode of the master: • All downstream slaves are in automatic mode (state = 3). • All downstream slaves have deactivated the substitute setpoint (SubstituteSetpointOn = FALSE).
One or more slaves have activated the substitute setpoint.	AllSlaveAutomaticState = TRUE, NoSlaveSubstituteSetpoint = FALSE	
One or more slaves are not in automatic mode and have activated the substitute setpoint.	AllSlaveAutomaticState = FALSE, NoSlaveSubstituteSetpoint = FALSE	

If pretuning or fine tuning is started for a master, PID_Temp aborts tuning in the following cases and displays an error with ErrorBits = 16#0020_0000:

- One or more slaves are not in automatic mode (AllSlaveAutomaticState = FALSE)
- One or more slaves have activated the substitute setpoint (NoSlaveSubstituteSetpoint = FALSE).

The subsequent operating mode changeover depends on ActivateRecoverMode.

8.4.5 Substitute setpoint

In order to specify a setpoint, PID_Temp offers a substitute setpoint at the SubstituteSetpoint tag in addition to the Setpoint parameter. This can be activated by setting SubstituteSetpointOn = TRUE or by selecting the corresponding check box in the commissioning editor.

The substitute setpoint allows you to specify the setpoint temporarily directly at the slave, for example during commissioning or tuning.

In this case, the interconnection of the output value of the master with the setpoint of the slave that is required for normal operation of the cascade control system does not have to be changed in the program

In order for a master to influence the process or to carry out tuning, the substitute setpoint has to be deactivated at all downstream slaves.

You can monitor the currently effective setpoint as it is used by the PID algorithm for calculation at the CurrentSetpoint tag.

8.4.6 Operating modes and fault response

The master or slave of a PID_Temp instance does not change the operating mode of this PID_Temp instance.

If a fault occurs at one of its slaves, the master remains in its current operating mode.

If a fault occurs at its master, the slave remains in its current operating mode. However, further operation of the slave then depends on the fault and the configured fault response of the master since the output value of the master is used as the setpoint of the slave:

- If ActivateRecoverMode = TRUE is configured at the master and the fault does not prevent the calculation of OutputHeat or OutputCool, the fault does not have any effect on the slave.
- If ActivateRecoverMode = TRUE is configured at the master and the fault prevents the calculation of OutputHeat or OutputCool, the master outputs the last valid output value or the configured substitute output value SubstituteOutput depending on SetSubstituteOutput. This is then used by the slave as the setpoint.

  PID_Temp is preconfigured so that the substitute output value 0.0 is output in this case (ActivateRecoverMode = TRUE, SetSubstituteOutput = TRUE, SubstituteOutput = 0.0). Configure a suitable substitute output value for your application or activate the use of the last valid PID output value (SetSubstituteOutput = FALSE).
- If ActivateRecoverMode = FALSE is configured at the master, the master changes to the "Inactive" mode when an error occurs and outputs OutputHeat = 0.0 and OutputCool = 0.0. The slave then uses 0.0 as the setpoint.

The fault response is located in the output settings in the configuration editor.

8.5 Multi-zone controlling with PID_Temp

Introduction

In a multi-zone control system, several sections, so-called zones, of a plant are controlled simultaneously to different temperatures. A multi-zone control system is characterized by the mutual influence of the temperature zones through thermal coupling, i.e. the process value of one zone can influence the process value of a different zone through thermal coupling. The strength that this influence has depends on the structure of the plant and the selected operating points of the zones.

Example: Extrusion plant as it is used, for example, in plastics processing.

The substance mixture that passes through the extruder has to be controlled to different temperatures for optimal processing. For example, different temperatures can be required at the filling point of the extruder than at the outlet nozzle. The individual temperature zones mutually influence each other through thermal coupling.

When PID_Temp is used in multi-zone control systems, each temperature zone is controlled by a separate PID_Temp instance.

Observe the following explanations if you want to use the PID_Temp in a multi-zone control system.

Separate pretuning for heating and cooling

Initial commissioning of a plant as a rule begins with the carrying out of pretuning in order to carry out initial setting of the PID parameters and control to the operating point. The pretuning for multi-zone control systems is often carried out simultaneously for all zones.

PID_Temp offers for controllers with activated heating and cooling and PID parameter switching as a method for heating/cooling (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) the possibility to perform the pretuning for heating and cooling in one step (Mode = 1, Heat.EnableTuning = TRUE, Cool.EnableTuning = TRUE).

However, it is advisable not to use this tuning for simultaneous pretuning of several PID_Temp instances in a multi-zone control system. Instead, first carry out the pretuning for heating (Mode = 1, Heat.EnableTuning = TRUE, Cool.EnableTuning = FALSE) and the pretuning for cooling (Mode = 1, Heat.EnableTuning = FALSE, Cool.EnableTuning = TRUE) separately.

Pretuning for cooling should not be started until all zones have completed pretuning for heating and have reached their operating points.

This reduces mutual influencing through thermal coupling between the zones during tuning.

Adapting the delay time

If PID_Temp is used in a multi-zone control system with strong thermal couplings between the zones, you should ensure that the adaption of the delay time is deactivated for pretuning with PIDSelfTune.SUT.AdaptDelayTime = 0. Otherwise, the determination of the delay time can be incorrect if the cooling of a zone is prevented by the thermal influence of other zones during the adapting of the delay time (heating is deactivated in this phase).

Temporary deactivation of cooling

PID_Temp offers the possibility of deactivating cooling temporarily in automatic mode for controllers with activated heating and cooling (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) by setting DisableCooling = TRUE.

This ensures that this controller does not cool in automatic mode during commissioning while the controllers of other zones have not yet completed tuning of heating. The tuning could otherwise be influenced negatively by the thermal coupling between the zones.

Procedure

You can proceed as follows during the commissioning of multi-zone control systems with relevant thermal couplings:

1. Set DisableCooling = TRUE for all controllers with activated heating and cooling.
2. Set PIDSelfTune.SUT.AdaptDelayTime = 0 for all controllers.
3. Specify the desired setpoints (Setpoint parameter) and start pretuning for heating (Mode = 1, Heat.EnableTuning = TRUE, Cool.EnableTuning = FALSE) simultaneously for all controllers.
4. Wait until all the controllers have completed pretuning for heating.
5. Set DisableCooling = FALSE for all controllers with activated heating and cooling.
6. Wait until the process values of all the zones are steady and close to the respective setpoint.

   If the setpoint cannot be reached permanently for a zone, the heating or cooling actuator is too weak.
7. Start pretuning for heating and cooling (Mode = 1, Heat.EnableTuning = FALSE, Cool.EnableTuning = TRUE) for all controllers with activated cooling.

NOTE

Limit violation of the process value

If the cooling is deactivated in automatic mode with DisableCooling = TRUE, this can cause the process value to exceed the setpoint and the process value limits while DisableCooling = TRUE. Observe the process values and intervene, if needed, if you use DisableCooling.

NOTE

Multi-zone control systems

For multi-zone control systems, the thermal couplings between the zones can result in increased overshoots, permanent or temporary violation of limits and permanent or temporary control deviations during commissioning or operation. Observe the process values and be ready to intervene. Depending on the system, it can be necessary to deviate from the procedure described above.

Synchronization of several fine tuning processes

If fine tuning is started from automatic mode with PIDSelfTune.TIR.RunIn = FALSE, PID_Temp tries to reach the setpoint with PID controlling and the current PID parameters. The actual tuning does not start until the setpoint is reached. The time required to reach the setpoint can be different for the individual zones of a multi-zone control system.

If you want to carry out fine tuning for several zones simultaneously, PID_Temp offers the possibility to synchronize these by waiting with the further tuning steps after the setpoint has been reached.

Procedure

This ensures that all the controllers have reached their setpoint when the actual tuning steps start. This reduces mutual influencing through thermal coupling between the zones during tuning.

Proceed as follows for controllers for whose zones you want to carry out fine tuning simultaneously:

1. Set PIDSelfTune.TIR.WaitForControlIn = TRUE for all controllers.

   These controllers have to be in automatic mode with PIDSelfTune.TIR.RunIn = FALSE.
2. Specify the desired setpoints (Setpoint parameters) and start fine tuning for all controllers.
3. Wait until PIDSelfTune.TIR.ControlInReady = TRUE at all controllers.
4. Set PIDSelfTune.TIR.FinishControlIn = TRUE for all controllers.

All controllers then start the actual tuning simultaneously.

8.6 Override control with PID_Temp

Override control

In case of override control, two or more controllers share one actuator. Only one controller has access to the actuator at any time and influences the process.

A logic operation decides which controller has access to the actuator. This decision is often made based on a comparison of the output values of all controllers, for example, in case of a maximum selection, the controller with the largest output value gets access to the actuator.

The selection based on the output value requires that all controllers operate in automatic mode. The controllers that do not have an effect on the actuator are updated. This is necessary to prevent windup effects and their negative impacts on the control response and the switchover between the controllers.

PID_Temp supports override controls as of version 1.1 by offering a simple process for updating the controllers that are not active: By using the OverwriteInitialOutputValue and PIDCtrl.PIDInit tags, you can preassign the integral action of the controller in automatic mode as though the PID algorithm had calculated PidOutputSum = OverwriteInitialOutputValue for the PID output value in the last cycle. To do this, OverwriteInitialOutputValue is interconnected with the PID output value of the controller that currently has access to the actuator. By setting the bit PIDCtrl.PIDInit, you trigger the preassignment of the integral action as well as the restart of the controller cycle and the PWM period. The subsequent calculation of the PID output value in the current cycle takes place based on the preassigned

(and synchronized for all controllers) integral action as well as the proportional action and integral action from the current control deviation. The derivative action is not active during the call with PIDCtrl.PIDInit = TRUE and therefore does not contribute to the output value.

This procedure ensures that the calculation of the current PID output value and thus the decision on which controller is to have access to the actuator is only based on the current process state and the PI parameters. Windup effects for controllers that are not active and thus incorrect decisions of the switchover logic are prevented.

Requirement

- PIDCtrl.PIDInit only takes effect if the integral action is activated (tags Retain.CtrlParams.Heat.Ti and Retain.CtrlParams.Cool.Ti > 0.0).
- You must assign PIDCtrl.PIDInit and OverwriteInitialOutputValue in your user program yourself (see example below). PID_Temp does not automatically change these tags.
- PIDCtrl.PIDInit only takes effect when PID_Temp is in automatic mode (parameter State = 3)
- If possible, select the sampling time of the PID algorithm (Retain.CtrlParams.Heat.Cycle and Retain.CtrlParams.Cool.Cycle tags) so that it is identical for all controllers, and call all controllers in the same cyclic interrupt OB. In this way, you ensure that the switchover does not take place within a controller cycle or a PWM period.

NOTE

Constant adaptation of the output value limits

Instead of the active updating of the controllers without access to the actuator described here, this is implemented alternatively by constant adaptation of the output value limits in other controller systems.

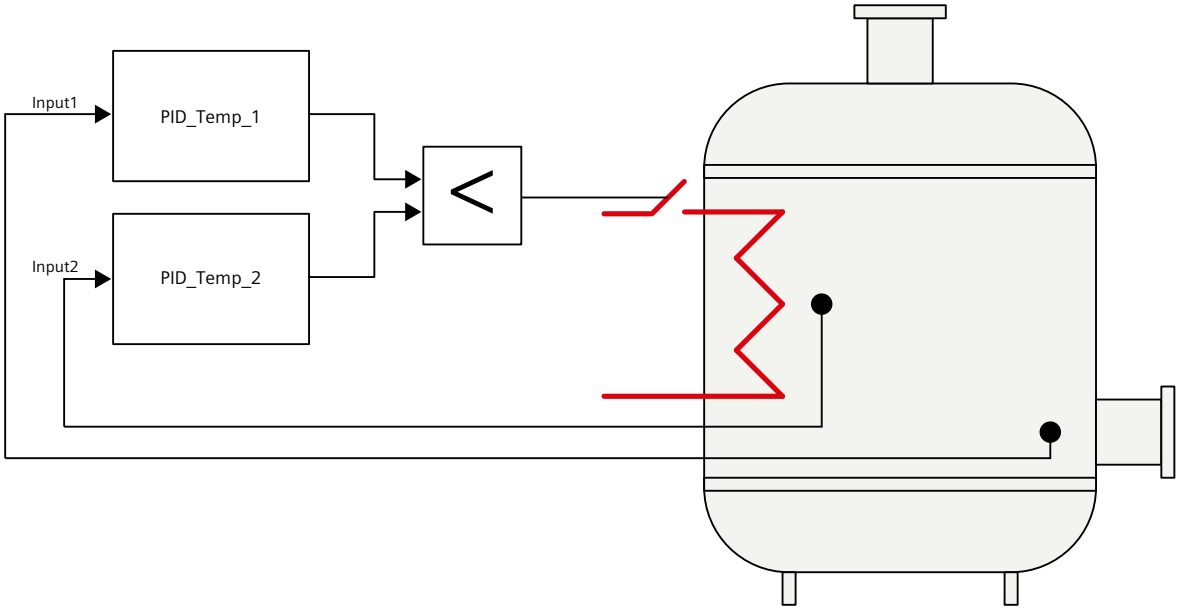
This is not possible with PID_Temp, because a change of the output value limits is not supported in automatic mode.

Example: Control of a large boiler

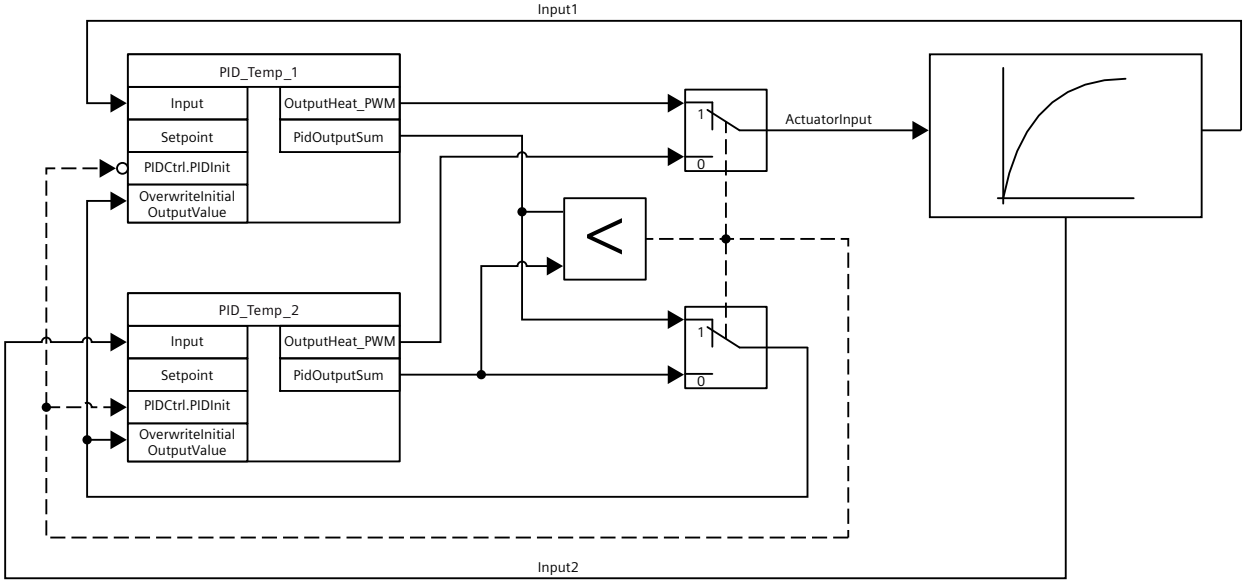
PID_Temp is used for control of a large boiler.

The main goal is to control the temperature Input1. The controller PID_Temp_1 is used for this purpose. In addition, the temperature Input2 is to be kept below a high limit at an additional measuring point with the limiting controller PID_Temp_2.

Both temperatures are influenced by only one heater. The output value of the controller corresponds to the heating power.



The heater is controlled with the pulse-width modulated output value of PID_Temp (parameter OutputHeat_PWM) by writing the program tag ActuatorInput. The setpoint for the temperature Input1 is specified at the parameter PID_Temp_1.Setpoint. The temperature high limit for the additional measuring point is specified as setpoint at the parameter PID_Temp_2.Setpoint.



Both controllers must share one heater as shared actuator. The logic that decides which controller gets access to the actuator is implemented by a minimum selection of the PID output value (in Real format, PidOutputSum parameter) in this case. Because the PID output value corresponds to the heating power, the controller that requires lower heating power gets the control.

In normal operation of the plant, the process value of the main controlled variable corresponds to the setpoint. The main controller PID_Temp_1 has settled on a stationary PID output value PID_Temp_1.PidOutputSum. The process value of the limiting controller Input2 in normal operation is significantly below the high limit that is specified as setpoint for PID_Temp_2. The limiting controller therefore wants to increase the heating power to increase its process value, which means it will calculate a PID output value PID_Temp_2.PidOutputSum that is greater than the output value of the main controller PID_Temp_1.PidOutputSum. The minimum selection of the switchover logic therefore gives the main controller PID_Temp_1 continued access to the actuator. In addition, it is ensured that PID_Temp_2 is updated by means of the assignments PID_Temp_2.OverwriteInitialOutputValue = PID_Temp_1.PidOutputSum and PID_Temp_2.PIDCtrl.PIDInit = TRUE.

If Input2 now approaches the high limit or exceeds it, for example due to a fault, the limiting controller PID_Temp_2 calculates a smaller PID output value to restrict the heating power and thus reduce Input2. If PID_Temp_2.PidOutputSum is less than PID_Temp_1.PidOutputSum, the limiting controller PID_Temp_2 receives access to the actuator through the minimum selection and reduces the heating power. It is ensured that PID_Temp_1 is updated by means of the assignments PID_Temp_1.OverwriteInitialOutputValue = PID_Temp_2.PidOutputSum and PID_Temp_1.PIDCtrl.PIDInit = TRUE.

The temperature at the additional measuring point Input2 drops. The temperature of the main controlled variable Input1 drops as well and cannot be held at the setpoint any longer.

Once the fault has been remedied, the Input2 will continue to drop and the heating power is further increased by the limiting controller. As soon as the main controller has calculated a lower heating power as output value, the plant returns to normal operation so that the main controller PID_Temp_1 once again has access to the actuator. This example can be implemented with the following SCL program code:

```
"PID_Temp_1"(Input := "Input1");
"PID_Temp_2"(Input := "Input2");
IF "PID_Temp_1".PidOutputSum <= "PID_Temp_2".PidOutputSum THEN
  "ActuatorInput" := "PID_Temp_1".OutputHeat_PWM;
  "PID_Temp_1".PIDCtrl.PIDInit := FALSE;
  "PID_Temp_2".PIDCtrl.PIDInit := TRUE;
  "PID_Temp_2".OverwriteInitialOutputValue := "PID_Temp_1".PidOutputSum;
ELSE
  "ActuatorInput" := "PID_Temp_2".OutputHeat_PWM;
  "PID_Temp_1".PIDCtrl.PIDInit := TRUE;
  "PID_Temp_2".PIDCtrl.PIDInit := FALSE;
  "PID_Temp_1".OverwriteInitialOutputValue := "PID_Temp_2".PidOutputSum;
END_IF;
```

8.7 Simulating PID_Temp with PLCSIM

NOTE

Simulation with PLCSIM

The simulation of PID_Temp with PLCSIM for CPU S7-1200 is not supported.

PID_Temp can only be simulated for CPU S7-1500 and CPU S7-1200 G2 with PLCSIM.

For the simulation with PLCSIM, the time behavior of the simulated PLC is not exactly identical to that of a "real" PLC. The actual cycle clock of a cyclic interrupt OB can have larger fluctuations with a simulated PLC than with "real" PLCs.

In the standard configuration, PID_Temp determines the time between calls automatically and monitors them for fluctuations.

For the simulation of PID_Temp with PLCSIM, for example, a sampling time error (ErrorBits = DW#16#00000800) can therefore be detected.

This results in ongoing tuning being aborted.

The response in automatic mode depends on the value of the ActivateRecoverMode tag.

To prevent this from happening, you should configure PID_Temp for simulation with PLCSIM as follows:

- CycleTime.EnEstimation = FALSE
- CycleTime.EnMonitoring = FALSE
- CycleTime.Value: Assign the cycle clock of the calling cyclic interrupt OB in seconds to this tag.

Using PID basic functions

9

9.1 CONT_C

9.1.1 Technology object CONT_C

The technology object CONT_C provides a continual PID-controller for automatic and manual mode. It corresponds to the instance data block of the instruction CONT_C. You can configure a pulse controller using the PULSEGEN instruction.

The proportional, integral (INT) and differential components (DIF) are switched parallel to each other and can be turned on and off individually. With this, P-, I, PI-, PD- and PID-controller can be set.

S7-1500
All parameters and tags of the technology object are retentive and can only be changed during download to the device if you completely download CONT_C.

See also

Overview of software controller (Page 44)

Add technology objects (Page 46)

Configure technology objects (Page 47)

Downloading technology objects to device (Page 49)

CONT_C (Page 431)

9.1.2 Configure controller difference CONT_C

Use process value periphery

To use the process value in the periphery format at the PV_PER input parameter, follow these steps:

1. Select the "Enable I/O" check box.
2. If the process value is available as a physical size, enter the factor and offset for the scaling in percent.
   The process value is then determined according to the following formula:
   PV = PV_PER × PV_FAC + PV_OFF

Use internal process values

To use the process value in the floating-point format at the PV_IN input parameter, follow these steps:

1. Clear the "Enable I/O" check box.

Control deviation

Set a dead zone range under the following requirement:

- The process value signal is noisy.
- The controller gain is high.
- The derivative action is activated.

The noise component of the process value causes strong deviations of the output value in this case. The dead zone suppresses the noise component in the steady controller state. The dead zone range specifies the size of the dead zone. With a dead zone range of 0.0, the dead zone is turned off.

See also

How CONT_C works (Page 432)

9.1.3 Configure the controller algorithm CONT_C

General

To determine which components of the control algorithm are activated, proceed as follows:

1. Select an entry from the "Controller structure" list.
   You can only specify required parameters for the selected controller structure.

Proportional action

1. If the controller structure contains a proportional action, enter the "proportional gain".

Integral action

1. If the controller structure contains an integral action, enter the integral action time.
2. To give the integral action an initialization value, select the check box "Initialize integral action" and enter the initialization value.
3. In order to permanently set the integral action to this initialization value, select the "Integral action hold" check box.

Derivative action

1. If the controller structure contains a derivative action, enter the derivative action time, the derivative action weighting and the delay time.

See also

How CONT_C works (Page 432)

9.1.4 Configure the output value CONT_C

General

You can set CONT_C in the manual or automatic mode.

1. To set a manual manipulated value, activate the option "Activate manual mode" option check box.
   You can specify a manual manipulated value on the input parameter MAN.

Manipulated value limits

The manipulated value is limited at the top and bottom so that it can only accept valid values. You cannot turn off the limitation. Exceeding the limits is displayed through the output parameters QLMN_HLM and QLMN_LLM.

1. Enter a value for the high and low manipulated value limits.
   If the manipulated value is a physical size, the units for the high and low manipulated value limits must match.

Scaling

The manipulated value can be scaled for output as a floating point and periphery value through a factor and an offset according to the following formula.

Scaled manipulated value = manipulated value x factor + offset

Default is a factor of 1.0 and an offset of 0.0.

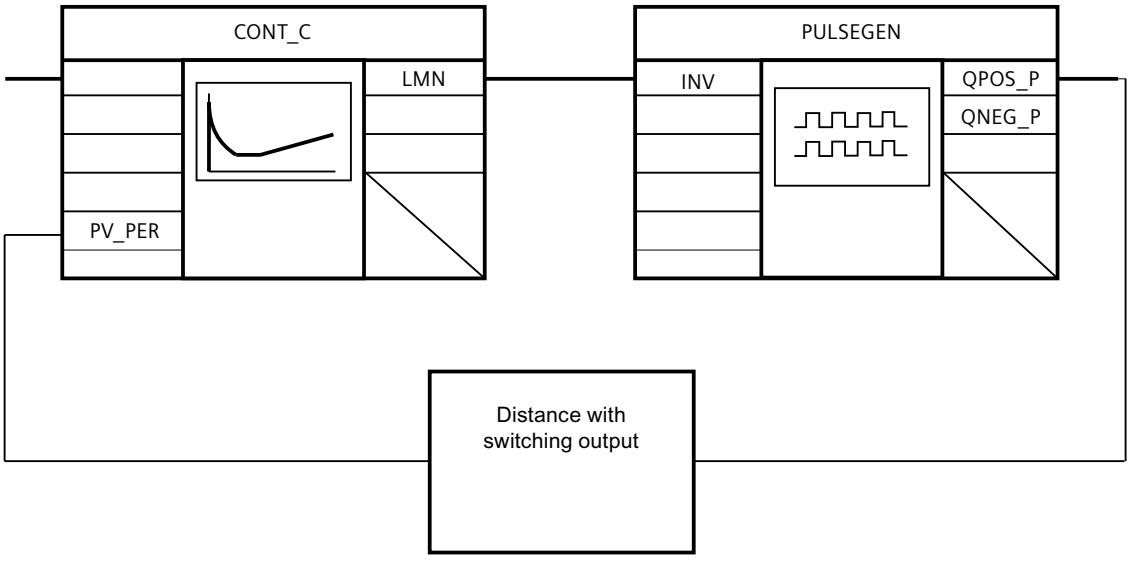
1. Enter a value for the factor and offset.

See also

How CONT_C works (Page 432)

9.1.5 Programming a pulse controller

With the continuous controller CONT_C and the pulse shaper PULSEGEN, you can implement a fixed setpoint controller with a switching output for proportional actuators. The following figure shows the signal flow of the control loop.



The continuous controller CONT_C forms the output value LMN that is converted by the pulse shaper PULSEGEN into pulse/break signals QPOS_P or QNEG_P.

See also

PULSEGEN (Page 442)

9.1.6 Commissioning CONT_C

Requirements

- The instruction and the technology object have been loaded to the CPU.

Procedure

To manually determine the optimal PID parameters, proceed as follows:

1. Click the "Start" icon.

   If there is no online connection, this will be established. The current values for the setpoint, process value and output value are recorded.
2. Enter new PID parameters in the "P", "I", "D" and "Delay time" fields.
3. Click on the icon "Send parameter to CPU" in the "Tuning" group.
4. Select the "Change setpoint" check box in the "Current values" group.
5. Enter a new setpoint and click the icon in the "Current values" group.

6. Clear the "Manual mode" check box.
   The controller works with the new PID parameters and controls the new setpoint.
7. Check the quality of the PID parameter to check the curve points.
8. Repeat steps 2 to 6 until you are satisfied with the controller results.

9.2 CONT_S

9.2.1 Technology object CONT_S

The technology object CONT_S provides a step controller for actuators with integrating behavior and is used to control technical temperature processes with binary output value output signals. The technology object corresponds to the instance data block of the CONT_S instruction. The operating principle is based on the PI control algorithm of the sampling controller. The step controller operates without a position feedback signal. Both manual and automatic mode are possible.

S7-1500
All parameters and tags of the technology object are retentive and can only be changed during download to the device if you completely download CONT_S.

See also

Overview of software controller (Page 44)
Add technology objects (Page 46)
Configure technology objects (Page 47)
Downloading technology objects to device (Page 49)
CONT_S (Page 437)

9.2.2 Configure controller difference CONT_S

Use process value periphery

To use the process value in the periphery format at the PV_PER input parameter, follow these steps:

1. Select the "Enable I/O" check box.
2. If the process value is available as a physical quantity, enter the factor and offset for the scaling in percent.
   The process value is then determined according to the following formula:
   PV = PV_PER × PV_FAC + PV_OFF

Use internal process values

To use the process value in the floating-point format at the PV_IN input parameter, follow these steps:

1. Clear the "Enable I/O" check box.

Control deviation

Set a deadband range under the following requirement:

- The process value signal is noisy.
- The controller gain is high.
- The derivative action is activated.

The noise component of the process value causes strong deviations of the manipulated variable in this case. The deadband suppresses the noise component in the steady controller state. The deadband range specifies the size of the deadband. With a deadband range of 0.0, the deadband is turned off.

See also

Mode of operation CONT_S (Page 438)

9.2.3 Configuring control algorithm CONT_S

PID algorithm

1. Enter the "proportional amplification" for the P-component.
2. Enter the integration time for the time behavior of the I-component.
   With an integration time of 0.0, the I-component is switched off.

See also

Mode of operation CONT_S (Page 438)

9.2.4 Configure manipulated value CONT_S

General

You can set CONT_S in the manual or automatic mode.

1. To set a manual manipulated value, activate the "Activate manual mode" option check box.
   Enter a manual manipulated value for the input parameters LMNUP and LMNDN.

Pulse generator

1. Enter the minimum impulse duration and minimum pause duration.
   The values must be greater than or equal to the cycle time for the input parameter CYCLE.
   The frequency of operation is reduced through this.
2. Enter the motor setting time.
   The value must be greater than or equal to the cycle time of the input parameter CYCLE.

See also

Mode of operation CONT_S (Page 438)

9.2.5 Commissioning CONT_S

Requirements

- The instruction and the technology object have been loaded to the CPU.

Procedure

To manually determine the optimal PID parameters, proceed as follows:

1. Click the "Start" icon.

   If there is no online connection, this will be established. The current values for the setpoint, process value and output value are recorded.
2. In the fields "P" and "I", enter a new proportional value and a new integration time.
3. Click on the icon "Send parameter to CPU" in the "Tuning" group.
4. Select the "Change setpoint" check box in the "Current values" group.
5. Enter a new setpoint and click the icon in the "Current values" group.
6. Clear the "Manual mode" check box.

   The controller works with the new parameters and controls the new setpoint.
7. Check the quality of the PID parameter to check the curve points.
8. Repeat steps 2 to 6 until you are satisfied with the controller results.

9.3 TCONT_CP

9.3.1 Technology object TCONT_CP

The technology object TCONT_CP provides a continual temperature controller with pulse generator. It corresponds to the instance data block of the instruction TCONT_CP. The operation is based on the PID control algorithm of the sampling controller. Both manual and automatic mode are possible.

The instruction TCONT_CP calculates the proportional, integral and derivative parameters for your controlled system during pretuning. "Fine tuning" can be used to tune the parameters further. You can also enter the PID parameters manually.

S7-1500
All parameters and tags of the technology object are retentive and can only be changed during download to the device if you completely download TCONT_CP.

See also

Overview of software controller (Page 44)
Add technology objects (Page 46)
Configure technology objects (Page 47)
Downloading technology objects to device (Page 49)
TCONT_CP (Page 450)

9.3.2 Configure TCONT_CP

9.3.2.1 Controller difference

Use process value periphery

To use the input parameter PV_PER, proceed as follows:

1. Select the entry "Periphery" from the "Source" list.
2. Select the "sensor type".
   Depending on the sensor type, the process value is scaled according to different formulas.
   - Standard
     Thermoelements; PT100/NI100

     PV = 0.1 × PV_PER × PV_FAC + PV_OFFS
   - Cooling;
     PT100/NI100

     PV = 0.01 × PV_PER × PV_FAC + PV_OFFS
   - Current/voltage

     PV = 100/27648 × PV_PER × PV_FAC + PV_OFFS
3. Enter the factor and offset for the scaling of the process value periphery.

Use internal process values

To use the input parameter PV_IN, proceed as follows:

1. Select the entry "Internal" from the "Source" list.

Control deviation

Set a deadband range under the following requirement:

- The process value signal is noisy.
- The controller gain is high.
- The derivative action is activated.

The noise component of the process value causes strong deviations of the manipulated variable in this case. The deadband suppresses the noise component in the steady controller state. The deadband range specifies the size of the deadband. With a deadband range of 0.0, the deadband is turned off.

See also

Mode of operation TCONT_CP (Page 451)

9.3.2.2 Controlling algorithm

General

1. Enter the "Sampling time PID algorithm".
   A controller sampling time should not exceed 10 % of the determined integratl action time of the controller (TI).
2. If the controller structure contains a proportional action, enter the "proportional gain".
   A negative proportional gain inverts the rule meaning.

Proportional action

For changes of the setpoint, it may lead to overshooting of the proportional action. Through the weighting of the proportional action, you can select how strongly the proportional action should react when setpoint changes are made. The weakening of the proportional action is reached through a compensation of the integral action.

1. To weaken the proportional action for setpoint changes, enter a "Proportional action weighting".
   - 1.0: Proportional action for setpoint change is fully effective
   - 0.0: Proportional action for setpoint change is not effective

Integral action

With a limitation of the manipulated value, the integral action is stopped. With a control deviation that moves the integral action in the direction of an internal setting range, the integral action is released again.

1. If the controller structure contains an integral action, enter the "integral action time". With an integral action time of 0.0, the integral action is switched off.
2. To give the integral action an initialization value, select the "Initialize integral action" check box and enter the "Initialization value".
   Upon restart or COM_RST = TRUE, the integral action is set to this value.

Derivative action

1. If the controller structure contains a derivative action, enter the derivative action time (TD) and the coefficients DT1 (D_F).
   With switched derivative action, the following equation should be maintained:
   TD = 0.5 × CYCLE× D_F.
   The delay time is calculated from this according to the formula:
   delay time = TD/D_F

Set PD-controller with operating point

1. Enter the integral action time 0.0.
2. Activate the "Initialize integral action" check box.
3. Enter the operating point as the initialization value.

Set P-controller with operating point

1. Set a PD-controller with an operating point.
2. Enter the derivative action time 0.0.
   The derivative action is disabled.

Control zone

The control zone limits the value range of the control deviation. If the control deviation is outside of this value range, the manipulated value limits are used.

With an occurrence in the control zone, the derivative action leads to a very quick reduction of the manipulated variable. Thus, the control zone only makes sense for switched on derivative actions. Without control zone, only the reducing proportional action would reduce the manipulated value. The control zone leads to a quick oscillation without over/under shooting if the emitted minimum or maximum manipulated values are removed from the manipulated value required for the new operating point.

1. Activate the "Activate" check box in the "control zone" group.
2. Enter a setpoint value in the "Width" input field from which the process value may deviate above or below.

See also

Mode of operation TCONT_CP (Page 451)

9.3.2.3 Manipulated value continual controller

Manipulated value limits

The manipulated value is limited at the top and bottom so that it can only accept valid values. You cannot turn off the limitation. Exceeding the limits is displayed through the output parameters QLMN_HLM and QLMN_LLM.

1. Enter a value for the high and low manipulated value limits.

Scaling

The manipulated value can be scaled for output as a floating point and periphery value through a factor and an offset according to the following formula.

Scaled manipulated value = manipulated value x factor + offset

Default is a factor of 1.0 and an offset of 0.0.

1. Enter a value for the factor and offset.

Pulse generator

The pulse generator must be turned on for a continual controller.

1. Disable the "Activate" option check box in the "Pulse generator" group.

See also

Mode of operation TCONT_CP (Page 451)

9.3.2.4 Manipulated value pulse controller

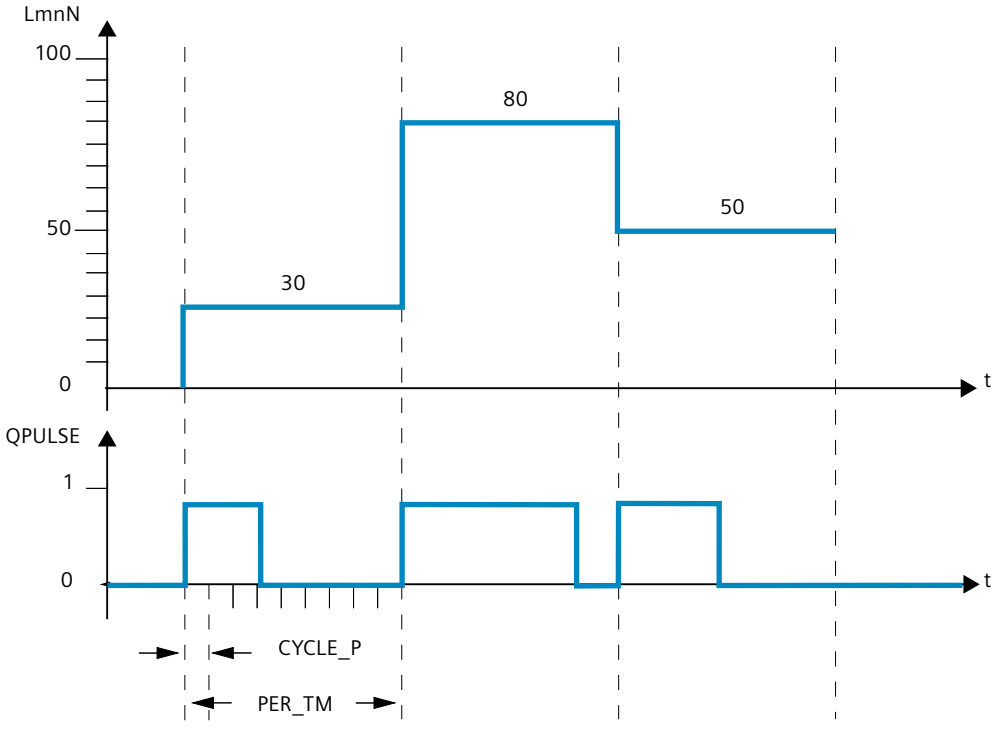
Pulse generator

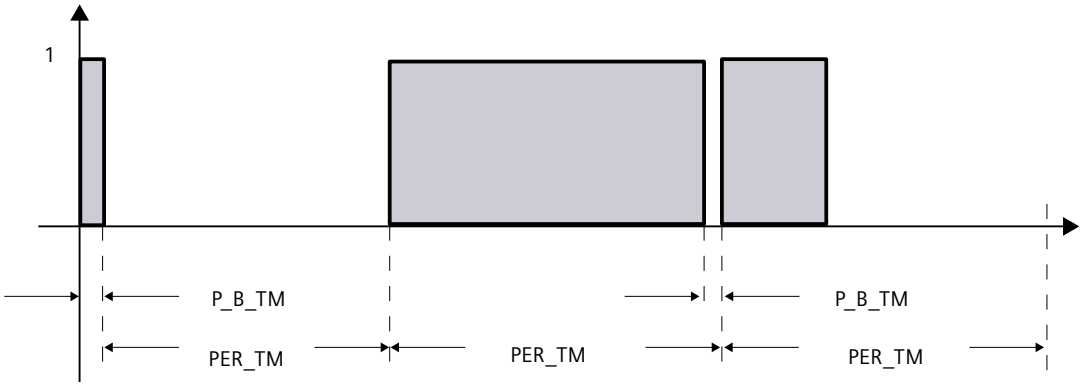
The analog manipulated value (LmnN) can be emitted through pulse-duration modulation on the output parameter QPULSE as an impulse sequence.

To use the pulse generator, proceed as follows:

1. Activate the "Activate" option check box in the "pulse generator" group.
2. Enter the "sampling time pulse generator", the "minimum impulse/break duration" and the "period duration".

The following graphics clarify the connection between the "sampling pulse generator" (CYCLE_P), the "minimum impulse/break duration" (P_B_TM) and the "period duration" (PER_TM):





Sampling time pulse generator

The sampling time pulse generator must agree with the time tact of the cyclic interrupt OB being called. The duration of the created impulse is always a whole number factor of this value. For an adequately precise manipulated value resolution, the following relationship should apply:
CYCLE_P ≤ PER_TM/50

Minimum impulse/break duration

Through the minimum impulse/break duration, short on or off times on the actuator are avoided. An impulse smaller than P_B_TM is suppressed.

Recommended are values P_B_TM ≤ 0.1 × PER_TM.

Period duration

The period duration should not exceed 20% of the determined integration time of the controller (TI):
PER_TM ≤ TI/5

Example for the effect of the parameter CYCLE_P, CYCLE and PER_TM:

Period duration PER_TM = 10 s

Sampling time PID-algorithm CYCLE = 1 s

Sampling time pulse generator CYCLE_P = 100 ms.

Every second, a new manipulated value, every 100 ms the comparison of the manipulated value occurs with the previously emitted impulse length and break length.

- If an impulse is emitted, there are 2 possibilities:
  - The calculated manipulated value is larger than the previous impulse length/PER_TM. Then the impulse is extended.
  - The calculated manipulated value is less than or equal to the previous impulse length/PER_TM. Then no impulse signal will be emitted.
- If no impulse is emitted, there are also 2 possibilities:
  - The value (100 % - calculated manipulated value) is greater than the previous break length / PER_TM. Then the break is extended.
  - The value (100 % - calculated manipulated value) is less than or equal to the previous break length / PER_TM. Then an impulse signal will be emitted.

See also

Mode of operation TCONT_CP (Page 451)

Operating principle of the pulse generator (Page 460)

9.3.3 Commissioning TCONT_CP

9.3.3.1 Optimization of TCONT_CP

Application possibilities

The controller optimization for heating or cooling processes from process type I is applicable. But you can use the block for processes with higher levels like process type II or III.

The PI/PID parameters are automatically determined and set. The controller draft is designed for an optimal disruption behavior The "precise" parameters resulting from this lead to overshooting of 10% to 40% of the jump height for setpoint jump heights.

Phases of controller optimization

For the controller optimization, individual phases are run through, which you can read on the parameter PHASE .

PHASE = 0

No tuning is running. TCONT_CP works in automatic or manual mode.

During PHASE = 0, you can make sure that the controlled system fulfills the requirements for an optimization.

At the end of the optimization, TCONT_CP changes back into PHASE = 0.

PHASE = 1

TCONT_CP is prepared for optimization. PHASE = 1 may only be started if the requirements for an optimization are fulfilled.

During PHASE = 1, the following values are determined:

- Process value noise NOISE_PV
- Initial slope PVDT0
- Average of the manipulated variable
- Sampling time PID algorithm CYCLE
- Sampling time pulse generator CYCLE_P

PHASE = 2

In phase 2, the process value attempts to detect the point of inflection with a constant manipulated variable. This method prevents the point of inflection from being found too early as a result of process variable noise.

With the pulse controller, the process variable is averaged over N pulse cycles and then made available to the controller stage. There is a further averaging of the process variable in the controller stage: Initially, this averaging is inactive; in other words, averaging always takes place over 1 cycle. As long as the noise exceeds a certain level, the number of cycles is doubled.

The period and amplitude of the noise are calculated. The search for the point of inflection is canceled and phase 2 is exited only when the gradient is always smaller than the maximum rise during the estimated period. TU and T_P_INF are, however, calculated at the actual point of inflection.

Tuning, however, is only ended when the following two conditions are met:

1. The process value is more than 2*NOISE_PV away from the point of inflection.
2. The process value has exceeded the point of inflection by 20%.

NOTE

When exciting the process using a setpoint step change, tuning is ended at the latest when the process value exceeds 75% of the setpoint step change (SP_INT-PV0) (see below).

PHASE = 3, 4, 5

The phases 3, 4 and 5 last 1 cycle each.

In Phase 3, the valid PI/PID parameters are saved before the optimization and the process parameter is calculated.

In Phase 4, the new PI/PID parameters are calculated.

In Phase 5, the new manipulated variable is calculated and the controlled system is given.

PHASE = 7

The process type is inspected in Phase 7, because TCONT_CP always changes to automatic mode after optimization. The automatic mode starts with LMN = LMN0 + 0.75*TUN_DLMN as a manipulated variable. The testing of the process type occurs **in the automatic mode** with the recently recalculated controller parameters and ends at the latest 0.35*TA (equilibrium time) after the point of inflection. If the process order deviates strongly from the estimated value, the controller parameters are newly calculated and STATUS_D is counted up by 1, otherwise, the controller parameters remain unchanged.

Then the optimization mode is complete and TCONT_CP is back in PHASE = 0. At the STATUS_H parameter, you can identify whether the tuning was successfully completed.

Premature cancellation of the optimization

In Phase 1, 2 or 3, you can cancel the optimization by resetting TUN_ON = FALSE without calculating new parameters. The controller starts in the automatic mode with LMN = LMN0 + TUN_DLMN. If the controller was in manual mode before the tuning, the old manual manipulated variable is output.

If the tuning is canceled in Phase 4, 5 or 7 with TUN_ON = FALSE, the determined controlled parameters are contained until then.

9.3.3.2 Requirements for an optimization

Transient response

The process must have a stable, asymptotic transient response with time lag.

The process value must settle to steady state after a step change of the manipulated variable. This therefore excludes processes that already show an oscillating response without control, as well as processes with no recovery (integrator in the control system).

⚠ WARNING

This may result in death, severe injury or considerable property damage.

During an tuning, the parameter MAN_ON is ineffective. Through this, the output value or process value may take on undesired - even extreme - values.

The output value is defined through the tuning. To cancel the tuning, you first have to set TUN_ON = FALSE. This makes MAN_ON effective again.

Guaranteeing a stationary initial state (phase 0)

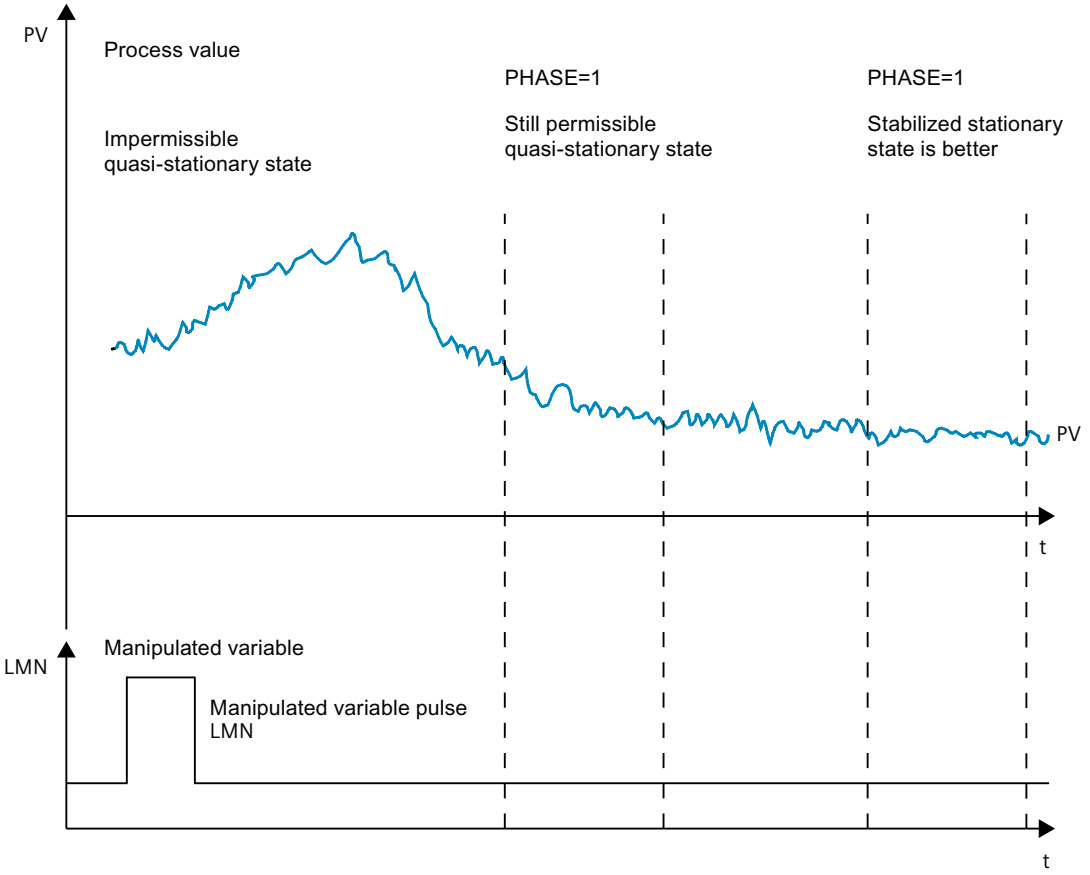
With lower-frequency oscillations of the process value, for example, due to incorrect controller parameters, the controller must be put in manual mode before the tuning is started and wait for the oscillation to stop. Alternatively, you could switch to a "soft" set PI controller (small loop gain large integration time).

Now you have to wait until the stationary state is reached, this means, until the process value and output value have a steady state. It is also permissible to have an asymptotic transient oscillation or slow drifting of the process value (stationary state, see the following image). The output value must be constant or fluctuate by a constant average.

NOTE

Avoid changing the manipulated variable shortly before starting the tuning. A change of the manipulated variable can occur in an unintended manner through the establishment of the test conditions (for example, closing an oven door)! If this does happen, you have to at least wait until the process value has an asymptotic transient oscillation in a stationary state again. Better controller parameters can be reached if you wait until the transient effect has completely subsided.

In the following image, the transient oscillation is illustrated in the stationary state:



Linearity and operating range

The process response must be linear across the operating range. Non-linear response occurs, for example, when an aggregation state changes. Tuning must take place in a linear part of the operating range.

This means, during tuning and normal control operation non-linear effects within the operating range must be insignificant. It is, however possible to retune the process when the operating point changes, providing tuning is repeated in the close vicinity of the new operating point and non-linearity does not occur during tuning.

If a specific static non-linearity (e.g., valve characteristics) is known, it is always advisable to compensate this with a polyline to linearize the process response.

Disturbance in temperature processes

Disturbances such as thermal transfer to neighboring zones must not influence the overall temperature process to any great extent. For example, when zones of an extruder are tuned, all zones must be heated up simultaneously.

9.3.3.3 Possibilities for optimization

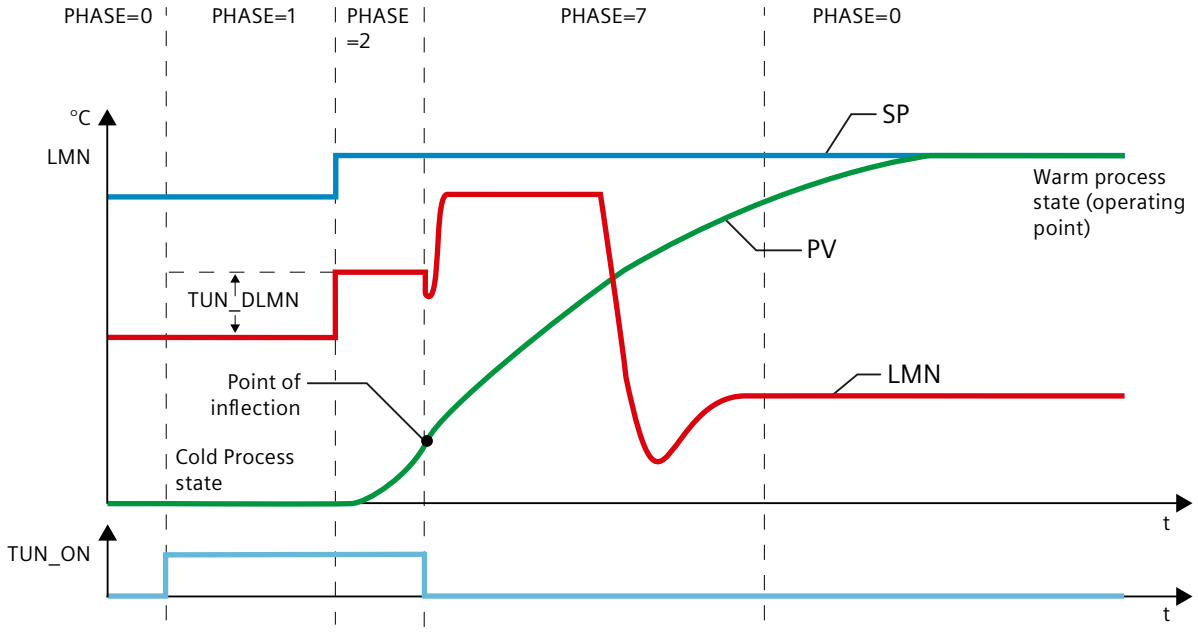
The following possibilities for tuning exist:

- Pretuning
- Fine tuning
- Manual fine-tuning in control mode

Pretuning

During this tuning, the working point is approached from the cold state through a setpoint jump.

With TUN_ON = TRUE, you can establish the tuning readiness. The controller switches from PHASE = 0 to PHASE = 1.



The tuning manipulated variable (LMN0 + TUN_DLMN) is activated by a setpoint change (transition phase 1 -> 2). The setpoint is not effective until the inflection point has been reached (automatic mode is not enabled until this point is reached).

The user is responsible for defining the output excitation delta (TUN_DLMN) according to the permitted process value change. The sign of TUN_DLMN must be set depending on the intended process value change (take into account the direction in which the control is operating).

The setpoint step change and TUN_DLMN must be suitably matched. If the value of TUN_DLMN is too high, there is a risk that the point of inflection will not be found before 75% of the setpoint step change is reached.

TUN_DLMN must nonetheless be high enough to ensure that the process value reaches at least 22 % of the setpoint step change. Otherwise, the process will remain in tuning mode (phase 2).

Remedy: Reduce the setpoint value during the inflection point search.

NOTE

If processes are extremely sluggish, it is advisable during tuning to specify a target setpoint that is somewhat lower than the desired operating point and to monitor the status bits and PV closely (risk of overshooting).

Tuning only in the linear range:

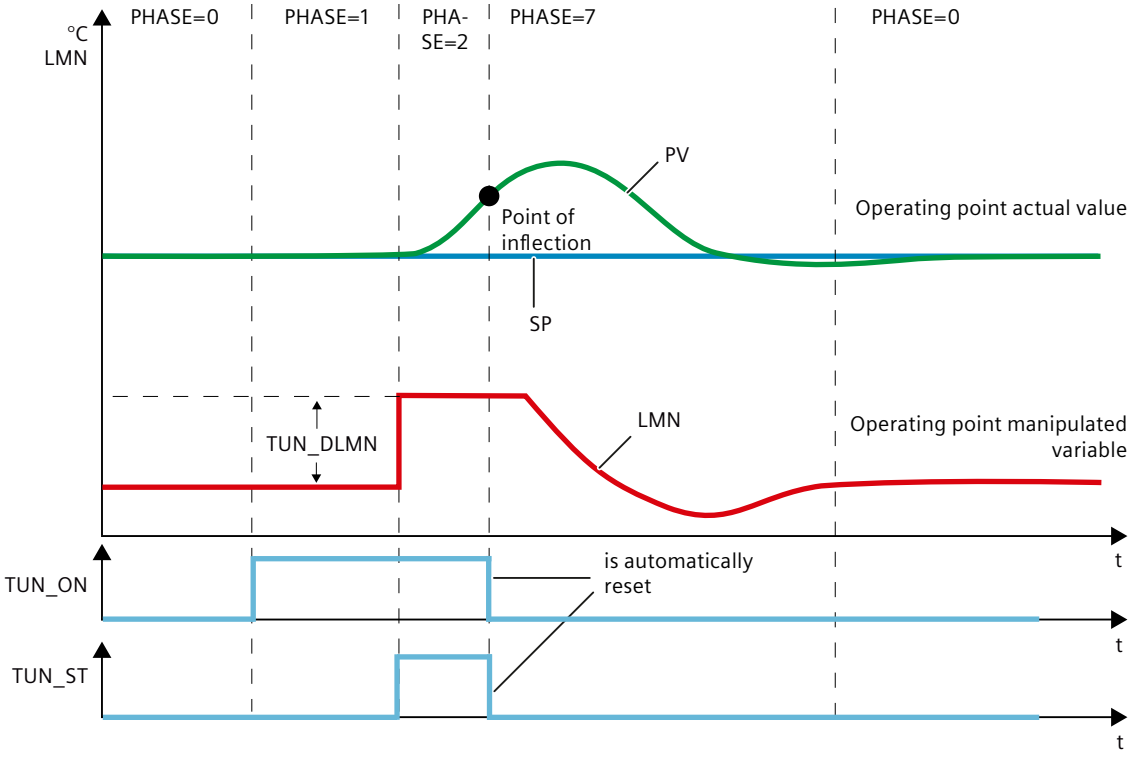
The signals of certain processes (e.g., zinc or magnesium smelters) will pass a non-linear area at the approach of the operating range (change in the state of aggregation).

By selecting a suitable setpoint step change, tuning can be limited to the linear range. When the process value has passed 75% of the setpoint step change (SP_INT-PV0), tuning is ended.

At the same time, TUN_DLMN should be reduced to the extent that the point of inflection is guaranteed to be found before 75% of the setpoint step change is reached.

Fine tuning

During this tuning, the process with a constant setpoint is activated through a output value jump.



The tuning manipulated variable (LMN0 + TUN_DLMN) is activated by setting the start bit TUN_ST (transition from phase 1 -> 2). When you modify the setpoint value, the new value will not take effect until the point of inflection has been reached (automatic mode will not be enabled until this point has been reached).

The user is responsible for defining the output excitation delta (TUN_DLMN) according to the permitted process value change. The sign of TUN_DLMN must be set depending on the intended process value change (take into account the direction in which the control is operating).

NOTICE
Safety off at 75% is not available when you excite the process via TUN_ST. Tuning is ended when the point of inflection is reached. However, in noisy processes the point of inflection may be significantly exceeded.

Manual fine-tuning in control mode

The following measures can be employed to achieve an overshoot-free setpoint response:

- Adapting the control zone
- Optimize command action
- Attenuation of control parameters
- Modifying control parameters

9.3.3.4 Tuning result

The left digit of STATUS_H displays the tuning status

STATUS_H	Result
0	Default or new controller parameters have not yet been found.
10000	Suitable control parameters found.
2xxxx	Control parameters have been found via estimated values; check the control response or check the STATUS_H diagnostic message and repeat controller tuning.
3xxxx	An operator error has occurred; check the STATUS_H diagnostic message and repeat controller tuning.

The CYCLE and CYCLE_P sampling times were already checked in phase 1.

The following controller parameters are updated on TCONT_CP:

- P (proportional GAIN)
- I (integration time TI)
- D (derivative time TD)
- Weighting of the proportional action PFAC_SP
- Coefficient DT1 (D_F)
- Control zone on/off CONZ_ON
- Control zone width CON_ZONE

The control zone is only activated if the process type is suitable (process type I and II) and a PID controller is used (CONZ_ON = TRUE).

Depending on PID_ON, control is implemented either with a PI or a PID controller. The old controller parameters are saved and can be retrieved with UNDO_PAR. A PI parameter record and a PID parameter record are saved additionally in the PI_CON and PID_CON structures. Using LOAD_PID and making a suitable setting for PID_ON, it is also possible to switch later between the tuned PI or PID parameters.

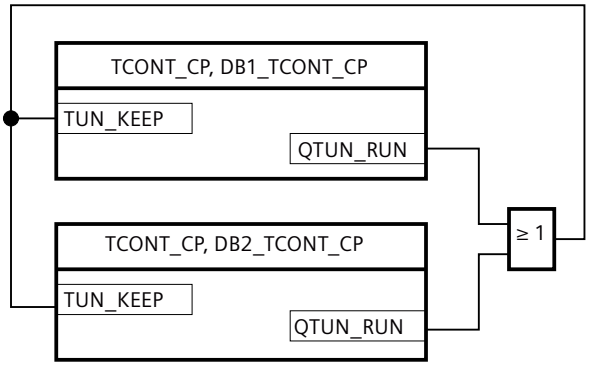
9.3.3.5 Parallel tuning of controller channels

Adjacent zones (strong heat coupling)

If two or more controllers are controlling the temperature, on a plate, for example (in other words, there are two heaters and two measured process values with strong heat coupling), proceed as follows:

1. OR the two outputs QTUN_RUN.
2. Interconnect each TUN_KEEP input with the output of the OR element.
3. Start both controllers by specifying a setpoint step change at the same time or by setting TUN_ST at the same time.

The following schematic illustrates the parallel tuning of controller channels.



Advantage:

Both controllers output LMN0 + TUN_DLMN until both controllers have left phase 2. This prevents the controller that completes tuning first from falsifying the tuning result of the other controller due to the change in its manipulated variable.

NOTICE
Reaching 75% of the setpoint step change causes an exiting of phase 2 and resetting of output QTUN_RUN. However, automatic mode does not start until TUN_KEEP is also 0.

Adjacent zones (weak heat coupling)

In general terms, tuning should be carried out to reflect the way in which the controller will operate subsequently. If zones are operated together during production such that the temperature differences between the zones remain the same, the temperature of the adjacent zones ought to be increased accordingly during tuning.

Differences in temperature at the beginning of the tuning are irrelevant since they will be compensated by the initial heating (-> initial rise = 0).

9.3.3.6 Fault descriptions and corrective measures

Compensating operator errors

Operator error	STATUS and action	Comment
TUN_ON and setpoint step change or TUN_ST are set simultaneously	Transition to phase 1; however, tuning is not started. • SP_INT = SP_{old} or • TUN_ST = FALSE	The setpoint change is canceled. This prevents the controller from settling to the new setpoint value and from leaving the stationary operating point unnecessarily.
Effective TUN_DLMN < 5% (end of phase 1)	STATUS_H = 30002 • Transition to phase 0 • TUN_ON = FALSE • SP = SP_{old}	Tuning is canceled. The setpoint change is canceled. This prevents the controller from settling to the new setpoint value and from leaving the stationary operating point unnecessarily.

Point of inflection not reached (only if excited by setpoint step change)

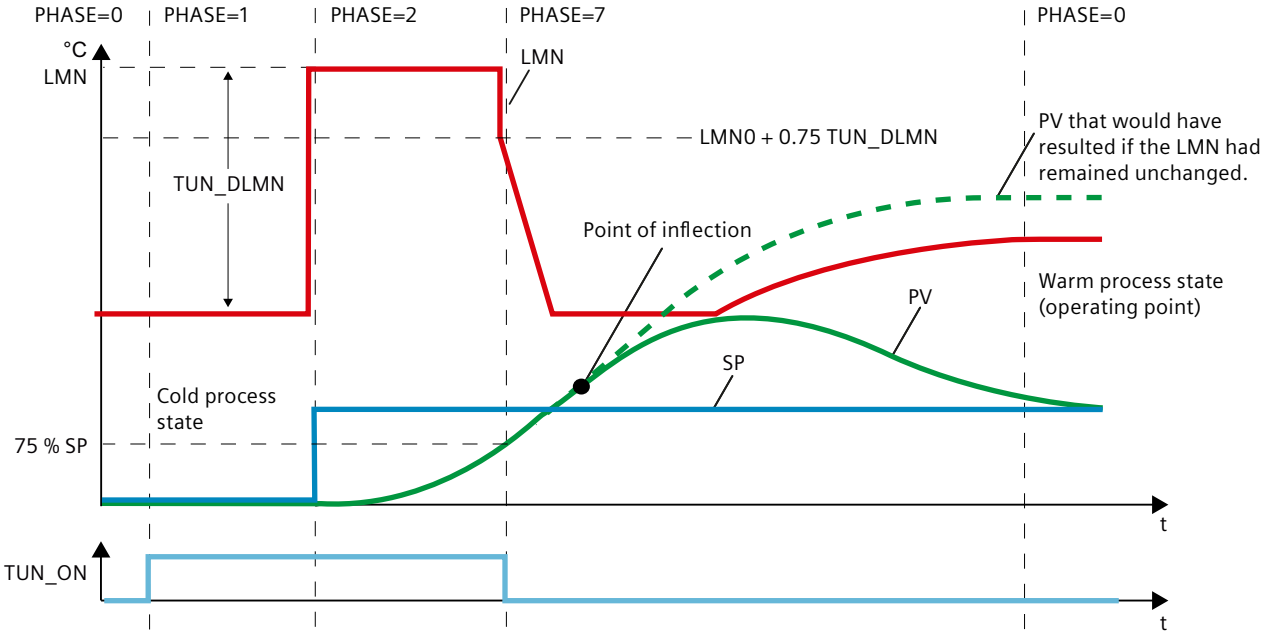
At the latest, tuning is ended when the process value has passed 75% of the setpoint step change (SP_INT-PV0). This is signaled by "inflection point not reached" in STATUS_H (2xx2x).

The currently valid setpoint always applies. By reducing the setpoint, it is possible to achieve an earlier end of the tuning function.

In typical temperature processes, cancelation of tuning at 75% of the setpoint step change is normally adequate to prevent overshoot. However, **caution** is advised, particularly in processes with a greater delay (TU/TA > 0.1, process type III). If manipulated variable excitation is too strong compared to the setpoint step change, the process value can overshoot heavily (up to a factor of 3).

In higher-order processes, if the point of inflection is still a long way off after reaching 75% of the setpoint step change, there will be significant overshoot. In addition, the controller parameters are too stringent. In this case, you should reduce the controller parameters or repeat the attempt.

The following schematic illustrates the overshoot of the process variable when the excitation is too strong (process type III):



In typical temperature processes, cancelation shortly before reaching the point of inflection is not critical in terms of the controller parameters.

If you repeat the attempt, reduce TUN_DLMN or increase the setpoint step change.

Principle: The value of the manipulated variable used for tuning must be suitable for the setpoint step change.

Error estimating the delay time or order

The delay time (STATUS_H = 2x1xx or 2x3xx) or order (STATUS_H = 21xxx or 22xxx) were not acquired correctly. Operation continues with an estimate that can lead to non-optimum controller parameters.

Repeat the tuning procedure and ensure that disturbances do not occur at the process value.

NOTE

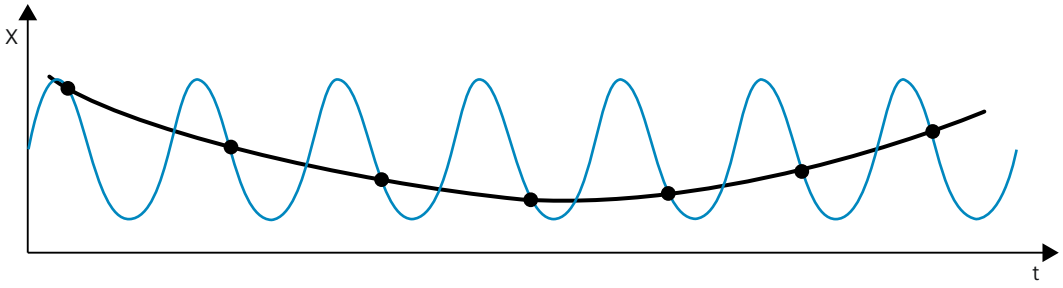
The special case of a PT1-only process is also indicated by STATUS_H = 2x1xx (TU <= 3*CYCLE). In this case, it is not necessary to repeat the attempt. Reduce the controller parameters if the control oscillates.

Quality of measuring signals (measurement noise, low-frequency interference)

The results of tuning can be distorted by measurement noise or by low-frequency interference. Note the following:

- If you encounter measurement noise, set the sampling frequency higher rather than lower. During one noise period, the process value should be sampled at least twice. In pulse mode, integrated mean value filtering can be helpful. This assumes, however, that the process variable PV is transferred to the instruction in the fast pulse cycle. The degree of noise should not exceed 5% of the useful signal change.
- High-frequency interference cannot be filtered out by TCONT_CP. This should be filtered earlier in the measuring sensor to prevent the aliasing effect.

  The following schematic illustrates the aliasing effect when the sampling time is too long:



- With low-frequency interference, it is relatively easy to ensure an adequately high sampling rate. However, the TCONT_CP must then generate a uniform measuring signal by having a large interval in the mean value filtering. Mean value filtering must extend over at least two noise periods. Internally in the block, this soon results in higher sampling times such that the accuracy of the tuning is adversely affected. Adequate accuracy is guaranteed with at least 40 noise periods up to the point of inflection.

  Possible remedy when repeating the attempt:

  Increase TUN_DLMN.

Overshoot

Overshoot can occur in the following situations:

Situation	Cause	Remedy
End of tuning	• Excitation by a too high manipulated value change compared with the set-point step change (see above). • PI controller activated by PID_ON = FALSE.	• Increase the setpoint step change or reduce the manipulated value step change. • If the process permits a PID control-ler, start tuning with PID_ON = TRUE.
Tuning in phase 7	Initially, less aggressive controller parame-ters were determined (process type III); these can lead to an overshoot in phase 7.	-
Control mode	PI controller with PFAC_SP = 1.0 for process type I.	If the process permits a PID controller, start tuning with PID_ON = TRUE.

9.3.3.7 Performing pretuning

Requirements

- The instruction and the technology object have been loaded to the CPU.

Procedure

To manually determine the optimum PID parameters for initial commissioning, follow these steps:

1. Click the "Start" icon.

   If there is no online connection, this will be established. The current values for the setpoint, process value and output value are recorded.
2. Select "Pretuning" from the "Mode" drop-down list.

   TCONT_CP is ready for tuning.
3. In the "Output value jump" field, specify how much the output value should be increased.
4. Enter a setpoint in the "Setpoint" field. The output value jump only takes effect when another setpoint is entered.
5. Click the "Start tuning" icon.

   The pretuning starts. The status of the tuning is displayed.

9.3.3.8 Performing fine tuning

Requirements

- The instruction and the technology object have been loaded to the CPU.

Procedure

To determine the optimal PID parameters at the operating point, follow these steps:

1. Click the "Start" icon.

   If there is no online connection, this will be established. The current values for the setpoint, process value and output value are recorded.
2. Select "Fine tuning" from the "Mode" drop-down list.

   TCONT_CP is ready for tuning.
3. In the "Output value jump" field, specify how much the output value should be increased.
4. Click the "Start tuning" icon.

   Fine tuning starts. The status of the tuning is displayed.

9.3.3.9 Cancelling pretuning or fine tuning

To cancel pretuning or fine tuning, click on the ■ icon, "Stop tuning".

If the PID parameters have not yet been calculated and stored, TCONT_CP starts in automatic mode LMN = LMN0 + TUN_DLMN. If the controller was in manual mode before the tuning, the old manual manipulated variable is output.

If the calculated PID parameters have already been saved, TCONT_CP starts in automatic mode and works with the previously determined PID parameters.

9.3.3.10 Manual fine-tuning in control mode

The following measures can be employed to achieve an overshoot-free setpoint response:

Adapting the control zone

During tuning, "TCONT_CP" determines a control zone CON_ZONE and activated if the process type is suitable (process type I and II) and a PID controller is used (CONZ_ON = TRUE). In control mode, you can modify the control zone or switch it off completely (with CONZ_ON = FALSE).

NOTE

Activating the control zone with higher-order processes (process type III) does not normally provide any benefit since the control zone is then larger than the control range that can be achieved with a 100% manipulated variable. There is also no advantage in activating the control zone for PI controllers.

Before you switch on the control zone manually, make sure that the control zone is not too narrow. If the control zone is set too narrow, oscillations occur in the manipulated variable and the process value.

Continuous attenuation of the control response with PFAC_SP

The control response can be attenuated with the PFAC_SP parameter. This parameter specifies the percentage of proportional component that is effective for setpoint step changes.

Regardless of the process type, PFAC_SP is set to a default value of 0.8 by the tuning function; you can later modify this value if required. To limit overshoot during setpoint step changes (with otherwise correct controller parameters) to approximately 2%, the following values are adequate for PFAC_SP:

	Process type I	**Process type II**	**Process type III**
	Typical temperature process	Intermediate range	Higher-order temperature process
PI	0.8	0.82	0.8
PID	0.6	0.75	0.96

Adjust the default factor (0.8) in the following situations, in particular:

- Process type I with PID (0.8 →0.6): Setpoint step changes within the control zone still lead to approximately 18% overshoot with PFAC_SP = 0.8.
- Process type III with PID (0.8 →0.96): Setpoint step changes with PFAC_SP = 0.8 are attenuated too strongly. This leads to a significantly slower response time.

Attenuation of control parameters

When a closed-loop control circuit oscillates or if overshoot occurs after setpoint step changes, you can reduce the controller GAIN (e.g., to 80% of the original value) and increase integral time TI (e.g., to 150% of the original value). If the analog output value of the continuous controller is converted to binary actuating signals by a pulse shaper, quantization noise may cause minor permanent oscillation. You can eliminate this by increasing the controller deadband DEADB_W.

Modifying control parameters

Proceed as follows to modify control parameters:

1. Save the current parameters with SAVE_PAR.
2. Modify the parameters.
3. Test the control response.

If the new parameter settings are worse than the old ones, retrieve the old parameters with UNDO_PAR.

9.3.3.11 Performing fine tuning manually

Requirements

- The instruction and the technology object have been loaded to the CPU.

Procedure

To manually determine the optimal PID parameters, proceed as follows:

1. Click the "Start" icon.

   If there is no online connection, this will be established. The current values for the setpoint, process value and output value are recorded.
2. Select "Manual" from the "Mode" drop-down list.
3. Enter the new PID parameters.
4. Click on the icon "Send parameter to CPU" in the "Tuning" group.
5. Select the "Change setpoint" check box in the "Current values" group.
6. Enter a new setpoint and click the icon in the "Current values" group.

7. Clear the "Manual mode" check box.
   The controller works with the new PID parameters and controls the new setpoint.
8. Check the quality of the PID parameter to check the curve points.
9. Repeat steps 3 to 8 until you are satisfied with the controller results.

9.4 TCONT_S

9.4.1 Technology object TCONT_S

The technology object TCONT_S provides a step controller for actuators with integrating behavior and is used to control technical temperature processes with binary output value output signals. The technology object corresponds to the instance data block of the TCONT_S instruction. The operating principle is based on the PI control algorithm of the sampling controller. The step controller operates without a position feedback signal. Both manual and automatic mode are possible.

S7-1500
All parameters and tags of the technology object are retentive and can only be changed during download to the device if you completely download TCONT_S.

See also

Overview of software controller (Page 44)
Add technology objects (Page 46)
Configure technology objects (Page 47)
Downloading technology objects to device (Page 49)
TCONT_S (Page 472)

9.4.2 Configure controller difference TCONT_S

Use process value periphery

To use the input parameter PV_PER, proceed as follows:

1. Select the entry "Periphery" from the "Source" list.
2. Select the "sensor type".
   Depending on the sensor type, the process value is scaled according to different formulas.
   - Standard
     Thermoelements; PT100/NI100
     PV = 0.1 × PV_PER × PV_FAC + PV_OFFS
   - Cooling;
     PT100/NI100
     PV = 0.01 × PV_PER × PV_FAC + PV_OFFS
   - Current/voltage
     PV = 100/27648 × PV_PER × PV_FAC + PV_OFFS
3. Enter the factor and offset for the scaling of the process value periphery.

Use internal process values

To use the input parameter PV_IN, proceed as follows:

1. Select the entry "Internal" from the "Source" list.

Control deviation

Set a dead zone range under the following requirement:

- The process value signal is noisy.
- The controller gain is high.
- The derivative action is activated.

The noise component of the process value causes strong deviations of the output value in this case. The dead zone suppresses the noise component in the steady controller state. The dead zone range specifies the size of the dead zone. With a dead zone range of 0.0, the dead zone is turned off.

See also

Mode of operation TCONT_S (Page 473)

9.4.3 Configure controller algorithm TCONT_S

General

1. Enter the "Sampling time PID algorithm".
   A controller sampling time should not exceed 10 % of the determined integral action time of the controller (TI).
2. If the controller structure contains a proportional action, enter the "proportional gain".
   A negative proportional gain inverts the rule meaning.

Proportional action

For changes of the setpoint, it may lead to overshooting of the proportional action. Through the weighting of the proportional action, you can select how strongly the proportional action should react when setpoint changes are made. The weakening of the proportional action is reached through a compensation of the integral action.

1. To weaken the proportional action for setpoint changes, enter a "Proportional action weighting".
   - 1.0: Proportional action for setpoint change is fully effective
   - 0.0: Proportional action for setpoint change is not effective

Integral action

1. If the controller structure contains an integral action, enter the "integral action time". With an integral action time of 0.0, the integral action is switched off.

See also

Mode of operation TCONT_S (Page 473)

9.4.4 Configure manipulated value TCONT_S

Pulse generator

1. Enter the minimum impulse duration and minimum pause duration.
   The values must be greater than or equal to the cycle time for the input parameter CYCLE.
   The frequency of operation is reduced through this.
2. Enter the motor setting time.
   The value must be greater than or equal to the cycle time of the input parameter CYCLE.

See also

Mode of operation TCONT_S (Page 473)

9.4.5 Commissioning TCONT_S

Requirements

- The instruction and the technology object have been loaded to the CPU.

Procedure

To manually determine the optimal PID parameters, proceed as follows:

1. Click the "Start" icon.
   If there is no online connection, this will be established. The current values for the setpoint, process value and output value are recorded.
2. Enter new PID parameters in the "P", "I" and weighting proportional action fields.
3. Click on the icon "Send parameter to CPU" in the "Tuning" group.
4. Select the "Change setpoint" check box in the "Current values" group.
5. Enter a new setpoint and click the icon in the "Current values" group.
6. Clear the "Manual mode" check box.
   The controller works with the new parameters and controls the new setpoint.
7. Check the quality of the PID parameter to check the curve points.
8. Repeat steps 2 to 6 until you are satisfied with the controller results.

Auxiliary functions

10

10.1 Polyline

Polyline

The Polyline instruction provides a function with the characteristic curve of the polyline whose points can be used, for example, to linearize the behavior of non-linear sensors.

More information

Compatibility with CPU and FW (Page 482)

Description Polyline (Page 483)

Operating principle Polyline (Page 485)

Input parameters of Polyline (Page 489)

Output parameters of Polyline (Page 489)

Static tags of Polyline (Page 489)

ErrorBits parameter (Page 491)

10.2 SplitRange

SplitRange

The SplitRange instruction splits the output value range of the PID controller into multiple subranges. These subranges enable control of a process that is influenced by multiple actuators.

More information

Compatibility with CPU and FW (Page 494)

SplitRange description (Page 494)

SplitRange input parameters (Page 497)

SplitRange static tags (Page 497)

SplitRange output parameters (Page 497)

ErrorBits parameter (Page 498)

10.3 RampFunction

RampFunction

The RampFunction instruction limits the slew rate of a signal. A signal jump at the input is output as ramp function of the output value, to achieve a smoother response, for example, without influencing the disturbance reaction.

More information

Compatibility with CPU and FW (Page 500)
RampFunction description (Page 500)
RampFunction mode of operation (Page 505)
RampFunction input parameters (Page 508)
RampFunction output parameters (Page 508)
RampFunction static tags (Page 509)
ErrorBits parameter (Page 510)

10.4 RampSoak

RampSoak

You can use this instruction to generate an output value that follows a configurable profile on a time-dependent basis. Every point of this profile has a target value and a time value. When the profile is executed, the target value of the current point is reached within the time value. The instruction can be used, for example, to provide a setpoint value profile for regulating a temperature process.

More information

Compatibility with CPU and FW (Page 513)
Description of RampSoak (Page 514)
Operating principle RampSoak (Page 516)
Input parameter RampSoak (Page 530)
Output parameter RampSoak (Page 531)
In-out parameter RampSoak (Page 531)
Static tags RampSoak (Page 532)
ErrorBits parameter (Page 533)

10.5 Filter_PT1

Filter_PT1

The instruction Filter_PT1 is a proportional transfer element with a first-order lag. You can use Filter_PT1 as a low-pass filter, delay element or process simulation block.

More information

Compatibility with CPU and FW (Page 537)
Description of Filter_PT1 (Page 538)
Operating principle Filter_PT1 (Page 544)
Input parameter Filter_PT1 (Page 546)
Output parameter Filter_PT1 (Page 546)
Static tags Filter_PT1 (Page 546)
ErrorBits parameter (Page 547)

10.6 Filter_PT2

Filter_PT2

The instruction Filter_PT2 is a proportional transfer element with a second-order lag. You can use Filter_PT2 as a low-pass filter, delay element or process simulation block.

More information

Compatibility with CPU and FW (Page 550)
Description of Filter_PT2 (Page 550)
Operating principle Filter_PT2 (Page 557)
Input parameter Filter_PT2 (Page 559)
Output parameter Filter_PT2 (Page 559)
Static tags Filter_PT2 (Page 559)
Description of Filter_PT2 (Page 550)

See also

ErrorBits parameter (Page 560)

10.7 Filter_DT1

Filter_DT1

The instruction Filter_DT1 is a differentiator with a first-order lag. You can use Filter_DT1 as a high-pass filter, differentiator, or feed-forward control.

More information

Compatibility with CPU and FW (Page 563)
Description of Filter_DT1 (Page 564)
Operating principle Filter_DT1 (Page 571)
Input parameter Filter_DT1 (Page 572)
Output parameter Filter_DT1 (Page 573)
Static tags Filter_DT1 (Page 573)
ErrorBits parameter (Page 574)

10.8 Filter_Universal

Filter_Universal

The Filter_Universal instruction is a configurable digital filter of the order 1 to 10. You can use Filter_Universal as a high-pass, low-pass, band-pass or band-stop filter.

More information

Compatibility with CPU and FW (Page 577)
Description Filter_Universal (Page 577)
Operating principle Filter_Universal (Page 579)
Input parameter Filter_Universal (Page 589)
Output parameter Filter_Universal (Page 589)
Static tags Filter_Universal (Page 590)
ErrorBits parameter (Page 591)

Instructions 11

11.1 PID_Compact

11.1.1 New features of PID_Compact

PID_Compact V3.0

- **Use with S7-1200 G2**

  As of PID_Compact V3.0, the instruction can also be used on an S7-1200 G2.

  Older versions of the instruction are not supported on S7-1200 G2.

  If you transfer programs from S7-1200 to S7-1200 G2, the version of PID_Compact will be changed to V3.0 at the next compile.
  Note the behavior changes described below that were introduced between your previous version of PID_Compact on CPU 1200 and PID_Compact V3.0.

- **Dead zone**

  If the process value is noisy, unnecessary fluctuations in the output value can be reduced by manually setting a dead zone width.

- **Active limitation of the integral action and change of the output value limits in automatic mode**

  In addition to the direction-dependent stopping of the integral component, this is now actively limited.

  This allows the change of the output value limits in automatic mode.

- **New tags Config.OutputSelect and Retain.CtrlParams.SetByUser**

  The tags Config.OutputSelect and Retain.CtrlParams.SetByUser replace the previous tags _Config.OutputSelect and _Retain.CtrlParams.SetByUser, which are only available via the Openness API.

  The tags Config.OutputSelect and Retain.CtrlParams.SetByUser are available both in the instance data block and via the Openness API.

  The existing values for the new tags Config.OutputSelect and Retain.CtrlParams.SetByUser are transferred to individual instances after switching to V3. For multi-instances, the new tags will have the default value after switching to V3. You restore the associated settings manually.

  If you have been using _Config.OutputSelect or _Retain.CtrlParams.SetByUser in your Openness application so far, replace them with the tags Config.OutputSelect and Retain.CtrlParams.SetByUser when you switch to PID_Compact V3.

PID_Compact V2.4

- **Initialization of the integral action**

  PID_Compact now initializes the integral action if you use OverwriteInitialOutputValue together with inverted control logic.

  If you have been using OverwriteInitialOutputValue together with inverted control logic up to now, please note that the sign of the output value changes with PID_Compact V2.4.

PID_Compact V2.3

- **Response of the output value when switching from "Inactive" operating mode to "Automatic mode"**

  The new option IntegralResetMode = 4 was added and defined as default. With IntegralResetMode = 4, the integral action is automatically preassigned when switching from "Inactive" operating mode to "Automatic mode" so that a control deviation results in a jump of the output value with identical sign.

- **Initialization of the integral action in automatic mode**

  The integral action can be initialized in automatic mode with the OverwriteInitialOutputValue and PIDCtrl.PIDInit tags. This simplifies the use of PID_Compact for override controls.

PID_Compact V2.2

- **Use with S7-1200**

  As of PID_Compact V2.2, the instruction with V2 functionality can also be used on S7-1200 as of firmware version 4.0.

PID_Compact V2.0

- **Response to errors**

  The response in the event of an error has been completely overhauled. PID_Compact now responds in a more fault-tolerant manner in the default setting. This reaction is set when copying PID_Compact V1.X from an S7-1200 CPU to an S7-1500 CPU.

NOTICE
Your system may be damaged. If you use the default setting, PID_Compact remains in automatic mode when the process value limits are exceeded. This may damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

  The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred. Use ErrorAck to acknowledge the errors and warnings without restarting the controller or clearing the integral action. Switching operating modes no longer clears errors that are no longer pending.

You can configure the responses in the event of an error with SetSubstituteOutput and ActivateRecoverMode.

- **Substitute output value**

  You can configure a substitute output value that is to be output if an error occurs.

- **Switching the operating mode**

  You specify the operating mode at the Mode in/out parameter and use a positive edge at ModeActivate to start the operating mode. The sRet.i_Mode tag has been omitted.

- **Multi-instance capability**

  You can call up PID_Compact as multi-instance DB.

- **Startup characteristics**

  The operating mode specified at the Mode parameter is also started on a falling edge at Reset and during a CPU cold restart, if RunModeByStartup = TRUE.

- **ENO characteristics**

  ENO is set depending on the operating mode.

  If State = 0, then ENO = FALSE.

  If State ≠ 0, then ENO = TRUE.

- **Setpoint value specification during tuning**

  You configure the permitted fluctuation of the setpoint during tuning at the CancelTuningLevel tag.

- **Value range for output value limits**

  The value 0.0 no longer has to fall within the output value limits.

- **Preassigning the integral action**

  Using the tags IntegralResetMode and OverwriteInitialOutputValue, you can determine the preassignment of the integral action when switching from "Inactive" operating mode to "Automatic mode".

- **Switching a disturbance variable on**

  You can switch a disturbance variable on at the Disturbance parameter.

- **Default value of PID parameters**

  The following default settings have been changed:

  – Proportional action weighting (PWeighting) from 0.0 to 1.0
  – Derivative action weighting (DWeighting) from 0.0 to 1.0
  – Coefficient for derivative delay (TdFiltRatio) from 0.0 to 0.2

- **Renaming tags**

  The static tags have been given new names that are compatible with PID_3Step.

PID_Compact V1.2

- **Manual mode on CPU startup**

  If ManualEnable = TRUE when the CPU starts, PID_Compact starts in manual mode. A rising edge at ManualEnable is not necessary.

- **Pretuning**

  If the CPU is switched off during pretuning, pretuning starts again when the CPU is switched back on.

PID_Compact V1.1

- **Manual mode on CPU startup**

  When the CPU starts up, PID_Compact only switches to manual mode with a rising edge at ManualEnable. Without rising edge, PID_Compact starts in the last operating mode in which ManualEnable was FALSE.

- **Reaction to reset**

  A rising edge at Reset resets the errors and warnings and clears the integral action. A falling edge at Reset triggers a switchover to the most recently active operating mode.

- **Default of process value high limit**

  The default value of r_Pv_Hlm has been changed to 120.0.

- **Monitoring the sampling time**

  – An error is no longer output when the current sampling time is ≥ 1.5 x current mean value or when the current sampling time is ≤ 0.5 x current mean value. The sampling time may deviate much more in automatic mode.

  – PID_Compact is compatible with FW as of V2.0.

- **Access to tags**

  The following tags can now be used in the user program.

  – i_Event_SUT

  – i_Event_TIR

  – r_Ctrl_Ioutv

- **Troubleshooting**

  PID_Compact now outputs the correct pulses when the shortest ON time is not equal to the shortest OFF time.

11.1.2 Compatibility with CPU and FW

The following table shows which version of PID_Compact can be used on which CPU.

CPU	FW	PID_Compact
S7-1200	as of V4.2	V2.3 V2.2 V1.2
	V4.0 to V4.1	V2.2 V1.2
	V3.x	V1.2 V1.1
	V2.x	V1.2 V1.1
S7-1200 G2	V1.0 or higher	V3.0
S7-1500	as of V3.1	V3.0 V2.4
	V3.0	V2.4
	V2.5 to V2.9	V2.4 V2.3 V2.2 V2.1 V2.0
	V2.0 and V2.1	V2.3 V2.2 V2.1 V2.0
	V1.5 to V1.8	V2.2 V2.1 V2.0
	V1.1	V2.1 V2.0
	V1.0	V2.0

11.1.3 CPU processing time and memory requirement PID_Compact as of V2

CPU processing time

Typical CPU processing times of the PID_Compact technology object as of Version V2.0, depending on CPU type and operating mode for standard, F, T and TF CPUs.

CPU	FW	Typ. CPU processing time Automatic mode	Typ. CPU processing time pre-tuning and fine tuning
CPU 1211	≥ V4.0	190 µs	270 µs
CPU 1212			
CPU 1214			
CPU 1215			

CPU 1217	≥ V4.0	190 µs	270 µs
CPU 1212 G2	≥ V1.0	100 µs	130 µs
CPU 1214 G2			
CPU 1216 G2	≥ V4.0	20 µs	30 µs
CPU 1217 G2			
CPU 1510SP	≤ V2.9	65 µs	80 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1515		50 µs	65 µs
CPU 1516			
CPU 1517	≤ V3.1	8 µs	12 µs
CPU 1518		4 µs	6 µs
CPU 1510SP	V3.0, V3.1	55 µs	70 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1514SP			
CPU 1515		40 µs	55 µs
CPU 1516			
CPU 1510SP	≥ V4.0	40 µs	55 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1514SP			
CPU 1515			
CPU 1516			
CPU 1516T		3 µs	4 µs
CPU 1517		2 µs	3 µs
CPU 1518		1 µs	2 µs

Typical CPU processing times of the PID_Compact technology object as of Version V2.0, depending on the CPU type and operating mode for R/H-CPUs in the RUN-Redundant system state.

CPU	FW	Typ. CPU processing time Automatic mode	Typ. CPU processing time pretuning and fine tuning
CPU 1513R	V3.0, V3.1	90 µs	140 µs
CPU 1515R		85 µs	100 µs
CPU 1513R	≥ V4.0	85 µs	100 µs
CPU 1515R			
CPU 1517H		4 µs	6 µs
CPU 1518HF			

Memory requirement

Memory requirement of an instance DB of the PID_Compact technology object as of Version V2.0.

Memory requirement	Memory requirement of the instance DB of PID_Compact V2.x	Memory requirement of the instance DB of PID_Compact V3.x
Load memory requirement	Approx. 3700 bytes	Approx. 3750 bytes
Total work memory requirement	788 bytes	802 bytes
Retentive work memory requirement	44 bytes	52 bytes

11.1.4 PID_Compact as of V2

11.1.4.1 Description of PID_Compact V3

Description

The PID_Compact instruction provides a PID controller with integrated tuning for actuators with proportional action.

The following operating modes are possible:

- Inactive
- Pretuning
- Fine tuning
- Automatic mode
- Manual mode
- Substitute output value with error monitoring

For a more detailed description of the operating modes, see the State parameter.

PID algorithm

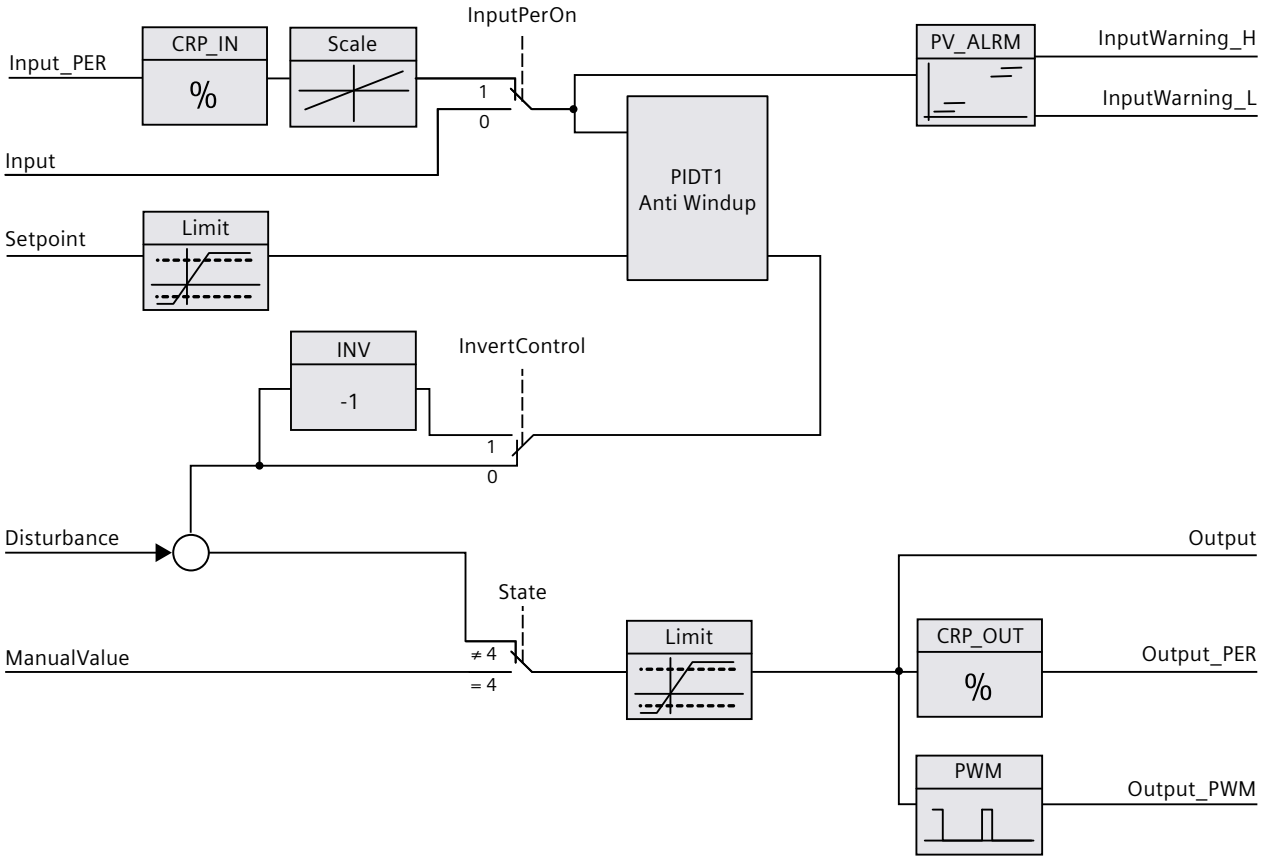
PID_Compact is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions. The PID algorithm operates according to the following equation (dead zone deactivated):

$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

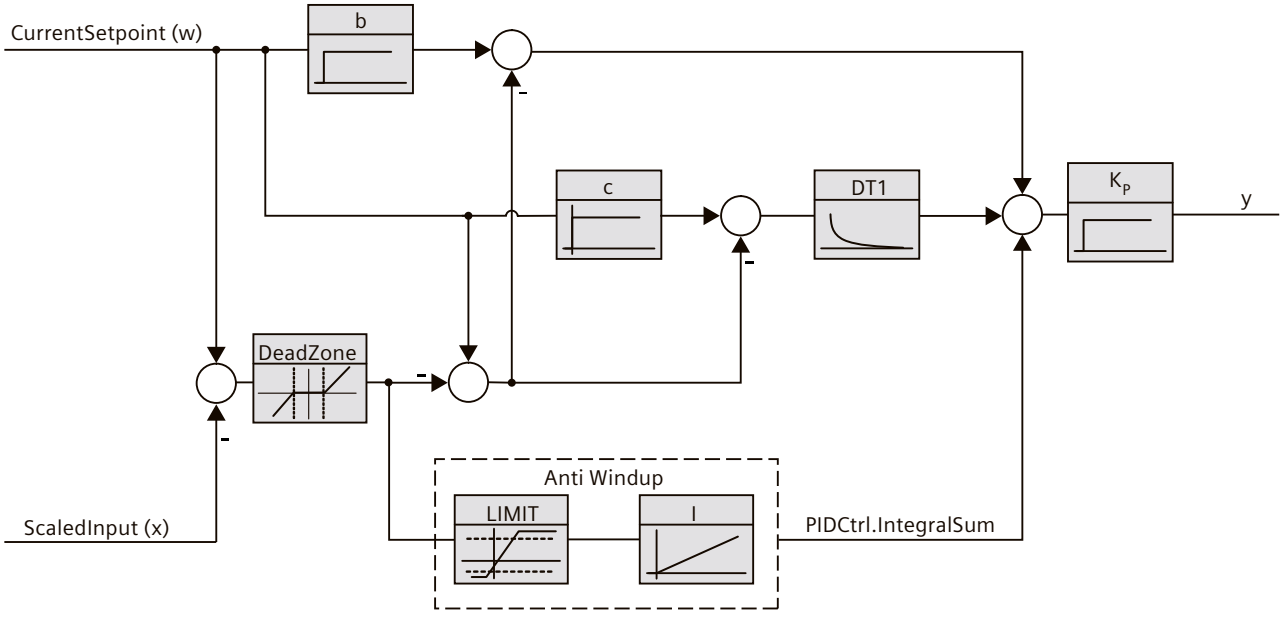
The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description	Associated parameters of the PID_Compact instruction
y	Output value of the PID algorithm	-
K_p	Proportional gain	Retain.CtrlParams.Gain
s	Laplace operator	-
b	Proportional action weighting	Retain.CtrlParams.PWeighting
w	Setpoint	CurrentSetpoint
x	Process value	ScaledInput
T_I	Integration time	Retain.CtrlParams.Ti
T_D	Derivative action time	Retain.CtrlParams.Td
a	Derivative delay coefficient (derivative delay T1 = a × T_D)	Retain.CtrlParams.TdFiltRatio
c	Derivative action weighting	Retain.CtrlParams.DWeighting
DeadZone	Dead zone width	Retain.CtrlParams.DeadZone

Block diagram of PID_Compact



Block diagram of PIDT1 with anti-windup



Call

PID_Compact is called in the constant time scale of a cyclic interrupt OB.

Download to device

The actual values of retentive tags are only updated when you download PID_Compact completely.

Download technology object to device

Startup

When the CPU starts up, PID_Compact starts in the operating mode saved in the Mode in/out parameter. To switch to "Inactive" operating mode during startup, set RunModeByStartup = FALSE.

Response to errors

The response in the event of an error is determined by the tags SetSubstituteOutput and ActivateRecoverMode. If ActivateRecoverMode = TRUE, the reaction additionally depends on the error that occurred.

SetSubstitu-teOutput	**ActivateR-ecoverMode**	**Configuration editor > output value > Set Output to**	**Reaction**
Not relevant	FALSE	Zero (inactive)	Switch to "Inactive" mode (State = 0) The value 0.0 is transferred to the actuator.
FALSE	TRUE	Current output value while error is pending	Switch to "Substitute output value with error monitoring" mode (State = 5) The current output value is transferred to the actuator while the error is pending.
TRUE	TRUE	Substitute output value while error is pending	Switch to "Substitute output value with error monitoring" mode (State = 5) The value at SubstituteOutput is transferred to the actuator while the error is pending.

In manual mode, PID_Compact uses ManualValue as output value, unless ManualValue is invalid. If ManualValue is invalid, SubstituteOutput is used. If ManualValue and SubstituteOutput are invalid, Config.OutputLowerLimit is used.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is reset by a rising edge at Reset or ErrorAck.

11.1.4.2 Description of PID_Compact V2

Description

The PID_Compact instruction provides a PID controller with integrated tuning for actuators with proportional action.

The following operating modes are possible:

- Inactive
- Pretuning
- Fine tuning
- Automatic mode
- Manual mode
- Substitute output value with error monitoring

For a more detailed description of the operating modes, see the State parameter.

PID algorithm

PID_Compact is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions. The PID algorithm operates according to the following transfer function:

$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

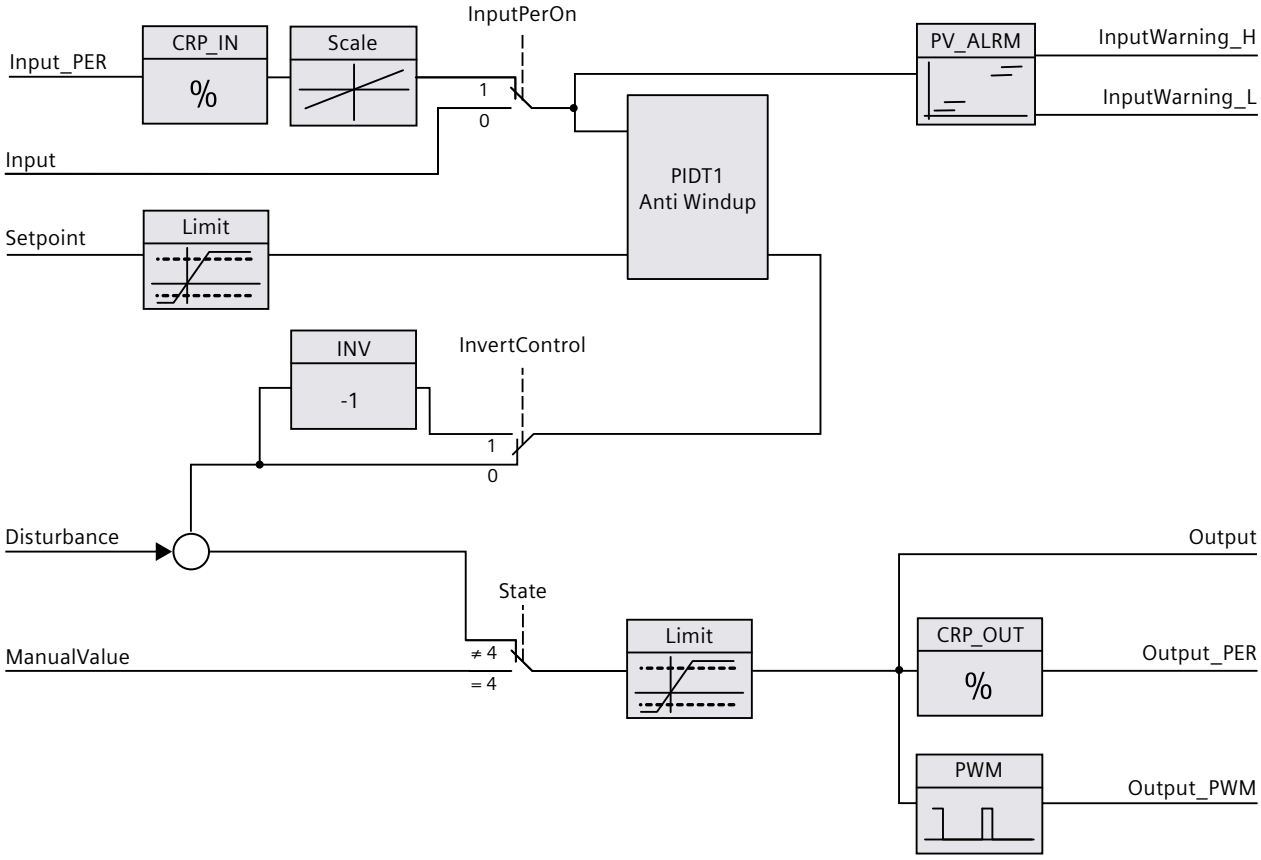
The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description	Associated parameters of the PID_Compact instruction
y	Output value of the PID algorithm	-
K_p	Proportional gain	Retain.CtrlParams.Gain
s	Laplace operator	-
b	Proportional action weighting	Retain.CtrlParams.PWeighting
w	Setpoint	CurrentSetpoint
x	Process value	ScaledInput
T_I	Integration time	Retain.CtrlParams.Ti
T_D	Derivative action time	Retain.CtrlParams.Td
a	Derivative delay coefficient (derivative delay T1 = a × T_D)	Retain.CtrlParams.TdFiltRatio
c	Derivative action weighting	Retain.CtrlParams.DWeighting

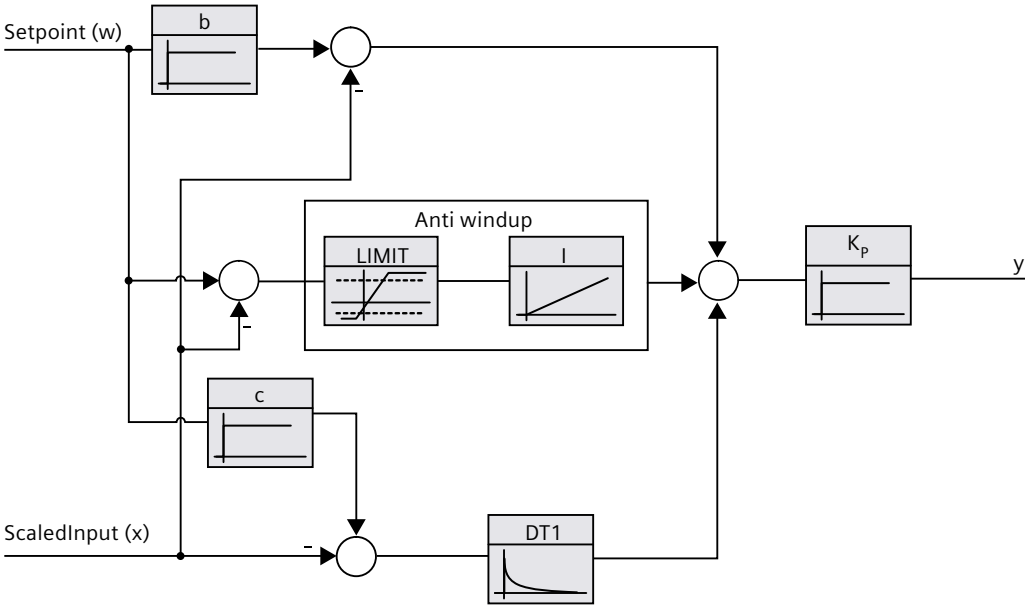
$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

Symbol	Description	Associated parameters of the **PID_Compact** instruction
y	Output value of the PID algorithm	-
K_p	Proportional gain	Retain.CtrlParams.Gain
s	Laplace operator	-
b	Proportional action weighting	Retain.CtrlParams.PWeighting
w	Setpoint	CurrentSetpoint
x	Process value	ScaledInput
T_I	Integration time	Retain.CtrlParams.Ti
T_D	Derivative action time	Retain.CtrlParams.Td
a	Derivative delay coefficient (derivative delay T1 = a × T_D)	Retain.CtrlParams.TdFiltRatio
c	Derivative action weighting	Retain.CtrlParams.DWeighting

Block diagram of PID_Compact



Block diagram of PIDT1 with anti-windup



Call

PID_Compact is called in the constant time scale of a cyclic interrupt OB.

Download to device

The actual values of retentive tags are only updated when you download PID_Compact completely.

Downloading technology objects to device (Page 49)

Startup

When the CPU starts up, PID_Compact starts in the operating mode saved in the Mode in/out parameter. To switch to "Inactive" operating mode during startup, set RunModeByStartup = FALSE.

Response to errors

The response in the event of an error is determined by the tags SetSubstituteOutput and ActivateRecoverMode. If ActivateRecoverMode = TRUE, the reaction additionally depends on the error that occurred.

SetSubstitu-teOutput	ActivateR-ecoverMode	Configuration editor > output value > Set Output to	Reaction
Not relevant	FALSE	Zero (inactive)	Switch to "Inactive" mode (State = 0) The value 0.0 is transferred to the actuator.
FALSE	TRUE	Current output value while error is pending	Switch to "Substitute output value with error monitoring" mode (State = 5) The current output value is transferred to the actuator while the error is pending.
TRUE	TRUE	Substitute output value while error is pending	Switch to "Substitute output value with error monitoring" mode (State = 5) The value at SubstituteOutput is transferred to the actuator while the error is pending.

In manual mode, PID_Compact uses ManualValue as output value, unless ManualValue is invalid. If ManualValue is invalid, SubstituteOutput is used. If ManualValue and SubstituteOutput are invalid, Config.OutputLowerLimit is used.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is reset by a rising edge at Reset or ErrorAck.

11.1.4.3 PID_Compact as of V2 operating principle

Monitoring process value limits

You specify the high limit and low limit of the process value in the Config.InputUpperLimit and Config.InputLowerLimit tags. If the process value is outside these limits, an error occurs (ErrorBits = 0001h).

You specify a high and low warning limit of the process value in the Config.InputUpperWarning and Config.InputLowerWarning tags. If the process value is outside these warning limits, a warning occurs (Warning = 0040h), and the InputWarning_H or InputWarning_L output parameter changes to TRUE.

Limiting the setpoint

You specify a high limit and low limit of the setpoint in the Config.SetpointUpperLimit and Config.SetpointLowerLimit tags. PID_Compact automatically limits the setpoint to the process value limits. You can limit the setpoint to a smaller range. PID_Compact checks whether this range falls within the process value limits. If the setpoint is outside these limits, the high or low limit is used as the setpoint, and output parameter SetpointLimit_H or SetpointLimit_L is set to TRUE.

The setpoint is limited in all operating modes.

Limiting the output value

You specify a high limit and low limit of the output value in the Config.OutputUpperLimit and Config.OutputLowerLimit tags. Output, ManualValue and SubstituteOutput are limited to these values. The output value limits must match the control logic.

The valid output value limit values depend on the Output used.

Output	-100.0 to 100.0%
Output_PER	-100.0 to 100.0%
Output_PWM	0.0 to 100.0%

Rule:

OutputUpperLimit > OutputLowerLimit

NOTE

Use with two or more actuators

PID_Compact is not suitable for use with two or more actuators (for example, in heating/cooling applications), because different actuators need different PID parameters to achieve a good control response. Use PID_Temp for applications with two actuators acting in opposite directions.

Substitute output value

In the event of an error, PID_Compact can output a substitute output value that you define at the SubstituteOutput tag. The substitute output value must be within the output value limits.

Monitoring signal validity

The values of the following parameters are monitored for validity when used:

- Setpoint
- Input
- Input_PER
- Disturbance
- ManualValue
- SubstituteOutput
- Output
- Output_PER
- Output_PWM

Monitoring of the sampling time PID_Compact

Ideally, the sampling time is equivalent to the cycle time of the calling OB. The PID_Compact instruction measures the time interval between two calls. This is the current sampling time. On every switchover of operating mode and during the initial startup, the mean value is formed from the first 10 sampling times. Too great a difference between the current sampling time and this mean value triggers an error (Error = 0800h).

The error occurs during tuning if:

- New mean value >= 1.1 x old mean value
- New mean value <= 0.9 x old mean value

The error occurs in automatic mode if:

- New mean value >= 1.5 x old mean value
- New mean value <= 0.5 x old mean value

If you deactivate the sampling time monitoring (CycleTime.EnMonitoring = FALSE), you can also call PID_Compact in OB1. You must then accept a lower control quality due to the deviating sampling time.

Sampling time of the PID algorithm

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_Compact are executed at every call.

If you use Output_PWM, the sampling time of the PID algorithm is used as the period duration of the pulse width modulation. The accuracy of the output signal is determined by the ratio of the PID algorithm sampling time to the cycle time of the OB. It is therefore recommended that the cycle time is a maximum of one tenth of the PID algorithm sampling time.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic. For cooling and discharge control systems, it may be necessary to invert the control logic. PID_Compact does not work with negative proportional gain. If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value. The control logic is also taken into account during pretuning and fine tuning.

11.1.4.4 Input parameters of PID_Compact as of V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-1

Parameter	Data type	Default	Description
Setpoint	REAL	0.0	Setpoint of the PID controller in automatic mode
Input	REAL	0.0	A tag of the user program is used as source for the process value. If you are using Input parameter, then Config.InputPerOn = FALSE must be set.
Input_PER	INT	0	An analog input is used as the source of the process value. If you are using Input_PER parameter, then Config.InputPerOn = TRUE must be set.
Disturbance	REAL	0.0	Disturbance variable or precontrol value
ManualEnable	BOOL	FALSE	• A FALSE -> TRUE edge activates "Manual mode", State = 4, Mode remains unchanged. As long as ManualEnable = TRUE, you cannot change the operating mode via a rising edge at ModeActivate or use the commissioning dialog. • A TRUE -> FALSE edge activates the operating mode that is specified by Mode. We recommend that you change the operating mode using ModeActivate only.
ManualValue	REAL	0.0	Manual value This value is used as the output value in manual mode. Values from Config.OutputLowerLimit to Config.OutputUpperLimit are permitted.
ErrorAck	BOOL	FALSE	• FALSE -> TRUE edge ErrorBits and Warning are reset.
Reset	BOOL	FALSE	Restarts the controller. • FALSE -> TRUE edge – Switch to "Inactive" mode – ErrorBits and Warnings are reset. • As long as Reset = TRUE, – PID_Compact remains in "Inactive" mode (State = 0). – You cannot change the operating mode with Mode and ModeActivate or ManualEnable. – You cannot use the commissioning dialog. • TRUE -> FALSE edge – If ManualEnable = FALSE, PID_Compact switches to the operating mode that is stored in the Mode parameter. – If Mode = 3, the integral action is treated as configured with the IntegralResetMode tag.
ModeActivate	BOOL	FALSE	• FALSE -> TRUE edge PID_Compact switches to the operating mode saved in the Mode parameter.

11.1.4.5 Output parameters of PID_Compact as of V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-2

Parameter	Data type	Default	Description
ScaledInput	REAL	0.0	Scaled process value
The "Output", "Output_PER", and "Output_PWM" outputs can be used concurrently.			
Output	REAL	0.0	Output value in REAL format
Output_PER	INT	0	Analog output value
Output_PWM	BOOL	FALSE	Pulse-width-modulated output value The output value is formed by variable On and Off times.
SetpointLimit_H	BOOL	FALSE	If SetpointLimit_H = TRUE, the absolute setpoint high limit is reached (Setpoint ≥ Config.SetpointUpperLimit). The setpoint is limited to Config.SetpointUpperLimit .
SetpointLimit_L	BOOL	FALSE	If SetpointLimit_L = TRUE, the absolute setpoint low limit has been reached (Setpoint ≤ Config.SetpointLowerLimit). The setpoint is limited to Config.SetpointLowerLimit .
InputWarning_H	BOOL	FALSE	If InputWarning_H = TRUE, the process value has reached or exceeded the warning high limit.
InputWarning_L	BOOL	FALSE	If InputWarning_L = TRUE, the process value has reached or fallen below the warning low limit.
State	INT	0	The State parameter (Page 274) shows the current operating mode of the PID controller. You can change the operating mode using the input parameter Mode and a rising edge at ModeActivate. • State = 0: Inactive • State = 1: Pre-tuning • State = 2: Fine tuning • State = 3: Automatic mode • State = 4: Manual mode • State = 5: Substitute output value with error monitoring
Error	BOOL	FALSE	If Error = TRUE, at least one error message is pending in this cycle.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 277) shows which error messages are pending. ErrorBits is retentive and is reset upon a rising edge at Reset or ErrorAck.

11.1.4.6 In/out parameter of PID_Compact as of V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-3

Parameter	Data type	Default	Description
Mode	INT	4	At Mode, specify the operating mode to which PID_Compact is to switch. Options are: • Mode = 0: Inactive • Mode = 1: Pretuning • Mode = 2: Fine tuning • Mode = 3: Automatic mode • Mode = 4: Manual mode The operating mode is activated by: • Rising edge at ModeActivate • Falling edge at Reset • Falling edge at ManualEnable • Cold restart of CPU if RunModeByStartup = TRUE Mode is retentive. A detailed description of the operating modes can be found in State and Mode as of V2 parameters (Page 274).

See also

State and Mode as of V2 parameters (Page 274)

11.1.4.7 Static tags of PID_Compact as of V2

NOTE

Change the tags identified with (1) only in "Inactive" mode to prevent malfunction of the PID controller.

Unless otherwise specified, the names of the following variables apply both to the data block and to access via the Openness API.

Tag	Data type	Default	Description
IntegralResetMode	INT	Up to V2.2: 1, as of V2.3: 4	The Tag IntegralResetMode as of V2 (Page 281) determines how the integral action PIDCtrl.IntegralSum is preassigned when switching from "Inactive" operating mode to "Automatic mode". This setting only works for one cycle. Options are: • IntegralResetMode = 0: Smooth • IntegralResetMode = 1: Delete • IntegralResetMode = 2: Hold • IntegralResetMode = 3: Preassign • IntegralResetMode = 4: Like setpoint change (only for PID_Compact with version ≥ 2.3)

Tag	Data type	Default	Description
OverwriteInitialOutputValue	REAL	0.0	If one of the following conditions is met, the integral action PIDCtrl.IntegralSum is preassigned automatically as if Output = OverwriteInitialOutputValue in the previous cycle: • IntegralResetMode = 3 when switching from "Inactive" operating mode to "Automatic mode" • IntegralResetMode = 3, TRUE -> FALSE edge at parameter Reset and parameter Mode = 3 • PIDCtrl.PIDInit = TRUE in "Automatic mode" (available as of PID_Compact version 2.3)
RunModeByStartup	BOOL	TRUE	Activate operating mode at Mode parameter after CPU restart If RunModeByStartup = TRUE, PID_Compact starts in the operating mode saved in the Mode parameter after CPU startup. If RunModeByStartup = FALSE, PID_Compact remains in "Inactive" mode after CPU startup.
LoadBackUp	BOOL	FALSE	If LoadBackUp = TRUE, the last set of PID parameters is reloaded from the CtrlParamsBackUp structure. The set was saved prior to the last tuning. LoadBackUp is automatically set back to FALSE.
PhysicalUnit	INT	0	Unit of measurement of the process value and setpoint, e.g., °C, or °F. PhysicalUnit serves the display in the editors and has no influence on the behavior of the control algorithm in the CPU. When importing PID_Compact up to Version 2.4 via the Openness API, PhysicalUnit is reset to the default value. As of Version 3.0, the value of PhysicalUnit is retained when importing.
PhysicalQuantity	INT	0	Physical quantity of the process value and setpoint, e.g., temperature. PhysicalQuantity serves the display in the editors and has no influence on the behavior of the control algorithm in the CPU. When importing PID_Compact up to Version 2.4 via the Openness API, PhysicalQuantity is reset to the default value. As of Version 3.0, the value of PhysicalQuantity is retained when importing.
ActivateRecoverMode	BOOL	TRUE	The ActivateRecoverMode tag as of V2 (Page 279) determines the response in the event of an error.
Warning	DWORD	0	Warning tag as of V2 (Page 280) shows the warnings since Reset = TRUE or ErrorAck =TRUE. Warning is retentive.
Progress	REAL	0.0	Progress of current tuning phase as a percentage (0.0 - 100.0)
CurrentSetpoint	REAL	0.0	CurrentSetpoint always displays the currently effective setpoint. This value is frozen during tuning.

Tag	Data type	Default	Description
CancelTuningLevel	REAL	10.0	Permissible fluctuation of setpoint during tuning. Tuning is not canceled until: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel
SubstituteOutput	REAL	0.0	Substitute output value When the following conditions are met, the substitute output value is used as the output value: • One or more errors are pending in automatic mode for which ActivateRecoverMode is in effect. • SetSubstituteOutput = TRUE • ActivateRecoverMode = TRUE Config.OutputUpperLimit ≥ SubstituteOutput ≥ Config.OutputLowerLimit
SetSubstituteOutput	BOOL	TRUE	Selection of the output value while an error is pending (State = 5) • If SetSubstituteOutput = TRUE and ActivateRecoverMode = TRUE, the SubstituteOutput substitute output value configured is output as long as an error is pending. • If SetSubstituteOutput = FALSE and ActivateRecoverMode = TRUE, the actuator remains at the current output value as long as an error is pending. • If ActivateRecoverMode = FALSE, SetSubstituteOutput is not effective. • If SubstituteOutput is invalid (ErrorBits = 16#0002_0000), the substitute output value cannot be output. In this case, the low limit of the output value (Config.OutputLowerLimit) is used as output value.
Config.InputPerOn(1)	BOOL	TRUE	If InputPerOn = TRUE, the Input_PER parameter is used for detecting the process value. If InputPerOn = FALSE, the Input parameter is used.
Config.InvertControl(1)	BOOL	FALSE	Invert control logic If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value.
Config.OutputSelect	INT	0	Selection of the output value (as of Version 3.0): • OutputSelect = 0: Output_PER (analog) • OutputSelect = 1: Output • OutputSelect = 2: Output_PWM Config.OutputSelect is used for configuring the controller in the TIA Portal and has no influence on the calculation of the output values in the CPU.
_Config.OutputSelect	INT	0	Selection of the output value (up to Version 2.4): • OutputSelect = 0: Output_PER (analog) • OutputSelect = 1: Output • OutputSelect = 2: Output_PWM _Config.OutputSelect is used for configuring the controller in the TIA Portal and has no influence on the calculation of the output values in the CPU.

Tag	Data type	Default	Description
			_Config.OutputSelect is not available in the data block and can only be configured in the configuration editor or via the Openness API. When importing PID_Compact via the Openness API, _Config.OutputSelect is reset to the default value.
Config.InputUpperLimit(1)	REAL	120.0	High limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is exceeded, an error is output and the reaction is determined by ActivateRecoverMode. At the I/O input, the process value can be a maximum of 18% higher than the standard range (overrange). This means the limit cannot be exceeded when you use an I/O input with the pre-setting for high limit and process value scaling. When pretuning is started, the difference between high and low limit of the process value is checked to determine whether the distance between setpoint and process value meets the necessary requirements. InputUpperLimit > InputLowerLimit
Config.InputLowerLimit(1)	REAL	0.0	Low limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is undershot, an error is output and the reaction is determined by ActivateRecoverMode. InputLowerLimit < InputUpperLimit
Config.InputUpperWarning(1)	REAL	3.402822e+38	Warning high limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is exceeded, a warning is output at the parameter. If you set InputUpperWarning outside the process value limits, the configured absolute process value high limit is used as the warning high limit. If you configure InputUpperWarning within the process value limits, this value is used as the warning high limit. InputUpperWarning > InputLowerWarning
Config.InputLowerWarning(1)	REAL	-3.402822e+38	Warning low limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is undershot, a warning is output at the Warning parameter. If you set InputLowerWarning outside the process value limits, the configured absolute process value low limit is used as the warning low limit. If you configure InputLowerWarning within the process value limits, this value is used as the warning low limit. InputLowerWarning < InputUpperWarning
Config.OutputUpperLimit	REAL	100.0	High limit of output value For details, see OutputLowerLimit 100.0 ≥ OutputUpperLimit > OutputLowerLimit
Config.OutputLowerLimit	REAL	0.0	Low limit of the output value For Output and Output_PER, the range of values from -100.0 to +100.0, including zero, is valid. At -100.0, Output_PER = -27648; at +100.0, Output_PER = 27648. For Output_PWM, the value range 0.0 to +100.0 applies. The output value limits must match the control logic.

Tag	Data type	Default	Description
			As of Version 3.0, PID_Compact supports the change of the output value limits in automatic mode. Up to version 2.4, these may only be changed in the inactive or manual modes. OutputLowerLimit < OutputUpperLimit
Config.SetpointUpperLimit(1)	REAL	3.402822e+38	High limit of setpoint Setpoint is monitored to ensure adherence to this limit. If the limit is exceeded, a warning is output at the Warning parameter. If you configure SetpointUpperLimit outside the process value limits, the configured process value absolute high limit is used as the setpoint high limit. If you configure SetpointUpperLimit within the process value limits, this value is used as the setpoint high limit. SetpointUpperLimit > SetpointLowerLimit
Config.SetpointLowerLimit(1)	REAL	-3.402822e+38	Low limit of the setpoint Setpoint is monitored to ensure adherence to this limit. If the limit is undershot, a warning is output at the Warning parameter. If you set SetpointLowerLimit outside the process value limits, the configured process value absolute low limit is used as the setpoint low limit. If you set SetpointLowerLimit within the process value limits, this value is used as the setpoint low limit. SetpointLowerLimit < SetpointUpperLimit
Config.MinimumOnTime(1)	REAL	0.0	The minimum ON time of the pulse width modulation in seconds is rounded to MinimumOnTime = n×CycleTime.Value 100000.0 ≥ MinimumOnTime ≥ 0.0
Config.MinimumOffTime(1)	REAL	0.0	The minimum OFF time of the pulse width modulation in seconds is rounded to MinimumOffTime = n×CycleTime.Value 100000.0 ≥ MinimumOffTime ≥ 0.0
Config.InputScaling.UpperPointIn(1)	REAL	27648.0	Scaling Input_PER high Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). UpperPointIn > LowerPointIn
Config.InputScaling.LowerPointIn(1)	REAL	0.0	Scaling Input_PER low Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). LowerPointIn < UpperPointIn
Config.InputScaling.UpperPointOut(1)	REAL	100.0	Scaled high process value Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). UpperPointOut > LowerPointOut

Tag	Data type	Default	Description
Config.InputScaling.LowerPointOut(1)	REAL	0.0	Scaled low process value Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). LowerPointOut < UpperPointOut
CycleTime.StartEstimation	BOOL	TRUE	If CycleTime.EnEstimation = TRUE, CycleTime.StartEstimation = TRUE starts the automatic determination of the PID_Compact sampling time (cycle time of the calling OB). Once measurement is complete, CycleTime.StartEstimation = FALSE is set.
CycleTime.EnEstimation	BOOL	TRUE	If CycleTime.EnEstimation = TRUE, the PID_Compact sampling time is determined automatically. If CycleTime.EnEstimation = FALSE, the PID_Compact sampling time is not determined automatically and must be configured correctly manually with CycleTime.Value.
CycleTime.EnMonitoring	BOOL	TRUE	If CycleTime.EnMonitoring = FALSE, the PID_Compact sampling time is not monitored. If PID_Compact cannot be executed within the sampling time, no error (ErrorBits=16#0000_0800) is output and PID_Compact does not respond as configured with ActivateRecoverMode.
CycleTime.Value(1)	REAL	0.1	PID_Compact sampling time (cycle time of the calling OB) in seconds CycleTime.Value is determined automatically and is usually equivalent to the cycle time of the calling OB.
You can load values from the CtrlParamsBackUp structure with LoadBackUp = TRUE.			
CtrlParamsBackUp.SetByUser	BOOL	FALSE	Saved value of Retain.CtrlParams.SetByUser (as of Version 3.0)
CtrlParamsBackUp.Gain	REAL	1.0	Saved proportional gain
CtrlParamsBackUp.Ti	REAL	20.0	Saved integration time in seconds
CtrlParamsBackUp.Td	REAL	0.0	Saved derivative action time in seconds
CtrlParamsBackUp.TdFiltRatio	REAL	0.2	Saved derivative delay coefficient
CtrlParamsBackUp.PWeighting	REAL	1.0	Saved proportional action weighting factor
CtrlParamsBackUp.DWeighting	REAL	1.0	Saved derivative action weighting factor
CtrlParamsBackUp.Cycle	REAL	1.0	Saved sampling time of PID algorithm in seconds
CtrlParamsBackUp.DeadZone	REAL	0.0	Saved dead zone width (as of Version 3.0)
PIDSelfTune.SUT.CalculateParams	BOOL	FALSE	The properties of the controlled system are saved during tuning. If SUT.CalculateParams = TRUE, the parameters for pretuning are recalculated according to these properties. This enables you to change the parameter calculation method without having to repeat controller tuning. SUT.CalculateParams is set to FALSE after the calculation.

Tag	Data type	Default	Description
PIDSelfTune.SUT.TuneRule	INT	0	Methods used to calculate parameters during pretuning: • SUT.TuneRule = 0: PID according to Chien, Hrones and Reswick • SUT.TuneRule = 1: PI according to Chien, Hrones and Reswick
PIDSelfTune.SUT.State	INT	0	The SUT.State tag indicates the current phase of pretuning: • State = 0: Initialize pretuning • State = 100: Calculate the standard deviation • State = 200: Find the point of inflection • State = 9900: Pretuning successful • State = 1: Pretuning not successful
PIDSelfTune.TIR.RunIn	BOOL	FALSE	With the RunIn tag, you can specify that fine tuning can also be performed without pretuning. • RunIn = FALSE Pretuning is started when fine tuning is started from inactive or manual mode. If the requirements for pretuning are not met, PID_Compact reacts as if RunIn = TRUE. If fine tuning is started from automatic mode, the system uses the existing PID parameters to control to the setpoint. Only then will fine tuning start. If pretuning is not possible, PID_Compact switches to the mode from which tuning was started. • RunIn = TRUE The pretuning is skipped. PID_Compact attempts to reach the setpoint with the minimum or maximum output value. This can produce increased overshoot. Fine tuning then starts automatically. RunIn is set to FALSE after fine tuning.
PIDSelfTune.TIR.CalculateParams	BOOL	FALSE	The properties of the controlled system are saved during tuning. If TIR.CalculateParams = TRUE, the parameters for fine tuning are recalculated according to these properties. This enables you to change the parameter calculation method without having to repeat controller tuning. TIR.CalculateParams is set to FALSE after the calculation.
PIDSelfTune.TIR.TuneRule	INT	0	Methods used to calculate parameters during fine tuning: • TIR.TuneRule = 0: PID automatic • TIR.TuneRule = 1: PID fast (faster control response with higher amplitudes of the output value than with TIR.TuneRule = 2) • TIR.TuneRule = 2: PID slow (slower control response with lower amplitudes of the output value than with TIR.TuneRule = 1) • TIR.TuneRule = 3: Ziegler-Nichols PID • TIR.TuneRule = 4: Ziegler-Nichols PI • TIR.TuneRule = 5: Ziegler-Nichols P To be able to repeat the calculation of the PID parameters with TIR.CalculateParams and TIR.TuneRule = 0, 1 or 2, the previous fine tuning also has to have been executed with TIR.TuneRule = 0, 1 or 2.

Tag	Data type	Default	Description
			If this is not the case, TIR.TuneRule = 3 is used. The recalculation of the PID parameters with TIR.CalculateParams and TIR.TuneRule = 3, 4 or 5 is always possible.
PIDSelfTune.TIR.State	INT	0	The TIR.State tag indicates the current phase of fine tuning: • State = -100 Fine tuning is not possible. Pretuning will be performed first. • State = 0: Initialize fine tuning • State = 200: Calculate the standard deviation • State = 300: Attempt to reach setpoint • State = 400: Attempt to reach setpoint with existing PID parameters (if pretuning was successful) • State = 500: Determine oscillation and calculate parameters • State = 9900: Fine tuning successful • State = 1: Fine tuning not successful
PIDCtrl.IntegralSum(1)	REAL	0.0	Current integral action
PIDCtrl.PIDInit	BOOL	FALSE	PIDCtrl.PIDInit is available as of PID_Compact version 2.3. If PIDCtrl.PIDInit = TRUE in "Automatic mode", the integral action PIDCtrl.IntegralSum is preassigned automatically as if Output = OverwriteInitialOutputValue in the previous cycle. This can be used for a Override control with PID_Compact as of V2 (Page 100).
Retain.CtrlParams.SetByUser(1)	BOOL	FALSE	Enable manual input of PID parameters (as of Version 3.0) If Retain.CtrlParams.SetByUser = TRUE, the PID parameters are editable. Retain.CtrlParams.SetByUser is used for configuring the controller in the TIA Portal and has no influence on the behavior of the control algorithm in the CPU. SetByUser is retentive.
_Retain.CtrlParams.SetByUser(1)	BOOL	FALSE	Enable manual input of PID parameters (up to Version 2.4) If _Retain.CtrlParams.SetByUser = TRUE, the PID parameters are editable. _Retain.CtrlParams.SetByUser is used for configuring the controller in the TIA Portal and has no influence on the behavior of the control algorithm in the CPU. _Retain.CtrlParams.SetByUser is not available in the data block and can only be configured in the configuration editor or via the Openness API. When importing PID_Compact via the Openness API, _Retain.CtrlParams.SetByUser is reset to the default value.
Retain.CtrlParams.Gain(1)	REAL	1.0	Active proportional gain PID_Compact does not work with a negative proportional gain. To invert the control logic, use the Config.InvertControl tag. Gain is retentive. Gain ≥ 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.Ti(1)	REAL	20.0	• CtrlParams.Ti > 0.0: Active integration time in seconds • CtrlParams.Ti = 0.0: Integral action is deactivated Ti is retentive. 100000.0 ≥ Ti ≥ 0.0
Retain.CtrlParams.Td(1)	REAL	0.0	• CtrlParams.Td > 0.0: Active derivative action time in seconds • CtrlParams.Td = 0.0: Derivative action is deactivated Td is retentive. 100000.0 ≥ Td ≥ 0.0
Retain.CtrlParams.TdFiltRatio(1)	REAL	0.2	Active derivative delay coefficient The derivative delay coefficient delays the effect of the derivative action. Derivative delay = derivative action time × derivative delay coefficient • 0.0: Derivative action is effective for one cycle only and therefore almost not effective. • 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant. • > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed. TdFiltRatio is retentive. TdFiltRatio ≥ 0.0
Retain.CtrlParams.PWeighting(1)	REAL	1.0	Active proportional action weighting The proportional action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Proportional action for setpoint change is fully effective • 0.0: Proportional action for setpoint change is not effective The proportional action is always fully effective when the process value is changed. PWeighting is retentive. 1.0 ≥ PWeighting ≥ 0.0
Retain.CtrlParams.DWeighting(1)	REAL	1.0	Active derivative action weighting The derivative action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Derivative action is fully effective upon setpoint change • 0.0: Derivative action is not effective upon setpoint change The derivative action is always fully effective when the process value is changed. DWeighting is retentive. 1.0 ≥ DWeighting ≥ 0.0
Retain.CtrlParams.Cycle(1)	REAL	1.0	Active sampling time of the PID algorithm in seconds CtrlParams.Cycle is calculated during tuning and rounded to an integer multiple of CycleTime.Value. CtrlParams.Cycle is used as time period of the pulse width modulation. Cycle is retentive. 100000.0 ≥ Cycle > 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.DeadZone(1)	REAL	0.0	Active dead zone width CtrlParams.DeadZone is available as of PID_Compact Version 3.0. With CtrlParams.DeadZone = 0.0, the dead zone is switched off. CtrlParams.DeadZone is not set automatically or adjusted during tuning. You must correctly configure CtrlParams.DeadZone manually. When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning. DeadZone is retentive. DeadZone ≥ 0.0

See also

ActivateRecoverMode tag as of V2 (Page 279)
Warning tag as of V2 (Page 280)
Downloading technology objects to device (Page 49)

11.1.4.8 Changing the interface of PID_Compact as of V2

The following table shows what has changed in the PID_Compact instruction interface.

PID_Compact V1	PID_Compact as of V2	Change
Input_PER	Input_PER	Data type from Word to Int
	Disturbance	New
	ErrorAck	New
	ModeActivate	New
Output_PER	Output_PER	Data type from Word to Int
Error	ErrorBits	Renamed
	Error	New
	Mode	New
sb_RunModeByStartup	RunModeByStartup	Function
	IntegralResetMode	
	OverwriteInitialOutputValue	New
	SetSubstituteOutput	New
	CancelTuningLevel	New
	SubstituteOutput	New

The following table shows which variables have been renamed.

PID_Compact V1.x	PID_Compact as of V2
sb_GetCycleTime	CycleTime.StartEstimation
sb_EnCyclEstimation	CycleTime.EnEstimation

PID_Compact V1.x	PID_Compact as of V2
sb_EnCyclMonitoring	CycleTime.EnMonitoring
sb_RunModeByStartup	RunModeByStartup
si_Unit	PhysicalUnit
si_Type	PhysicalQuantity
sd_Warning	Warning
sBackUp.r_Gain	CtrlParamsBackUp.Gain
sBackUp.r_Ti	CtrlParamsBackUp.Ti
sBackUp.r_Td	CtrlParamsBackUp.Td
sBackUp.r_A	CtrlParamsBackUp.TdFiltRatio
sBackUp.r_B	CtrlParamsBackUp.PWeighting
sBackUp.r_C	CtrlParamsBackUp.DWeighting
sBackUp.r_Cycle	CtrlParamsBackUp.Cycle
sPid_Calc.r_Cycle	CycleTime.Value
sPid_Calc.b_RunIn	PIDSelfTune.TIR.RunIn
sPid_Calc.b_CalcParamSUT	PIDSelfTune.SUT.CalculateParams
sPid_Calc.b_CalcParamTIR	PIDSelfTune.TIR.CalculateParams
sPid_Calc.i_CtrlTypeSUT	PIDSelfTune.SUT.TuneRule
sPid_Calc.i_CtrlTypeTIR	PIDSelfTune.TIR.TuneRule
sPid_Calc.r_Progress	Progress
sPid_Cmpt.r_Sp_Hlm	Config.SetpointUpperLimit
sPid_Cmpt.r_Sp_Llm	Config.SetpointLowerLimit
sPid_Cmpt.r_Pv_Norm_IN_1	Config.InputScaling.LowerPointIn
sPid_Cmpt.r_Pv_Norm_IN_2	Config.InputScaling.UpperPointIn
sPid_Cmpt.r_Pv_Norm_OUT_1	Config.InputScaling.LowerPointOut
sPid_Cmpt.r_Pv_Norm_OUT_2	Config.InputScaling.UpperPointOut
sPid_Cmpt.r_Lmn_Hlm	Config.OutputUpperLimit
sPid_Cmpt.r_Lmn_Llm	Config.OutputLowerLimit
sPid_Cmpt.b_Input_PER_On	Config.InputPerOn
sPid_Cmpt.b_LoadBackUp	LoadBackUp
sPid_Cmpt.b_InvCtrl	Config.InvertControl
sPid_Cmpt.r_Lmn_Pwm_PPTm	Config.MinimumOnTime
sPid_Cmpt.r_Lmn_Pwm_PBTm	Config.MinimumOffTime
sPid_Cmpt.r_Pv_Hlm	Config.InputUpperLimit
sPid_Cmpt.r_Pv_Llm	Config.InputLowerLimit
sPid_Cmpt.r_Pv_HWrn	Config.InputUpperWarning
sPid_Cmpt.r_Pv_LWrn	Config.InputLowerWarning
sParamCalc.i_Event_SUT	PIDSelfTune.SUT.State
sParamCalc.i_Event_TIR	PIDSelfTune.TIR.State

PID_Compact V1.x	PID_Compact as of V2
sRet.i_Mode	sRet.i_Mode has been omitted. The operating mode is changed using Mode and ModeActivate.
sRet.r_Ctrl_Gain	Retain.CtrlParams.Gain
sRet.r_Ctrl_Ti	Retain.CtrlParams.Ti
sRet.r_Ctrl_Td	Retain.CtrlParams.Td
sRet.r_Ctrl_A	Retain.CtrlParams.TdFiltRatio
sRet.r_Ctrl_B	Retain.CtrlParams.PWeighting
sRet.r_Ctrl_C	Retain.CtrlParams.DWeighting
sRet.r_Ctrl_Cycle	Retain.CtrlParams.Cycle

11.1.4.9 State and Mode as of V2 parameters

Correlation of the parameters

The State parameter shows the current operating mode of the PID controller. You cannot change the State parameter.

With a rising edge at ModeActivate, PID_Compact switches to the operating mode saved in the Mode in-out parameter.

When the CPU is switched on or switches from Stop to RUN mode, PID_Compact starts in the operating mode that is saved in the Mode parameter. To retain PID_Compact in "Inactive" mode, set RunModeByStartup = FALSE.

Meaning of values

State / Mode	Description of operating mode
0	Inactive In "Inactive" operating mode, the output value 0.0 is always output, regardless of Config.OutputUpperLimit and Config.OutputLowerLimit. Pulse width modulation is off.
1	Pretuning The pretuning determines the process response to a jump change of the output value and searches for the point of inflection. The PID parameters are calculated from the maximum rate of rise and dead time of the controlled system. You obtain the best PID parameters when you perform pretuning and fine tuning. Pretuning requirements: • Inactive (State = 0), manual mode (State = 4), or automatic mode (State = 3) • ManualEnable = FALSE • Reset = FALSE • The process value must not be too close to the setpoint. |Setpoint - Input| > 0.3 * | Config.InputUpperLimit - Config.InputLowerLimit| and |Setpoint - Input| > 0.5 * |Setpoint| • The setpoint and the process value lie within the configured limits. The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise.

State / Mode	Description of operating mode
	The setpoint is frozen in the CurrentSetpoint tag. Tuning is canceled when: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel Before the PID parameters are recalculated, they are backed up and can be reactivated with LoadBackUp. The controller switches to automatic mode following successful pretuning. If pretuning is unsuccessful, the switchover of the operating mode is dependent on ActivateRecoverMode. The phase of pretuning is indicated with PIDSelfTune.SUT.State. For starting pretuning in Automatic mode, it is recommended to perform the required setpoint change simultaneously with the rising edge at ModeActivate. If the setpoint is changed first and the pretuning is started later, the output value in automatic mode is adjusted accordingly and causes a change to the process value. This can have a negative effect on the subsequent pretuning or prevent it from starting.
2	Fine tuning Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are recalculated based on the amplitude and frequency of this oscillation. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. You obtain the best PID parameters when you perform pretuning and fine tuning. PID_Compact automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The setpoint is frozen in the CurrentSetpoint tag. Tuning is canceled when: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel Before the PID parameters are recalculated, they are backed up and can be reactivated with LoadBackUp. Requirements for fine tuning: • No disturbances are expected. • The setpoint and the process value lie within the configured limits. • ManualEnable = FALSE • Reset = FALSE • Automatic (State = 3), inactive (State = 0) or manual (State = 4) mode Fine tuning proceeds as follows when started from: • Automatic mode (State = 3) Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning. PID_Compact controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. • Inactive (State = 0) or manual mode (State = 4) If the requirements for pretuning are met, pretuning is started. The determined PID parameters will be used for control until the control loop has stabilized and the requirements for fine tuning have been met. If the process value for pretuning is already too near the setpoint or PIDSelfTune.TIR.RunIn = TRUE, an attempt is made to reach the setpoint with the minimum or maximum output value. This can produce increased overshoot. Only then will fine tuning start. The controller switches to automatic mode following successful fine tuning. If fine tuning is unsuccessful, the switchover of the operating mode is dependent on ActivateRecoverMode. The "Fine tuning" phase is indicated with PIDSelfTune.TIR.State.
3	Automatic mode In automatic mode, PID_Compact corrects the controlled system in accordance with the parameters specified. The controller switches to automatic mode if one the following requirements is fulfilled: • Pretuning successfully completed • Fine tuning successfully completed • Changing of the Mode in-out parameter to the value 3 and a rising edge at ModeActivate. The switchover from automatic mode to manual mode is only bumpless if carried out in the commissioning editor. The ActivateRecoverMode tag is taken into consideration in automatic mode.

State / Mode	Description of operating mode
4	Manual mode In manual mode, you specify a manual output value in the ManualValue parameter. You can also activate this operating mode using ManualEnable = TRUE. We recommend that you change the operating mode using Mode and ModeActivate only. The switchover from manual mode to automatic mode is bumpless. Manual mode is also possible when an error is pending.
5	Substitute output value with error monitoring The control algorithm is deactivated. The SetSubstituteOutput tag determines which output value is output in this operating mode. • SetSubstituteOutput = FALSE: Last valid output value • SetSubstituteOutput = TRUE: Substitute output value You cannot activate this operating mode using Mode = 5. In the event of an error, it is activated instead of "Inactive" operating mode if all the following conditions are met: • Automatic mode (Mode = 3) • ActivateRecoverMode = TRUE • One or more errors have occurred in which ActivateRecoverMode is effective. As soon as the errors are no longer pending, PID_Compact switches back to automatic mode.

ENO characteristics

If State = 0, then ENO = FALSE.

If State ≠ 0, then ENO = TRUE.

Automatic switchover of operating mode during commissioning

Automatic mode is activated following successful pretuning or fine tuning. The following table shows how Mode and State change during successful pretuning.

Cycle no.	Mode	State	Action
0	4	4	Set Mode = 1
1	1	4	Set ModeActivate = TRUE
1	4	1	Value of State is saved in Mode parameter Pretuning is started
n	4	1	Pretuning successfully completed
n	3	3	Automatic mode is started

PID_Compact automatically switches the operating mode in the event of an error. The following table shows how Mode and State change during pretuning with errors.

Cycle no.	Mode	State	Action
0	4	4	Set Mode = 1
1	1	4	Set ModeActivate = TRUE

Cycle no.	Mode	State	Action
1	4	1	Value of State is saved in Mode parameter Pretuning is started
n	4	1	Pretuning canceled
n	4	4	Manual mode is started

If ActivateRecoverMode = TRUE, the operating mode that is saved in the Mode parameter is activated. At the start of pretuning or fine tuning, PID_Compact has saved the value of State in the Mode in/out parameter. PID_Compact therefore switches to the operating mode from which tuning was started.

If ActivateRecoverMode = FALSE, the system switches to "Inactive" operating mode.

See also

Output parameters of PID_Compact as of V2 (Page 262)

11.1.4.10 ErrorBits as of V2 parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

In manual mode, PID_Compact uses ManualValue as output value. The exception is Errorbits = 16#0001_0000.

ErrorBits (DW#16#...)	Description
0000_0000	There is no error.
0000_0001	The "Input" parameter is outside the process value limits. • Input > Config.InputUpperLimit or • Input < Config.InputLowerLimit If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Compact remains in automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter.
0000_0002	Invalid value at "Input_PER" parameter. Check whether an error is pending at the analog input. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Compact outputs the configured substitute output value. As soon as the error is no longer pending, PID_Compact switches back to automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter.
0000_0004	Error during fine tuning. The oscillation of the process value could not be maintained. If ActivateRecoverMode = TRUE before the error occurred, PID_Compact cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0008	Error at start of pretuning. The process value is too close to the setpoint. Start fine tuning. If ActivateRecoverMode = TRUE before the error occurred, PID_Compact cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0010	The setpoint was changed during tuning. You can set the permitted fluctuation of the setpoint at the CancelTuningLevel tag. If ActivateRecoverMode = TRUE before the error occurred, PID_Compact cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0020	Pretuning is not permitted during fine tuning. If ActivateRecoverMode = TRUE before the error occurred, PID_Compact remains in fine tuning mode.

ErrorBits (DW#16#...)	Description
0000_0080	Error during pretuning. The output value limits are not configured correctly or the process value does not react as expected. Make sure that: • The limits of the output value are configured correctly and match the control logic. • It is possible to change the output value so that the process value approaches the setpoint. The output value is not already limited by the corresponding output value limit before the pretuning. Example: With normal control logic and a process value that is below the setpoint, the output value must not have reached the high limit before the start of the pretuning. • The process value does not show a strong oscillation before the start of the pretuning. For starting a pretuning in automatic mode, it is recommended to perform the required setpoint change simultaneously with the rising edge at ModeActivate. This prevents the output value from running into the limitation between the setpoint change and the start of the pretuning. Alternatively, this can also be achieved by starting from manual mode or "Inactive" mode. If ActivateRecoverMode = TRUE before the error occurred, PID_Compact cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0100	Error during fine tuning resulted in invalid parameters. If ActivateRecoverMode = TRUE before the error occurred, PID_Compact cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0200	Invalid value at "Input" parameter: Value has an invalid number format. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Compact outputs the configured substitute output value. As soon as the error is no longer pending, PID_Compact switches back to automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter.
0000_0400	Calculation of output value failed. Check the PID parameters. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Compact outputs the configured substitute output value. As soon as the error is no longer pending, PID_Compact switches back to automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter.
0000_0800	Sampling time error: PID_Compact is not called within the sampling time of the cyclic interrupt OB. It is recommended to call PID_Compact in a cyclic interrupt OB without conditions and to activate or deactivate it via the operating mode at the Mode parameter. Conditional calls or the call in OB1 can have a negative effect on the control quality. Monitoring of the sampling time can be disabled with CycleTime.EnMonitoring = FALSE. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Compact remains in automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter. If this error occurred during simulation with PLCSIM, see the notes under Simulating PID_Compact as of V2 with PLCSIM (Page 104).
0000_1000	Invalid value at "Setpoint" parameter: Value has an invalid number format. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Compact outputs the configured substitute output value. As soon as the error is no longer pending, PID_Compact switches back to automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter.
0001_0000	Invalid value at ManualValue parameter. Value has an invalid number format. If ActivateRecoverMode = TRUE before an error occurred, PID_Compact uses SubstituteOutput as the output value. As soon as you specify a valid value in ManualValue, PID_Compact uses it as the output value.

ErrorBits (DW#16#...)	Description
0002_0000	Invalid value at SubstituteOutput tag. Value has an invalid number format. PID_Compact uses the output value low limit as the output value. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_Compact switches back to automatic mode.
0004_0000	Invalid value at Disturbance parameter. Value has an invalid number format. If automatic mode was active and ActivateRecoverMode = TRUE before the error occurred, Disturbance is set to zero. PID_Compact remains in automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Compact switches to the operating mode saved in the Mode parameter. If Disturbance in the current phase has no effect on the output value, tuning is not be canceled.

11.1.4.11 ActivateRecoverMode tag as of V2

The ActivateRecoverMode tag determines the response in the event of an error. The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred.

Automatic mode

NOTICE
Your system may be damaged. If ActivateRecoverMode = TRUE, PID_Compact remains in automatic mode even if there is an error and the process limit values are exceeded. This may damage your system. It is essential to configure how your controlled system responds in the event of an error to protect your system from damage.

ActivateRecover-Mode	Description
FALSE	PID_Compact automatically switches to "Inactive" mode in the event of an error. The controller is only activated by a falling edge at Reset or a rising edge at ModeActivate.
TRUE	If errors occur frequently in automatic mode, this setting has a negative effect on the control response, because PID_Compact switches between the calculated output value and the substitute output value at each error. In this case, check the ErrorBits parameter and eliminate the cause of the error. If one or more of the following errors occur, PID_Compact stays in automatic mode: • 0001h: The "Input" parameter is outside the process value limits. • 0800h: Sampling time error • 40000h: Invalid value at Disturbance parameter. If one or more of the following errors occur, PID_Compact switches to "Substitute output value with error monitoring" mode: • 0002h: Invalid value at Input_PER parameter. • 0200h: Invalid value at Input parameter. • 0400h: Calculation of output value failed. • 1000h: Invalid value at Setpoint parameter. If the following error occurs, PID_Compact switches to "Substitute output value with error monitoring" mode and moves the actuator to Config.OutputLowerLimit: • 20000h: Invalid value at SubstituteOutput tag. Value has an invalid number format. This characteristics are independent of SetSubstituteOutput. As soon as the errors are no longer pending, PID_Compact switches back to automatic mode.

Pretuning and fine tuning

ActivateRecover-Mode	Description
FALSE	PID_Compact automatically switches to "Inactive" mode in the event of an error. The controller is only activated by a falling edge at Reset or a rising edge at ModeActivate.
TRUE	If the following error occurs, PID_Compact remains in the active mode: • 0020h: Pretuning is not permitted during fine tuning. The following errors are ignored: • 10000h: Invalid value at ManualValue parameter. • 20000h: Invalid value at SubstituteOutput tag. When any other error occurs, PID_Compact cancels the tuning and switches to the mode from which tuning was started.

Manual mode

ActivateRecoverMode is not effective in manual mode.

11.1.4.12 Warning tag as of V2

If several warnings are pending simultaneously, the values of the Warning tag are displayed with binary addition. The display of the warning 16#0000_0003, for example, indicates that the warnings 0000_0001 and 0000_0002 are pending simultaneously.

Warning (DW#16#....)	Description
0000_0000	No warning pending.
0000_0001	The point of inflection was not found during pretuning.
0000_0004	The setpoint was limited to the configured limits.
0000_0008	Not all the necessary controlled system properties were defined for the selected method of calculation. Instead, the PID parameters were calculated using the TIR.TuneRule = 3 method.
0000_0010	The operating mode could not be changed because Reset = TRUE or ManualEnable = TRUE.
0000_0020	The cycle time of the calling OB limits the sampling time of the PID algorithm. Improve results by using shorter OB cycle times.
0000_0040	The process value exceeded one of its warning limits.
0000_0080	Invalid value at Mode. The operating mode is not switched.
0000_0100	The manual value was limited to the limits of the controller output.
0000_0200	The specified rule for tuning is not supported. No PID parameters are calculated.
0000_1000	The substitute output value cannot be reached because it is outside the output value limits.

The following warnings are deleted as soon as the cause is eliminated:

- 16#0000_0001
- 16#0000_0004
- 16#0000_0008
- 16#0000_0040
- 16#0000_0100

All other warnings are cleared with a rising edge at Reset or ErrorAck.

11.1.4.13 Tag IntegralResetMode as of V2

The IntegralResetMode tag determines how the integral action PIDCtrl.IntegralSum is preassigned:

- When switching from "Inactive" operating mode to "Automatic mode"
- With edge TRUE -> FALSE at parameter Reset and parameter Mode = 3

This setting only works for one cycle and only takes effect if the integral action is activated (Retain.CtrlParams.Ti > 0.0 tags).

IntegralReset-Mode	Description
0	Smooth The value of PIDCtrl.IntegralSum is preassigned so that the switchover is bumpless, which means "Automatic mode" starts with the output value = 0.0 (Output parameter) and there is no jump of the output value regardless of the control deviation (setpoint – process value).
1	Delete We recommend setting the weighting of the proportional action (Retain.CtrlParams.PWeighting) to 1.0 when this option is used. The value of PIDCtrl.IntegralSum is deleted. Any control deviation will cause a jump change of the output value. The direction of the output value jump depends on the configured weighting of the proportional action (Retain.CtrlParams.PWeighting tag) and the control deviation: • Proportional action weighting = 1.0: Output value jump and control deviation have identical signs. Example: If the process value is less than the setpoint (positive control deviation), the output value jumps to a positive value. • Proportional action weighting < 1.0: For large control deviations, the output value jump and control deviation have identical signs. Example: If the process value is much less than the setpoint (positive control deviation), the output value jumps to a positive value. For small control deviations, the output value jump and control deviation have different signs. Example: If the process value is just below the setpoint (positive control deviation), the output value jumps to a negative value. This is usually not desirable, because it results in a temporary increase in the control deviation. The smaller the configured weighting of the proportional action, the greater the control deviation must be to receive an output value jump with identical sign. We recommend setting the weighting of the proportional action (Retain.CtrlParams.PWeighting) to 1.0 when this option is used. Otherwise, you may experience the undesirable behavior described for small control deviations. Alternatively, you can also use IntegralResetMode = 4. This option guarantees identical signs of the output value jump and control deviation independent of the configured weighting of the proportional action and the control deviation.

IntegralReset-Mode	Description
2	Hold The value of PIDCtrl.IntegralSum is not changed. You can define a new value using the user program.
3	Preassign The value of PIDCtrl.IntegralSum is automatically preassigned as if Output = OverwriteInitialOutputValue in the last cycle.
4	Like setpoint change (only for PID_Compact with version ≥ 2.3) The value of PIDCtrl.IntegralSum is automatically preassigned so that a similar output value jump results as for a PI controller in automatic mode in case of a setpoint change from the current process value to the current setpoint. Any control deviation will cause a jump change of the output value. Output value jump and control deviation have identical signs. Example: If the process value is less than the setpoint (positive control deviation), the output value jumps to a positive value. This is independent of the configured weighting of the proportional action and the control deviation.

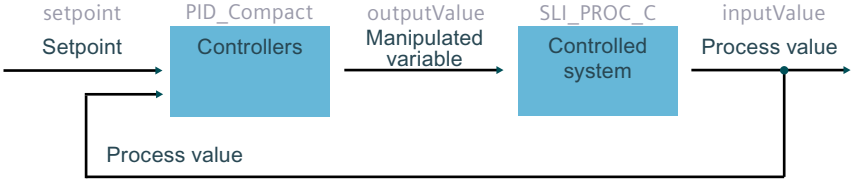
If IntegralResetMode is assigned a value outside the valid value range, PID_Compact behaves as with the preassignment of IntegralResetMode:

- PID_Compact up to V2.2: IntegralResetMode = 1
- PID_Compact as of V2.3: IntegralResetMode = 4

All statements made above regarding the sign of the output value jump are based on a normal control logic (Config.InvertControl = FALSE tag). With an inverted control logic (Config.InvertControl = TRUE), the output value jump will have a reverse sign.

11.1.4.14 Example program for PID_Compact V2

In the following example, you are controlling temperature values with the technology object of the instruction "PID_Compact". The temperature values are simulated based on a block which simulates a delay element of the third order (PT3 element). The PID parameters of the technology object can be set automatically via the pretuning.



Data storage

Create seven tags in a global data block for storage of the interconnection data.

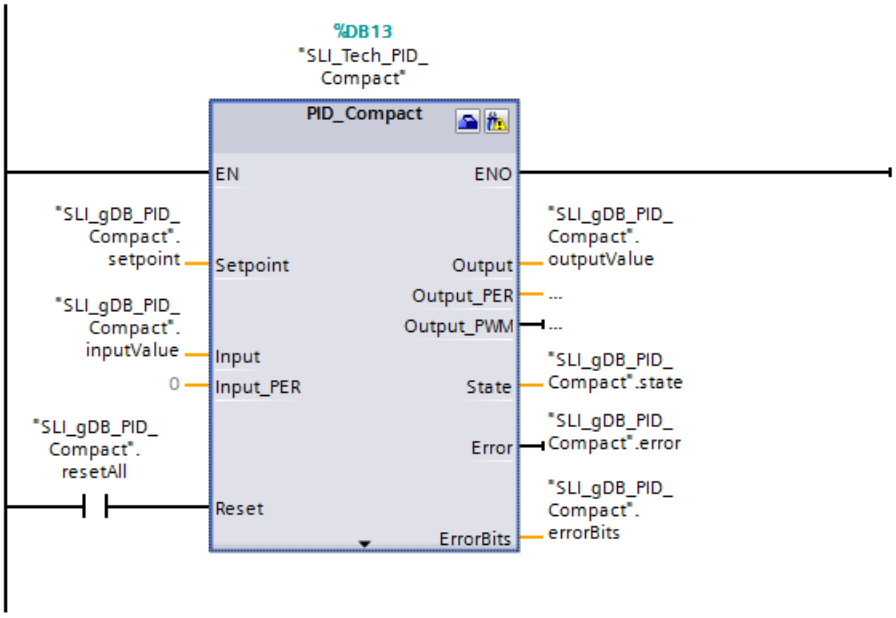
SLI_gDB_PID_Compact

	Name	Data type	Start value
1	Static		
2	setpoint	Real	75.0
3	inputValue	Real	0.0
4	outputValue	Real	0.0
5	state	Int	0
6	error	Bool	false
7	errorBits	DWord	16#0
8	resetAll	Bool	false

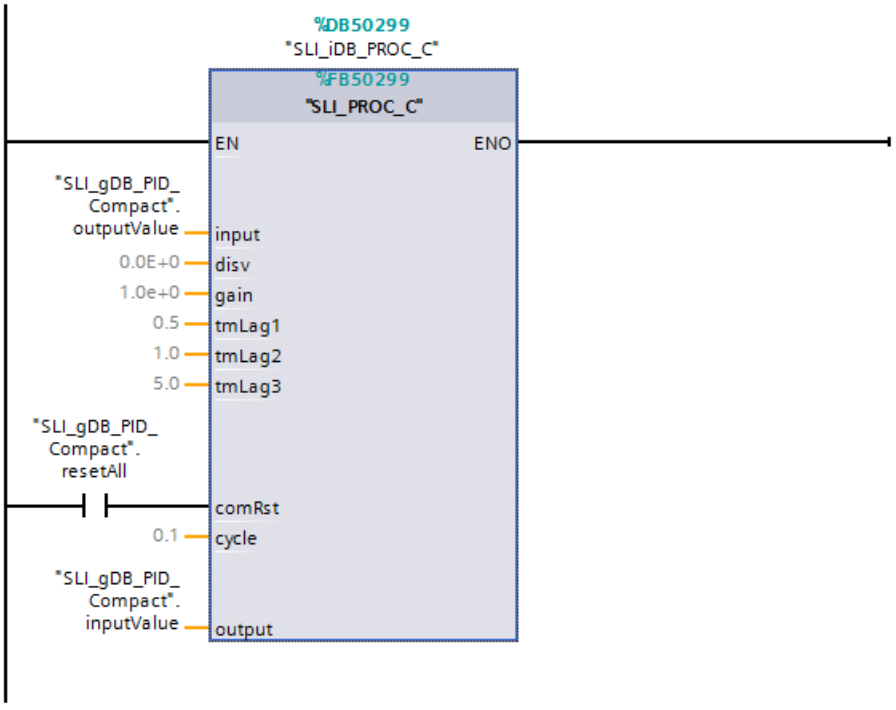
Interconnection of the parameters

You call the following interconnections in a cyclic interrupt OB.

Network 1: You interconnect the parameters of the instruction "PID_Compact" as follows.

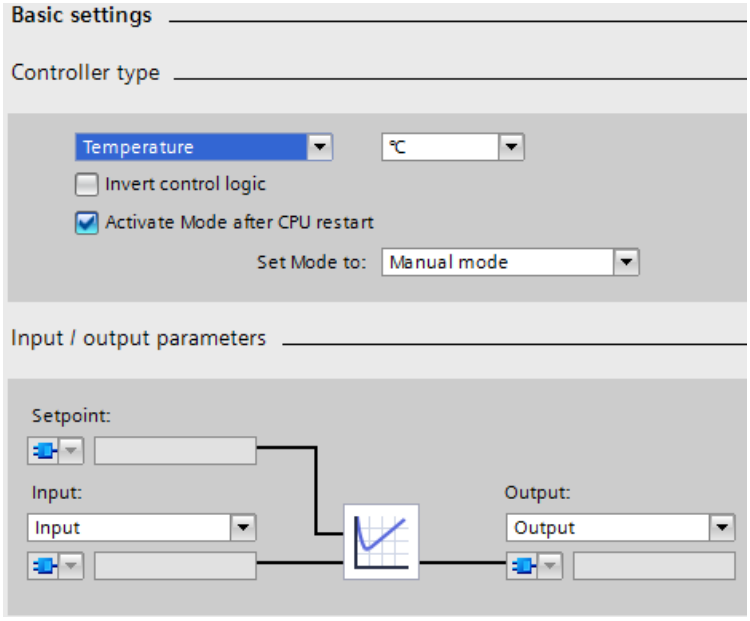


Network 2: You interconnect the parameters of the block simulating the temperature values "SLI_PROC_C" as follows.



Technology object

You configure the technology object with the properties of the instruction "PID_Compact" or by using the path Technology object > Configuration. The controller type and the input/output parameters are important for the example. With the controller type, you make a preselection for the unit of the value to the controlled. In this example, "Temperature" with the unit "°C" is used as controller type. The parameters of the "PID_Compact" are already interconnected with global tags. Therefore, the information on use of the parameters Input and Output is sufficient.



Procedure for starting the control

After the download to the CPU the PID_Compact is in manual mode with manual value 0.0. To start the control, follow these steps:

1. Open the Commissioning of the technology object "SLI_Tech_PID_Compact".
2. Click the "Start" button in the "Measurement" area.



Measurement starts and PID_Compact can be activated.

3. Pretuning is selected.

   Click the "Start" button in the "Tuning mode" area.

   A pretuning is performed. The PID parameters are automatically adjusted to the process. After the completion of the pretuning PID_Compact switches to automatic mode.

NOTE

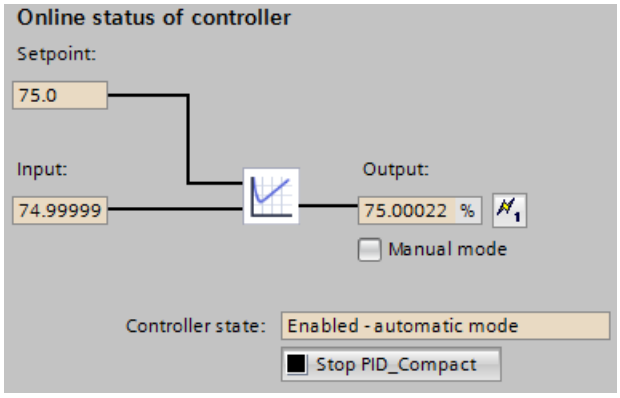
Alternative to start PID_Compact

Alternatively, you can switch PID_Compact to automatic mode in the "Online status of controller" area with the "Stop PID_Compact" / "Start PID_Compact" without pretuning. In this case the controller uses default values for the PID parameters and shows a worse controller behavior for the application case.

Procedure for stopping control

To stop and exit PID_Compact and the program, follow these steps:

1. Click the "Stop PID_Compact" button in the technology object "SLI_Tech_PID_Compact" in the "Online status of controller" area.



   The instruction "PID_Compact" exits the control and outputs the value "0.0" as manipulated variable.

2. Click the "Stop" button in the "Measurement" area.
3. To set the process value immediately to the value "0.0", follow these steps:

   In the block "SLI_OB_PID_Compact", set the "resetAll" tag to the value "TRUE", and then to the value "FALSE".

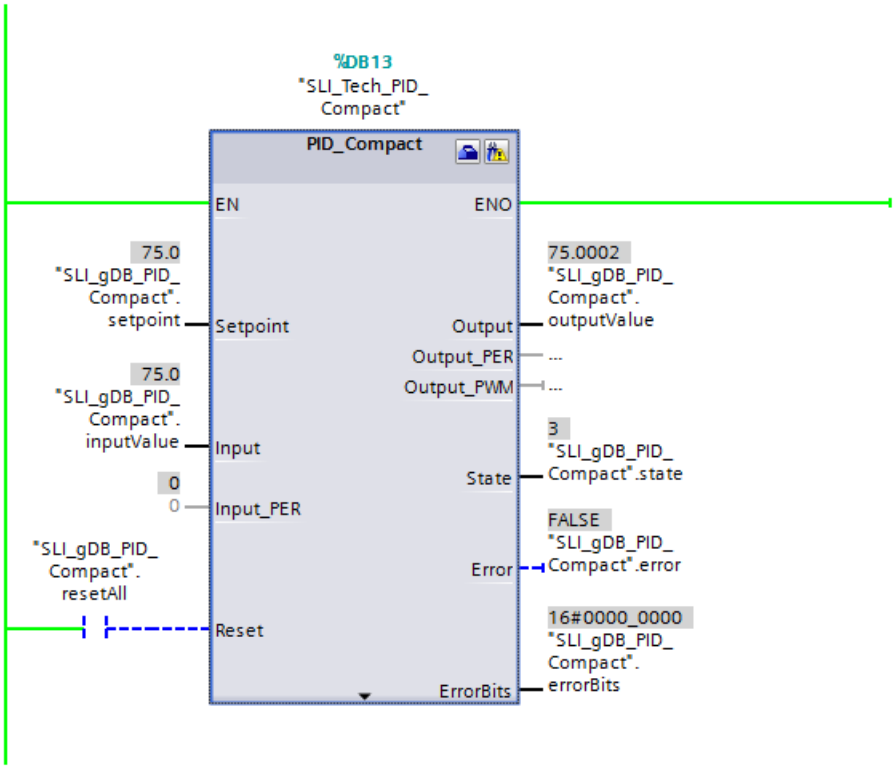
"PID_Compact" instruction

The setpoint for the temperature that is to be controlled is specified at the parameter Setpoint ("setpoint"). The control is started when the instruction "PID_Compact" was started with the technology object. The instruction "PID_Compact" outputs a manipulated variable at the output parameter Output ("outputValue"). The process value of the temperature is transferred to the instruction "PID_Compact" with the input parameter Input ("inputValue").

The instruction "PID_Compact" adjusts the manipulated variable ("outputValue") depending on the history of the difference between setpoint ("setpoint") and process value ("inputValue") . The process is repeated so that the process value ("inputValue") approaches the setpoint ("setpoint") through the manipulated variable ("outputValue").

The current operating mode of the instruction "PID_Compact" is displayed at the output parameter State ("state"). After pretuning (the value of "state" is "1"), the PID_Compact switches to automatic mode (the value is "3").

The output parameter Error ("error") currently shows that no error is pending. The output parameter ErrorBits ("errorBits") provides information on the error type in case of error. If an error occurs, this can be acknowledged in the technology object, in the optimization status area with the "ErrorAck" button.

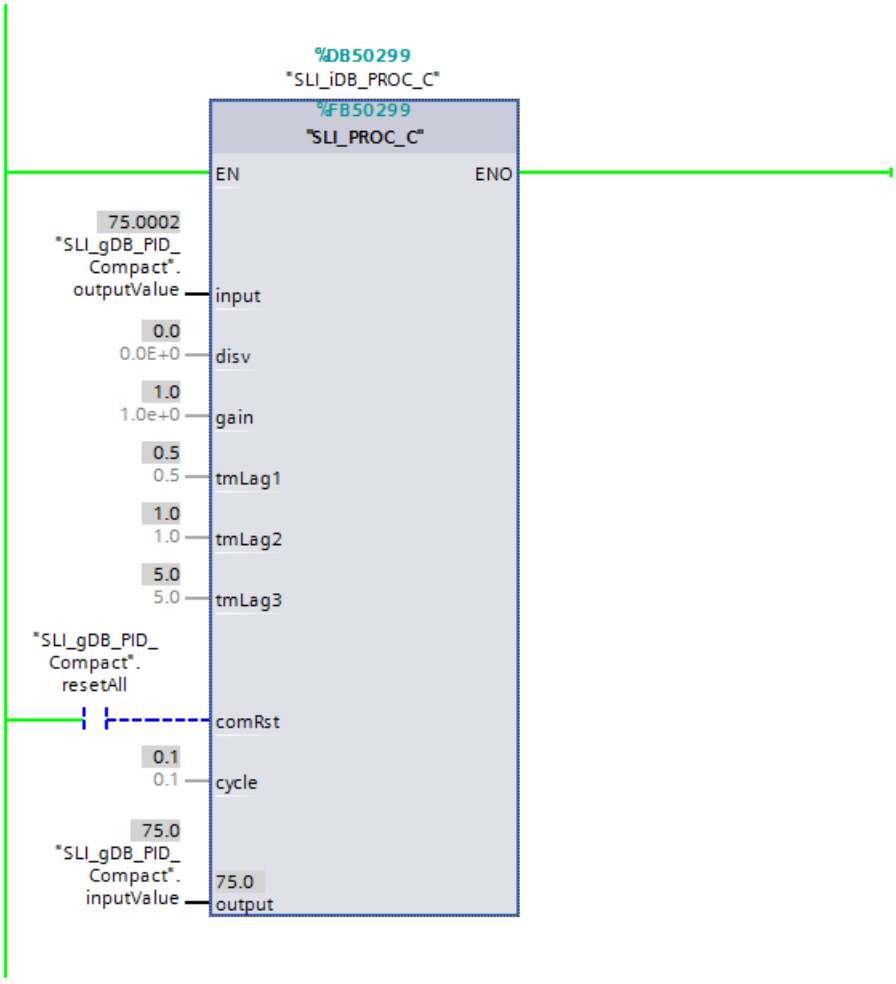


"SLI_PROC_C" block

The "SLI_PROC_C" block simulates the process value ("inputValue") of the rising temperature of a plant. The block "SLI_PROC_C" contains the manipulated variable of the controller ("outputValue) and simulates the temperature behavior of the process. This temperature is fed as process value ("inputValue") into the controller.

A change in the values of the "resetAll" tag (of the comRst parameter) has the following effects:

Parameter comRst ("resetAll")	**The instruction "PID_Compact" is running**	**The instruction "PID_Compact" was stopped**
comRst ("resetAll") remains set to the value "FALSE"	The "SLI_PROC_C" block outputs a new process value ("inputValue") based on a manipulated variable ("outputValue").	The "SLI_PROC_C" block does not receive a manipulated variable > "0.0", but it still outputs a new process value > "0.0".
comRst ("resetAll"): Change from "FALSE" to the value "TRUE"	Both manipulated variable ("outputValue") and output process value ("inputValue") are reset to "0.0".	The output process value ("inputValue") / the temperature of the "SLI_PROC_C" block is reset to "0.0".
comRst ("resetAll"): Change from "TRUE" to the value "FALSE"	Temperature control starts again.	The output process value / the temperature ("inputValue") remains "0.0".



Program code

You can find additional information about the program code for the above-named example under the keyword "Sample Library for Instructions".

11.1.5 PID_Compact V1

11.1.5.1 Description of PID_Compact V1

Description

The PID_Compact instruction provides a PID controller with integrated tuning for automatic and manual mode.

Call

PID_Compact is called in the constant interval of the cycle time of the calling OB (preferably in a cyclic interrupt OB).

Download to device

The actual values of retentive tags are only updated when you download PID_Compact completely.

Downloading technology objects to device (Page 49)

Startup

At the startup of the CPU, PID_Compact starts in the operating mode that was last active. To retain PID_ Compact in "Inactive" mode, set sb_RunModeByStartup = FALSE.

Monitoring of the sampling time PID_Compact

Ideally, the sampling time is equivalent to the cycle time of the calling OB. The PID_Compact instruction measures the time interval between two calls. This is the current sampling time. On every switchover of operating mode and during the initial startup, the mean value is formed from the first 10 sampling times. Too great a difference between the current sampling time and this mean value triggers an error (Error = 0800 hex) and PID_Compact switches to "Inactive" mode.

PID_Compact as of Version 1.1 is set to "Inactive" mode during controller tuning under the following conditions:

- New mean value >= 1.1 x old mean value
- New mean value <= 0.9 x old mean value

In automatic mode, PID_Compact, as of Version 1.1, is set to "Inactive" mode under the following conditions:

- New mean value >= 1.5 x old mean value
- New mean value <= 0.5 x old mean value

During controller tuning and in automatic mode, PID_Compact 1.0 is set to "Inactive" operating mode under the following conditions:

- New mean value >= 1.1 x old mean value
- New mean value <= 0.9 x old mean value
- Current sampling time >= 1.5 x current mean value
- Current sampling time <= 0.5 x current mean value

Sampling time of the PID algorithm

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_Compact are executed at every call.

PID algorithm

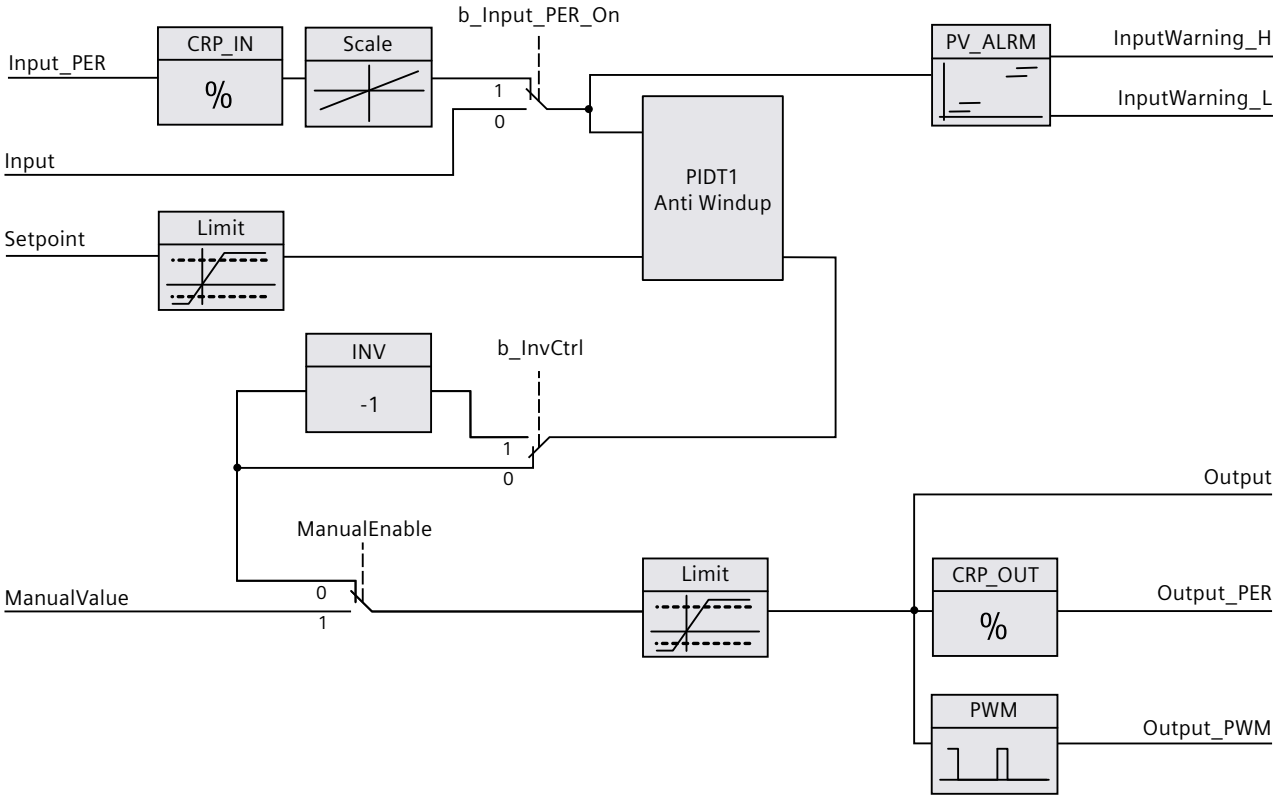
PID_Compact is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions. The following equation is used to calculate the transfer function:

$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s} (w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1} (c \cdot w - x) \right]$$

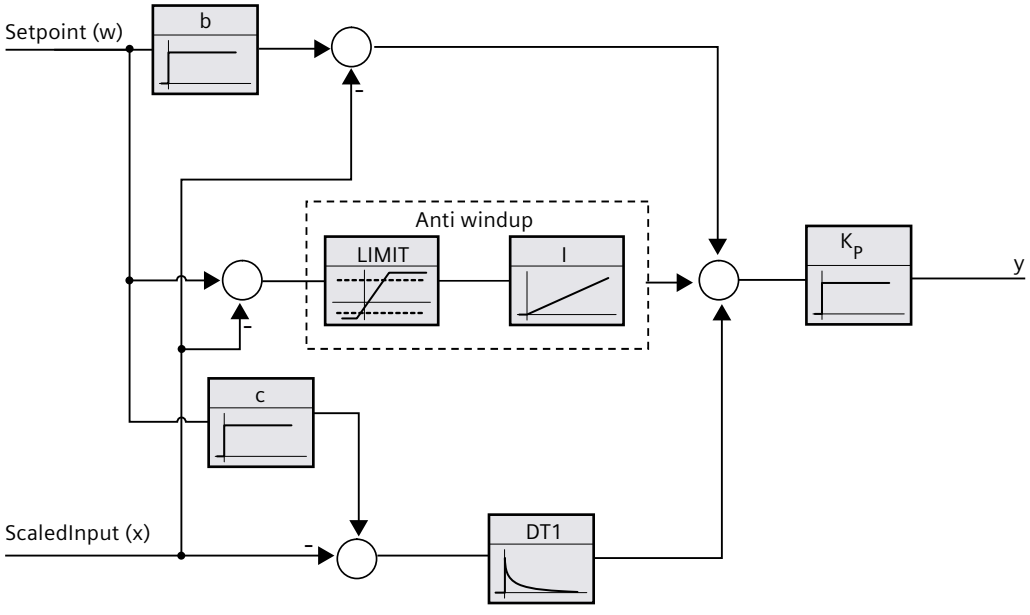
The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
y	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (derivative delay T1 = a × T_D)
c	Derivative action weighting

Block diagram of PID_Compact



Block diagram of PIDT1 with anti-windup



Response to errors

If errors occur, they are output in parameter Error, and PID_Compact changes to "Inactive" mode. Reset the errors using the Reset parameter.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic. For cooling and discharge control systems, it may be necessary to invert the control logic. PID_Compact does not work with negative proportional gain. If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value. The control logic is also taken into account during pretuning and fine tuning.

See also

Control mode V1 (Page 106)

11.1.5.2 Input parameters of PID_Compact V1

Table 11-4

Parameter	Data type	Default	Description
Setpoint	REAL	0.0	Setpoint of the PID controller in automatic mode
Input	REAL	0.0	A variable of the user program is used as source for the process value. If you are using parameter Input, then sPid_Cmpt.b_Input_PER_On = FALSE must be set.
Input_PER	WORD	W#16#0	Analog input as the source of the process value If you are using parameter Input_PER, then sPid_Cmpt.b_Input_PER_On = TRUE must be set.
ManualEnable	BOOL	FALSE	• A FALSE -> TRUE edge selects "Manual mode", while State = 4, sRet.i_Mode remains unchanged. • A TRUE -> FALSE edge selects the most recently active operating mode, State =sRet.i_Mode. A change of sRet.i_Mode will not take effect during ManualEnable = TRUE. The change of sRet.i_Mode will only be considered upon a TRUE -> FALSE edge at ManualEnable . **PID_Compact V1.2 and PID_Compact V1.0** If at start of the CPU ManualEnable = TRUE, PID_Compact starts in manual mode. A rising edge (FALSE > TRUE) at ManualEnable is not necessary. **PID_Compact V1.1** At the start of the CPU, PID_Compact only switches to manual mode with a rising edge (FALSE->TRUE) at ManualEnable . Without rising edge, PID_Compact starts in the last operating mode in which ManualEnable was FALSE.
ManualValue	REAL	0.0	Manual value This value is used as the output value in manual mode.
Reset	BOOL	FALSE	The Reset parameter (Page 302) restarts the controller.

11.1.5.3 Output parameters of PID_Compact V1

Table 11-5

Parameter	Data type	Default	Description
ScaledInput	REAL	0.0	Output of the scaled process value
Outputs "Output", "Output_PER", and "Output_PWM" can be used concurrently.			
Output	REAL	0.0	Output value in REAL format
Output_PER	WORD	W#16#0	Analog output value
Output_PWM	BOOL	FALSE	Pulse-width-modulated output value The output value is formed by minimum On and Off times.
SetpointLimit_H	BOOL	FALSE	If SetpointLimit_H = TRUE, the setpoint absolute high limit is reached. The setpoint in the CPU is limited to the configured setpoint absolute high limit. The configured process value absolute high limit is the default for the setpoint high limit. If you set sPid_Cmpt.r_Sp_Hlm to a value within the process value limits, this value is used as the setpoint high limit.
SetpointLimit_L	BOOL	FALSE	If SetpointLimit_L = TRUE, the setpoint absolute low limit has been reached. In the CPU, the setpoint is limited to the configured setpoint absolute low limit. The configured process value absolute low limit is the default setting for the setpoint low limit. If you set sPid_Cmpt.r_Sp_Llm to a value within the process value limits, this value is used as the setpoint low limit.
InputWarning_H	BOOL	FALSE	If InputWarning_H = TRUE, the process value has reached or exceeded the warning high limit.
InputWarning_L	BOOL	FALSE	If InputWarning_L = TRUE, the process value has reached or fallen below the warning low limit.
State	INT	0	The State parameter (Page 299) shows the current operating mode of the PID controller. To change the operating mode, use variable sRet.i_Mode. • State = 0: Inactive • State = 1: pretuning • State = 2: fine tuning • State = 3: Automatic mode • State = 4: Manual mode
Error	DWORD	W#16#0	The Error parameter (Page 301) indicates the error messages. Error = 0000: No error pending.

11.1.5.4 Static tags of PID_Compact V1

NOTE

You must not change tags that are not listed. These are used for internal purposes only.

Change the tags identified with (1) only in "Inactive" mode to prevent malfunction of the PID controller. "Inactive" mode is forced by setting the "sRet.i_Mode" tag to "0".

Table 11-6

Tag	Data type	Default	Description
sb_GetCycleTime	BOOL	TRUE	If sb_GetCycleTime = TRUE, the automatic determination of the cycle time is started. CycleTime.StartEstimation = FALSE once measurement is complete.
sb_EnCyclEstimation	BOOL	TRUE	If sb_EnCyclEstimation = TRUE, the PID_Compact sampling time is calculated.
sb_EnCyclMonitoring	BOOL	TRUE	If sb_EnCyclMonitoring = FALSE, the PID_Compact sampling time is not monitored. If it is not possible to execute PID_Compact within the sampling time, an 0800 error is not output and PID_Compact does not change to "Inactive" mode.
sb_RunModeByStartup	BOOL	TRUE	Activate Mode after CPU restart If sb_RunModeByStartup = FALSE, the controller remains inactive after a CPU startup. If sb_RunModeByStartup = TRUE, the controller returns to the last active operating mode after a CPU restart.
si_Unit	INT	0	Unit of measurement of the process value and setpoint, e.g., °C, or °F.
si_Type	INT	0	Physical quantity of the process value and setpoint, e.g., temperature.
sd_Warning	DWORD	DW#16#0	Variable sd_warning (Page 303) displays the warnings generated since the reset, or since the last change of the operating mode.
sBackUp.r_Gain	REAL	1.0	Saved proportional gain You can reload values from the sBackUp structure with sPid_Cmpt.b_LoadBackUp = TRUE.
sBackUp.r_Ti	REAL	20.0	Saved integral action time [s]
sBackUp.r_Td	REAL	0.0	Saved derivative action time [s]
sBackUp.r_A	REAL	0.0	Saved derivative delay coefficient
sBackUp.r_B	REAL	0.0	Saved proportional action weighting factor
sBackUp.r_C	REAL	0.0	Saved derivative action weighting factor
sBackUp.r_Cycle	REAL	1.0	Saved sampling time of PID algorithm
sPid_Calc.r_Cycle(1)	REAL	0.1	Sampling time of the PID_Compact instruction r_Cycle is determined automatically and is usually equivalent to the cycle time of the calling OB.

Tag	Data type	Default	Description
sPid_Calc.b_RunIn	BOOL	FALSE	• b_RunIn = FALSE Pretuning is started when fine tuning is started from inactive or manual mode. If the requirements for pretuning are not met, PID_Compact reacts as if b_RunIn = TRUE. If fine tuning is started from automatic mode, the system uses the existing PID parameters to control to the setpoint. Only then will fine tuning start. If pretuning is not possible, PID_Compact switches to "Inactive" mode. • b_RunIn = TRUE The pretuning is skipped. PID_3Compact tries to reach the setpoint with minimum or maximum output value. This can produce increased overshoot. Fine tuning then starts automatically. b_RunIn is set to FALSE after fine tuning.
sPid_Calc.b_CalcParamSUT	BOOL	FALSE	The parameters for pretuning will be recalculated if b_CalcParamSUT = TRUE. This enables you to change the parameter calculation method without having to repeat controller tuning. b_CalcParamSUT is set to FALSE after the calculation.
sPid_Calc.b_CalcParamTIR	BOOL	FALSE	The parameters for fine tuning will be recalculated if b_CalcParamTIR = TRUE. This enables you to change the parameter calculation method without having to repeat controller tuning. b_CalcParamTIR will be set to FALSE after calculation.
sPid_Calc.i_CtrlTypeSUT	INT	0	Methods used to calculate parameters during pretuning: • i_CtrlTypeSUT = 0: PID according to Chien, Hrones and Reswick • i_CtrlTypeSUT = 1: PI according to Chien, Hrones and Reswick
sPid_Calc.i_CtrlTypeTIR	INT	0	Methods used to calculate parameters during fine tuning: • i_CtrlTypeTIR = 0: PID automatic • i_CtrlTypeTIR = 1: PID fast (faster control response with higher amplitudes of the output value than with i_CtrlTypeTIR = 2) • i_CtrlTypeTIR = 2: PID slow (slower control response with lower amplitudes of the output value than with i_CtrlTypiTIR = 1) • i_CtrlTypeTIR = 3: Ziegler-Nichols PID • i_CtrlTypeTIR = 4: Ziegler-Nichols PI • i_CtrlTypeTIR = 5: Ziegler-Nichols P To be able to repeat the calculation of the PID parameters with b_CalcParamTIR and i_CtrlTypeTIR = 0, 1 or 2, the previous fine tuning also has to have been executed with i_CtrlTypeTIR = 0, 1 or 2. If this is not the case, i_CtrlTypeTIR = 3 is used. The recalculation of the PID parameters with b_CalcParamTIR and i_CtrlTypeTIR = 3, 4 or 5 is always possible.
sPid_Calc.r_Progress	REAL	0.0	Progress of tuning as a percentage (0.0 - 100.0)

Tag	Data type	Default	Description
sPid_Cmpt.r_Sp_Hlm(1)	REAL	+3.402822e+-38	High limit of setpoint If you configure sPid_Cmpt.r_Sp_Hlm outside the process value limits, the configured process value absolute high limit is used as the setpoint high limit. If you configure sPid_Cmpt.r_Sp_Hlm within the process value limits, this value is used as the setpoint high limit.
sPid_Cmpt.r_Sp_Llm(1)	REAL	-3.402822e+3-8	Low limit of the setpoint If you set sPid_Cmpt.r_Sp_Llm outside the process value limits, the configured process value absolute low limit is used as the setpoint low limit. If you set sPid_Cmpt.r_Sp_Llm within the process value limits, this value is used as the setpoint low limit.
sPid_Cmpt.r_Pv_Norm_IN_1(1)	REAL	0.0	Scaling Input_PER low Input_PER is converted to a percentage based on the two value pairs r_Pv_Norm_OUT_1, r_Pv_Norm_IN_1 and r_Pv_Norm_OUT_2, r_Pv_Norm_IN_2 of the sPid_Cmpt structure.
sPid_Cmpt.r_Pv_Norm_IN_2(1)	REAL	27648.0	Scaling Input_PER high Input_PER is converted to a percentage based on the two value pairs r_Pv_Norm_OUT_1, r_Pv_Norm_IN_1 and r_Pv_Norm_OUT_2, r_Pv_Norm_IN_2 of the sPid_Cmpt structure.
sPid_Cmpt.r_Pv_Norm_OUT_1(1)	REAL	0.0	Scaled low process value Input_PER is converted to a percentage based on the two value pairs r_Pv_Norm_OUT_1, r_Pv_Norm_IN_1 and r_Pv_Norm_OUT_2, r_Pv_Norm_IN_2 of the sPid_Cmpt structure.
sPid_Cmpt.r_Pv_Norm_OUT_2(1)	REAL	100.0	Scaled high process value Input_PER is converted to a percentage based on the two value pairs r_Pv_Norm_OUT_1, r_Pv_Norm_IN_1 and r_Pv_Norm_OUT_2, r_Pv_Norm_IN_2 of the sPid_Cmpt structure.
sPid_Cmpt.r_Lmn_Hlm(1)	REAL	100.0	Output value high limit for output parameter "Output"
sPid_Cmpt.r_Lmn_Llm(1)	REAL	0.0	Low output value limit for output parameter "Output"
sPid_Cmpt.b_Input_PER_On(1)	BOOL	TRUE	If b_Input_PER_On = TRUE, the Input_PER parameter is used. If b_Input_PER_On = FALSE, the Input parameter is used.
sPid_Cmpt.b_LoadBackUp	BOOL	FALSE	Activate the back-up parameter set. If an optimization has failed, you can reactivate the previous PID parameters by setting this bit.
sPid_Cmpt.b_InvCtrl(1)	BOOL	FALSE	Invert control logic If b_InvCtrl = TRUE, an increasing control deviation causes a reduction in the output value.
sPid_Cmpt.r_Lmn_Pwm_PPTm(1)	REAL	0.0	The minimum ON time of the pulse width modulation in seconds is rounded to r_Lmn_Pwm_PPTm = r_Cycle or r_Lmn_Pwm_PPTm = n*r_Cycle

Tag	Data type	Default	Description
sPid_Cmpt.r_Lmn_Pwm_PBTm(1)	REAL	0.0	The minimum OFF time of the pulse width modulation in seconds is rounded to r_Lmn_Pwm_PBTm = r_Cycle or r_Lmn_Pwm_PBTm = n*r_Cycle
sPid_Cmpt.r_Pv_Hlm(1)	REAL	120.0	High limit of the process value At the I/O input, the process value can be a maximum of 18% higher than the standard range (overrange). An error is no longer reported for a violation of the "Process value high limit". Only a wire-break and a short-circuit are recognized and the PID_Compact switches to "Inactive" mode. r_Pv_Hlm > r_Pv_Llm
sPid_Cmpt.r_Pv_Llm(1)	REAL	0.0	Low limit of the process value r_Pv_Llm < r_Pv_Hlm
sPid_Cmpt.r_Pv_HWrn(1)	REAL	+3.402822e+-38	Warning high limit of the process value If you set r_Pv_HWrn outside the process value limits, the configured process value absolute high limit is used as the warning high limit. If you configure r_Pv_HWrn within the process value limits, this value is used as the warning high limit. r_Pv_HWrn > r_Pv_LWrn r_Pv_HWrn ≤ r_Pv_Hlm
sPid_Cmpt.r_Pv_LWrn(1)	REAL	-3.402822e+3-8	Warning low limit of the process value If you set r_Pv_LWrn outside the process value limits, the configured process value absolute low limit is used as the warning low limit. If you configure r_Pv_LWrn within the process value limits, this value is used as the warning low limit. r_Pv_LWrn < r_Pv_HWrn r_Pv_LWrn ≥ r_Pv_LWrn
sPidCalc.i_Ctrl_IOutv(1)	REAL	0.0	Current integral action
sParamCalc.i_Event_SUT	INT	0	Variable i_Event_SUT (Page 304) indicates the current phase of "pretuning":
sParamCalc.i_Event_TIR	INT	0	Variable i_Event_TIR (Page 304) indicates the current phase of "fine tuning":
sRet.i_Mode	INT	0	The operating mode is changed edge-triggered. The following operating mode is enabled on a change to • i_Mode = 0: "Inactive" mode (controller stop) • i_Mode = 1: "Pretuning" mode • i_Mode = 2: "Fine tuning" mode • i_Mode = 3: "Automatic" mode • i_Mode = 4: "Manual" mode i_Mode is retentive.
sRet.r_Ctrl_Gain(1)	REAL	1.0	Active proportional gain Gain is retentive.
sRet.r_Ctrl_Ti(1)	REAL	20.0	• r_Ctrl_Ti > 0.0: Active integral action time • r_Ctrl_Ti = 0.0: Integral action is deactivated r_Ctrl_Ti is retentive.

Tag	Data type	Default	Description
sRet.r_Ctrl_Td(1)	REAL	0.0	• r_Ctrl_Td > 0.0: Active derivative action time • r_Ctrl_Td = 0.0: Derivative action is deactivated r_Ctrl_Td is retentive.
sRet.r_Ctrl_A(1)	REAL	0.0	Active derivative delay coefficient r_Ctrl_A is retentive.
sRet.r_Ctrl_B(1)	REAL	0.0	Active proportional action weighting r_Ctrl_B is retentive.
sRet.r_Ctrl_C(1)	REAL	0.0	Active derivative action weighting r_Ctrl_C is retentive.
sRet.r_Ctrl_Cycle(1)	REAL	1.0	Active sampling time of the PID algorithm r_Ctrl_Cycle is calculated during tuning and rounded to an integer multiple of r_Cycle. r_Ctrl_Cycle is used as time period of the pulse width modulation. r_Ctrl_Cycle is retentive.

See also

Downloading technology objects to device (Page 49)

11.1.5.5 Parameters State and sRet.i_Mode V1

Correlation of the parameters

The State parameter indicates the current operating mode of the PID controller. You cannot modify the State parameter.

You need to modify the sRet.i_Mode tag to change the operating mode. This also applies when the value for the new operating mode is already in sRet.i_Mode. First set sRet.i_Mode = 0 and then sRet.i_Mode = 3. Provided the current operating mode of the controller supports this change, State is set to the value of sRet.i_Mode.

When PID_Compact automatically switches the operating mode, the following applies: State != sRet.i_Mode.

Examples:

- Successful pretuning
  State = 3 and sRet.i_Mode = 1
- Error
  State = 0 and sRet.i_Mode remains at the same value, e.g sRet.i_Mode = 3
- ManualEnalbe = TRUE
  State = 4 and sRet.i_Mode remain at the previous value, for example, sRet.i_Mode = 3

NOTE

You wish to repeat successful fine tuning without exiting automatic mode with i_Mode = 0.

Setting sRet.i_Mode to an invalid value such as 9999 for one cycle has no effect on State. Set Mode = 2 in the next cycle. You can generate a change to sRet.i_Mode without first switching to "inactive" mode.

Meaning of values

State / sRet.i_Mode	Description of the operating mode
0	Inactive The controller is switched off. The controller was in "inactive" mode before pretuning was performed. The PID controller will change to "inactive" mode when running if an error occurs or if the "Deactivate controller" icon is clicked in the commissioning window.
1	Pretuning The pretuning determines the process response to a jump of the output value and searches for the point of inflection. The optimized PID parameters are calculated as a function of the maximum rate of rise and dead time of the controlled system. Pretuning requirements: • The controller is in inactive mode or manual mode • ManualEnable = FALSE • The process value must not be too close to the setpoint. |Setpoint - Input| > 0.3 * |sPid_Cmpt.r_Pv_Hlm - sPid_Cmpt.r_Pv_Llm| and |Setpoint - Input| > 0.5 * |Setpoint| • The setpoint may not be changed during pretuning. The higher the stability of the process value, the easier it is to calculate the PID parameters and increase precision of the result. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. PID parameters are backed up before they are recalculated and can be reactivated with sPid_Cmpt.b_LoadBackUp. There is a change to automatic mode following successful pretuning and to "inactive" mode following unsuccessful pretuning. The phase of pretuning is indicated with Tag i_Event_SUT V1 (Page 304).
2	Fine tuning Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are optimized based on the amplitude and frequency of this oscillation. The differences between the process response during pretuning and fine tuning are analyzed. All PID parameters are recalculated on the basis of the findings. PID parameters from fine tuning usually have better master control and disturbance behavior than PID parameters from pretuning. PID_Compact automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. PID parameters are backed up before they are recalculated and can be reactivated with sPid_Cmpt.b_LoadBackUp. Requirements for fine tuning: • No disturbances are expected. • The setpoint and the process value lie within the configured limits. • The setpoint may not be changed during fine tuning. • ManualEnable = FALSE • Automatic (State = 3), inactive (State = 0) or manual (State = 4) mode Fine tuning proceeds as follows when started in: • Automatic mode (State = 3) Start fine tuning in automatic mode if you wish to improve the existing PID parameters using controller tuning. PID_Comact will regulate using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. • Inactive (State = 0) or manual (State = 4) mode If the requirements for pretuning are met, pretuning is started. The PID parameters established will be used for adjustment until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. If pretuning is not possible, PID_Compact will change to "Inactive" mode.

State / sRet.i_Mode	Description of the operating mode
	An attempt is made to reach the setpoint with a minimum or maximum output value if the process value for pretuning is already too near the setpoint or sPid_Calc.b_RunIn = TRUE. This can produce increased overshoot. The controller will change to "automatic mode" after successfully completed "fine tuning" and to "inactive" mode if "fine tuning" has not been successfully completed. The "Fine tuning" phase is indicated with Tag i_Event_TIR V1 (Page 304).
3	Automatic mode In automatic mode, PID_Compact corrects the controlled system in accordance with the parameters specified. The controller changes to automatic mode if one the following conditions is fulfilled: • Pretuning successfully completed • Fine tuning successfully completed • Change of variable sRet.i_Mode to the value 3. After CPU startup or change from Stop to RUN mode, PID_Compact will start in the most recently active operating mode. To retain PID_Compact in "Inactive" mode, set sb_RunModeByStartup = FALSE.
4	Manual mode In manual mode, you specify a manual output value in the ManualValue parameter. This operating mode is enabled if sRet.i_Mode = 4, or at the rising edge on ManualEnable. If ManualEnable changes to TRUE, only State will change. sRet.i_Mode will retain its current value. PID_Compact will return to the previous operating mode upon a falling edge at ManualEnable. The change to automatic mode is bumpless.

See also

Output parameters of PID_Compact V1 (Page 294)

Pretuning V1 (Page 116)

Fine tuning V1 (Page 118)

"Manual" mode V1 (Page 120)

Tag i_Event_SUT V1 (Page 304)

Tag i_Event_TIR V1 (Page 304)

11.1.5.6 Error V1 parameter

If several errors are pending simultaneously, the values of the error codes are displayed with binary addition. The display of error code 0003, for example, indicates that the errors 0001 and 0002 are pending simultaneously.

Error (DW#16#...)	Description
0000	There is no error.
0001	The "Input" parameter is outside the process value limits. • Input > sPid_Cmpt.r_Pv_Hlm or • Input < sPid_Cmpt.r_Pv_Llm You cannot move the actuator again until you eliminate the error.
0002	Invalid value at "Input_PER" parameter. Check whether an error is pending at the analog input.
0004	Error during fine tuning. Oscillation of the process value could not be maintained.
0008	Error at start of pretuning. The process value is too close to the setpoint. Start fine tuning.
0010	The setpoint was changed during tuning.
0020	Pretuning is not permitted in automatic mode or during fine tuning.

Error (DW#16#...)	Description
0080	Error during pretuning. The output value limits are not configured correctly or the process value does not react as expected. Check whether the limits of the output value are configured correctly and match the control logic. Also make sure that the process value does not oscillate strongly before starting pretuning.
0100	Error during tuning resulted in invalid parameters.
0200	Invalid value at "Input" parameter: Value has an invalid number format.
0400	Calculation of output value failed. Check the PID parameters.
0800	Sampling time error: PID_Compact is not called within the sampling time of the cyclic interrupt OB. If this error occurred during simulation with PLCSIM, see the notes under Simulating PID_Compact V1 with PLCSIM (Page 121).
1000	Invalid value at "Setpoint" parameter: Value has an invalid number format.

See also

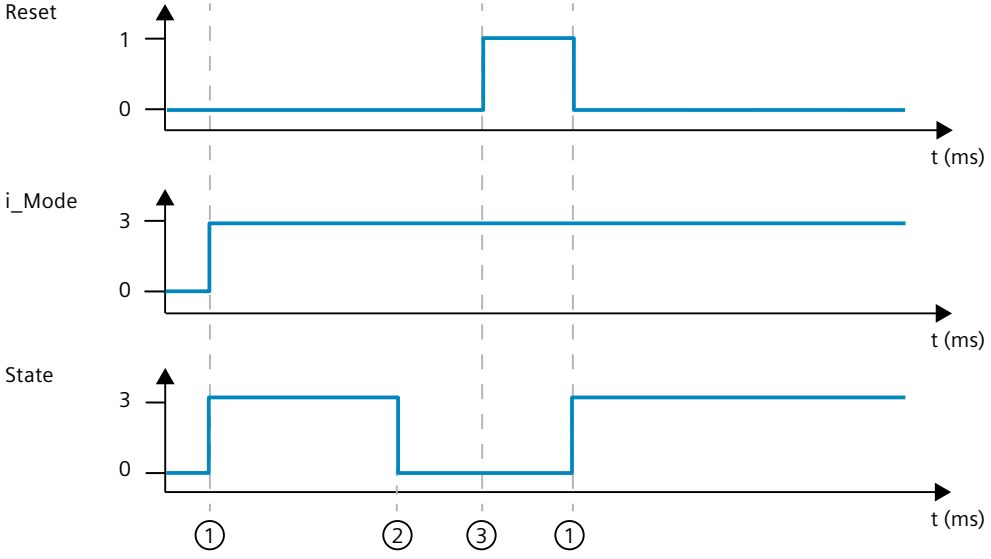
Output parameters of PID_Compact V1 (Page 294)

11.1.5.7 Reset V1 parameter

The response to Reset = TRUE depends on the version of the PID_Compact instruction.

Reset response PID_Compact as of Version 1.1

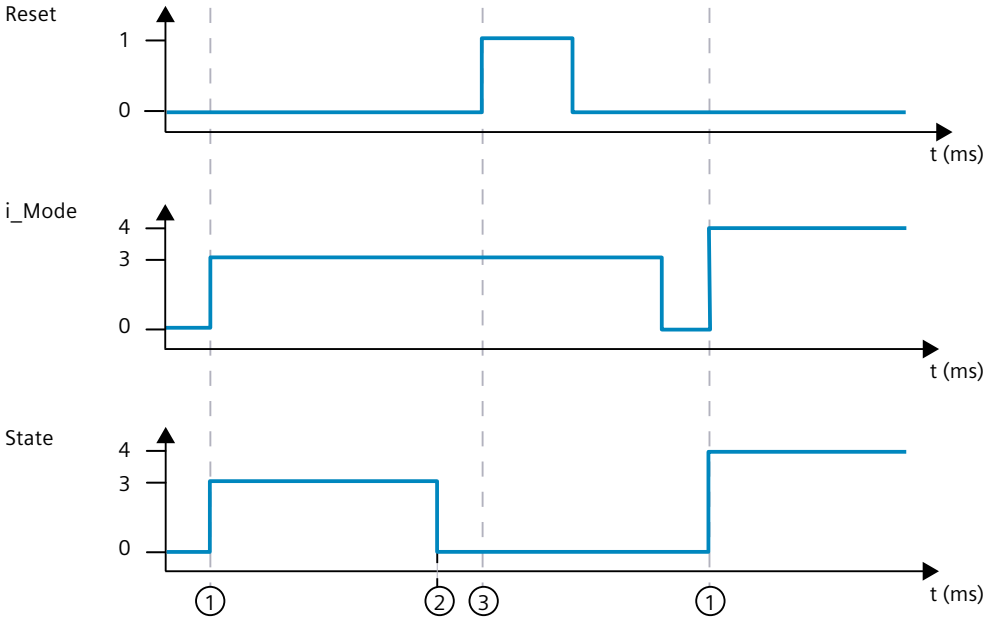
A rising edge at Reset triggers a change to "Inactive" mode; errors and warnings are reset and the integral action is deleted. A falling edge at Reset triggers a change to the most recently active operating mode. If automatic mode was active before, the integral action is preassigned in such a way that the switchover is bumpless.



① Activation
② Error
③ Reset

Reset response PID_Compact V.1.0

A rising edge at Reset triggers a change to "Inactive" mode; errors and warnings are reset and the integral action is deleted. The controller is not reactivated until the next edge at i_Mode.



① Activation
② Error
③ Reset

11.1.5.8 Tag sd_warning V1

If several warnings are pending, the values of variable sd_warning are displayed by means of binary addition. The display of warning 0003, for example, indicates that the warnings 0001 and 0002 are also pending.

sd_warning (DW#16#....)	Description
0000	No warning pending.
0001	The point of inflection was not found during pretuning.
0002	Oscillation increased during fine tuning.
0004	The setpoint was outside the set limits.
0008	Not all the necessary controlled system properties were defined for the selected method of calculation. The PID parameters were instead calculated using the "i_CtrlTypeTIR = 3" method.
0010	The operating mode could not be changed because ManualEnable = TRUE.
0020	The cycle time of the calling OB limits the sampling time of the PID algorithm. Improve results by using shorter OB cycle times.
0040	The process value exceeded one of its warning limits.

The following warnings are deleted as soon as the cause is dealt with:

- 0004
- 0020
- 0040

All other warnings are cleared with a rising edge at Reset.

11.1.5.9 Tag i_Event_SUT V1

i_Event_SUT	Name	Description
0	SUT_INIT	Initialize pretuning
100	SUT_STDABW	Calculate the standard deviation
200	SUT_GET_POI	Find the point of inflection
9900	SUT_IO	Pretuning successful
1	SUT_NIO	Pretuning not successful

See also

Static tags of PID_Compact V1 (Page 295)
Parameters State and sRet.i_Mode V1 (Page 299)

11.1.5.10 Tag i_Event_TIR V1

i_Event_TIR	Name	Description
-100	TIR_FIRST_SUT	Fine tuning is not possible. Pretuning will be executed first.
0	TIR_INIT	Initialize fine tuning
200	TIR_STDABW	Calculate the standard deviation
300	TIR_RUN_IN	Attempt to reach the setpoint
400	TIR_CTRLN	Attempt to reach the setpoint with the existing PID parameters (if pretuning has been successful)
500	TIR_OSZIL	Determine oscillation and calculate parameters
9900	TIR_IO	Fine tuning successful
1	TIR_NIO	Fine tuning not successful

See also

Static tags of PID_Compact V1 (Page 295)
Parameters State and sRet.i_Mode V1 (Page 299)

11.2 PID_3Step

11.2.1 New features of PID_3Step

PID_3Step V2.3

- **Use with S7-1200 G2**

  As of PID_3Step V2.3, the instruction can also be used on an S7-1200 G2.

  Older versions of the instruction are not supported on S7-1200 G2.

- **Monitoring the travel time**

  As of PID_3Step Version 2.3 the monitoring and limiting of the travel time can be deactivated with Config.VirtualActuatorLimit = 0.0.

PID_3Step V2.2

- **Use with S7-1200**

  As of PID_3Step V2.2, the instruction with V2 functionality can also be used on S7-1200 as of firmware version 4.0.

PID_3Step V2.0

- **Reaction to error**

  The reaction to ActivateRecoverMode = TRUE has been completely overhauled. PID_3Step reacts in a more fault tolerant manner in the default setting.

NOTICE
Your system may be damaged. If you use the default setting, PID_3Step remains in automatic mode even if the process value limits are exceeded. This may damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

  You use the ErrorAck input parameter to acknowledge the errors and warnings without restarting the controller or clearing the integral action.

  Switching operating modes does not acknowledge errors that are no longer pending.

- **Switching the operating mode**

  You specify the operating mode at the Mode in/out parameter and use a positive edge at ModeActivate to start the operating mode. The Retain.Mode tag has been omitted.

  The transition time measurement can no longer be started with GetTransitTime.Start, but only with Mode = 6 and a positive edge at ModeActivate.

- **Multi-instance capability**

  You can call up PID_3Step as multi-instance DB.

- **Startup characteristics**

  The operating mode specified at the Mode parameter is also started on a falling edge at Reset and during a CPU cold restart, if RunModeByStartup = TRUE.

- **ENO characteristics**

  ENO is set depending on the operating mode.

  If State = 0, then ENO = FALSE.

  If State ≠ 0, then ENO = TRUE.

- **Manual mode**

  The Manual_UP and Manual_DN input parameters no longer function as edge-triggered parameters. Edge-triggered manual mode continues to be possible using the ManualUpInternal and ManualDnInternal tags.

  In "Manual mode without endstop signals" (Mode = 10), the endstop signals Actuator_H and Actuator_L are ignored even though they are activated.

- **Default value of PID parameters**

  The following default settings have been changed:

  – Proportional action weighting (PWeighting) from 0.0 to 1.0

  – Derivative action weighting (DWeighting) from 0.0 to 1.0

  – Coefficient for derivative delay (TdFiltRatio) from 0.0 to 0.2

- **Limiting of motor transition time**

  You configure the maximum percentage of the motor transition time that the actuator will travel in one direction in the Config.VirtualActuatorLimit tag.

- **Setpoint value specification during tuning**

  You configure the permitted fluctuation of the setpoint during tuning at the CancelTuningLevel tag.

- **Switching a disturbance variable on**

  You can switch a disturbance variable on at the Disturbance parameter.

- **Troubleshooting**

  If the endstop signals are not activated (ActuatorEndStopOn = FALSE), ScaledFeedback is determined without Actuator_H or Actuator_L.

PID_3Step V1.1

- **Manual mode on CPU startup**

  If ManualEnable = TRUE when the CPU starts, PID_3Step starts in manual mode. A rising edge at ManualEnable is not necessary.

- **Reaction to error**

  The ActivateRecoverMode tag is no longer effective in manual mode.

- **Troubleshooting**

  The Progress tag is reset following successful tuning or transition time measurement.

11.2.2 Compatibility with CPU and FW

The following table shows which version of PID_3Step can be used on which CPU.

CPU	FW	PID_3Step
S7-1200	as of V4.2	V2.3 V2.2 V1.1
	V4.0 to V4.1	V2.2 V1.1
	V3.x	V1.1 V1.0
	V2.x	V1.1 V1.0
S7-1200 G2	V1.0 or higher	V2.3
S7-1500	as of V3.0	V2.3
	V2.0 to V2.9	V2.3 V2.2 V2.1 V2.0
	V1.5 to V1.8	V2.2 V2.1 V2.0
	V1.1	V2.1 V2.0
	V1.0	V2.0

11.2.3 CPU processing time and memory requirement PID_3Step V2.x

CPU processing time

Typical CPU processing times of the PID_3Step technology object as of Version V2.0, depending on CPU type and operating mode for standard, F, T and TF CPUs.

CPU	FW	Typ. CPU processing time Automatic mode	Typ. CPU processing time pre-tuning and fine tuning
CPU 1211	≥ V4.0	260 µs	310 µs
CPU 1212			
CPU 1214			
CPU 1215			
CPU 1217			
CPU 1212 G2	≥ V1.0	120 µs	140 µs
CPU 1214 G2			
CPU 1216 G2	≥ V4.0	25 µs	35 µs
CPU 1217 G2			
CPU 1510SP	≤ V2.9	80 µs	95 µs

CPU 1511	≤ V2.9	80 µs	95 µs
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1515		70 µs	80 µs
CPU 1516			
CPU 1517	≤ V3.1	11 µs	15 µs
CPU 1518		5 µs	7 µs
CPU 1510SP	V3.0, V3.1	65 µs	85 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1514SP			
CPU 1515		55 µs	70 µs
CPU 1516			
CPU 1510SP	≥ V4.0	55 µs	65 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1514SP			
CPU 1515			
CPU 1516			
CPU 1516T		3 µs	5 µs
CPU 1517		2 µs	3 µs
CPU 1518		1 µs	2 µs

Typical CPU processing times of the PID_3Step technology object as of Version V2.0, depending on the CPU type and operating mode for R/H-CPUs in the RUN-Redundant system state.

CPU	**FW**	**Typ. CPU processing time Automatic mode**	**Typ. CPU processing time pre-tuning and fine tuning**
CPU 1513R	V3.0, V3.1	110 µs	150 µs
CPU 1515R		100 µs	120 µs
CPU 1513R	≥ V4.0	100 µs	120 µs

CPU 1515R	≥ V4.0	100 µs	120 µs
CPU 1517H		4 µs	6 µs
CPU 1518HF			

Memory requirement

Memory requirement of an instance DB of the PID_3Step technology object as of Version V2.0.

Memory requirement	Memory requirement of the instance DB of PID_3Step V2.x
Load memory requirement	Approx. 4400 bytes
Total work memory requirement	1040 bytes
Retentive work memory requirement	60 bytes

11.2.4 PID_3Step V2

11.2.4.1 Description of PID_3Step V2

Description

You use the PID_3Step instruction to configure a PID controller with self tuning for valves or actuators with integrating behavior.

The following operating modes are possible:

- Inactive
- Pretuning
- Fine tuning
- Automatic mode
- Manual mode
- Approach substitute output value
- Transition time measurement
- Error monitoring
- Approach substitute output value with error monitoring
- Manual mode without endstop signals

For a more detailed description of the operating modes, see the State parameter.

PID algorithm

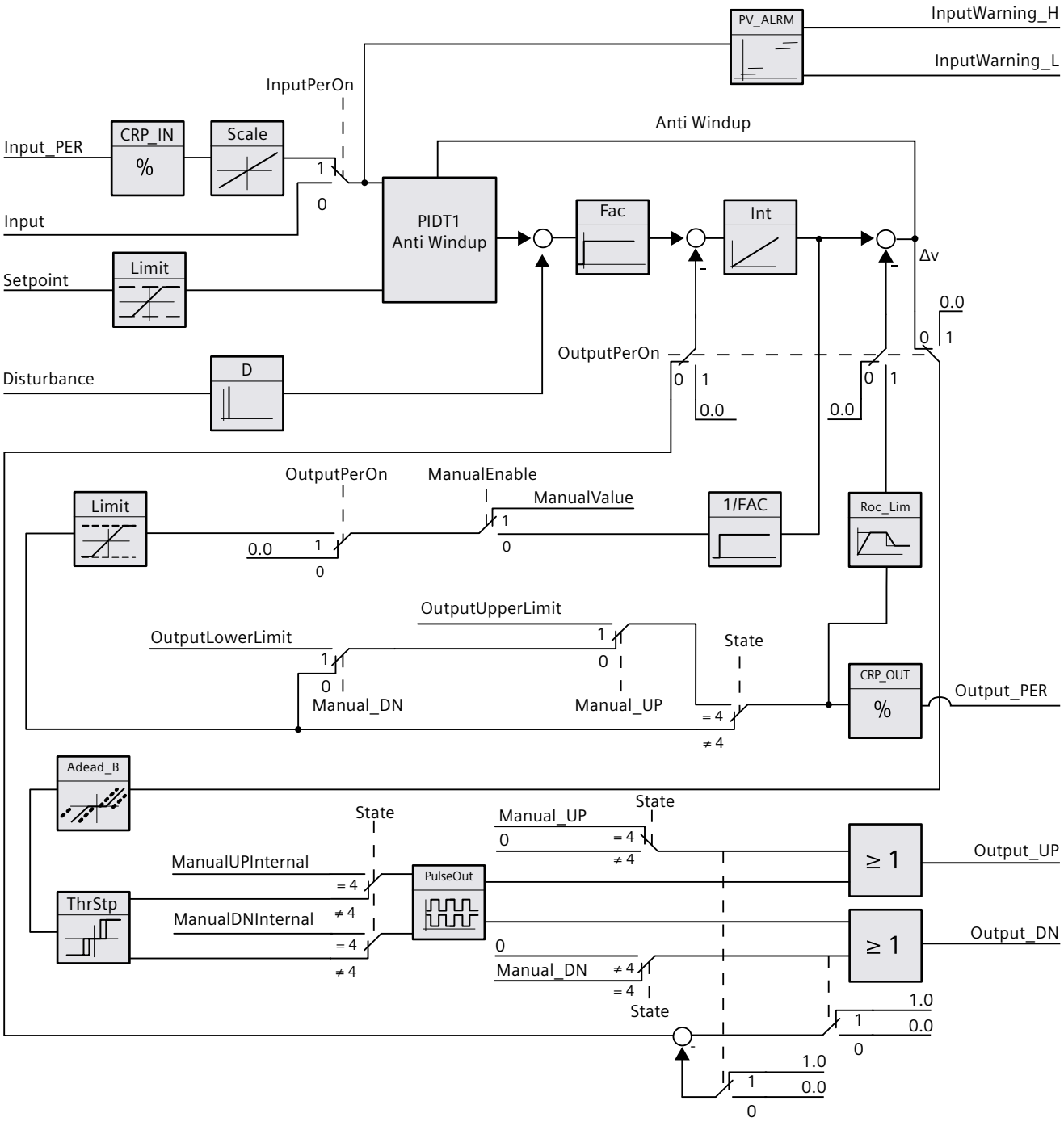
PID_3Step is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions. The PID algorithm operates according to the following transfer function:

$$\Delta y = K_p \cdot s \cdot \left[(b \cdot w - x) + \frac{1}{T_I \cdot s}(w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1}(c \cdot w - x)\right]$$

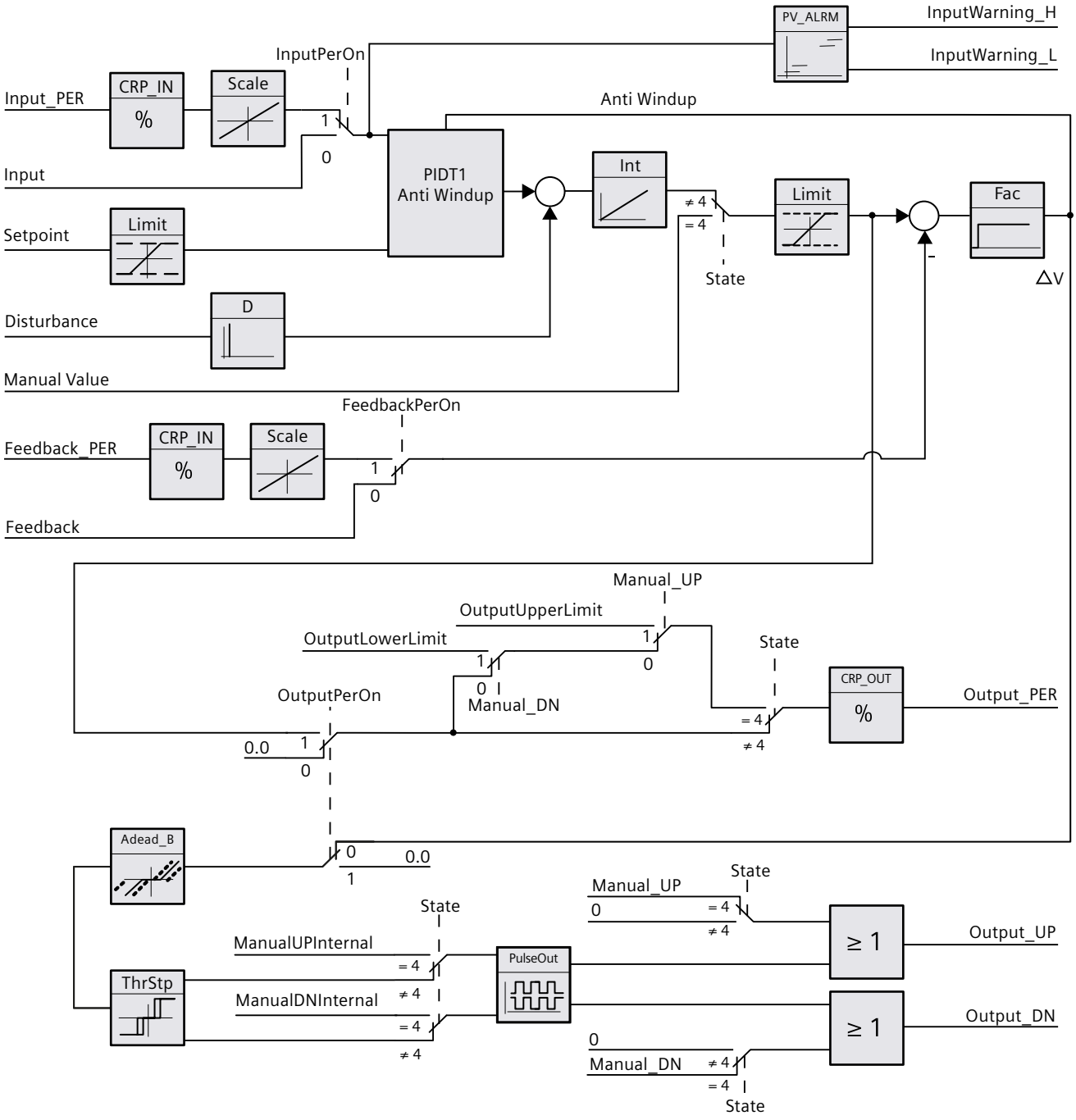
The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
Δy	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (derivative delay T1 = a × T_D)
c	Derivative action weighting

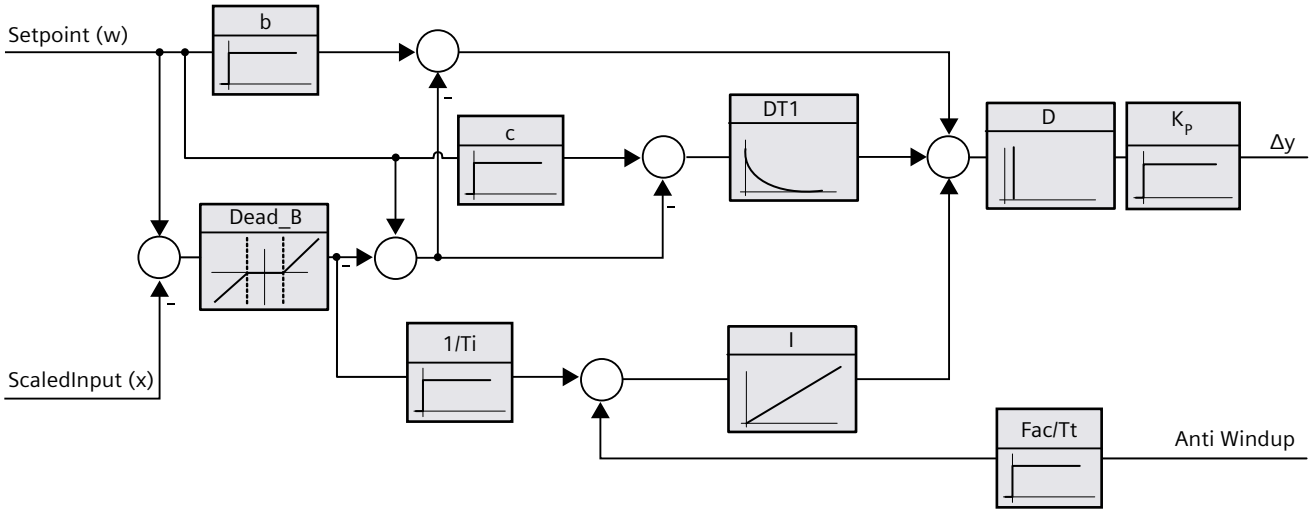
Block diagram without position feedback



Block diagram with position feedback



Block diagram of PIDT1 with anti-windup



Call

PID_3Step is called in the constant time scale of a cyclic interrupt OB.

Download to device

The actual values of retentive tags are only updated when you download PID_3Step completely.

Downloading technology objects to device (Page 49)

Startup

When the CPU starts up, PID_3Step starts in the operating mode saved in the Mode in/out parameter. To retain PID_3Step in "Inactive" mode, set RunModeByStartup = FALSE.

Response to errors

In automatic mode and during commissioning, the response in the event of an error depends on the ErrorBehaviour and ActivateRecoverMode tags. In manual mode, the reaction is independent of ErrorBehaviour and ActivateRecoverMode. If ActivateRecoverMode = TRUE, the reaction additionally depends on the error that occurred.

ErrorBehaviour	ActivateRecoverMode	Configuration editor > actuator setting > Set Output to	Reaction
FALSE	FALSE	Current output value	Switch to "Inactive" mode (State = 0) The actuator remains in the current position.
FALSE	TRUE	Current output value while error is pending	Switch to "Error monitoring" mode (State = 7) The actuator remains in the current position while the error is pending.
TRUE	FALSE	Substitute output value	Switch to "Approach substitute output value" mode (State = 5) The actuator moves to the configured substitute output value. Switch to "Inactive" mode (State = 0) The actuator remains in the current position.
TRUE	TRUE	Substitute output value while error is pending	Switch to "Approach substitute output value with error monitoring" mode (State = 8) The actuator moves to the configured substitute output value. Switch to "Error monitoring" mode (State = 7)

In manual mode, PID_3Step uses ManualValue as output value, unless the following errors occur:

- 2000h: Invalid value at Feedback_PER parameter.
- 4000h: Invalid value at Feedback parameter.
- 8000h: Error during digital position feedback.

You can only change the position of the actuator with Manual_UP and Manual_DN, not with ManualValue.

The Error parameter indicates whether an error has occurred in this cycle. The ErrorBits parameter shows which errors have occurred. ErrorBits is reset by a rising edge at Reset or ErrorAck.

See also

State and Mode V2 parameters (Page 331)
ErrorBits V2 parameter (Page 336)
Configuring PID_3Step V2 (Page 123)

11.2.4.2 Mode of operation of PID_3Step V2

Monitoring process value limits

You specify the high limit and low limit of the process value in the Config.InputUpperLimit and Config.InputLowerLimit tags. If the process value is outside these limits, an error occurs (ErrorBits = 0001h).

You specify a high and low warning limit of the process value in the Config.InputUpperWarning and Config.InputLowerWarning tags. If the process value is outside these warning limits, a warning occurs (Warning = 0040h), and the InputWarning_H or InputWarning_L output parameter changes to TRUE.

Limiting the setpoint

You specify a high limit and low limit of the setpoint in the Config.SetpointUpperLimit and Config.SetpointLowerLimit tags. PID_3Step automatically limits the setpoint to the process value limits. You can limit the setpoint to a smaller range. PID_3Step checks whether this range falls within the process value limits. If the setpoint is outside these limits, the high or low limit is used as the setpoint, and output parameter SetpointLimit_H or SetpointLimit_L is set to TRUE.

The setpoint is limited in all operating modes.

Limiting the output value

You specify a high limit and low limit of the output value in the Config.OutputUpperLimit and Config.OutputLowerLimit tags. The output value limits must be within "Low endstop" and "High endstop".

- High endstop: Config.FeedbackScaling.UpperPointOut
- Low endstop: Config.FeedbackScaling.LowerPointOut

Rule:

UpperPointOut ≥ OutputUpperLimit > OutputLowerLimit ≥ LowerPointOut

The valid values for "High endstop" and "Low endstop" depend upon:

- FeedbackOn
- FeedbackPerOn
- OutputPerOn

OutputPerOn	FeedbackOn	FeedbackPerOn	LowerPointOut	UpperPointOut
FALSE	FALSE	FALSE	Cannot be set (0.0%)	Cannot be set (100.0%)
FALSE	TRUE	FALSE	-100.0% or 0.0%	0.0% or +100.0%
FALSE	TRUE	TRUE	-100.0% or 0.0%	0.0% or +100.0%
TRUE	FALSE	FALSE	Cannot be set (0.0%)	Cannot be set (100.0%)
TRUE	TRUE	FALSE	-100.0% or 0.0%	0.0% or +100.0%
TRUE	TRUE	TRUE	-100.0% or 0.0%	0.0% or +100.0%

If OutputPerOn = FALSE and FeedbackOn = FALSE, you cannot limit the output value. Output_UP and Output_DN are then reset upon Actuator_H = TRUE or Actuator_L = TRUE. If endstop signals are also not present, Output_UP and Output_DN are reset after a travel time of Config.VirtualActuatorLimit × Retain.TransitTime/100. As of PID_3Step Version 2.3 the monitoring and limiting of the travel time can be deactivated with Config.VirtualActuatorLimit = 0.0.

The output value is 27648 at 100% and -27648 at -100%. PID_3Step must be able to completely close the valve.

NOTE

Use with two or more actuators

PID_3 Step is not suitable for use with two or more actuators (for example, in heating/cooling applications), because different actuators need different PID parameters to achieve a good control response.

Substitute output value

If an error has occurred, PID_3Step can output a substitute output value and move the actuator to a safe position that is specified in the SavePosition tag. The substitute output value must be within the output value limits.

Monitoring signal validity

The values of the following parameters are monitored for validity when used:

- Setpoint
- Input
- Input_PER
- Input_PER
- Feedback
- Feedback_PER
- Disturbance
- ManualValue
- SavePosition
- Output_PER

Monitoring the PID_3Step sampling time

Ideally, the sampling time is equivalent to the cycle time of the calling OB. The PID_3Step instruction measures the time interval between two calls. This is the current sampling time. On every switchover of operating mode and during the initial startup, the mean value is formed from the first 10 sampling times. Too great a difference between the current sampling time and this mean value triggers an error (ErrorBits = 0800h).

The error occurs during tuning if:

- New mean value >= 1.1 x old mean value
- New mean value <= 0.9 x old mean value

The error occurs in automatic mode if:

- New mean value >= 1.5 x old mean value
- New mean value <= 0.5 x old mean value

If you deactivate the sampling time monitoring (CycleTime.EnMonitoring = FALSE), you can also call PID_3Step in OB1. You must then accept a lower control quality due to the deviating sampling time.

Sampling time of the PID algorithm

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_3Step are executed at every call.

Measuring the motor transition time

The motor transition time is the time in seconds the motor requires to move the actuator from the closed to the opened state. The actuator is moved in one direction for a maximum time of Config.VirtualActuatorLimit × Retain.TransitTime/100. PID_3Step requires the motor transition time to be as accurate as possible for good controller results. The data in the actuator documentation contains average values for this type of actuator. The value for the specific actuator used may differ. You can measure the motor transition time during commissioning. The output value limits are not taken into consideration during the motor transition time measurement. The actuator can travel to the high or the low endstop.

The motor transition time is taken into consideration in the calculation of the analog output value as well as in the calculation of the digital output values. It is mainly required for correct operation during auto-tuning and the anti-windup behavior. You should therefore configure the motor transition time with the value that the motor requires to move the actuator from the closed to the opened state.

If no relevant motor transition time is in effect in your process (e.g. with solenoid valves), so that the output value has a direct and full effect on the process, use PID_Compact instead.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic. For cooling and discharge control systems, it may be necessary to invert the control logic. PID_3Step does not work with negative proportional gain. If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value. The control logic is also taken into account during pretuning and fine tuning.

See also

Configuring PID_3Step V1 (Page 142)

11.2.4.3 Changing the PID_3Step V2 interface

The following table shows what has changed in the PID_3Step instruction interface.

PID_3Step V1	PID_3Step V2	Change
Input_PER	Input_PER	Data type from Word to Int
Feedback_PER	Feedback_PER	Data type from Word to Int
	Disturbance	New
Manual_UP	Manual_UP	Function
Manual_DN	Manual_DN	Function
	ErrorAck	New
	ModeActivate	New
Output_PER	Output_PER	Data type from Word to Int
	ManualUPInternal	New
	ManualDNInternal	New
	CancelTuningLevel	New
	VirtualActuatorLImit	New
Config.Loadbackup	Loadbackup	Renamed
Config.TransitTime	Retain.TransitTime	Renamed and retentivity added
GetTransitTime.Start		Replaced by Mode and ModeActivate
SUT.CalculateSUTParams	SUT.CalculateParams	Renamed
SUT.TuneRuleSUT	SUT.TuneRule	Renamed
TIR.CalculateTIRParams	TIR.CalculateParams	Renamed
TIR.TuneRuleTIR	TIR.TuneRule	Renamed
Retain.Mode	Mode	Function Declaration of static for in-out parameters

11.2.4.4 Input parameters of PID_3Step V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-7

Parameter	Data type	Default	Description
Setpoint	REAL	0.0	Setpoint of the PID controller in automatic mode
Input	REAL	0.0	A tag of the user program is used as source for the process value. If you are using Input parameter, then Config.InputPerOn = FALSE must be set.
Input_PER	INT	0	An analog input is used as the source of the process value. If you are using Input_PER parameter, then Config.InputPerOn = TRUE must be set.
Actuator_H	BOOL	FALSE	Digital position feedback of the valve for the high endstop If Actuator_H = TRUE, the valve is at the high endstop and is no longer moved towards this direction.
Actuator_L	BOOL	FALSE	Digital position feedback of the valve for the low endstop If Actuator_L = TRUE, the valve is at the low endstop and is no longer moved towards this direction.
Feedback	REAL	0.0	Position feedback of the valve If you are using Feedback parameter, then Config.FeedbackPerOn = FALSE must be set.
Feedback_PER	INT	0	Analog position feedback of a valve If you are using Feedback_PER parameter, then Config.FeedbackPerOn = TRUE must be set. Feedback_PER is scaled based on the tags: • Config.FeedbackScaling.LowerPointIn • Config.FeedbackScaling.UpperPointIn • Config.FeedbackScaling.LowerPointOut • Config.FeedbackScaling.UpperPointOut
Disturbance	REAL	0.0	Disturbance variable or precontrol value
ManualEnable	BOOL	FALSE	• A FALSE -> TRUE edge activates "Manual mode", while State = 4, Mode remains unchanged. As long as ManualEnable = TRUE, you cannot change the operating mode via a rising edge at ModeActivate or use the commissioning dialog. • A TRUE -> FALSE edge activates the operating mode that is specified by Mode. We recommend that you change the operating mode using ModeActivate only.
ManualValue	REAL	0.0	In manual mode, you specify the absolute position of the valve. ManualValue will only be evaluated if you are using Output_PER, **or** if position feedback is available.
Manual_UP	BOOL	FALSE	• Manual_UP = TRUE The valve is opened even if you are using Output_PER or a position feedback. The valve is no longer moved if the high endstop has been reached. See also Config.VirtualActuatorLimit

Parameter	Data type	Default	Description
			• Manual_UP = FALSE If you are using Output_PER or a position feedback, the valve is moved to ManualValue. Otherwise, the valve is no longer moved. If Manual_UP and Manual_DN are set to TRUE simultaneously, the valve is not moved.
Manual_DN	BOOL	FALSE	• Manual_DN = TRUE The valve is closed even if you are using Output_PER or a position feedback. The valve is no longer moved if the low endstop has been reached. See also Config.VirtualActuatorLimit • Manual_DN = FALSE If you are using Output_PER or a position feedback, the valve is moved to ManualValue. Otherwise, the valve is no longer moved.
ErrorAck	BOOL	FALSE	• FALSE -> TRUE edge ErrorBits and Warning are reset.
Reset	BOOL	FALSE	Restarts the controller. • FALSE -> TRUE edge – Switch to "Inactive" mode – ErrorBits and Warnings are reset. • As long as Reset = TRUE, – PID_3Step remains in "Inactive" mode (State = 0). – You cannot change the operating mode with Mode and ModeActivate or ManualEnable. – You cannot use the commissioning dialog. • TRUE -> FALSE edge – If ManualEnable = FALSE, PID_3Step switches to the operating mode that is stored in the Mode parameter. – If Mode = 3, the switchover to automatic mode is bumpless.
ModeActivate	BOOL	FALSE	• FALSE -> TRUE edge PID_3Step switches to the operating mode saved in the Mode parameter.

11.2.4.5 Output parameters of PID_3Step V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-8

Parameter	Data type	Default	Description
ScaledInput	REAL	0.0	Scaled process value
ScaledFeedback	REAL	0.0	Scaled position feedback For an actuator without position feedback, the position of the actuator indicated by ScaledFeedback is very imprecise. ScaledFeedback may only be used for rough estimation of the current position in this case.
Output_UP	BOOL	FALSE	Digital output value for opening the valve If Config.OutputPerOn = FALSE, the Output_UP parameter is used.

Parameter	Data type	Default	Description
Output_DN	BOOL	FALSE	Digital output value for closing the valve If Config.OutputPerOn = FALSE, the Output_DN parameter is used.
Output_PER	INT	0	Analog output value If Config.OutputPerOn = TRUE, Output_PER is used. Use Output_PER if you are using a valve as actuator which is triggered via an analog output and controlled with a continuous signal, e.g. 0...10V or 4...20mA. The value at Output_PER corresponds to the target position of the valve, e.g. Output_PER = 13824, when the valve is to be opened by 50%.
SetpointLimit_H	BOOL	FALSE	If SetpointLimit_H = TRUE, the absolute high limit of setpoint is reached (Setpoint ≥ Config.SetpointUpperLimit). The setpoint is limited to Config.SetpointUpperLimit .
SetpointLimit_L	BOOL	FALSE	If SetpointLimit_L = TRUE, the absolute low limit of the setpoint has been reached (Setpoint ≤ Config.SetpointLowerLimit). The setpoint is limited to Config.SetpointLowerLimit .
InputWarning_H	BOOL	FALSE	If InputWarning_H = TRUE, the process value has reached or exceeded the warning high limit.
InputWarning_L	BOOL	FALSE	If InputWarning_L = TRUE, the process value has reached or fallen below the warning low limit.
State	INT	0	The State parameter (Page 331) shows the current operating mode of the PID controller. You can change the operating mode using the input parameter Mode and a rising edge at ModeActivate. • State = 0: Inactive • State = 1: Pretuning • State = 2: Fine tuning • State = 3: Automatic mode • State = 4: Manual mode • State = 5: Approach substitute output value • State = 6: Transition time measurement • State = 7: Error monitoring • State = 8: Approach substitute output value with error monitoring • State = 10: Manual mode without endstop signals
Error	BOOL	FALSE	If Error = TRUE, at least one error message is pending in this cycle.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 336) shows which error messages are pending. ErrorBits is retentive and is reset upon a rising edge at Reset or ErrorAck.

See also

State and Mode V2 parameters (Page 331)

ErrorBits V2 parameter (Page 336)

11.2.4.6 In/out parameters of PID-3Step V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-9

Parameter	Data type	Default	Description
Mode	INT	4	At the Mode parameter, you specify the operating mode to which PID_3Step is to switch. Options are: • Mode = 0: Inactive • Mode = 1: Pretuning • Mode = 2: Fine tuning • Mode = 3: Automatic mode • Mode = 4: Manual mode • Mode = 6: Transition time measurement • Mode = 10: Manual mode without endstop signals The operating mode is activated by: • Rising edge at ModeActivate • Falling edge at Reset • Falling edge at ManualEnable • Cold restart of CPU if RunModeByStartup = TRUE Mode is retentive. A detailed description of the operating modes can be found in State and Mode V2 parameters (Page 331).

11.2.4.7 Static tags of PID_3Step V2

NOTE

Change the tags identified with (1) only in "Inactive" mode to prevent malfunction of the PID controller.

The names of the following variables apply both to the data block and to access via the Openness API.

Tag	Data type	Default	Description
ManualUpInternal	BOOL	FALSE	In manual mode, each rising edge opens the valve by 5% of the total control range or for the duration of the minimum motor transition time. ManualUpInternal is only evaluated if you are not using Output_PER or a position feedback. This tag is used in the commissioning dialog.
ManualDnInternal	BOOL	FALSE	In manual mode, every rising edge closes the valve by 5% of the total control range or for the duration of the minimum motor transition time. ManualDnInternal is only evaluated if you are not using Output_PER or position feedback. This tag is used in the commissioning dialog.

Tag	Data type	Default	Description
ActivateRecoverMode	BOOL	TRUE	The ActivateRecoverMode V2 (Page 338) tag determines the response in the event of an error.
RunModeByStartup	BOOL	TRUE	Activate operating mode at Mode parameter after CPU restart If RunModeByStartup = TRUE, PID_3Step starts in the operating mode saved in the Mode parameter after CPU startup. If RunModeByStartup = FALSE, PID_3Step remains in "Inactive" mode after CPU startup.
LoadBackUp	BOOL	FALSE	If LoadBackUp = TRUE, the last set of PID parameters is reloaded. The set was saved prior to the last tuning. LoadBackUp is automatically set back to FALSE.
PhysicalUnit	INT	0	Unit of measurement of the process value and setpoint, e.g., °C, or °F. PhysicalUnit serves the display in the editors and has no influence on the behavior of the control algorithm in the CPU. When importing PID_3Step via the Openness API, PhysicalUnit is reset to the default value.
PhysicalQuantity	INT	0	Physical quantity of the process value and setpoint, e.g., temperature PhysicalQuantity serves the display in the editors and has no influence on the behavior of the control algorithm in the CPU. When importing PID_3Step via the Openness API, PhysicalQuantity is reset to the default value.
ErrorBehaviour	BOOL	FALSE	If ErrorBehaviour = FALSE and an error has occurred, the valve stays at its current position and the controller switches directly to "Inactive" or "Error monitoring" mode. If ErrorBehaviour = TRUE and an error occurs, the actuator moves to the substitute output value and only then switches to "Inactive" or "Error monitoring" mode. If the following errors occur, you can no longer move the valve to a configured substitute output value. • 2000h: Invalid value at Feedback_PER parameter. • 4000h: Invalid value at Feedback parameter. • 8000h: Error during digital position feedback. • 20000h: Invalid value at SavePosition tag.
Warning	DWORD	DW#16#0	The Warning tag (Page 331) shows the warnings since Reset = TRUE or ErrorAck =TRUE. Warning is retentive. Cyclic warnings (for example, process value warning) are shown until the cause of the warning is removed. They are automatically deleted once their cause has gone. Non-cyclic warnings (for example, point of inflection not found) remain and are deleted like errors.
SavePosition	REAL	0.0	Substitute output value If ErrorBehaviour = TRUE, the actuator is moved to a position that is safe for the plant when an error occurs. As soon as the substitute output value has been reached, PID_3Step switches the operating mode according to ActivateRecoverMode. The permitted value range is determined by the configuration. • Config.FeedbackOn = FALSE and Config.OutputPerOn = FALSE: SavePosition = 0.0 or 100.0 • Config.FeedbackOn = TRUE or Config.OutputPerOn = TRUE: Config.OutputUpperLimit ≥ SavePosition ≥ Config.OutputLowerLimit
CurrentSetpoint	REAL	0.0	Currently active setpoint. This value is frozen at the start of tuning.

Tag	Data type	Default	Description
CancelTuningLevel	REAL	10.0	Permissible fluctuation of setpoint during tuning. Tuning is not canceled until: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel
Progress	REAL	0.0	Progress of tuning as a percentage (0.0 - 100.0)
Config.InputPerOn(1)	BOOL	TRUE	If InputPerOn = TRUE, the Input_PER parameter is used. If InputPerOn = FALSE, the Input parameter is used.
Config.OutputPerOn(1)	BOOL	FALSE	If OutputPerOn = TRUE, the Output_PER parameter is used. If OutputPerOn = FALSE, the Ouput_UP and Output_DN parameters are used.
Config.InvertControl(1)	BOOL	FALSE	Invert control logic If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value.
Config.FeedbackOn(1)	BOOL	FALSE	If FeedbackOn = FALSE, a position feedback is simulated. Position feedback is generally activated when FeedbackOn = TRUE.
Config.FeedbackPerOn(1)	BOOL	FALSE	FeedbackPerOn only takes effect when FeedbackOn = TRUE. If FeedbackPerOn = TRUE, the analog input is used for the position feedback (Feedback_PER parameter). If FeedbackPerOn = FALSE, the Feedback parameter is used for the position feedback.
Config.ActuatorEndStopOn(1)	BOOL	FALSE	If ActuatorEndStopOn = TRUE, the digital position feedback Actuator_L and Actuator_H are taken into consideration.
Config.InputUpperLimit(1)	REAL	120.0	High limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. At the I/O input, the process value can be a maximum of 18% higher than the standard range (overrange). An error is no longer signaled due to a violation of the "Process value high limit". Only a wire-break and a short-circuit are recognized and PID_3Step reacts according to the configured reaction to error. InputUpperLimit > InputLowerLimit
Config.InputLowerLimit(1)	REAL	0.0	Low limit of the process value InputLowerLimit < InputUpperLimit
Config.InputUpperWarning(1)	REAL	+3.40282-2e+38	Warning high limit of the process value If you set InputUpperWarning outside the process value limits, the configured absolute process value high limit is used as the warning high limit. If you configure InputUpperWarning within the process value limits, this value is used as the warning high limit. InputUpperWarning > InputLowerWarning InputUpperWarning ≤ InputUpperLimit
Config.InputLowerWarning(1)	REAL	-3.402822e+38	Warning low limit of the process value If you set InputLowerWarning outside the process value limits, the configured absolute process value low limit is used as the warning low limit. If you configure InputLowerWarning within the process value limits, this value is used as the warning low limit. InputLowerWarning < InputUpperWarning InputLowerWarning ≥ InputLowerLimit

Tag	Data type	Default	Description
Config.OutputUpperLimit(1)	REAL	100.0	High limit of output value The following value range is permitted: UpperPointOut ≥ OutputUpperLimit > OutputLowerLimit For more details, see OutputLowerLimit.
Config.OutputLowerLimit(1)	REAL	0.0	Low limit of the output value The following value range is permitted: OutputUpperLimit > OutputLowerLimit ≥ LowerPointOut When using Output_PER, an output value limit of -100% corresponds to the value Output_PER = -27648; 100% correspond to the value Output_PER = 27648. If OutputPerOn = FALSE and FeedbackOn = FALSE, OutputLowerLimit and OutputUpperLimit are not evaluated. Output_UP and Output_DN are then reset at Actuator_H = TRUE or Actuator_L = TRUE (if ActuatorEndStopOn = TRUE) or after a travel time of Config.VirtualActuatorLimit * Retain.TransitTime/100 (if ActuatorEndStopOn = FALSE).
Config.SetpointUpperLimit(1)	REAL	+3.40282-2e+38	High limit of setpoint If you set SetpointUpperLimit outside the process value limits, the configured absolute process value high limit is preassigned as the setpoint high limit. If you configure SetpointUpperLimit within the process value limits, this value is used as the setpoint high limit.
Config.SetpointLowerLimit(1)	REAL	-3.402822e+38	Low limit of the setpoint If you set SetpointLowerLimit outside the process value limits, the configured absolute process value low limit is preassigned as the setpoint low limit. If you set SetpointLowerLimit within the process value limits, this value is used as the setpoint low limit.
Config.MinimumOnTime(1)	REAL	0.0	Minimum ON time Minimum time in seconds for which the servo drive must be switched on. Config.MinimumOnTime only takes effect when Output_UP and Output_DN are used (Config.OutputPerOn = FALSE).
Config.MinimumOffTime(1)	REAL	0.0	Minimum OFF time Minimum time in seconds for which the servo drive must be switched off. Config.MinimumOffTime only takes effect when Output_UP and Output_DN are used (Config.OutputPerOn = FALSE).
Config.VirtualActuatorLimit(1)	REAL	150.0	If all the following conditions have been satisfied, the actuator is moved in one direction for the maximum period of VirtualActuatorLimit × Retain.TransitTime/100 and the warning 2000h is output: • Config.OutputPerOn = FALSE • Config.ActuatorEndStopOn = FALSE • Config.FeedbackOn = FALSE If Config.OutputPerOn = FALSE and Config.ActuatorEndStopOn = TRUE or Config.FeedbackOn = TRUE, only the warning 2000h is output. If Config.OutputPerOn = TRUE, VirtualActuatorLimit is not taken into consideration. As of PID_3Step Version 2.3 the monitoring and limiting of the travel time can be deactivated with Config.VirtualActuatorLimit = 0.0.

Tag	Data type	Default	Description
Config.InputScaling.Upper-PointIn(1)	REAL	27648.0	Scaling Input_PER high Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.InputScaling.Lower-PointIn(1)	REAL	0.0	Scaling Input_PER low Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.InputScaling.UpperPoin-tOut(1)	REAL	100.0	Scaled high process value Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.InputScaling.LowerPoin-tOut(1)	REAL	0.0	Scaled low process value Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.FeedbackScaling.Upper-PointIn(1)	REAL	27648.0	Scaling Feedback_PER high Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure.
Config.FeedbackScaling.Lower-PointIn(1)	REAL	0.0	Scaling Feedback_PER low Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure.
Config.FeedbackScaling.Upper-PointOut(1)	REAL	100.0	High endstop Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure. The permitted value range is determined by the configuration. • FeedbackOn = FALSE: UpperPointOut = 100.0 • FeedbackOn = TRUE: UpperPointOut = 100.0 or 0.0 UpperPointOut ≠ LowerPointOut
Config.FeedbackScaling.Lower-PointOut(1)	REAL	0.0	Low endstop Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure. The permitted value range is determined by the configuration. • FeedbackOn = FALSE: LowerPointOut = 0.0 • FeedbackOn = TRUE: LowerPointOut = 0.0 or -100.0 LowerPointOut ≠ UpperPointOut
GetTransitTime.InvertDirection	BOOL	FALSE	If InvertDirection = FALSE, the valve is fully opened, closed, and then reopened in order to determine the valve transition time. If InvertDirection = TRUE, the valve is fully closed, opened, and then closed again.
GetTransitTime.SelectFeedback	BOOL	FALSE	If SelectFeedback = TRUE, then Feedback_PER, or Feedback is taken into consideration in the transition time measurement. If SelectFeedback = FALSE, then Actuator_H and Actuator_L are taken into consideration in the transition time measurement.

Tag	Data type	Default	Description
GetTransitTime.State	INT	0	Current phase of the transition time measurement • State = 0: Inactive • State = 1: Open valve completely • State = 2: Close valve completely • State = 3: Move valve to target position (NewOutput) • State = 4: Transition time measurement successfully completed • State = 5: Transition time measurement canceled
GetTransitTime.NewOutput	REAL	0.0	Target position for transition time measurement with position feedback The target position must be between "High endstop" and "Low endstop". The difference between NewOutput and ScaledFeedback must be at least 50% of the permissible control range.
CycleTime.StartEstimation	BOOL	TRUE	If StartEstimation = TRUE, the measurement of the PID_3Step sampling time is started. CycleTime.StartEstimation = FALSE once measurement is complete.
CycleTime.EnEstimation	BOOL	TRUE	If EnEstimation = TRUE, the PID_3Step sampling time is calculated. If CycleTime.EnEstimation = FALSE, the PID_3Step sampling time is not calculated and you need to correct the configuration of CycleTime.Value manually.
CycleTime.EnMonitoring	BOOL	TRUE	If EnMonitoring = TRUE, the PID_3Step sampling time is monitored. If it is not possible to execute PID_3Step within the sampling time, the error 0800h is output and the operating mode is switched. ActivateRecoverMode and ErrorBehaviour determine which operating mode is switched to. If EnMonitoring = FALSE, the PID_3Step sampling time is not monitored, the error 0800h is not output, and the operating mode is not switched.
CycleTime.Value(1)	REAL	0.1	PID_3Step sampling time in seconds CycleTime.Value is determined automatically and is usually equivalent to the cycle time of the calling OB.
CtrlParamsBackUp.SetByUser	BOOL	FALSE	Saved value of Retain.CtrlParams.SetByUser You can reload values from the CtrlParamsBackUp structure with LoadBackUp = TRUE.
CtrlParamsBackUp.Gain	REAL	1.0	Saved proportional gain
CtrlParamsBackUp.Ti	REAL	20.0	Saved integration time in seconds
CtrlParamsBackUp.Td	REAL	0.0	Saved derivative action time in seconds
CtrlParamsBackUp.TdFiltRatio	REAL	0.2	Saved derivative delay coefficient
CtrlParamsBackUp.PWeighting	REAL	1.0	Saved proportional action weighting
CtrlParamsBackUp.DWeighting	REAL	1.0	Saved derivative action weighting
CtrlParamsBackUp.Cycle	REAL	1.0	Saved sampling time of PID algorithm in seconds
CtrlParamsBackUp.InputDeadBand	REAL	0.0	Saved deadzone width of the control deviation
PIDSelfTune.SUT.CalculateParams	BOOL	FALSE	The properties of the controlled system are saved during tuning. If CalculateParams = TRUE, the PID parameters are recalculated on the basis of these properties. The PID parameters are calculated using the method set in TuneRule. CalculateParams is set to FALSE following calculation.

Tag	Data type	Default	Description
PIDSelfTune.SUT.TuneRule	INT	1	Methods used to calculate parameters during pretuning: • SUT.TuneRule = 0: PID fast I (faster control response with higher amplitudes of the output value than with SUT.TuneRule =1) • SUT.TuneRule = 1: PID slow I (slower control response with lower amplitudes of the output value than with SUT.TuneRule = 0) • SUT.TuneRule = 2: Chien, Hrones and Reswick PID • SUT.TuneRule = 3: Chien, Hrones, Reswick PI • SUT.TuneRule = 4: PID fast II (faster control response with higher amplitudes of the output value than with SUT.TuneRule = 5) • SUT.TuneRule = 5: PID slow II (slower control response with lower amplitudes of the output value than with SUT.TuneRule = 4) The methods SUT.TuneRule = 0 and 1 differ from the methods SUT.TuneRule = 4 and 5 only in the calculation of the proportional gain: When SUT.TuneRule = 0 and 1, the proportional gain is calculated based on the compensation time of the process. When SUT.TuneRule = 4 and 5, this happens based on the delay time of the process. SUT.TuneRule = 4 and 5 returns a higher value for the proportional gain and thus a faster control response with higher amplitudes of the output value than with SUT.TuneRule = 0 and 1.
PIDSelfTune.SUT.State	INT	0	The SUT.State tag indicates the current phase of pretuning: • State = 0: Initialize pretuning • State = 50: Determine start position without position feedback • State = 100: Calculate the standard deviation • State = 200: Find the point of inflection • State = 300: Determine the rise time • State = 9900: Pretuning successful • State = 1: Pretuning not successful
PIDSelfTune.TIR.RunIn	BOOL	FALSE	With the RunIn tag, you can specify that fine tuning can also be performed without pretuning. • RunIn = FALSE Pretuning is started when fine tuning is started from inactive or manual mode. If fine tuning is started from automatic mode, the system uses the existing PID parameters to control to the setpoint. Only then will fine tuning start. If pretuning is not possible, PID_3Step switches to the mode from which tuning was started. • RunIn = TRUE The pretuning is skipped. PID_3Step attempts to reach the setpoint with the minimum or maximum output value. This can produce increased overshoot. Only then will fine tuning start. RunIn is set to FALSE after fine tuning.
PIDSelfTune.TIR.Calculate-Params	BOOL	FALSE	The properties of the controlled system are saved during tuning. If CalculateParams = TRUE, the PID parameters are recalculated on the basis of these properties. The PID parameters are calculated using the method set in TuneRule. CalculateParams is set to FALSE following calculation.

Tag	Data type	Default	Description
PIDSelfTune.TIR.TuneRule	INT	0	Methods used to calculate parameters during fine tuning: • TIR.TuneRule = 0: PID automatic • TIR.TuneRule = 1: PID fast (faster control response with higher amplitudes of the output value than with TIR.TuneRule = 2) • TIR.TuneRule = 2: PID slow (slower control response with lower amplitudes of the output value than with TIR.TuneRule = 1) • TIR.TuneRule = 3: Ziegler-Nichols PID • TIR.TuneRule = 4: Ziegler-Nichols PI • TIR.TuneRule = 5: Ziegler-Nichols P To be able to repeat the calculation of the PID parameters with TIR.CalculateParams and TIR.TuneRule = 0, 1 or 2, the previous fine tuning also has to have been executed with TIR.TuneRule = 0, 1 or 2. If this is not the case, TIR.TuneRule = 3 is used. The recalculation of the PID parameters with TIR.CalculateParams and TIR.TuneRule = 3, 4 or 5 is always possible.
PIDSelfTune.TIR.State	INT	0	The TIR.State tag indicates the current phase of fine tuning: • State = -100 Fine tuning is not possible. Pretuning will be performed first. • State = 0: Initialize fine tuning • State = 200: Calculate the standard deviation • State = 300: Attempt to reach the setpoint with the maximum or minimum output value • State = 400: Attempt to reach the setpoint with existing PID parameters (if pretuning was successful) • State = 500: Determine oscillation and calculate parameters • State = 9900: Fine tuning successful • State = 1: Fine tuning not successful
Retain.TransitTime(1)	REAL	30.0	Motor transition time in seconds Time in seconds the actuating drive requires to move the valve from the closed to the opened state. TransitTime is retentive.
Retain.CtrlParams.SetByUser(1)	BOOL	FALSE	If SetByUser = FALSE, the PID parameters are determined automatically and PID_3Step operates with a dead zone at the output value. The deadzone width is calculated during tuning on the basis of the standard deviation of the output value and saved in Retain.CtrlParams.OutputDeadBand. If SetByUser = TRUE, the PID parameters are entered manually and PID_3 Step operates without a dead zone at the output value. Retain.CtrlParams.OutputDeadBand = 0.0 SetByUser is retentive.
Retain.CtrlParams.Gain(1)	REAL	1.0	Active proportional gain To invert the control logic, use the Config.InvertControl tag. Negative values at Gain also invert the control logic. We recommend you use only InvertControl to set the control logic. The control logic is also inverted if InvertControl = TRUE and Gain < 0.0. Gain is retentive.
Retain.CtrlParams.Ti(1)	REAL	20.0	• Ti > 0.0: Active integration time in seconds • Ti = 0.0: Integral action is deactivated Ti is retentive.
Retain.CtrlParams.Td(1)	REAL	0.0	• Td > 0.0: Active derivative action time in seconds • Td = 0.0: Derivative action is deactivated Td is retentive.

Tag	Data type	Default	Description
Retain.CtrlParams.TdFiltRatio(1)	REAL	0.2	Active derivative delay coefficient The derivative delay coefficient delays the effect of the derivative action. Derivative delay = derivative action time × derivative delay coefficient • 0.0: Derivative action is effective for one cycle only and therefore almost not effective. • 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant. • > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed. TdFiltRatio is retentive.
Retain.CtrlParams.PWeighting(1)	REAL	1.0	Active proportional action weighting The proportional action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Proportional action for setpoint change is fully effective • 0.0: Proportional action for setpoint change is not effective The proportional action is always fully effective when the process value is changed. PWeighting is retentive.
Retain.CtrlParams.DWeighting(1)	REAL	1.0	Active derivative action weighting The derivative action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Derivative action is fully effective upon setpoint change • 0.0: Derivative action is not effective upon setpoint change The derivative action is always fully effective when the process value is changed. DWeighting is retentive.
Retain.CtrlParams.Cycle(1)	REAL	1.0	Active sampling time of PID algorithm in seconds, rounded to an integer multiple of the cycle time of the calling OB. Cycle is retentive.
Retain.CtrlParams.InputDeadBand(1)	REAL	0.0	Deadzone width of the control deviation InputDeadBand is retentive.

See also

State and Mode V2 parameters (Page 331)
Tag ActivateRecoverMode V2 (Page 338)
Downloading technology objects to device (Page 49)

11.2.4.8 State and Mode V2 parameters

Correlation of the parameters

The State parameter shows the current operating mode of the PID controller. You cannot change the State parameter.

With a rising edge at ModeActivate, PID_3Step switches to the operating mode saved in the Mode in-out parameter.

When the CPU is switched on or switches from Stop to RUN mode, PID_3Step starts in the operating mode that is saved in the Mode parameter. To retain PID_3Step in "Inactive" mode, set RunModeByStartup = FALSE.

Meaning of values

State	Description of operating mode
0	Inactive The controller is switched off and no longer changes the valve position. The change from Inactive mode to Automatic mode is bumpless.
1	Pretuning The pretuning determines the process response to a pulse of the output value and searches for the point of inflection. The PID parameters are calculated from the maximum rate of rise and dead time of the controlled system. You obtain the best PID parameters when you perform pretuning and fine tuning. Pretuning requirements: • The motor transition time has been configured or measured. • Inactive (State = 0), manual mode (State = 4), or automatic mode (State = 3) • ManualEnable = FALSE • Reset = FALSE • The setpoint and the process value lie within the configured limits. The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher as compared to the noise. This is most likely the case in operating modes "Inactive" and "manual mode". The setpoint is frozen in the CurrentSetpoint tag. Tuning is canceled when: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel Before the PID parameters are recalculated, they are backed up and can be reactivated with LoadBackUp. The controller switches to automatic mode following successful pretuning. If pretuning is unsuccessful, the switchover of operating mode is dependent on ActivateRecoverMode and ErrorBehaviour. The phase of pretuning is indicated with PIDSelfTune.SUT.State.
2	Fine tuning Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are recalculated based on the amplitude and frequency of this oscillation. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. You obtain the best PID parameters when you perform pretuning and fine tuning. PID_3Step automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The setpoint is frozen in the CurrentSetpoint tag. Tuning is canceled when: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel The PID parameters are backed up before fine tuning. They can be reactivated with LoadBackUp.

State	Description of operating mode
	Requirements for fine tuning: • The motor transition time has been configured or measured. • The setpoint and the process value lie within the configured limits. • ManualEnable = FALSE • Reset = FALSE • Automatic (State = 3), inactive (State = 0) or manual (State = 4) mode Fine tuning proceeds as follows when started from: • Automatic mode (State = 3) Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning. PID_3Step controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. • Inactive (State = 0) or manual mode (State = 4) If the requirements for pretuning are met, pretuning is started. The determined PID parameters will be used for control until the control loop has stabilized and the requirements for fine tuning have been met. If PIDSelfTune.TIR.RunIn = TRUE, pretuning is skipped and an attempt is made to reach the setpoint with the minimum or maximum output value. This can produce increased overshoot. Fine tuning then starts automatically. The controller switches to automatic mode following successful fine tuning. If fine tuning is unsuccessful, the switchover of operating mode is dependent on ActivateRecoverMode and ErrorBehaviour. The phase of fine tuning is indicated with PIDSelfTune.TIR.State.
3	Automatic mode In automatic mode, PID_3Step controls the controlled system in accordance with the parameters specified. The controller switches to automatic mode if one the following requirements is fulfilled: • Pretuning successfully completed • Fine tuning successfully completed • Changing of the Mode in-out parameter to the value 3 and a rising edge at ModeActivate. The switchover from automatic mode to manual mode is only bumpless if carried out in the commissioning editor. The ActivateRecoverMode tag is taken into consideration in automatic mode.
4	Manual mode In manual mode, you specify manual output values in the Manual_UP and Manual_DN parameters or ManualValue parameter. Whether or not the actuator can be moved to the output value in the event of an error is described in the ErrorBits parameter. You can also activate this operating mode using ManualEnable = TRUE. We recommend that you change the operating mode using Mode and ModeActivate only. The switchover from manual mode to automatic mode is bumpless. Manual mode is also possible when an error is pending.
5	Approach substitute output value This operating mode is activated in the event of an error, if Errorbehaviour = TRUE and ActivateRecoverMode = FALSE.. PID_3Step moves the actuator to the substitute output value and then switches to "Inactive" mode.
6	Transition time measurement The time that the motor needs to completely open the valve from the closed condition is determined. This operating mode is activated when Mode = 6 and ModeActivate = TRUE is set. If endstop signals are used to measure the transition time, the valve will be opened completely from its current position, closed completely, and opened completely again. If GetTransitTime.InvertDirection = TRUE, this behavior is inverted. If position feedback is used to measure the transition time, the actuator will be moved from its current position to a target position. The output value limits are not taken into consideration during the transition time measurement. The actuator can travel to the high or the low endstop.

State	Description of operating mode
7	Error monitoring The control algorithm is switched off and no longer changes the valve position. This operating mode is activated instead of "Inactive" mode in the event of an error. All the following conditions must be met: • Automatic mode (Mode = 3) • Errorbehaviour = FALSE • ActivateRecoverMode = TRUE • One or more errors have occurred in which ActivateRecoverMode (Page 338) is effective. As soon as the errors are no longer pending, PID_3Step switches back to automatic mode.
8	Approach substitute output value with error monitoring This operating mode is activated instead of "approach substitute output value" mode when an error occurs. PID_3Step moves the actuator to the substitute output value and then switches to "error monitoring" mode. All the following conditions must be met: • Automatic mode (Mode = 3) • Errorbehaviour = TRUE • ActivateRecoverMode = TRUE • One or more errors have occurred in which ActivateRecoverMode (Page 338) is effective. As soon as the errors are no longer pending, PID_3Step switches back to automatic mode.
10	Manual mode without endstop signals The endstop signals are **not** taken into consideration, even though Config.ActuatorEndStopOn = TRUE. The output value limits are not taken into consideration. Otherwise, PID_3Step behaves the same as in manual mode.

ENO characteristics

If State = 0, then ENO = FALSE.

If State ≠ 0, then ENO = TRUE.

Automatic switchover of operating mode during commissioning

Automatic mode is activated following successful pretuning or fine tuning. The following table shows how Mode and State change during successful pretuning.

Cycle no.	Mode	State	Action
0	4	4	Set Mode = 1
1	1	4	Set ModeActivate = TRUE
1	4	1	Value of State is saved in Mode parameter Pretuning is started
n	4	1	Pretuning successfully completed
n	3	3	Automatic mode is started

PID_3Step automatically switches the operating mode in the event of an error. The following table shows how Mode and State change during pretuning with errors.

Cycle no.	Mode	State	Action
0	4	4	Set Mode = 1
1	1	4	Set ModeActivate = TRUE
1	4	1	Value of State is saved in Mode parameter Pretuning is started
n	4	1	Pretuning canceled
n	4	4	Manual mode is started

If ActivateRecoverMode = TRUE, the operating mode that is saved in the Mode parameter is activated. At the start of transition time measurement, pretuning, or fine tuning, PID_3Step saved the value of State in the Mode in/out parameter. PID_3Step therefore switches to the operating mode from which transition time measurement or tuning was started.

If ActivateRecoverMode = FALSE, "Inactive" or "Approach substitute output value" mode is activated.

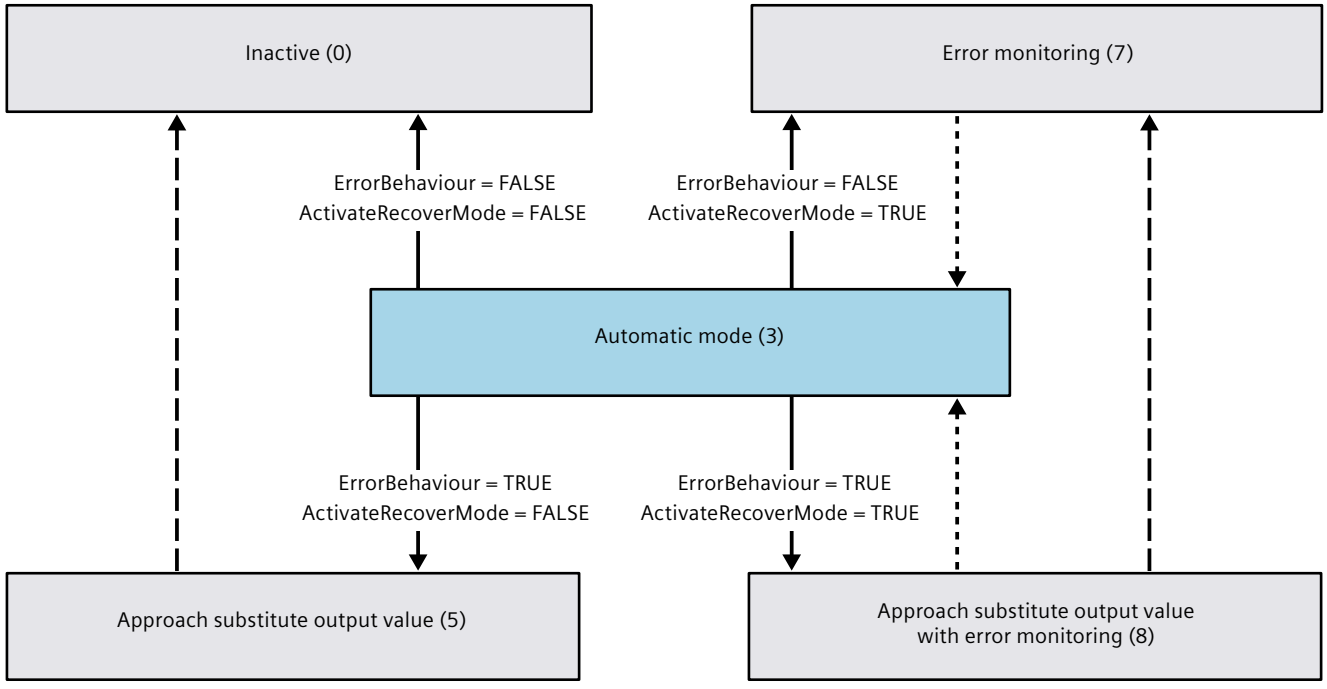
Automatic switchover of operating mode after transition time measurement

If ActivateRecoverMode = TRUE, the operating mode that is saved in the Mode parameter is activated after successful transition time measurement.

If ActivateRecoverMode = FALSE, the system switches to "Inactive" operating mode after successful transition time measurement.

Automatic switchover of operating mode in automatic mode

PID_3Step automatically switches the operating mode in the event of an error. The following diagram illustrates the influence of ErrorBehaviour and ActivateRecoverMode on this switchover of operating mode.



Automatic switchover of operating mode in the event of an error

Automatic switchover of operating mode once the current operation has been completed.

Automatic switchover of operating mode when error is no longer pending.

See also

Tag ActivateRecoverMode V2 (Page 338)
ErrorBits V2 parameter (Page 336)

11.2.4.9 ErrorBits V2 parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

If there is a position feedback, PID_3Step uses ManualValue as output value in manual mode. The exception is Errorbits = 16#0001_0000.

ErrorBits (DW#16#...)	Description
0000_0000	There is no error.
0000_0001	The "Input" parameter is outside the process value limits. • Input > Config.InputUpperLimit or • Input < Config.InputLowerLimit If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_3Step remains in automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_0002	Invalid value at "Input_PER" parameter. Check whether an error is pending at the analog input. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode. As soon as the error is no longer pending, PID_3Step switches back to automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_0004	Error during fine tuning. The oscillation of the process value could not be maintained. If ActivateRecoverMode = TRUE before the error occurred, PID_3Step cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0010	The setpoint was changed during tuning. You can set the permitted fluctuation of the setpoint at the CancelTuningLevel tag. If ActivateRecoverMode = TRUE before the error occurred, PID_3Step cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0020	Pretuning is not permitted during fine tuning. If ActivateRecoverMode = TRUE before the error occurred, PID_3Step remains in fine tuning mode.
0000_0080	Error during pretuning. The output value limits are not configured correctly or the process value does not react as expected. Make sure that: • The limits of the output value are configured correctly and match the control logic. • It is possible to change the output value so that the process value approaches the setpoint. The output value is not already limited by the corresponding output value limit before the start of pretuning and the actuator has not yet reached the corresponding endstop. Example: With normal control logic and a process value that is below the setpoint, the output value must not have reached the high limit and the actuator must not have reached the high endstop before the start of the pretuning. • The process value does not show a strong oscillation before the start of the pretuning. If ActivateRecoverMode = TRUE before the error occurred, PID_3Step cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0100	Error during fine tuning resulted in invalid parameters. If ActivateRecoverMode = TRUE before the error occurred, PID_3Step cancels the tuning and switches to the operating mode saved in the Mode parameter.

ErrorBits (DW#16#...)	Description
0000_0200	Invalid value at "Input" parameter: Value has an invalid number format. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode. As soon as the error is no longer pending, PID_3Step switches back to automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_0400	Calculation of output value failed. Check the PID parameters. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode. As soon as the error is no longer pending, PID_3Step switches back to automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_0800	Sampling time error: PID_3Step is not called within the sampling time of the cyclic interrupt OB. It is recommended to call PID_3Step in a cyclic interrupt OB without conditions and to activate or deactivate it via the operating mode at the Mode parameter. Conditional calls or the call in OB1 can have a negative effect on the control quality. Monitoring of the sampling time can be disabled with CycleTime.EnMonitoring = FALSE. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_3Step remains in automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter. If this error occurred during simulation with PLCSIM, see the notes under Simulating PID_3Step V2 with PLCSIM (Page 142).
0000_1000	Invalid value at "Setpoint" parameter: Value has an invalid number format. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode. As soon as the error is no longer pending, PID_3Step switches back to automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_2000	Invalid value at Feedback_PER parameter. Check whether an error is pending at the analog input. The actuator cannot be moved to the substitute output value and remains in its current position. In manual mode, you can change the position of the actuator only with Manual_UP and Manual_DN, and not with ManualValue. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_4000	Invalid value at Feedback parameter. Value has an invalid number format. The actuator cannot be moved to the substitute output value and remains in its current position. In manual mode, you can change the position of the actuator only with Manual_UP and Manual_DN, and not with ManualValue. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode. If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0000_8000	Error during digital position feedback. Actuator_H = TRUE and Actuator_L = TRUE. The actuator cannot be moved to the substitute output value and remains in its current position. Manual mode is not possible in this state. In order to move the actuator from this state, you must deactivate the "Actuator endstop" (Config.ActuatorEndStopOn = FALSE) or switch to manual mode without endstop signals (Mode = 10). If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.

ErrorBits (DW#16#...)	Description
	If pretuning, fine tuning, or transition time measurement mode and ActivateRecoverMode = TRUE were active before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter.
0001_0000	Invalid value at ManualValue parameter. Value has an invalid number format. The actuator cannot be moved to the manual value and remains in its current position. Specify a valid value in ManualValue or move the actuator in manual mode with Manual_UP and Manual_DN.
0002_0000	Invalid value at SavePosition tag. Value has an invalid number format. The actuator cannot be moved to the substitute output value and remains in its current position.
0004_0000	Invalid value at Disturbance parameter. Value has an invalid number format. If automatic mode was active and ActivateRecoverMode = TRUE before the error occurred, Disturbance is set to zero. PID_3Step remains in automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_3Step switches to the operating mode saved in the Mode parameter. If Disturbance in the current phase has no effect on the output value, tuning is not be canceled. The error has no effect during transition time measurement.

11.2.4.10 Tag ActivateRecoverMode V2

The ActivateRecoverMode tag determines the reaction to error. The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred.

NOTICE
Your system may be damaged. If ActivateRecoverMode = TRUE, PID_3Step remains in automatic mode even if the process limit values are exceeded. This may damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

Automatic mode

ActivateRecover-Mode	Description
FALSE	In the event of an error, PID_3Step switches to "Inactive" or "Approach substitute output value" mode. The controller is only activated by a falling edge at Reset or a rising edge at ModeActivate.
TRUE	If errors occur frequently in automatic mode, this setting has a negative effect on the control response, because PID_3Step switches between the calculated output value and the substitute output value at each error. In this case, check the ErrorBits parameter and eliminate the cause of the error. If one or more of the following errors occur, PID_3Step stays in automatic mode: • 0001h: The "Input" parameter is outside the process value limits. • 0800h: Sampling time error • 40000h: Invalid value at Disturbance parameter.

ActivateRecover-Mode	Description
	If one or more of the following errors occur, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode: • 0002h: Invalid value at Input_PER parameter. • 0200h: Invalid value at Input parameter. • 0400h: Calculation of output value failed. • 1000h: Invalid value at Setpoint parameter. If one or more of the following errors occur, PID_3Step can no longer move the actuator: • 2000h: Invalid value at Feedback_PER parameter. • 4000h: Invalid value at Feedback parameter. • 8000h: Error during digital position feedback. • 20000h: Invalid value at SavePosition tag. Value has an invalid number format. The characteristics are independent of ErrorBehaviour. As soon as the errors are no longer pending, PID_3Step switches back to automatic mode.

Pretuning, fine tuning, and transition time measurement

ActivateRecover-Mode	Description
FALSE	In the event of an error, PID_3Step switches to "Inactive" or "Approach substitute output value" mode. The controller is only activated by a falling edge at Reset or a rising edge at ModeActivate. The controller changes to "Inactive" mode after successful transition time measurement.
TRUE	If the following error occurs, PID_3Step remains in the active mode: • 0020h: Pretuning is not permitted during fine tuning. The following errors are ignored: • 10000h: Invalid value at ManualValue parameter. • 20000h: Invalid value at SavePosition tag. When any other error occurs, PID_3Step cancels the tuning and switches to the mode from which tuning was started.

Manual mode

ActivateRecoverMode is not effective in manual mode.

See also

Static tags of PID_3Step V2 (Page 322)
State and Mode V2 parameters (Page 331)

11.2.4.11 Tag Warning V2

If several warnings are pending simultaneously, their values are displayed with binary addition. The display of warning 16#0000_0005, for example, indicates that the warnings 16#0000_0001 and 16#0000_0004 are pending simultaneously.

Warning (DW#16#...)	Description
0000_0000	No warning pending.
0000_0001	The point of inflection was not found during pretuning.
0000_0004	The setpoint was limited to the configured limits.
0000_0008	Not all the necessary controlled system properties were defined for the selected method of calculation. Instead, the PID parameters were calculated using the TIR.TuneRule = 3 method.
0000_0010	The operating mode could not be changed because Reset = TRUE or ManualEnable = TRUE.
0000_0020	The cycle time of the calling OB limits the sampling time of the PID algorithm. Improve results by using shorter OB cycle times.
0000_0040	The process value exceeded one of its warning limits.
0000_0080	Invalid value at Mode. The operating mode is not switched.
0000_0100	The manual value was limited to the limits of the controller output.
0000_0200	The specified rule for tuning is not supported. No PID parameters are calculated.
0000_0400	The transition time cannot be measured because the actuator settings do not match the selected measuring method.
0000_0800	The difference between the current position and the new output value is too small for transition time measurement. This can produce incorrect results. The difference between the current output value and new output value must be at least 50% of the entire control range.
0000_1000	The substitute output value cannot be reached because it is outside the output value limits.
0000_2000	The actuator was moved in one direction for longer than Config.VirtualActuatorLimit × Retain.TransitTime. Check whether the actuator has reached an endstop signal.

The following warnings are deleted as soon as the cause is eliminated:

- 16#0000_0001
- 16#0000_0004
- 16#0000_0008
- 16#0000_0040
- 16#0000_0100
- 16#0000_2000

All other warnings are cleared with a rising edge at Reset or ErrorAck.

11.2.5 PID_3Step V1

11.2.5.1 Description PID_3Step V1

Description

You use the PID_3Step instruction to configure a PID controller with self tuning for valves or actuators with integrating behavior.

The following operating modes are possible:

- Inactive
- Pretuning
- Fine tuning
- Automatic mode
- Manual mode
- Approach substitute output value
- Transition time measurement
- Approach substitute output value with error monitoring
- Error monitoring

For a more detailed description of the operating modes, see the State parameter.

PID algorithm

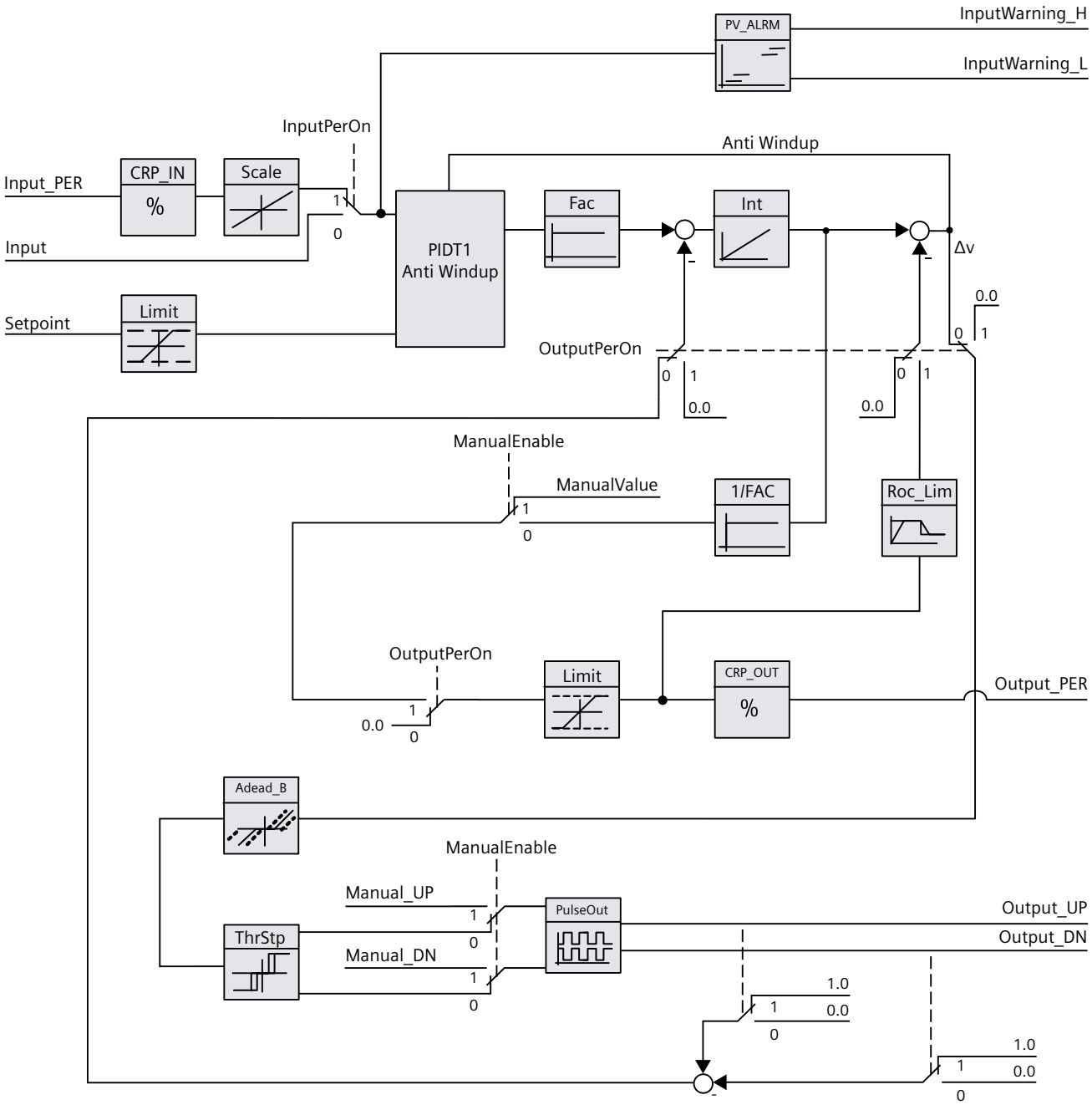
PID_3Step is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions. The following equation is used to calculate the transfer function.

$$\Delta y = K_p \cdot s \cdot \left[(b \cdot w - x) + \frac{1}{T_I \cdot s}(w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1}(c \cdot w - x)\right]$$

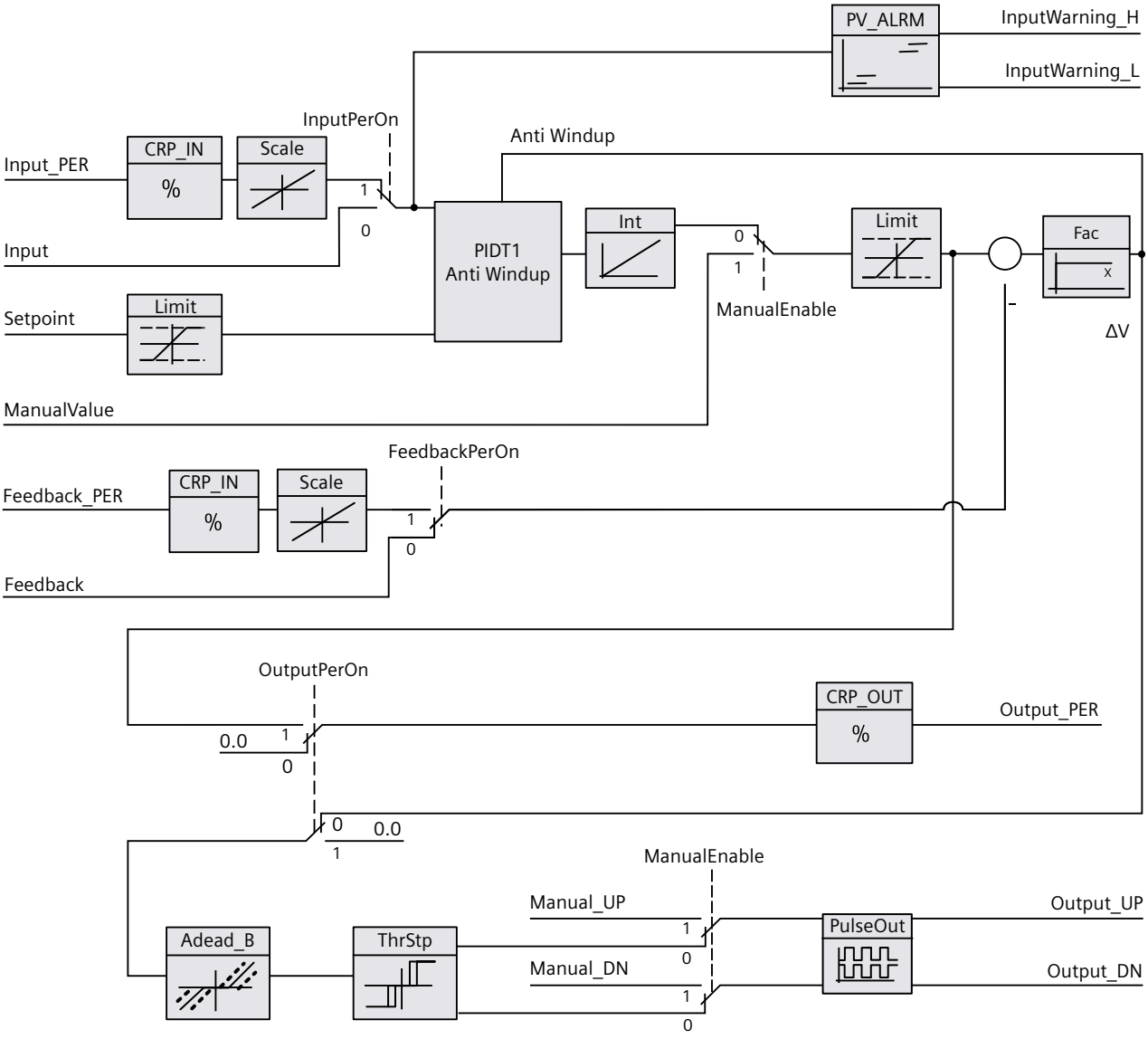
The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description
Δy	Output value of the PID algorithm
K_p	Proportional gain
s	Laplace operator
b	Proportional action weighting
w	Setpoint
x	Process value
T_I	Integration time
T_D	Derivative action time
a	Derivative delay coefficient (T1 = a × TD)
c	Derivative action weighting

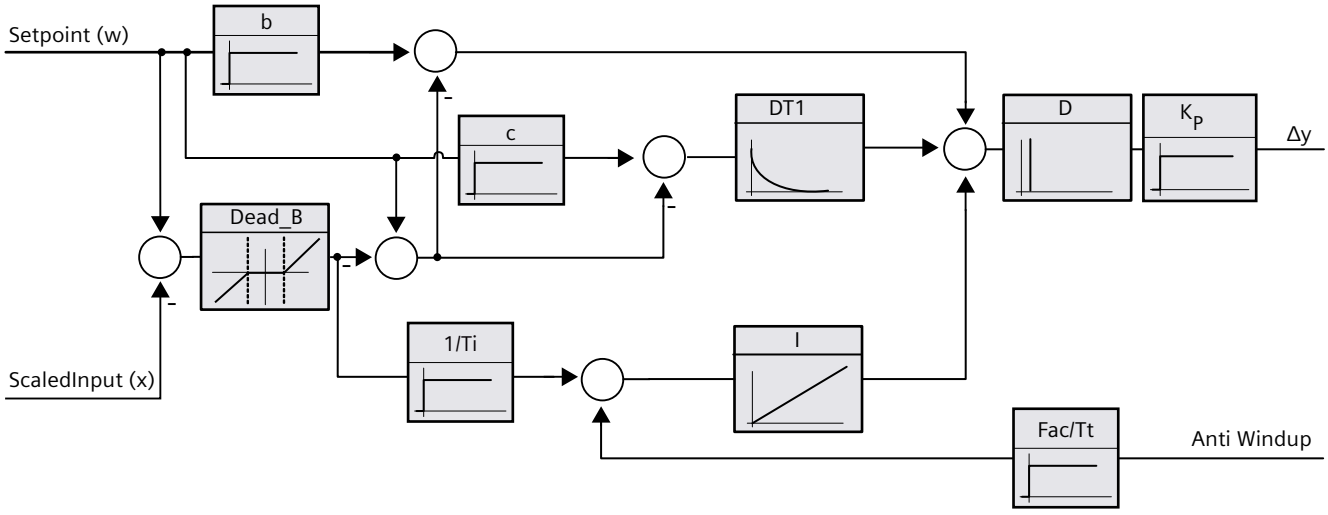
Block diagram without position feedback



Block diagram with position feedback



Block diagram of PIDT1 with anti-windup



Call

PID_3Step is called in the constant interval of the cycle time of the calling OB (preferably in a cyclic interrupt OB).

Download to device

The actual values of retentive tags are only updated when you download PID_3Step completely.

Downloading technology objects to device (Page 49)

Startup

At the startup of the CPU, PID_3Step starts in the operating mode that was last active. To retain PID_3Step in "Inactive" mode, set RunModeByStartup = FALSE.

Response to errors

If errors occur, these are output in the Error parameter. You configure the reaction of PID_3Step using the ErrorBehaviour and ActivateRecoverMode tags.

ErrorBehaviour	ActivateRecoverMode	Actuator setting configuration Set Output to	Reaction
0	FALSE	Current output value	Switch to "Inactive" mode (Mode = 0)
0	TRUE	Current output value while error is pending	Switch to "Error monitoring" mode (Mode = 7)
1	FALSE	Substitute output value	Switch to "Approach substitute output value" mode (Mode = 5) Switch to "Inactive" mode (Mode = 0)
1	TRUE	Substitute output value while error is pending	Switch to "Approach substitute output value with error monitoring" mode (Mode = 8) Switch to "Error monitoring" mode (Mode = 7)

The ErrorBits parameter shows which errors have occurred.

See also

State and Retain.Mode V1 parameters (Page 358)
ErrorBits V1 parameter (Page 364)
Configuring PID_3Step V1 (Page 142)

11.2.5.2 Operating principle PID_3Step V1

Monitoring process value limits

You specify the high limit and low limit of the process value in the Config.InputUpperLimit and Config.InputLowerLimit tags. If the process value is outside these limits, an error occurs (ErrorBits = 0001hex).

You specify a high and low warning limit of the process value in the Config.InputUpperWarning and Config.InputLowerWarning tags. If the process value is outside these warning limits, a warning occurs (Warnings = 0040hex), and the InputWarning_H or InputWarning_L output parameter changes to TRUE.

Limiting the setpoint

You specify a high limit and low limit of the setpoint in the Config.SetpointUpperLimit and Config.SetpointLowerLimit tags. PID_3Step automatically limits the setpoint to the process value limits. You can limit the setpoint to a smaller range. PID_3Step checks whether this range falls within the process value limits. If the setpoint is outside these limits, the high or low limit is used as the setpoint, and output parameter SetpointLimit_H or SetpointLimit_L is set to TRUE.

The setpoint is limited in all operating modes.

Limiting the output value

You specify a high limit and low limit of the output value in the Config.OutputUpperLimit and Config.OutputLowerLimit tags. The output value limits must be within "Low endstop" and "High endstop".

- High endstop: Config.FeedbackScaling.UpperPointOut
- Low endstop: Config.FeedbackScaling.LowerPointOut

Rule:

UpperPointOut ≥ OutputUpperLimit > OutputLowerLimit ≥ LowerPointOut

The valid values for "High endstop" and "Low endstop" depend upon:

- FeedbackOn
- FeedbackPerOn
- OutputPerOn

OutputPerOn	FeedbackOn	FeedbackPerOn	LowerPointOut	UpperPointOut
FALSE	FALSE	FALSE	Cannot be set (0.0%)	Cannot be set (100.0%)
FALSE	TRUE	FALSE	-100.0% or 0.0%	0.0% or +100.0%
FALSE	TRUE	TRUE	-100.0% or 0.0%	0.0% or +100.0%
TRUE	FALSE	FALSE	Cannot be set (100.0%)	Cannot be set (100.0%)
TRUE	TRUE	FALSE	-100.0% or 0.0%	0.0% or +100.0%
TRUE	TRUE	TRUE	-100.0% or 0.0%	0.0% or +100.0%

If OutputPerOn = FALSE and FeedbackOn = FALSE, you cannot limit the output value. The digital outputs are reset with Actuator_H = TRUE or Actuator_L = TRUE, or after a travel time amounting to 110% of the motor transition time.

The output value is 27648 at 100% and -27648 at -100%. PID_3Step must be able to completely close the valve. Therefore, zero must be included in the output value limits.

NOTE

Use with two or more actuators

PID_3 Step is not suitable for use with two or more actuators (for example, in heating/cooling applications), because different actuators need different PID parameters to achieve a good control response.

Substitute output value

If an error has occurred, PID_3Step can output a substitute output value and move the actuator to a safe position that is specified in the SavePosition tag. The substitute output value must be within the output value limits.

Monitoring signal validity

The values of the following parameters are monitored for validity:

- Setpoint
- Input
- Input_PER
- Feedback
- Feedback_PER
- Output

Monitoring the PID_3Step sampling time

Ideally, the sampling time is equivalent to the cycle time of the calling OB. The PID_3Step instruction measures the time interval between two calls. This is the current sampling time. On every switchover of operating mode and during the initial startup, the mean value is formed from the first 10 sampling times. Too great a difference between the current sampling time and this mean value triggers an error (ErrorBits = 0800 hex).

PID_3Step is set to "Inactive" mode during tuning under the following conditions:

- New mean value >= 1.1 x old mean value
- New mean value <= 0.9 x old mean value

In automatic mode, PID_3Step is set to "Inactive" mode under the following conditions:

- New mean value >= 1.5 x old mean value
- New mean value <= 0.5 x old mean value

Sampling time of the PID algorithm

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the cycle time. All other functions of PID_3Step are executed at every call.

Measuring the motor transition time

The motor transition time is the time in seconds the motor requires to move the actuator from the closed to the opened state. The maximum time that the actuator is moved in one direction is 110% of the motor transition time. PID_3Step requires the motor transition time to be as accurate as possible for good controller results. The data in the actuator documentation contains average values for this type of actuator. The value for the specific actuator used may differ. You can measure the motor transition time during commissioning. The output value limits are not taken into consideration during the motor transition time measurement. The actuator can travel to the high or the low endstop.

The motor transition time is taken into consideration in the calculation of the analog output value as well as in the calculation of the digital output values. It is mainly required for correct

operation during auto-tuning and the anti-windup behavior. You should therefore configure the motor transition time with the value that the motor requires to move the actuator from the closed to the opened state.

If no relevant motor transition time is in effect in your process (e.g. with solenoid valves), so that the output value has a direct and full effect on the process, use PID_Compact instead.

Control logic

An increase of the output value is generally intended to cause an increase in the process value. This is referred to as a normal control logic. For cooling and discharge control systems, it may be necessary to invert the control logic. PID_3Step does not work with negative proportional gain. If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value. The control logic is also taken into account during pretuning and fine tuning.

See also

Configuring PID_3Step V1 (Page 142)

11.2.5.3 PID_3Step V1 input parameters

Table 11-10

Parameters	Data type	Default	Description
Setpoint	REAL	0.0	Setpoint of the PID controller in automatic mode
Input	REAL	0.0	A tag of the user program is used as source for the process value. If you are using Input parameter, then Config.InputPerOn = FALSE must be set.
Input_PER	WORD	W#16#0	An analog input is used as the source of the process value. If you are using Input_PER parameter, then Config.InputPerOn = TRUE must be set.
Actuator_H	BOOL	FALSE	Digital position feedback of the valve for the high endstop If Actuator_H = TRUE, the valve is at the high endstop and is no longer moved towards this direction.
Actuator_L	BOOL	FALSE	Digital position feedback of the valve for the low endstop If Actuator_L = TRUE, the valve is at the low endstop and is no longer moved towards this direction.
Feedback	REAL	0.0	Position feedback of the valve If you are using Feedback parameter, then Config.FeedbackPerOn = FALSE must be set.
Feedback_PER	WORD	W#16#0	Analog position feedback of a valve If you are using Feedback_PER parameter, then Config.FeedbackPerOn = TRUE must be set. Feedback_PER is scaled based on the tags: • Config.FeedbackScaling.LowerPointIn • Config.FeedbackScaling.UpperPointIn • Config.FeedbackScaling.LowerPointOut • Config.FeedbackScaling.UpperPointOut

Parameters	Data type	Default	Description
ManualEnable	BOOL	FALSE	• A FALSE -> TRUE edge selects "Manual mode", while State = 4, Retain.Mode remains unchanged. • A TRUE -> FALSE edge selects the most recently active operating mode A change of Retain.Mode will not take effect during ManualEnable = TRUE. The change of Retain.Mode will only be considered upon a TRUE -> FALSE edge at ManualEnable . **PID_3Step V1.1**If ManualEnable = TRUE when the CPU starts, PID_3Step starts in manual mode. A rising edge (FALSE > TRUE) at ManualEnable is not necessary. **PID_3Step V1.0** At the start of the CPU, PID_3Step only switches to manual mode with a rising edge (FALSE->TRUE) at ManualEnable . Without rising edge, PID_3Step starts in the last operating mode in which ManualEnable was FALSE.
ManualValue	REAL	0.0	In manual mode, you specify the absolute position of the valve. ManualValue will only be evaluated if you are using OutputPer, **or** if position feedback is available.
Manual_UP	BOOL	FALSE	In manual mode, every rising edge opens the valve by 5% of the total control range, or for the duration of the minimum motor transition time. Manual_UP is evaluated only if you are not using Output_PER and there is no position feedback available.
Manual_DN	BOOL	FALSE	In manual mode, every rising edge closes the valve by 5% of the total control range, or for the duration of the minimum motor transition time. Manual_DN is evaluated only if you are not using Output_PER and there is no position feedback available.
Reset	BOOL	FALSE	Restarts the controller. • FALSE -> TRUE edge – Switch to "Inactive" mode – ErrorBits and Warning are reset – Intermediate controller values are reset (PID parameters are retained) • TRUE -> FALSE edge – Change in most recent active mode – If automatic mode was active before, switchover to automatic mode is bumpless.

11.2.5.4 PID_3Step V1 output parameters

Table 11-11

Parameter	Data type	Default	Description
ScaledInput	REAL	0.0	Scaled process value
ScaledFeedback	REAL	0.0	Scaled position feedback For an actuator without position feedback, the position of the actuator indicated by ScaledFeedback is very imprecise. ScaledFeedback may only be used for rough estimation of the current position in this case.
Output_UP	BOOL	FALSE	Digital output value for opening the valve If Config.OutputPerOn = FALSE, the Output_UP parameter is used.

Parameter	Data type	Default	Description
Output_DN	BOOL	FALSE	Digital output value for closing the valve If Config.OutputPerOn = FALSE, the Output_DN parameter is used.
Output_PER	WORD	W#16#0	Analog output value If Config.OutputPerOn = TRUE, Output_PER is used. Use Output_PER if you are using a valve as actuator which is triggered via an analog output and controlled with a continuous signal, e.g. 0...10V or 4...20mA. The value at Output_PER corresponds to the target position of the valve, e.g. Output_PER = 13824, when the valve is to be opened by 50%.
SetpointLimit_H	BOOL	FALSE	If SetpointLimit_H = TRUE, the absolute high limit of setpoint is reached. In the CPU, the setpoint is limited to the configured absolute setpoint high limit. The configured absolute process value high limit is the default for the setpoint high limit. If you configure Config.SetpointUpperLimit to a value within the process value limits, this value is used as the setpoint high limit.
SetpointLimit_L	BOOL	FALSE	If SetpointLimit_L = TRUE, the absolute low limit of the setpoint has been reached. In the CPU, the setpoint is limited to the configured absolute setpoint low limit. The configured absolute process value low limit is the default setting for the setpoint low limit. If you configure Config.SetpointLowerLimit to a value within the process value limits, this value is used as the setpoint low limit.
InputWarning_H	BOOL	FALSE	If InputWarning_H = TRUE, the process value has reached or exceeded the warning high limit.
InputWarning_L	BOOL	FALSE	If InputWarning_L = TRUE, the process value has reached or fallen below the warning low limit.
State	INT	0	The State parameter (Page 358) shows the current operating mode of the PID controller. You change the operating mode with the Retain.Mode tag. • State = 0: Inactive • State = 1: Pretuning • State = 2: Fine tuning • State = 3: Automatic mode • State = 4: Manual mode • State = 5: Approach substitute output value • State = 6: Transition time measurement • State = 7: Error monitoring • State = 8: Approach substitute output value with error monitoring
Error	BOOL	FALSE	If Error = TRUE, at least one error message is pending.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 364) indicates the error messages.

See also

State and Retain.Mode V1 parameters (Page 358)

ErrorBits V1 parameter (Page 364)

11.2.5.5 PID_3Step V1 static tags

NOTE

You must not change tags that are not listed. These are used for internal purposes only.

Change the tags identified with (1) only in "Inactive" mode to prevent malfunction of the PID controller. "Inactive" mode is forced by setting the "Retain.Mode" tag to "0".

Table 11-12

Tag	Data type	Default	Description
ActivateRecoverMode	BOOL	TRUE	The ActivateRecoverMode tag (Page 366) determines the response in the event of an error.
RunModeByStartup	BOOL	TRUE	Activate Mode after CPU restart If RunModeByStartup = TRUE, the controller returns to the last active operating mode after a CPU restart. If RunModeByStartup = FALSE, the controller remains inactive after a CPU startup.
PhysicalUnit	INT	0	Unit of measurement of the process value and setpoint, e.g., °C, or °F.
PhysicalQuantity	INT	0	Physical quantity of the process value and setpoint, e.g., temperature
ErrorBehaviour	INT	0	If ErrorBehaviour = 0 and an error has occurred, the valve stays at its current position and the controller switches directly to "Inactive" or "Error monitoring" mode. If ErrorBehaviour = 1 and an error occurs, the actuator moves to the substitute output value and only then switches to "Inactive" or "Error monitoring" mode. If the following errors occur, you can no longer move the valve to a configured substitute output value. • 2000h: Invalid value at Feedback_PER parameter. • 4000h: Invalid value at Feedback parameter. • 8000h: Error during digital position feedback.
Warning	DWORD	DW#16#0	The Warning tag (Page 358) displays the warnings generated since a Reset or since the last operating mode switchover. Cyclic warnings (for example, process value warning) are shown until the cause of the warning is removed. They are automatically deleted once their cause has gone. Non-cyclic warnings (for example, point of inflection not found) remain and are deleted like errors.
SavePosition	REAL	0.0	Substitute output value If ErrorBehaviour = 1 and an error occurs, the actuator moves to a safe position for the plant and only then switches to "Inactive" mode.

Tag	Data type	Default	Description
			The permitted value range is determined by the configuration. • Config.FeedbackOn = FALSE and Config.OutputPerOn = FALSE: SavePosition = 0.0 or 100.0 • Config.FeedbackOn = TRUE or Config.OutputPerOn = TRUE: Config.OutputUpperLimit ≥ SavePosition ≥ Config.OutputLowerLimit
CurrentSetpoint	REAL	0.0	Currently active setpoint. This value is frozen at the start of tuning.
Progress	REAL	0.0	Progress of tuning as a percentage (0.0 - 100.0)
Config.InputPerOn(1)	BOOL	TRUE	If InputPerOn = TRUE, the Input_PER parameter is used. If InputPerOn = FALSE, the Input parameter is used.
Config.OutputPerOn(1)	BOOL	FALSE	If OutputPerOn = TRUE, the Output_PER parameter is used. If OutputPerOn = FALSE, the Ouput_UP and Output_DN parameters are used.
Config.LoadBackUp	BOOL	FALSE	If LoadBackUp = TRUE, the last set of PID parameters is reloaded. The set was saved prior to the last tuning. LoadBackUp is automatically set back to FALSE.
Config.InvertControl(1)	BOOL	FALSE	Invert control logic If InvertControl = TRUE, an increasing control deviation causes a reduction in the output value.
Config.FeedbackOn(1)	BOOL	FALSE	If FeedbackOn = FALSE, a position feedback is simulated. Position feedback is generally activated when FeedbackOn = TRUE.
Config.FeedbackPerOn(1)	BOOL	FALSE	FeedbackPerOn only takes effect when FeedbackOn = TRUE. If FeedbackPerOn = TRUE, the analog input is used for the position feedback (Feedback_PER parameter). If FeedbackPerOn = FALSE, the Feedback parameter is used for the position feedback.
Config.ActuatorEndStopOn(1)	BOOL	FALSE	If ActuatorEndStopOn = TRUE, the digital position feedback Actuator_L and Actuator_H are taken into consideration.
Config.InputUpperLimit(1)	REAL	120.0	High limit of the process value At the I/O input, the process value can be a maximum of 18% higher than the standard range (overrange). An error is no longer signaled due to a violation of the "Process value high limit". Only a wire-break and a short-circuit are recognized and PID_3Step reacts according to the configured reaction to error. InputUpperLimit > InputLowerLimit
Config.InputLowerLimit(1)	REAL	0.0	Low limit of the process value InputLowerLimit < InputUpperLimit
Config.InputUpperWarning(1)	REAL	+3.40282-2e+38	Warning high limit of the process value If you set InputUpperWarning outside the process value limits, the configured absolute process value high limit is used as the warning high limit. If you configure InputUpperWarning within the process value limits, this value is used as the warning high limit. InputUpperWarning > InputLowerWarning InputUpperWarning ≤ InputUpperLimit

Tag	Data type	Default	Description
Config.InputLowerWarning(1)	REAL	-3.402822 e+38	Warning low limit of the process value If you set InputLowerWarning outside the process value limits, the configured absolute process value low limit is used as the warning low limit. If you configure InputLowerWarning within the process value limits, this value is used as the warning low limit. InputLowerWarning < InputUpperWarning InputLowerWarning ≥ InputLowerLimit
Config.OutputUpperLimit(1)	REAL	100.0	High limit of output value The following value range is permitted: UpperPointOut ≥ OutputUpperLimit > OutputLowerLimit For more details, see OutputLowerLimit.
Config.OutputLowerLimit(1)	REAL	0.0	Low limit of the output value The following value range is permitted: OutputUpperLimit > OutputLowerLimit ≥ LowerPointOut When using Output_PER, an output value limit of -100% corresponds to the value Output_PER = -27648; 100% correspond to the value Output_PER = 27648. If OutputPerOn = FALSE and FeedbackOn = FALSE, OutputLowerLimit and OutputUpperLimit are not evaluated. Output_UP and Output_DN are then reset at Actuator_H = TRUE or Actuator_L = TRUE (if ActuatorEndStopOn = TRUE) or after a travel time of 110% * Config.TransitTime (if ActuatorEndStopOn = FALSE).
Config.SetpointUpperLimit(1)	REAL	+3.40282-2e+38	High limit of setpoint If you set SetpointUpperLimit outside the process value limits, the configured absolute process value high limit is preassigned as the setpoint high limit. If you configure SetpointUpperLimit within the process value limits, this value is used as the setpoint high limit.
Config.SetpointLowerLimit(1)	REAL	-3.402822e+38	Low limit of the setpoint If you set SetpointLowerLimit outside the process value limits, the configured absolute process value low limit is preassigned as the set-point low limit. If you set SetpointLowerLimit within the process value limits, this value is used as the setpoint low limit.
Config.MinimumOnTime(1)	REAL	0.0	Minimum ON time Minimum time in seconds for which the servo drive must be switched on. Config.MinimumOnTime only takes effect when Output_UP and Output_DN are used (Config.OutputPerOn = FALSE).
Config.MinimumOffTime(1)	REAL	0.0	Minimum OFF time Minimum time in seconds for which the servo drive must be switched off. Config.MinimumOffTime only takes effect when Output_UP and Output_DN are used (Config.OutputPerOn = FALSE).
Config.TransitTime(1)	REAL	30.0	Motor transition time Time in seconds the actuating drive requires to move the valve from the closed to the opened state.
Config.InputScaling.Upper-PointIn(1)	REAL	27648.0	Scaling Input_PER high Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.

Tag	Data type	Default	Description
Config.InputScaling.LowerPointIn(1)	REAL	0.0	Scaling Input_PER low Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.InputScaling.UpperPointOut(1)	REAL	100.0	Scaled high process value Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.InputScaling.LowerPointOut(1)	REAL	0.0	Scaled low process value Input_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the InputScaling structure.
Config.FeedbackScaling.UpperPointIn(1)	REAL	27648.0	Scaling Feedback_PER high Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure.
Config.FeedbackScaling.LowerPointIn(1)	REAL	0.0	Scaling Feedback_PER low Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure.
Config.FeedbackScaling.UpperPointOut(1)	REAL	100.0	High endstop Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure. The permitted value range is determined by the configuration. • FeedbackOn = FALSE: UpperPointOut = 100.0 • FeedbackOn = TRUE: UpperPointOut = 100.0 or 0.0 UpperPointOut ≠ LowerPointOut
Config.FeedbackScaling.LowerPointOut(1)	REAL	0.0	Low endstop Feedback_PER is converted to a percentage based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn of the FeedbackScaling structure. The permitted value range is determined by the configuration. • FeedbackOn = FALSE: LowerPointOut = 0.0 • FeedbackOn = TRUE: LowerPointOut = 0.0 or -100.0 LowerPointOut ≠ UpperPointOut
GetTransitTime.InvertDirection	BOOL	FALSE	If InvertDirection = FALSE, the valve is fully opened, closed, and then reopened in order to determine the valve transition time. If InvertDirection = TRUE, the valve is fully closed, opened, and then closed again.
GetTransitTime.SelectFeedback	BOOL	FALSE	If SelectFeedback = TRUE, then Feedback_PER, or Feedback is taken into consideration in the transition time measurement. If SelectFeedback = FALSE, then Actuator_H and Actuator_L are taken into consideration in the transition time measurement.
GetTransitTime.Start	BOOL	FALSE	If Start = TRUE, the transition time measurement is started.

Tag	Data type	Default	Description
GetTransitTime.State	INT	0	Current phase of the transition time measurement • State = 0: Inactive • State = 1: Open valve completely • State = 2: Close valve completely • State = 3: Move valve to target position (NewOutput) • State = 4: Transition time measurement successfully completed • State = 5: Transition time measurement canceled
GetTransitTime.NewOutput	REAL	0.0	Target position for transition time measurement with position feedback The target position must be between "High endstop" and "Low endstop". The difference between NewOutput and ScaledFeedback must be at least 50% of the permissible control range.
CycleTime.StartEstimation	BOOL	TRUE	If StartEstimation = TRUE, the measurement of the PID_3Step sampling time is started. CycleTime.StartEstimation = FALSE once measurement is complete.
CycleTime.EnEstimation	BOOL	TRUE	If EnEstimation = TRUE, the PID_3Step sampling time is calculated.
CycleTime.EnMonitoring	BOOL	TRUE	If EnMonitoring = TRUE, the PID_3Step sampling time is monitored. If it is not possible to execute PID_3Step within the sampling time, the error 0800h is output and the operating mode is switched. ActivateRecoverMode and ErrorBehaviour determine which operating mode is switched to. If EnMonitoring = FALSE, the PID_3Step sampling time is not monitored, the error 0800h is not output, and the operating mode is not switched.
CycleTime.Value(1)	REAL	0.1	PID_3Step sampling time in seconds CycleTime.Value is determined automatically and is usually equivalent to the cycle time of the calling OB.
CtrlParamsBackUp.SetByUser	BOOL	FALSE	Saved value of Retain.CtrlParams.SetByUser You can reload values from the CtrlParamsBackUp structure with Config.LoadBackUp = TRUE.
CtrlParamsBackUp.Gain	REAL	1.0	Saved proportional gain
CtrlParamsBackUp.Ti	REAL	20.0	Saved integral action time
CtrlParamsBackUp.Td	REAL	0.0	Saved derivative action time
CtrlParamsBackUp.TdFiltRatio	REAL	0.0	Saved derivative delay coefficient
CtrlParamsBackUp.PWeighting	REAL	0.0	Saved proportional action weighting
CtrlParamsBackUp.DWeighting	REAL	0.0	Saved derivative action weighting
CtrlParamsBackUp.Cycle	REAL	1.0	Saved sampling time of PID algorithm
CtrlParamsBackUp.InputDeadBand	REAL	0.0	Saved deadzone width of the control deviation
PIDSelfTune.SUT.CalculateSUTParams	BOOL	FALSE	The properties of the controlled system are saved during tuning. If CalculateSUTParams = TRUE, the PID parameters are recalculated on the basis of these properties. The PID parameters are calculated using the method set in TuneRuleSUT. CalculateSUTParams is set to FALSE following calculation.

Tag	Data type	Default	Description
PIDSelfTune.SUT.TuneRuleSUT	INT	1	Methods used to calculate parameters during pretuning: • TuneRuleSUT = 0: PID fast I (faster control response with higher amplitudes of the output value than with TuneRuleSUT = 1) • TuneRuleSUT = 1: PID slow I (slower control response with lower amplitudes of the output value than with TuneRuleSUT = 0) • TuneRuleSUT = 2: Chien, Hrones and Reswick PID • TuneRuleSUT = 3: Chien, Hrones, Reswick PI • TuneRuleSUT = 4: PID fast II (faster control response with higher amplitudes of the output value than with TuneRuleSUT = 5) • TuneRuleSUT = 5: PID slow II (slower control response with lower amplitudes of the output value than with TuneRuleSUT = 4) The methods TuneRuleSUT = 0 and 1 differ from the methods TuneRuleSUT = 4 and 5 only in the calculation of the proportional gain: When TuneRuleSUT = 0 and 1, the proportional gain is calculated based on the compensation time of the process. When TuneRuleSUT = 4 and 5, this happens based on the delay time of the process. TuneRuleSUT = 4 and 5 returns a higher value for the proportional gain and thus a faster control response with higher amplitudes of the output value than with TuneRuleSUT = 0 and 1.
PIDSelfTune.SUT.State	INT	0	The SUT.State tag indicates the current phase of pretuning:
PIDSelfTune.TIR.RunIn	BOOL	FALSE	• RunIn = FALSE Pretuning is started when fine tuning is started from inactive or manual mode. If fine tuning is started from automatic mode, the system uses the existing PID parameters to control to the setpoint. Only then will fine tuning start. If pretuning is not possible, PID_3Step switches to "Inactive" mode. • RunIn = TRUE The pretuning is skipped. PID_3Step attempts to reach the setpoint with the minimum or maximum output value. This can produce increased overshoot. Only then will fine tuning start. RunIn is set to FALSE after fine tuning.
PIDSelfTune.TIR.CalculateTIRParams	BOOL	FALSE	The properties of the controlled system are saved during tuning. If CalculateTIRParams = TRUE, the PID parameters are recalculated on the basis of these properties. The PID parameters are calculated using the method set in TuneRuleTIR. CalculateTIRParams is set to FALSE following calculation.
PIDSelfTune.TIR.TuneRuleTIR	INT	0	Methods used to calculate parameters during fine tuning: • TuneRuleTIR = 0: PID automatic • TuneRuleTIR = 1: PID fast (faster control response with higher amplitudes of the output value than with TuneRuleTIR = 2) • TuneRuleTIR = 2: PID slow (slower control response with lower amplitudes of the output value than with TuneRuleTIR = 1) • TuneRuleTIR = 3: Ziegler-Nichols PID • TuneRuleTIR = 4: Ziegler-Nichols PI • TuneRuleTIR = 5: Ziegler-Nichols P To be able to repeat the calculation of the PID parameters with CalculateTIRParams and TuneRuleTIR = 0, 1 or 2, the previous fine tuning also has to have been executed with TuneRuleTIR = 0, 1 or 2. If this is not the case, TuneRuleTIR = 3 is used. The recalculation of the PID parameters with CalculateTIRParams and TuneRuleTIR = 3, 4 or 5 is always possible.

Tag	Data type	Default	Description
PIDSelfTune.TIR.State	INT	0	The TIR.State tag indicates the current phase of "fine tuning":
Retain.Mode	INT	0	A change to the value of Retain.Mode initiates a switch to another operating mode. The following operating mode is enabled upon a change of Mode to: • Mode = 0: Inactive • Mode = 1: Pretuning • Mode = 2: Fine tuning • Mode = 3: Automatic mode • Mode = 4: Manual mode • Mode = 5: Approach substitute output value • Mode = 6: Transition time measurement • Mode = 7: Error monitoring • Mode = 8: Approach substitute output value with error monitoring Mode is retentive.
Retain.CtrlParams.SetByUser(1)	BOOL	FALSE	If SetByUser = FALSE, the PID parameters are determined automatically and PID_3Step operates with a dead zone at the output value. The deadzone width is calculated during tuning on the basis of the standard deviation of the output value and saved in Retain.CtrlParams.OutputDeadBand. If SetByUser = TRUE, the PID parameters are entered manually and PID_3 Step operates without a dead zone at the output value. Retain.CtrlParams.OutputDeadBand = 0.0 SetByUser is retentive.
Retain.CtrlParams.Gain(1)	REAL	1.0	Active proportional gain Gain is retentive.
Retain.CtrlParams.Ti(1)	REAL	20.0	• Ti > 0.0: Active integral action time • Ti = 0.0: Integral action is deactivated Ti is retentive.
Retain.CtrlParams.Td(1)	REAL	0.0	• Td > 0.0: Active derivative action time • Td = 0.0: Derivative action is deactivated Td is retentive.
Retain.CtrlParams.TdFiltRatio(1)	REAL	0.0	Active derivative delay coefficient TdFiltRatio is retentive.
Retain.CtrlParams.PWeighting(1)	REAL	0.0	Active proportional action weighting PWeighting is retentive.
Retain.CtrlParams.DWeighting(1)	REAL	0.0	Active derivative action weighting DWeighting is retentive.
Retain.CtrlParams.Cycle(1)	REAL	1.0	Active sampling time of PID algorithm in seconds, rounded to an integer multiple of the cycle time of the calling OB. Cycle is retentive.
Retain.CtrlParams.InputDeadBand(1)	REAL	0.0	Deadzone width of the control deviation InputDeadBand is retentive.

See also

State and Retain.Mode V1 parameters (Page 358)
Tag ActivateRecoverMode V1 (Page 366)
Downloading technology objects to device (Page 49)

11.2.5.6 State and Retain.Mode V1 parameters

Correlation of the parameters

The State parameter shows the current operating mode of the PID controller. You cannot change the State parameter.

To switch from one operating mode to another, you must change the Retain.Mode tag. This also applies when the value for the new operating mode is already in Retain.Mode. For example, set Retain.Mode = 0 first and then Retain.Mode = 3. Provided the current operating mode of the controller permits this switchover, State will be set to the value of Retain.Mode.

When PID_3Step automatically switches from one operating mode to another, the following applies: State != Retain.Mode.

Examples:

- After successful pretuning
  State = 3 and Retain.Mode = 1
- In the event of an error
  State = 0 and Retain.Mode remain at the previous value, for example, Retain.Mode = 3
- ManualEnalbe = TRUE
  State = 4 and Retain.Mode remain at the previous value, e.g., Retain.Mode = 3

NOTE

You want, for example, to repeat successful fine tuning without exiting automatic mode with Mode = 0.

Setting Retain.Mode to an invalid value such as 9999 for one cycle has no effect on State. Set Mode = 2 in the next cycle. In this way, you can generate a change to Retain.Mode without first switching to "Inactive" mode.

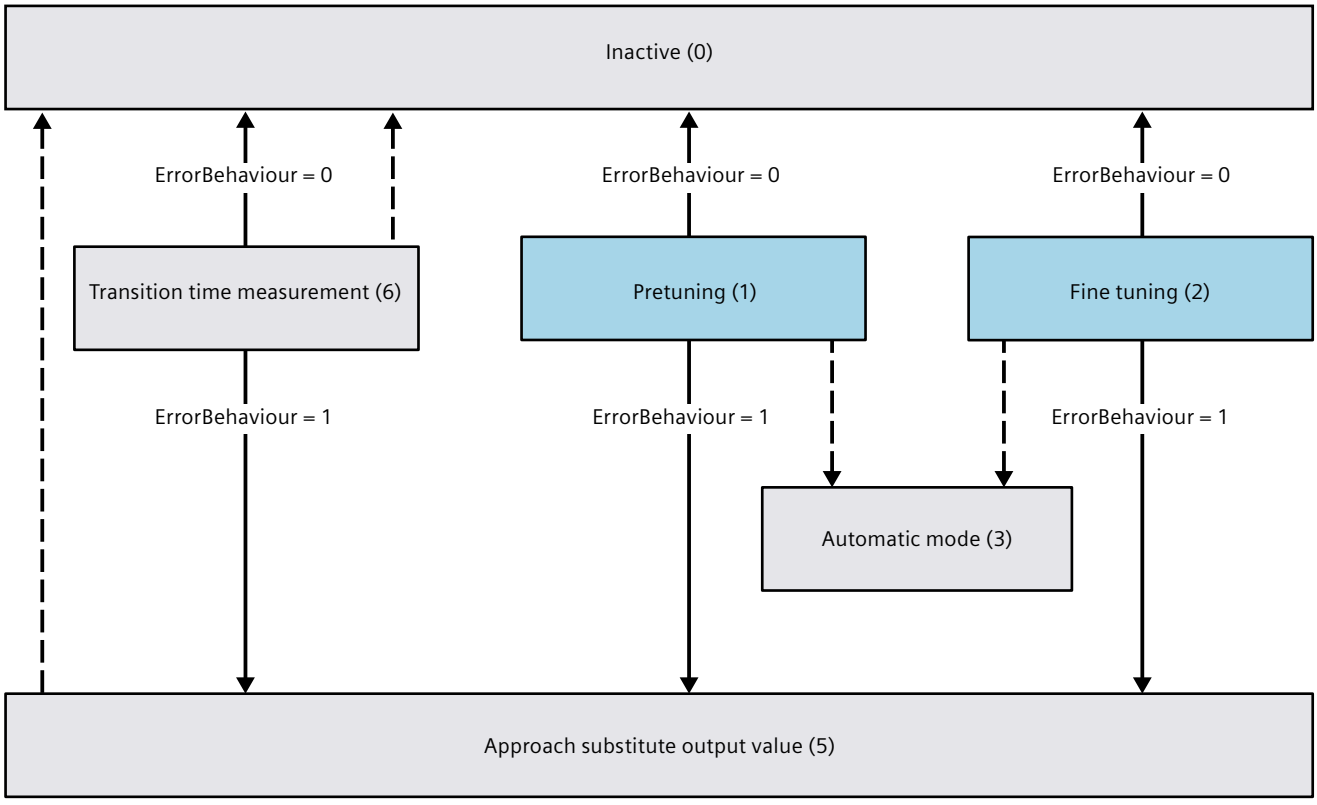
Meaning of values

State / Retain.Mode	Description
0	Inactive The controller is switched off and no longer changes the valve position.
1	Pretuning The pretuning determines the process response to a pulse of the output value and searches for the point of inflection. The optimized PID parameters are calculated as a function of the maximum rate of rise and dead time of the controlled system. Pretuning requirements: • State = 0 or State = 4 • ManualEnable = FALSE • The motor transition time has been configured or measured. • The setpoint and the process value lie within the configured limits. The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher as compared to the noise. Before the PID parameters are recalculated, they are backed up and can be reactivated with Config.LoadBackUp. The setpoint is frozen in the CurrentSetpoint tag. The controller switches to automatic mode following successful pretuning and to "Inactive" mode following unsuccessful pretuning. The pretuning phase is indicated with the SUT.State tag.
2	Fine tuning Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are tuned based on the amplitude and frequency of this oscillation. The differences between the process response during pretuning and fine tuning are analyzed. All PID parameters are recalculated from the results. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. PID_3Step automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. The PID parameters are backed up before fine tuning. They can be reactivated with Config.LoadBackUp. The setpoint is frozen in the CurrentSetpoint tag. Requirements for fine tuning: • The motor transition time has been configured or measured. • The setpoint and the process value lie within the configured limits. • ManualEnable = FALSE • Automatic (State = 3), inactive (State = 0) or manual (State = 4) mode Fine tuning proceeds as follows when started from: • Automatic mode (State = 3) Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning. PID_3Step controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. • Inactive (State = 0) or manual mode (State = 4) Pretuning is always started first. The determined PID parameters will be used for control until the control loop has stabilized and the requirements for fine tuning have been met. If PIDSelfTune.TIR.RunIn = TRUE, pretuning is skipped and an attempt is made to reach the setpoint with the minimum or maximum output value. This can produce increased overshoot. Fine tuning then starts automatically. The controller switches to automatic mode following successful fine tuning. If fine tuning was not successful, the controller switches to "Inactive" mode. The fine tuning phase is indicated with the TIR.State tag.

State / Retain.Mode	Description
3	Automatic mode In automatic mode, PID_3Step controls the controlled system in accordance with the parameters specified. The controller switches to automatic mode if one the following requirements is fulfilled: • Pretuning successfully completed • Fine tuning successfully completed • Changing the Retain.Mode tag to the value 3. When the CPU is switched on or switches from Stop to RUN mode, PID_3Step starts in the most recently active operating mode. To retain PID_3Step in "Inactive" mode, set RunModeByStartup = FALSE. The ActivateRecoverMode tag is taken into consideration in automatic mode.
4	Manual mode In manual mode, you specify manual output values in the Manual_UP and Manual_DN parameters or ManualValue parameter. Whether or not the actuator can be moved to the output value in the event of an error is described in the ErrorBits parameter. This operating mode is enabled if Retain.Mode = 4, or on a rising edge at ManualEnable. If ManualEnable changes to TRUE, only State changes. Retain.Mode retains its current value. On a falling edge at ManualEnable, PID_3Step returns to the previous operating mode. The switchover to automatic mode is bumpless. **PID_3Step V1.1** Manual mode is always possible in the event of an error. **PID_3Step V1.0** Manual mode is dependent on the ActivateRecoverMode tag in the event of an error.
5	Approach substitute output value This operating mode is activated in the event of an error or when Reset = TRUE if Errorbehaviour = 1 and ActivateRecoverMode = FALSE.. PID_3Step moves the actuator to the substitute output value and then switches to "Inactive" mode.
6	Transition time measurement The time that the motor needs to completely open the valve from the closed condition is determined. This operating mode is activated when GetTransitTime.Start = TRUE is set. If endstop signals are used to measure the transition time, the valve will be opened completely from its current position, closed completely, and opened completely again. If GetTransitTime.InvertDirection = TRUE, this behavior is inverted. If position feedback is used to measure the transition time, the actuator will be moved from its current position to a target position. The output value limits are not taken into consideration during the transition time measurement. The actuator can travel to the high or the low endstop.
7	Error monitoring The control algorithm is switched off and no longer changes the valve position. This operating mode is activated instead of "Inactive" mode in the event of an error. All the following conditions must be met: • Mode = 3 (automatic mode) • Errorbehaviour = 0 • ActivateRecoverMode = TRUE • One or more errors have occurred in which ActivateRecoverMode (Page 366) is effective. As soon as the errors are no longer pending, PID_3Step switches back to automatic mode.
8	Approach substitute output value with error monitoring This operating mode is activated instead of "Approach substitute output value" mode in the event of an error. PID_3Step moves the actuator to the substitute output value and then switches to "Error monitoring" mode. All the following conditions must be met: • Mode = 3 (automatic mode) • Errorbehaviour = 1 • ActivateRecoverMode = TRUE • One or more errors have occurred in which ActivateRecoverMode (Page 366) is effective. As soon as the errors are no longer pending, PID_3Step switches back to automatic mode.

Automatic switchover of operating mode during commissioning

PID_3Step automatically switches the operating mode in the event of an error. The following diagram illustrates the influence of ErrorBehaviour on the switchover of operating mode from transition time measurement, pretuning, and fine tuning modes.

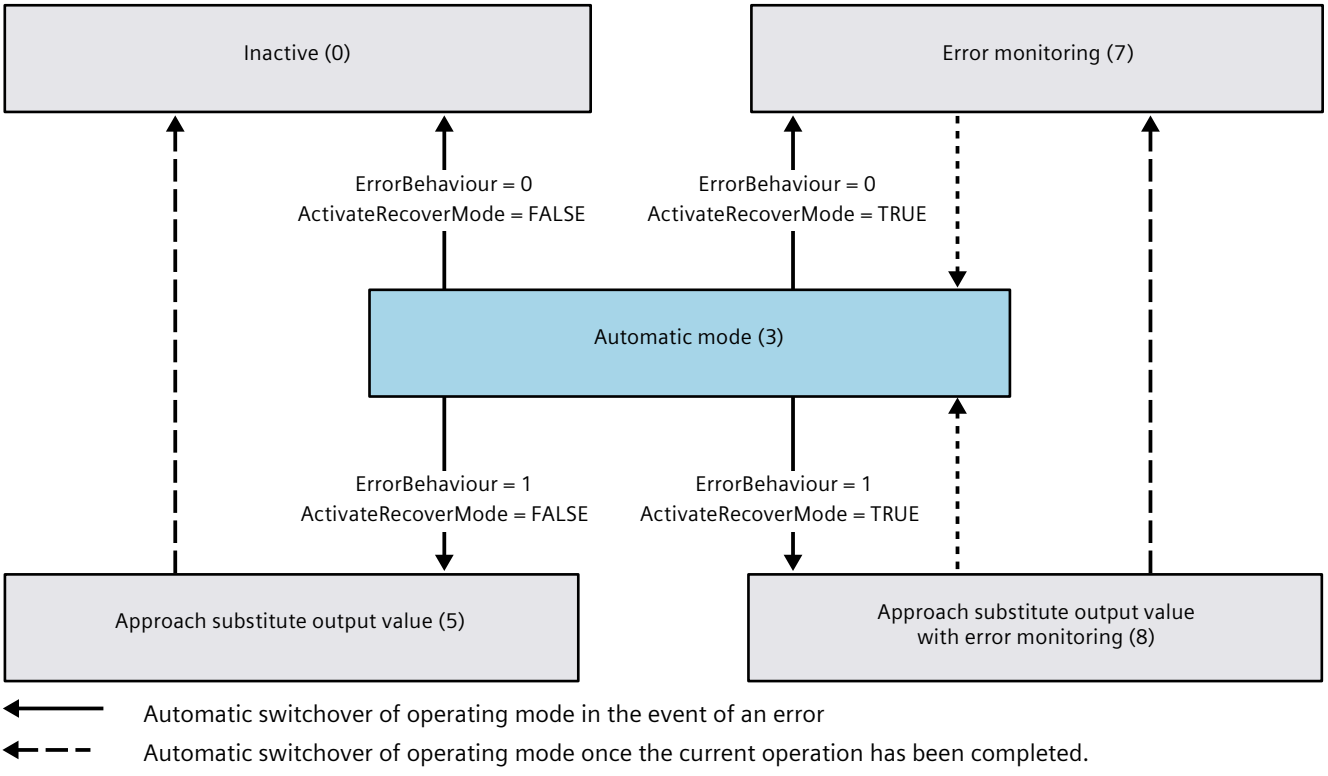


Automatic switchover of operating mode in the event of an error

Automatic switchover of operating mode once the current operation has been completed.

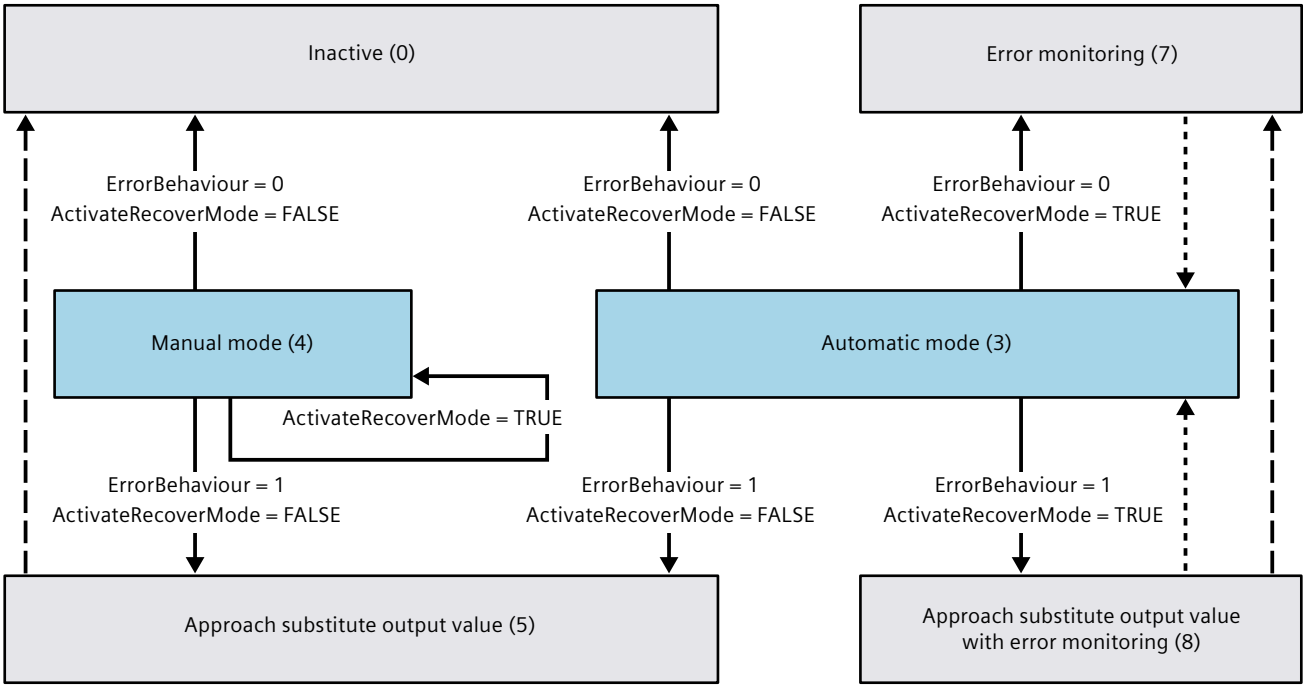
Automatic switchover of operating mode in automatic mode (PID_3Step V1.1)

PID_3Step automatically switches the operating mode in the event of an error. The following diagram illustrates the influence of ErrorBehaviour and ActivateRecoverMode on this switchover of operating mode.



Automatic switchover of operating mode in automatic and manual modes (PID_3Step V1.0)

PID_3Step automatically switches the operating mode in the event of an error. The following diagram illustrates the influence of ErrorBehaviour and ActivateRecoverMode on this switchover of operating mode.



Automatic switchover of operating mode in the event of an error

Automatic switchover of operating mode once the current operation has been completed.

Automatic switchover of operating mode when error is no longer pending.

See also

Tag ActivateRecoverMode V1 (Page 366)

ErrorBits V1 parameter (Page 364)

11.2.5.7 ErrorBits V1 parameter

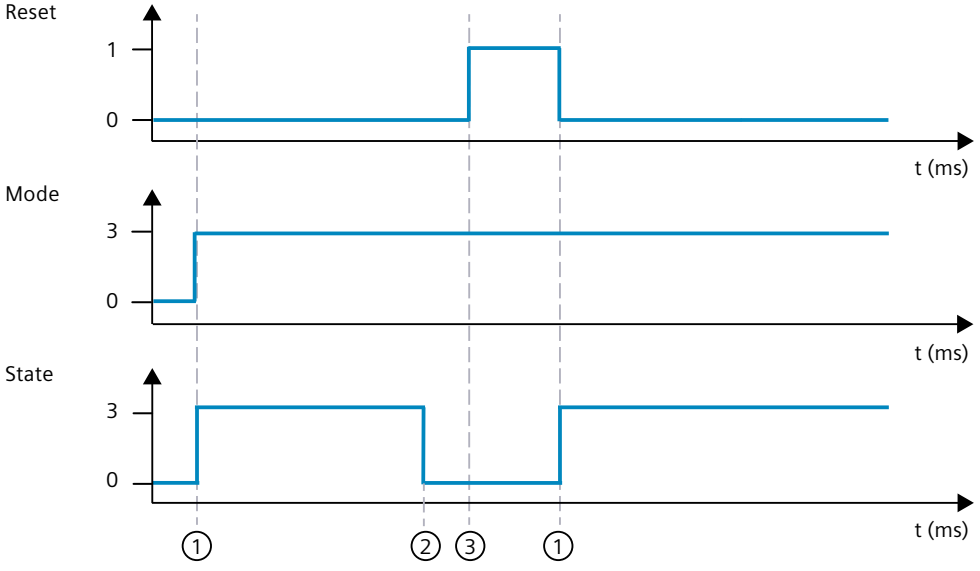
If several errors are pending simultaneously, the values of the error codes are displayed with binary addition. The display of error code 0003, for example, indicates that the errors 0001 and 0002 are pending simultaneously.

ErrorBits (DW#16#...)	Description
0000	There is no error.
0001	The "Input" parameter is outside the process value limits. • Input > Config.InputUpperLimit or • Input < Config.InputLowerLimit If ActivateRecoverMode = TRUE and ErrorBehaviour = 1, the actuator moves to the substitute output value. If ActivateRecoverMode = TRUE and ErrorBehaviour = 0, the actuator stops in its current position. If ActivateRecoverMode = FALSE, the actuator stops in its current position. PID_3Step V1.1 You can move the actuator in manual mode. PID_3Step V1.0 Manual mode is not possible in this state. You cannot move the actuator again until you eliminate the error.
0002	Invalid value at "Input_PER" parameter. Check whether an error is pending at the analog input. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.
0004	Error during fine tuning. Oscillation of the process value could not be maintained.
0020	Pretuning is not permitted in automatic mode or during fine tuning.
0080	Error during pretuning. The output value limits are not configured correctly or the process value does not react as expected. Check whether the limits of the output value are configured correctly and match the control logic. Also make sure that the process value does not oscillate strongly before starting pretuning.
0100	Error during fine tuning resulted in invalid parameters.
0200	Invalid value at "Input" parameter: Value has an invalid number format. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.
0400	Calculation of output value failed. Check the PID parameters.
0800	Sampling time error: PID_3Step is not called within the sampling time of the cyclic interrupt OB. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode. If this error occurred during simulation with PLCSIM, see the notes under Simulating PID_3Step V1 with PLCSIM (Page 160).
1000	Invalid value at "Setpoint" parameter: Value has an invalid number format. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.
2000	Invalid value at Feedback_PER parameter. Check whether an error is pending at the analog input. The actuator cannot be moved to the substitute output value and remains in its current position. Manual mode is not possible in this state. You must deactivate position feedback (Config. FeedbackOn = FALSE) to move the actuator from this state. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.

ErrorBits (DW#16#...)	Description
4000	Invalid value at Feedback parameter. Value has an invalid number format. The actuator cannot be moved to the substitute output value and remains in its current position. Manual mode is not possible in this state. You must deactivate position feedback (Config. FeedbackOn = FALSE) to move the actuator from this state. If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.
8000	Error during digital position feedback. Actuator_H = TRUE and Actuator_L = TRUE. The actuator cannot be moved to the substitute output value and remains in its current position. Manual mode is not possible in this state. In order to move the actuator from this state, you must deactivate the "Actuator endstop" (Config.ActuatorEndStopOn = FALSE). If automatic mode was active before the error occurred, ActivateRecoverMode = TRUE, and the error is no longer pending, PID_3Step switches back to automatic mode.

11.2.5.8 Reset V1 parameter

A rising edge at Reset triggers a change to "Inactive" mode, and errors and warnings are reset. A falling edge at Reset triggers a change to the most recently active operating mode. If automatic mode was active before, switchover to automatic mode is bumpless.



① Activation
② Error
③ Reset

11.2.5.9 Tag ActivateRecoverMode V1

The effect of the ActivateRecoverMode variable depends on the version of the PID_3Step.

Behavior in version 1.1

The ActivateRecoverMode variable determines the behavior in the event of an error in automatic mode. ActivateRecoverMode is not effective during pretuning, fine tuning and transition time measurement.

ActivateRecover-Mode	Description
FALSE	In the event of an error, PID_3Step switches to "Inactive" or "Approach substitute output value" operating mode. The controller is activated by a reset or a change in Retain.Mode.
TRUE	If errors occur frequently in automatic mode, this setting has a negative effect on the control response. In this case, check the ErrorBits parameter and eliminate the cause of the error. If one or more errors occur, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode: • 0002h: Invalid value at parameter Input_PER. • 0200h: Invalid value at parameter Input. • 0800h: Sampling time error • 1000h: Invalid value at parameter Setpoint. • 2000h: Invalid value at parameter Feedback_PER. • 4000h: Invalid value at parameter Feedback. • 8000h: Error in digital position feedback. With errors 2000h, 4000h and 8000h, PID_3Step **cannot** approach the configured substitute output value. As soon as the errors are no longer pending, PID_3Step switches back to automatic mode.

Behavior in version 1.0

The ActivateRecoverMode variable determines the behavior in the event of an error in automatic and manual mode. ActivateRecoverMode is not effective during pretuning, fine tuning and transition time measurement.

ActivateRecover-Mode	Description
FALSE	In the event of an error, PID_3Step switches to "Inactive" or "Approach substitute output value" operating mode. The controller is activated by a reset or a change in Retain.Mode.
TRUE	**Errors in automatic mode** If errors occur frequently in automatic mode, this setting has a negative effect on the control response. In this case, check the ErrorBits parameter and eliminate the cause of the error. If one or more errors occur, PID_3Step switches to "Approach substitute output value with error monitoring" or "Error monitoring" mode: • 0002h: Invalid value at parameter Input_PER. • 0200h: Invalid value at parameter Input. • 0800h: Sampling time error • 1000h: Invalid value at parameter Setpoint. • 2000h: Invalid value at parameter Feedback_PER. • 4000h: Invalid value at parameter Feedback. • 8000h: Error in digital position feedback. With errors 2000h, 4000h and 8000h, PID_3Step **cannot** approach the configured substitute output value.

ActivateRecover-Mode	Description
	As soon as the errors are no longer pending, PID_3Step switches back to automatic mode. **Errors in manual mode** If one or more of the following errors occur, PID_3Step stays in manual mode: • 0002h: Invalid value at parameter Input_PER. • 0200h: Invalid value at parameter Input. • 0800h: Sampling time error • 1000h: Invalid value at parameter Setpoint. • 2000h: Invalid value at parameter Feedback_PER. • 4000h: Invalid value at parameter Feedback. • 8000h: Error in digital position feedback. With errors 2000h, 4000h and 8000h, you **cannot** move the valve to a suitable position.

See also

PID_3Step V1 static tags (Page 351)
State and Retain.Mode V1 parameters (Page 358)

11.2.5.10 Tag Warning V1

If several warnings are pending simultaneously, their values are displayed with binary addition. The display of warning 0003, for example, indicates that the warnings 0001 and 0002 are pending simultaneously.

Warning (DW#16#...)	Description
0000	No warning pending.
0001	The point of inflection was not found during pretuning.
0002	Oscillation increased during fine tuning.
0004	The setpoint was limited to the configured limits.
0008	Not all the necessary controlled system properties were defined for the selected method of calculation. The PID parameters were instead calculated using the TuneRuleTIR = 3 method.
0010	The operating mode could not be changed because ManualEnable = TRUE.
0020	The cycle time of the calling OB limits the sampling time of the PID algorithm. Improve results by using shorter OB cycle times.
0040	The process value exceeded one of its warning limits.
0080	Invalid value at Retain.Mode. The operating mode is not switched.
0100	The manual value was limited to the limits of the controller output.
0200	The rule used for tuning produces an incorrect result, or is not supported.
0400	Method selected for transition time measurement not suitable for actuator. The transition time cannot be measured because the actuator settings do not match the selected measuring method.
0800	The difference between the current position and the new output value is too small for transition time measurement. This can produce incorrect results. The difference between the current output value and new output value must be at least 50% of the entire control range.
1000	The substitute output value cannot be reached because it is outside the output value limits.

The following warnings are deleted as soon as the cause is eliminated:

- 0004
- 0020
- 0040
- 0100

All other warnings are cleared with a rising edge at Reset.

11.2.5.11 Tag SUT.State V1

SUT.State	Name	Description
0	SUT_INIT	Initialize pretuning
50	SUT_TPDN	Determine start position without position feedback
100	SUT_STDABW	Calculate the standard deviation
200	SUT_GET_POI	Find the point of inflection
300	SUT_GET_RISETM	Determine the rise time
9900	SUT_IO	Pretuning successful
1	SUT_NIO	Pretuning not successful

11.2.5.12 Tag TIR.State V1

TIR.State	Name	Description
-100	TIR_FIRST_SUT	Fine tuning is not possible. Pretuning will be executed first.
0	TIR_INIT	Initialize fine tuning
200	TIR_STDABW	Calculate the standard deviation
300	TIR_RUN_IN	Attempt to reach the setpoint with the maximum or minimum output value
400	TIR_CTRLN	Attempt to reach the setpoint with the existing PID parameters (if pretuning has been successful)
500	TIR_OSZIL	Determine oscillation and calculate parameters
9900	TIR_IO	Fine tuning successful
1	TIR_NIO	Fine tuning not successful

11.3 PID_Temp

11.3.1 New features of PID_Temp

PID_Temp V2.0

- **Use for exclusive cooling applications**

  From PID_Temp V2 the instruction can also be used for exclusive cooling applications.

  The heating output can be deactivated via Config.ActivateHeating = FALSE.

  Pretuning for cooling is also possible without prior pretuning for heating.

- **Temporary deactivation of heating**

  PID_Temp V2.0 offers the possibility of deactivating heating temporarily in automatic mode for controllers with active heating and cooling (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) by setting DisableHeating = TRUE.

- **Manual stopping of the integral action**

  The integral action can be held in positive or negative direction by the static tags PIDCtrl.IntegralHoldPositive and PIDCtrl.IntegralHoldNegative.

- **Active limitation of the integral action and change of the output value limits in automatic mode**

  In addition to the direction-dependent stopping of the integral component, this is actively limited.

  This allows the change of the output value limits in automatic mode.

- **Improved anti-windup behavior in the cascade**

  The handling of the integral action of a master controller when its slave controllers are in limitation depends on the direction.

PID_Temp V1.1

- **Use with S7-1200 G2**

  As of PID_Temp V1.1, the instruction can also be used on an S7-1200 G2.

  Older versions of the instruction are not supported on S7-1200 G2.

- **Response of the output value on switchover from "Inactive" operating mode to "Automatic mode"**

  The new option IntegralResetMode = 4 was added and defined as default. With IntegralResetMode = 4, the integral action is automatically preassigned when switching from "Inactive" mode to "Automatic mode" so that a control deviation results in a jump of the PID output value with identical sign.

- **Initialization of the integral action in automatic mode**

  The integral action can be initialized in automatic mode with the OverwriteInitialOutputValue and PIDCtrl.PIDInit tags. This simplifies the use of PID_Temp for override controls.

11.3.2 Compatibility with CPU and FW

The following table shows which version of PID_Temp can be used on which CPU.

CPU	FW	PID_Temp
S7-1200	as of V4.2	V1.1 V1.0
	V4.1	V1.0
S7-1200 G2	as of V4.1	V2.0 V1.1
	V1.0 to V4.0	V1.1
S7-1500	as of V4.1	V2.0 V1.1
	V3.0 to V4.0	V1.1
	V2.0 to V2.9	V1.1 V1.0
	V1.7 to V1.8	V1.0

11.3.3 CPU processing time and memory requirement as of PID_Temp V1

CPU processing time

Typical CPU processing times of the PID_Temp technology object as of Version V1.0, depending on CPU type and operating mode for standard, F, T and TF CPUs.

CPU	FW	Typ. CPU processing time Automatic mode	Typ. CPU processing time pre-tuning and fine tuning
CPU 1211	≥ V4.1	290 µs	450 µs
CPU 1212			
CPU 1214			
CPU 1215			
CPU 1217			
CPU 1212 G2	≥ V1.0	130 µs	180 µs
CPU 1214 G2			
CPU 1216 G2	≥ V4.0	25 µs	45 µs
CPU 1217 G2			
CPU 1510SP	≤ V2.9	85 µs	140 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1515		80 µs	110 µs

CPU 1516	≤ V2.9	80 µs	110 µs
CPU 1517	≤ V3.1	12 µs	18 µs
CPU 1518		6 µs	9 µs
CPU 1510SP	V3.0, V3.1	75 µs	110 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1514SP			
CPU 1515		60 µs	90 µs
CPU 1516			
CPU 1510SP	≥ V4.0	60 µs	80 µs
CPU 1511			
CPU 1511C			
CPU 1512C			
CPU 1512SP			
CPU 1513			
CPU 1514SP			
CPU 1515			
CPU 1516			
CPU 1516T		4 µs	8 µs
CPU 1517		3 µs	6 µs
CPU 1518		2 µs	4 µs

Typical CPU processing times of the PID_Temp technology object as of Version V1.0, depending on the CPU type and operating mode for R/H-CPUs in the RUN-Redundant system state.

CPU	**FW**	**Typ. CPU processing time Automatic mode**	**Typ. CPU processing time pre-tuning and fine tuning**
CPU 1513R	V3.0, V3.1	110 µs	160 µs
CPU 1515R		100 µs	140 µs
CPU 1513R	≥ V4.0	100 µs	140 µs
CPU 1515R			
CPU 1517H		5 µs	8 µs
CPU 1518HF			

Memory requirement

Memory requirement of an instance DB of the PID_Temp technology object as of Version V1.0.

Memory requirement	Memory requirement of the instance DB of PID_Temp V1	Memory requirement of the instance DB of PID_Temp V2.x
Load memory requirement	Approx. 4700 bytes	Approx. 4750 bytes
Total work memory requirement	1280 bytes	1306 bytes
Retentive work memory requirement	100 bytes	100 bytes

11.3.4 PID_Temp

11.3.4.1 Description of PID_Temp

Description

The PID_Temp instruction provides a PID controller with integrated tuning for temperature processes. PID_Temp can be used for exclusive heating or heating/cooling applications.

From PID_Temp V2 the instruction can also be used for exclusive cooling applications.

The following operating modes are possible:

- Inactive
- Pretuning
- Fine tuning
- Automatic mode
- Manual mode
- Substitute output value with error monitoring

For a more detailed description of the operating modes, see the State parameter.

PID algorithm

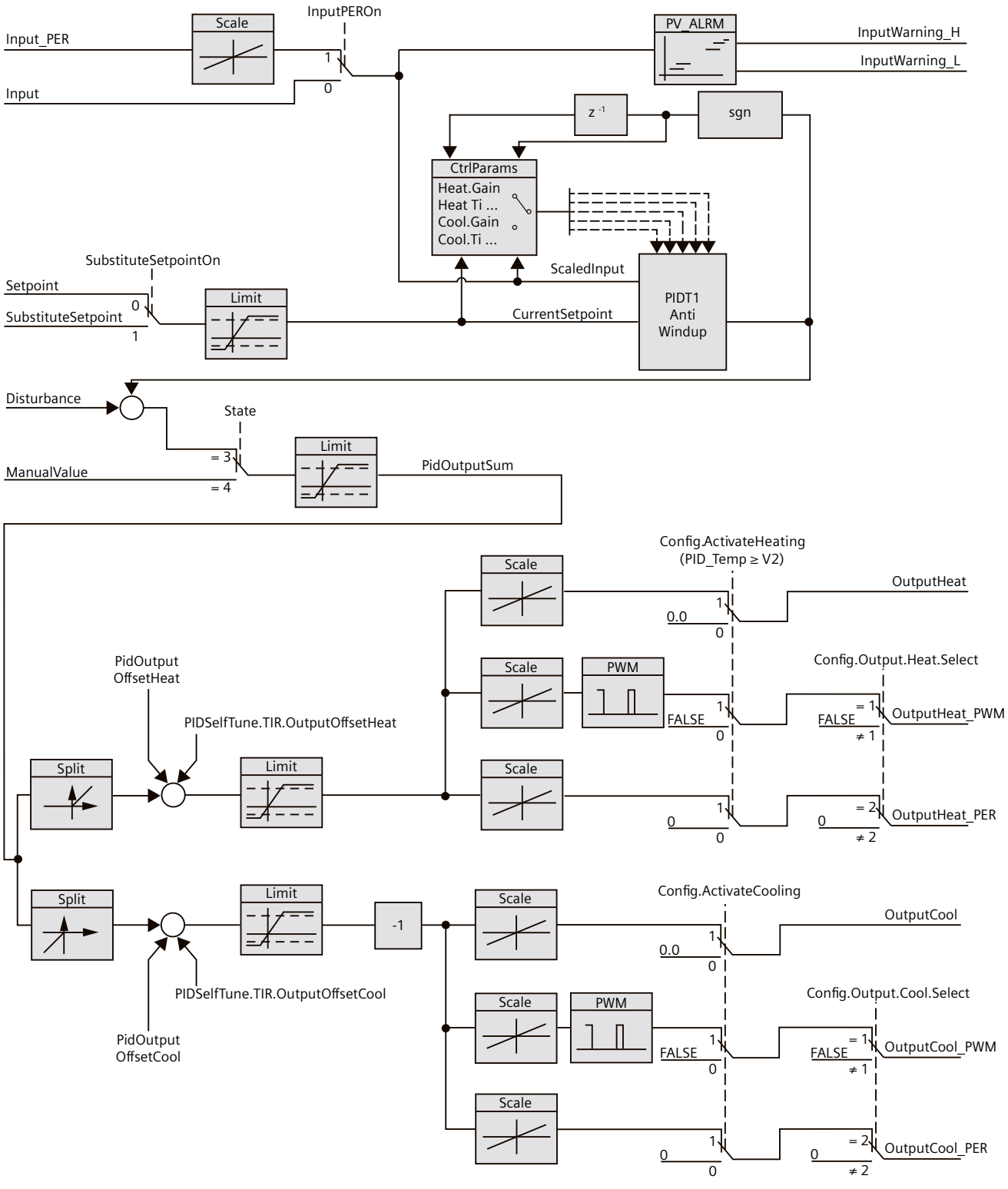
PID_Temp is a PIDT1 controller with anti-windup and weighting of the proportional and derivative actions. The PID algorithm operates according to the following transfer function (control zone and dead zone deactivated):

$$y = K_p \left[(b \cdot w - x) + \frac{1}{T_I \cdot s}(w - x) + \frac{T_D \cdot s}{a \cdot T_D \cdot s + 1}(c \cdot w - x)\right]$$

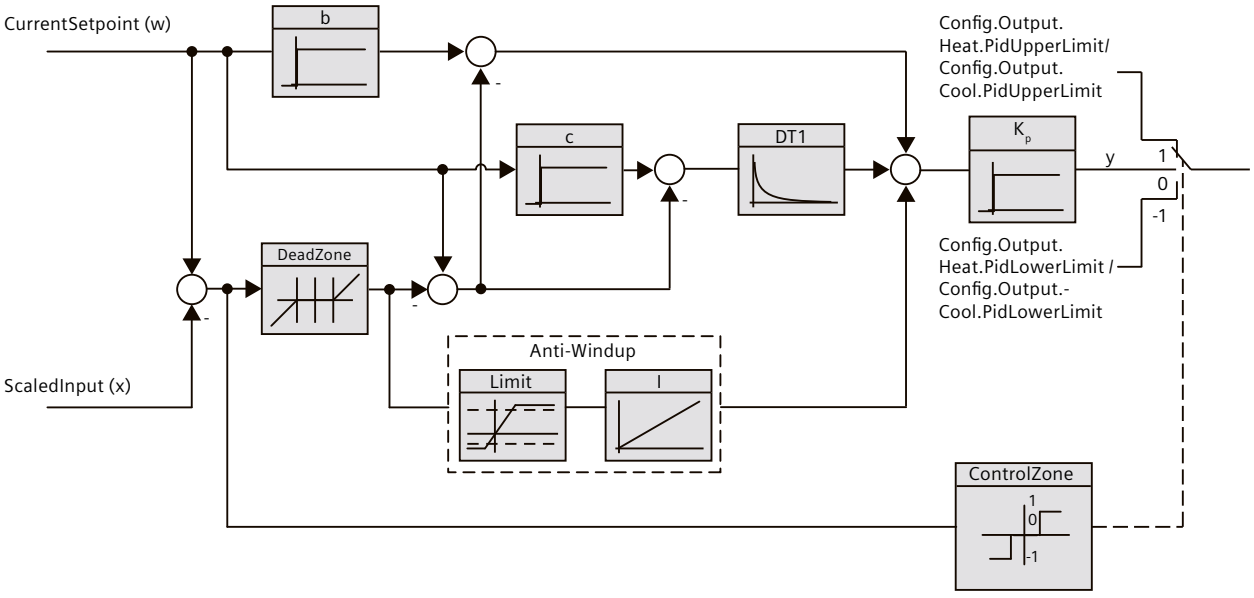
The table below shows the meaning of the icons used in the transfer function and in the subsequent figures:

Icon	Description	Associated parameters of the PID_Temp instruction
y	Output value of the PID algorithm	-
K_p	Proportional gain	Retain.CtrlParams.Heat.Gain Retain.CtrlParams.Cool.Gain CoolFactor
s	Laplace operator	-
b	Proportional action weighting	Retain.CtrlParams.Heat.PWeighting Retain.CtrlParams.Cool.PWeighting
w	Setpoint	CurrentSetpoint
x	Process value	ScaledInput
T_I	Integration time	Retain.CtrlParams.Heat.Ti Retain.CtrlParams.Cool.Ti
T_D	Derivative action time	Retain.CtrlParams.Heat.Td Retain.CtrlParams.Cool.Td
a	Derivative delay coefficient (derivative delay T1 = a × T_D)	Retain.CtrlParams.Heat.TdFiltRatio Retain.CtrlParams.Cool.TdFiltRatio
c	Derivative action weighting	Retain.CtrlParams.Heat.DWeighting Retain.CtrlParams.Cool.DWeighting
DeadZone	Dead zone width	Retain.CtrlParams.Heat.DeadZone Retain.CtrlParams.Cool.DeadZone
ControlZone	Control zone width	Retain.CtrlParams.Heat.ControlZone Retain.CtrlParams.Cool.ControlZone

PID_Temp block diagram



Block diagram of PIDT1 with anti-windup



Call

PID_Temp is called in the constant time scale of a cyclic interrupt OB.

Download to device

The actual values of retentive tags are only updated when you download PID_Temp completely.

Download technology object to device (Page 49)

Startup

When the CPU starts up, PID_Temp starts in the operating mode saved in the Mode in/out parameter. To switch to "Inactive" operating mode during startup, set RunModeByStartup = FALSE.

Response to errors

The response in the event of an error is determined by the tags SetSubstituteOutput and ActivateRecoverMode. If ActivateRecoverMode = TRUE, the behavior also depends on the error that has occurred.

SetSubstitu-teOutput	**ActivateR-ecoverMode**	**Configuration editor > Basic settings of output > Set PidOutputSum to**	**Reaction**
Not relevant	FALSE	Zero (inactive)	Switch to "Inactive" (State = 0) mode The output value of the PID algorithm and all outputs for heating and cooling are set to 0. The scaling of the outputs for heating and cooling is not active.
FALSE	TRUE	Current value while error is pending	Switch to "Substitute output value with error monitoring" mode (State = 5) The current output value is transferred to the actuator while the error is pending.
TRUE	TRUE	Substitute output value while error is pending	Switch to "Substitute output value with error monitoring" mode (State = 5) The value at SubstituteOutput is transferred to the actuator while the error is pending.

In manual mode, PID_Temp uses ManualValue as output value, unless ManualValue is invalid.

- If ManualValue is invalid, SubstituteOutput is used.
- If ManualValue and SubstituteOutput are invalid, Config.Output.Heat.PidLowerLimit or Config.Output.Cool.PidUpperLimit is used.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is reset by a rising edge at Reset or ErrorAck.

11.3.4.2 Mode of operation of PID_Temp

Monitoring process value limits

You specify the high limit and low limit of the process value in the Config.InputUpperLimit and Config.InputLowerLimit tags. If the process value is outside these limits, an error occurs (ErrorBits = 16#0000_0001).

You specify a high and low warning limit of the process value in the Config.InputUpperWarning and Config.InputLowerWarning tags. If the process value is outside these warning limits, a warning occurs (Warning = 16#0000_0040), and the InputWarning_H or InputWarning_L output parameter changes to TRUE.

Limiting the setpoint

You specify a high limit and low limit of the setpoint in the Config.SetpointUpperLimit and Config.SetpointLowerLimit tags. PID_Temp automatically limits the setpoint to the process value limits. You can limit the setpoint to a smaller area. PID_Temp checks whether this area is within the process value limits. If the setpoint is outside these limits, the high or low limit is used as the setpoint, and output parameter SetpointLimit_H or SetpointLimit_L is set to TRUE.

The setpoint is limited in all operating modes.

Substitute setpoint

You can specify a substitute setpoint at the SubstituteSetpoint tag and activate it with SubstituteSetpointOn = TRUE. In this way, you can temporarily specify the setpoint directly, for example for a slave controller in a cascade, without having to change the user program. The limits set for the setpoint also apply to the substitute setpoint.

Heating and cooling

With the default setting Config.ActivateHeating = TRUE and Config.ActivateCooling = FALSE, PID_Temp only uses the outputs for heating (OutputHeat, OutputHeat_PWM, OutputHeat_PER). The output value of the PID algorithm (PidOutputSum) is scaled and output at the outputs for heating. You specify with Config.Output.Heat.Select if OutputHeat_PWM or OutputHeat_PER is calculated. OutputHeat is always calculated.

With Config.ActivateCooling = TRUE, you can also activate the outputs for cooling (OutputCool, OutputCool_PWM, OutputCool_PER). If the heating and cooling is activated, positive output values of the PID algorithm (PidOutputSum) are scaled and output at the outputs for heating. Negative output values of the PID algorithm are scaled and output at the outputs for cooling. You specify with Config.Output.Cool.Select if OutputCool_PWM or OutputCool_PER is calculated. OutputCool is always calculated.

The following methods are available to calculate the PID output value with activated heating and cooling:

- Cooling factor (Config.AdvancedCooling = FALSE):

  The output value calculation for cooling takes place with the PID parameters for heating, taking into consideration the configurable cooling factor Config.CoolFactor. This method is suitable if the heating and cooling actuators have a similar time response but different gains. If this method is selected, pretuning and fine tuning for cooling as well as the PID parameter set for cooling are not available. You can only execute the tuning for heating.

- PID parameter switching (Config.AdvancedCooling = TRUE):

  The output value calculation for cooling takes place by means of a separate PID parameter set. Based on the calculated output value and the control deviation, the PID algorithm decides whether the PID parameter for heating or cooling is used. This method is suitable if the heating and cooling actuators have different time responses and different gains. Tuning for heating and cooling is available if this method is selected.

As of PID_Temp V2, with Config.ActivateHeating = FALSE you can also deactivate the outputs for heating (OutputHeat, OutputHeat_PWM, OutputHeat_PER) and with Config.ActivateCooling = TRUE you can activate only the outputs for cooling. This means you can use PID_Temp for exclusive cooling applications.

In this configuration, the output value is calculated using the PID parameters for cooling. PID_Temp continues to work with normal control logic: If the setpoint value is below the process value, this results in a negative output value of the PID algorithm (PidOutputSum). This is scaled and output as a positive value at the outputs for cooling. A lower output value of the PID algorithm (PidOutputSum) or a lower manual value (ManualValue) leads to a higher value at the outputs for cooling due to the scaling.

Example with default setting: ManualValue = -50.0 -> OutputCool = 50.0, ManualValue = -100.0 -> OutputCool = 100.0

Output value limits and scaling

Depending on the operating mode, the PID output value (PidOutputSum) is calculated automatically by the PID algorithm or by the manual value (ManualValue) or the configured substitute output value (SubstituteOutput).

The PID output value is limited as defined in the configuration.

- If heating is activated and cooling is deactivated, Config.Output.Heat.PidUpperLimit is the high limit and Config.Output.Heat.PidLowerLimit the low limit.
- If heating and cooling are activated, Config.Output.Heat.PidUpperLimit is the high limit and Config.Output.Cool.PidLowerLimit the low limit.
- If heating is deactivated and cooling is activated, Config.Output.Cool.PidUpperLimit is the high limit and Config.Output.Cool.PidLowerLimit the low limit.

The PID output value is scaled and output at the outputs for heating and cooling. Scaling can be defined separately for each output and is specified in the structures Config.Output.Heat or Config.Output.Cool with 2 value pairs each:

Output	Value pair	Parameter
OutputHeat	Value pair 1	PID output value high limit (heating) Config.Output.Heat.PidUpperLimit, Scaled high output value (heating) Config.Output.Heat.UpperScaling
	Value pair 2	PID output value low limit (heating) Config.Output.Heat.PidLowerLimit, Scaled low output value (heating) Config.Output.Heat.LowerScaling
OutputHeat_PWM	Value pair 1	PID output value high limit (heating) Config.Output.Heat.PidUpperLimit, Scaled high PWM output value (heating) Config.Output.Heat.PwmUpperScaling
	Value pair 2	PID output value low limit (heating) Config.Output.Heat.PidLowerLimit, Scaled low PWM output value (heating) Config.Output.Heat.PwmLowerScaling
OutputHeat_PER	Value pair 1	PID output value high limit (heating) Config.Output.Heat.PidUpperLimit, Scaled high analog output value (heating) Config.Output.Heat.PerUpperScaling
	Value pair 2	PID output value low limit (heating) Config.Output.Heat.PidLowerLimit, Scaled low analog output value (heating) Config.Output.Heat.PerLowerScaling
OutputCool	Value pair 1	PID output value low limit (cooling) Config.Output.Cool.PidLowerLimit, Scaled high output value (cooling) Config.Output.Cool.UpperScaling
	Value pair 2	PID output value high limit (cooling) Config.Output.Cool.PidUpperLimit, Scaled low output value (cooling) Config.Output.Cool.LowerScaling
OutputCool_PWM	Value pair 1	PID output value low limit (cooling) Config.Output.Cool.PidLowerLimit, Scaled high PWM output value (cooling) Config.Output.Cool.PwmUpperScaling

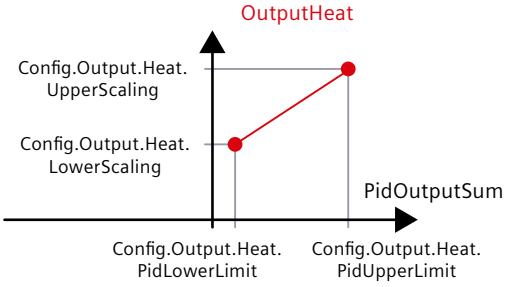
When the heating and cooling are activated, Config.Output.Heat.PidLowerLimit and Config.Output.Cool.PidUpperLimit must have the value 0.0.

Output	Value pair	Parameter
OutputCool_PWM	Value pair 2	PID output value high limit (cooling) Config.Output.Cool.PidUpperLimit, Scaled low PWM output value (cooling) Config.Output.Cool.PwmLowerScaling
OutputCool_PER	Value pair 1	PID output value low limit (cooling) Config.Output.Cool.PidLowerLimit, Scaled high analog output value (cooling) Config.Output.Cool.PerUpperScaling
	Value pair 2	PID output value high limit (cooling) Config.Output.Cool.PidUpperLimit, Scaled low analog output value (cooling) Config.Output.Cool.PerLowerScaling

When the heating and cooling are activated, Config.Output.Heat.PidLowerLimit and Config.Output.Cool.PidUpperLimit must have the value 0.0.

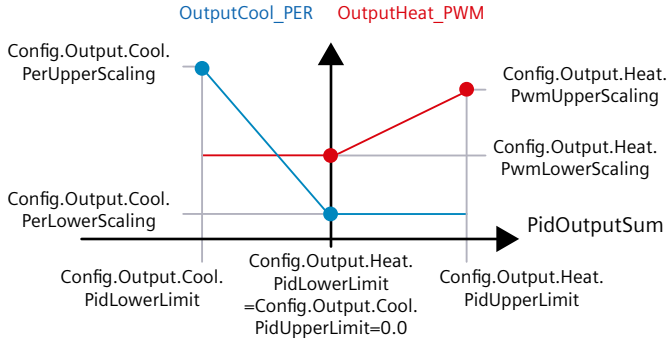
Example:

Output scaling when using output OutputHeat (cooling deactivated; Config.Output.Heat.PidLowerLimit may be unequal to 0.0):



Example:

Output scaling when using output OutputHeat_PWM and OutputCool_PER (heating and cooling activated; Config.Output.Heat.PidLowerLimit and Config.Output.Cool.PidUpperLimit must have the value 0.0):



With the exception of the "Inactive" operating mode, the value at an output is always located between its scaled high output value and scaled low output value, for example, for OutputHeat always between Config.Output.Heat.UpperScaling and Config.Output.Heat.LowerScaling.

If you want to limit the value at the associated output, you therefore have to adapt these scaling values as well.

Cascading

PID_Temp supports you when you use cascade control (see: Program creation (Page 198)).

Substitute output value

In the event of an error, PID_Temp can output a substitute output value that you define at the SubstituteOutput tag. The substitute output value must be within the limits for the PID output value. The values at the outputs for heating and cooling resulting from the substitute output value are the result of the configured output scaling.

Monitoring signal validity

The values of the following parameters are monitored for validity when used:

- Setpoint
- SubstituteSetpoint
- Input
- Input_PER
- Disturbance
- ManualValue
- SubstituteOutput
- PID parameters in the structures Retain.CtrlParams.Heat and Retain.CtrlParams.Cool.

Monitoring the sampling time PID_Temp

Ideally, the sampling time is equivalent to the cycle time of the cyclic interrupt OB. The PID_Temp instruction measures the time interval between two calls. This is the current sampling time. On every switchover of operating mode and during the initial startup, the mean value is formed from the first 10 sampling times. Too great a difference between the current sampling time and this mean value triggers an error (Error = 16#0000_0800).

The error occurs during tuning if:

- New mean value >= 1.1 x old mean value
- New mean value <= 0.9 x old mean value

The error occurs in automatic mode if:

- New mean value >= 1.5 x old mean value
- New mean value <= 0.5 x old mean value

If you deactivate the sampling time monitoring (CycleTime.EnMonitoring = FALSE), you can also call PID_Temp in OB1. You must then accept a lower control quality due to the deviating sampling time.

Sampling time of the PID algorithm

The controlled system needs a certain amount of time to respond to changes in the output value. It is therefore not advisable to calculate the output value in every cycle. The sampling time of the PID algorithm (Retain.CtrlParams.Heat.Cycle or Retain.CtrlParams.Cool.Cycle) represents the time between two calculations of the output value. It is calculated during tuning and rounded to a multiple of the sampling time PID_Temp (CycleTime.Value). All other functions of the PID_Temp are executed at every call.

If heating and cooling are activated with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.Advanced.Cooling = TRUE), the PID_Temp uses a separate sampling time of the PID algorithm for heating and cooling. In all other configurations, only the sampling time of the PID algorithm for heating or cooling is used.

If you use OutputHeat_PWM or OutputCool_PWM, the sampling time of the PID algorithm is used as the period duration of the pulse width modulation. The accuracy of the output signal is determined by the ratio of the PID algorithm sampling time to the cycle time of the OB. The cycle time should be no more than a tenth of the PID algorithm sampling time.

If the sampling time of the PID algorithm and thus the period duration of the pulse width modulation is very high when OutputHeat_PWM or OutputCool_PWM is used, you can specify a deviating shorter period duration with the Config.Output.Heat.PwmPeriode or Config.Output.Cool.PwmPeriode (Page 428) parameters in order to improve smoothing of the process value.

Control logic

PID_Temp can be used for heating or heating/cooling applications. From PID_Temp V2 the instruction can also be used for exclusive cooling applications. PID_Temp works firmly with normal control logic.

An increase of the PID output value (PidOutputSum) is intended to increase the process value. The values at the outputs for heating and cooling resulting from the PID output value are the result of the configured output scaling.

An inverted control logic or negative proportional gain are not supported.

If you only need an output value for your application in which an increase is to reduce the process value (for example, discharge control), you can use PID_Compact with inverted control logic.

11.3.4.3 Input parameters of PID_Temp

The names of the following parameters apply both to the data block and to access via the Openness API.

Parameter	Data type	Default	Description
Setpoint	REAL	0.0	Setpoint of the PID controller in automatic mode Permissible value range: Config.SetpointUpperLimit ≥ Setpoint ≥ Config.SetpointLowerLimit Config.InputUpperLimit ≥ Setpoint ≥ Config.InputLowerLimit
Input	REAL	0.0	A tag of the user program is used as source for the process value. If you are using Input parameter, then Config.InputPerOn = FALSE must be set.
Input_PER	INT	0	An analog input is used as the source of the process value. If you are using Input_PER parameter, then Config.InputPerOn = TRUE must be set.
Disturbance	REAL	0.0	Disturbance variable or precontrol value
ManualEnable	BOOL	FALSE	• A FALSE -> TRUE edge activates "Manual mode", State = 4, Mode remains unchanged. As long as ManualEnable = TRUE, you cannot change the operating mode via a rising edge at ModeActivate or use the commissioning dialog. • A TRUE -> FALSE edge activates the operating mode that is specified by Mode. We recommend that you change the operating mode using Mode and ModeActivate only.
ManualValue	REAL	0.0	Manual value This value is used as the PID output value (PidOutputSum) in manual mode. The values at the outputs for heating and cooling resulting from this manual value are the result of the configured output scaling (structures Config.Output.Heat and Config.Output.Cool). For controllers with activated heating output and cooling output (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), define: • a positive manual value to output the value at the outputs for heating • a negative manual value to output the value at the outputs for cooling The permitted value range is determined by the configuration. • Heating output activated (Config.ActivateHeating = TRUE) and cooling output deactivated (Config.ActivateCooling = FALSE): Config.Output.Heat.PidUpperLimit ≥ ManualValue ≥ Config.Output.Heat.PidLowerLimit • Heating output activated (Config.ActivateHeating = TRUE) and cooling output activated (Config.ActivateCooling = TRUE): Config.Output.Heat.PidUpperLimit ≥ ManualValue ≥ Config.Output.Cool.PidLowerLimit • Heating output deactivated (Config.ActivateHeating = FALSE) and cooling output activated (Config.ActivateCooling = TRUE): Config.Output.Cool.PidUpperLimit ≥ ManualValue ≥ Config.Output.Cool.PidLowerLimit

Parameter	Data type	Default	Description
ErrorAck	BOOL	FALSE	• FALSE -> TRUE edge ErrorBits and Warning are reset.
Reset	BOOL	FALSE	Restarts the controller. • FALSE -> TRUE edge – Switch to "Inactive" mode – ErrorBits and Warning are reset. • As long as Reset = TRUE, – PID_Temp remains in "Inactive" mode (State = 0). – you cannot change the operating mode with Mode and ModeActivate or ManualEnable – You cannot use the commissioning dialog. • TRUE -> FALSE edge – If ManualEnable = FALSE, PID_Temp switches to the operating mode that is stored in the Mode parameter. – If Mode = 3 (automatic mode), the integral action is treated as configured with the tag IntegralResetMode.
ModeActivate	BOOL	FALSE	• FALSE -> TRUE edge PID_Temp switches to the operating mode that is saved at the Mode input.

11.3.4.4 Output parameters of PID_Temp

The names of the following parameters apply both to the data block and to access via the Openness API.

Parameter	Data type	Default	Description
ScaledInput	REAL	0.0	Scaled process value
OutputHeat	REAL	0.0	Output value (heating) in REAL format The PID output value (PidOutputSum) is scaled with the two value pairs Config.Output.Heat.PidUpperLimit, Config.Output.Heat.UpperScaling and Config.Output.Heat.PidLowerLimit, Config.Output.Heat.LowerScaling and output in REAL format at OutputHeat. For PID_Temp V1.x OutputHeat is always calculated. For PID_Temp as of V2, OutputHeat is only calculated if the heating output is activated (Config.ActivateHeating = TRUE).
OutputCool	REAL	0.0	Output value (cooling) in REAL format The PID output value (PidOutputSum) is scaled with the two value pairs Config.Output.Cool.PidUpperLimit, Config.Output.Cool.LowerScaling and Config.Output.Cool.PidLowerLimit, Config.Output.Cool.UpperScaling and output in REAL format at OutputCool. OutputCool is only calculated if the cooling output is activated (Config.ActivateCooling = TRUE).
OutputHeat_PER	INT	0	Analog output value (heating) The PID output value (PidOutputSum) is scaled with the two value pairs Config.Output.Heat.PidUpperLimit, Config.Output.Heat.PerUpperScaling and Config.Output.Heat.PidLowerLimit, Config.Output.Heat.PerLowerScaling and output as analog value at OutputHeat_PER. OutputHeat_PER is only calculated if the heating output is activated (Config.ActivateHeating = TRUE) and Config.Output.Heat.Select = 2.

Parameter	Data type	Default	Description
OutputCool_PER	INT	0	Analog output value (cooling) The PID output value (PidOutputSum) is scaled via the two value pairs Config.Output.Cool.PidUpperLimit, Config.Output.Cool.PerLowerScaling and Config.Output.Cool.PidLowerLimit, Config.Output.Cool.PerUpperScaling and output as an analog value at OutputCool_PER. OutputCool_PER is only calculated if the cooling output is activated (Config.ActivateCooling = TRUE) and Config.Output.Cool.Select = 2.
OutputHeat_PWM	BOOL	FALSE	Pulse-width modulated output value (heating) The PID output value (PidOutputSum) is scaled with the two value pairs Config.Output.Heat.PidUpperLimit, Config.Output.Heat.PwmUpperScaling and Config.Output.Heat.PidLowerLimit, Config.Output.Heat.PwmLowerScaling and output as pulse-width modulated value (variable switch on and switch off times) at OutputHeat_PWM. OutputHeat_PWM is only calculated if the heating output is activated (Config.ActivateHeating = TRUE) and Config.Output.Heat.Select = 1.
OutputCool_PWM	BOOL	FALSE	Pulse-width modulated output value (cooling) The PID output value (PidOutputSum) is scaled with the two value pairs Config.Output.Cool.PidUpperLimit, Config.Output.Cool.PwmLowerScaling and Config.Output.Cool.PidLowerLimit, Config.Output.Cool.PwmUpperScaling and output as pulse-width modulated value (variable switch on and switch off times) at OutputCool_PWM. OutputCool_PWM is only calculated if the cooling output is activated (Config.ActivateCooling = TRUE) and Config.Output.Cool.Select = 1.
SetpointLimit_H	BOOL	FALSE	If SetpointLimit_H = TRUE, the absolute high limit of setpoint is reached (Setpoint ≥ Config.SetpointUpperLimit or Setpoint ≥ Config.InputUpperLimit). The setpoint high limit is the minimum of Config.SetpointUpperLimit and Config.InputUpperLimit.
SetpointLimit_L	BOOL	FALSE	If SetpointLimit_L = TRUE, the absolute low limit of the setpoint has been reached (Setpoint ≤ Config.SetpointLowerLimit or Setpoint ≤ Config.InputLowerLimit). The setpoint low limit is the maximum of Config.SetpointLowerLimit and Config.InputLowerLimit.
InputWarning_H	BOOL	FALSE	If InputWarning_H = TRUE, the process value has reached or exceeded the warning high limit (ScaledInput ≥ Config.InputUpperWarning).
InputWarning_L	BOOL	FALSE	If InputWarning_L = TRUE, the process value has reached or fallen below the warning low limit (ScaledInput ≤ Config.InputLowerWarning).
State	INT	0	The State parameter (Page 416) shows the current operating mode of the PID controller. You can change the operating mode using the input parameter Mode and a rising edge at ModeActivate. For pretuning and fine tuning, you specify with Heat.EnableTuning and Cool.EnableTuning whether tuning takes place for heating or cooling. • State = 0: Inactive • State = 1: Pretuning • State = 2: Fine tuning • State = 3: Automatic mode • State = 4: Manual mode • State = 5: Substitute output value with error monitoring
Error	BOOL	FALSE	If Error = TRUE, at least one error message is pending in this cycle.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 422) shows which error messages are pending. ErrorBits is retentive and is reset with a rising edge at Reset or ErrorAck.

11.3.4.5 In/out parameters of PID_Temp V2

The names of the following parameters apply both to the data block and to access via the Openness API.

Parameter	Data type	Default	Description
Mode	INT	4	At Mode, specify the operating mode to which PID_Temp is to switch. Options are: • Mode = 0: Inactive • Mode = 1: Pretuning • Mode = 2: Fine tuning • Mode = 3: Automatic mode • Mode = 4: Manual mode The operating mode is activated by: • Rising edge at ModeActivate • Falling edge at Reset • Falling edge at ManualEnable • Cold restart of CPU if RunModeByStartup = TRUE For pretuning and fine tuning, you specify with Heat.EnableTuning and Cool.EnableTuning whether tuning takes place for heating or cooling. Mode is retentive. A detailed description of the operating modes can be found in State and Mode parameters (Page 416).
Master	DWORD	DW#16#0	Interface for cascade control (Page 196) If this PID_Temp instance is used as slave controller in a cascade (Config.Cascade.IsSlave = TRUE), assign the Master parameter at the instruction call with the Slave parameter of the master controller. Example: Call of a slave controller "PID_Temp_2" with master controller "PID_Temp_1" in SCL: --- `"PID_Temp_2"(Master := "PID_Temp_1".Slave, Setpoint := "PID_Temp_1".OutputHeat);` --- Slave controllers exchange information about operating mode, limitation and substitute setpoint with their master controller via this interface. Keep in mind that the call of the master controller has to take place before the call of the slave controller in the same cyclic interrupt OB.
Slave	DWORD	DW#16#0	Interface for cascade control Slave controllers exchange information about operating mode, limitation and substitute setpoint with their master controller via this interface. See description of Master parameter.

See also

PID_Temp state and mode parameters (Page 416)

Program creation (Page 198)

11.3.4.6 Static tags of PID_Temp

NOTE

Change the tags identified with (1) only in "Inactive" mode to prevent malfunction of the PID controller.

The names of the following variables apply both to the data block and to access via the Openness API.

Tag	Data type	Default	Description
IntegralResetMode	Int	V1.0: 1, as of version V1.1: 4	The IntegralResetMode tag (Page 430) determines how the integral action PIDCtrl.IOutputOld is preassigned when switching from "Inactive" operating mode to "Automatic mode". This setting only works for one cycle. • IntegralResetMode = 0: Smooth • IntegralResetMode = 1: Delete • IntegralResetMode = 2: Hold • IntegralResetMode = 3: Preassign • IntegralResetMode = 4: Like setpoint change (only for PID_Temp with version ≥ 1.1)
OverwriteInitialOutputValue	REAL	0.0	If one of the following conditions is met, the integral action PIDCtrl.IOutputOld is preassigned automatically as if PIDOutputSum = OverwriteInitialOutputValue in the previous cycle: • IntegralResetMode = 3 when switching from "Inactive" operating mode to "Automatic mode" • IntegralResetMode = 3, TRUE -> FALSE edge at parameter Reset and parameter Mode = 3 • PIDCtrl.PIDInit = TRUE in "Automatic mode" (available as of PID_Temp Version 1.1)
RunModeByStartup	BOOL	TRUE	Activate operating mode at Mode parameter after CPU restart • If RunModeByStartup = TRUE, PID_Temp starts in the operating mode stored in the Mode parameter after CPU startup. • If RunModeByStartup = FALSE, PID_Temp remains in "Inactive" mode after CPU startup.
LoadBackUp	BOOL	FALSE	If LoadBackUp = TRUE, the last set of PID parameters is reloaded from the CtrlParamsBackUp structure. The set was saved prior to the last tuning. LoadBackUp is automatically set back to FALSE. The acceptance is bumpless.
SetSubstituteOutput	BOOL	TRUE	Selection of the output value while an error is pending (State = 5): • If SetSubstituteOutput = TRUE and ActivateRecoverMode = TRUE, the configured substitute output value SubstituteOutput is output as a PID output value as long as an error is pending. • If SetSubstituteOutput = FALSE and ActivateRecoverMode = TRUE, the actuator remains at the current PID output value as long as an error is pending.

Tag	Data type	Default	Description
			• If ActivateRecoverMode = FALSE, SetSubstituteOutput does not take effect. • If SubstituteOutput is invalid (ErrorBits = 16#0002_0000), the substitute output value cannot be output. In this case, Config.Output.Heat.PidLowerLimit or Config.Output.Cool.PidUpperLimit is used as a PID output value.
PhysicalUnit	INT	0	Unit of measurement of the process value and setpoint, e.g., °C, or °F. PhysicalUnit serves the display in the editors and has no influence on the behavior of the control algorithm in the CPU. When importing PID_Temp up to V1.1 via the Openness API, PhysicalUnit is reset to the default value. When importing PID_Temp as of V2.0 via the Openness API, the value of PhysicalUnit is retained.
PhysicalQuantity	INT	0	Physical quantity of the process value and setpoint, e.g., temperature. PhysicalQuantity serves the display in the editors and has no influence on the behavior of the control algorithm in the CPU. When importing PID_Temp up to V1.1 via the Openness API, PhysicalQuantity is reset to the default value. When importing PID_Temp as of V2.0 via the Openness API, the value of PhysicalQuantity is retained.
ActivateRecoverMode	BOOL	TRUE	The ActivateRecoverMode (Page 425) tag determines the response in the event of an error.
Warning	DWORD	0	The Warning (Page 426) tag shows the warnings since Reset = TRUE or ErrorAck =TRUE. Warning is retentive.
Progress	REAL	0.0	Progress of current tuning phase as a percentage (0.0 - 100.0)
CurrentSetpoint	REAL	0.0	CurrentSetpoint always displays the currently effective setpoint. This value is frozen during tuning.
CancelTuningLevel	REAL	10.0	Permissible fluctuation of setpoint during tuning. Tuning is not canceled until: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel
SubstituteOutput	REAL	0.0	The substitute output value is used as PID output value as long as the following conditions are met: • One or more errors are pending in automatic mode for which ActivateRecoverMode is in effect • SetSubstituteOutput = TRUE • ActivateRecoverMode = TRUE The values at the outputs for heating and cooling resulting from the substitute output value are the result of the configured output scaling (structures Config.Output.Heat and Config.Output.Cool).

Tag	Data type	Default	Description
			For controllers with activated heating output and cooling output (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), define: • a positive substitute output value to output the value at the outputs for heating • a negative substitute output value to output the value at the outputs for cooling The permitted value range is determined by the configuration. • Heating output activated (Config.ActivateHeating = TRUE) and cooling output deactivated (Config.ActivateCooling = FALSE): Config.Output.Heat.PidUpperLimit ≥ SubstituteOutput ≥ Config.Output.Heat.PidLowerLimit • Heating output activated (Config.ActivateHeating = TRUE) and cooling output activated (Config.ActivateCooling = TRUE): Config.Output.Heat.PidUpperLimit ≥ SubstituteOutput ≥ Config.Output.Cool.PidLowerLimit • Heating output deactivated (Config.ActivateHeating = FALSE) and cooling output activated (Config.ActivateCooling = TRUE): Config.Output.Cool.PidUpperLimit ≥ SubstituteOutput ≥ Config.Output.Cool.PidLowerLimit
PidOutputSum	REAL	0.0	PID output value PidOutputSum displays the output value of the PID algorithm. Depending on the operating mode, it is either calculated automatically or defined by the manual value or the configured substitute output value. The values at the outputs for heating and cooling resulting from the PID output value are the result of the configured output scaling (Config.Output.Heat and Config.Output.Cool structures). The PidOutputSum is limited as defined in the configuration. • Heating output activated (Config.ActivateHeating = TRUE) and cooling output deactivated (Config.ActivateCooling = FALSE): Config.Output.Heat.PidUpperLimit ≥ PidOutputSum ≥ Config.Output.Heat.PidLowerLimit • Heating output activated (Config.ActivateHeating = TRUE) and cooling output activated (Config.ActivateCooling = TRUE): Config.Output.Heat.PidUpperLimit ≥ PidOutputSum ≥ Config.Output.Cool.PidLowerLimit • Heating output deactivated (Config.ActivateHeating = FALSE) and cooling output activated (Config.ActivateCooling = TRUE): Config.Output.Cool.PidUpperLimit ≥ PidOutputSum ≥ Config.Output.Cool.PidLowerLimit

Tag	Data type	Default	Description
PidOutputOffsetHeat	REAL	0.0	Offset of the PID output value for heating PidOutputOffsetHeat is added to the value that results from PidOutputSum for the heating branch. Enter a positive value for PidOutputOffsetHeat to receive a positive offset at the outputs for heating. The resulting values at the outputs for heating are the result of the configured output scaling (Config.Output.Heat structure). This offset can be used for actuators which need a fixed minimum value, for example, fans with minimum speed. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE).
PidOutputOffsetCool	REAL	0.0	Offset of the PID output value for cooling PidOutputOffsetCool is added to the value that results from PidOutputSum for the cooling branch. Enter a negative value for PidOutputOffsetCool to receive a positive offset at the outputs for cooling. The resulting values at the outputs for cooling are the result of the configured output scaling (Config.Output.Cool structure). This offset can be used for actuators which need a fixed minimum value, for example, fans with minimum speed. Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE).
SubstituteSetpointOn	BOOL	FALSE	Activates the substitute setpoint as controller setpoint. • FALSE = the Setpoint parameter is used. • TRUE = the SubstituteSetpoint parameter is used as setpoint SubstituteSetpointOn can be used to specify the setpoint of a slave controller in a cascade directly without having to change the user program.
SubstituteSetpoint	REAL	0.0	Substitute setpoint If SubstituteSetpointOn = TRUE, the SubstituteSetpoint parameter is used as setpoint. Permissible value range: Config.SetpointUpperLimit ≥ SubstituteSetpoint ≥ Config.SetpointLowerLimit, Config.InputUpperLimit ≥ SubstituteSetpoint ≥ Config.InputLowerLimit
DisableHeating	BOOL	FALSE	DisableHeating = TRUE deactivates the heating branch for heating/cooling controllers (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) in automatic mode by limiting PidOutputSum to the high limit 0.0. PidOutputOffsetHeat and the output scaling for the heating outputs remain active. This parameter is set/reset by the user manually and is not automatically reset by the PID_Temp instruction. DisableHeating is available as of PID_Temp Version 2.0.
DisableCooling	BOOL	FALSE	DisableCooling = TRUE deactivates the cooling branch for heating/cooling controllers (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) in automatic mode by limiting PidOutputSum to the low limit 0.0. PidOutputOffsetCool and the output scaling for the cooling outputs remain active.

Tag	Data type	Default	Description
			DisableCooling can be used for tuning of multi-zone applications (Page 203) to temporarily deactivate the cooling branch as long as all controllers have not completed their tuning yet. This parameter is set/reset by the user manually and is not automatically reset by the PID_Temp instruction.
AllSlaveAutomaticState	BOOL	FALSE	If this PID_Temp instance is used as master controller in a cascade (Config.Cascade.IsMaster = TRUE), AllSlaveAutomaticState = TRUE indicates that all slave controllers are in automatic mode. Tuning, manual mode or automatic mode of the master controller can only be executed accurately if all slave controllers are in automatic mode. AllSlaveAutomaticState is only determined if you interconnect the master controller and slave controller with the Master and Slave parameters. For details, see the Master parameter.
NoSlaveSubstituteSetpoint	BOOL	FALSE	If this PID_Temp instance is used as master controller in a cascade (Config.Cascade.IsMaster = TRUE), NoSlaveSubstituteSetpoint = TRUE indicates that no slave controller has activated its substitute setpoint. Tuning, manual mode or automatic mode of the master controller can only be executed accurately if no slave controller has activated its substitute setpoint. NoSlaveSubstituteSetpoint is only determined if you interconnect the master controller and slave controller with the Master and Slave parameters. For details, see the Master parameter.
Heat.EnableTuning	BOOL	TRUE	Enabling of tuning for heating Heat.EnableTuning must be set for the following tuning (at the same time or prior to the start with Mode and ModeActivate): • Pretuning heating • Pretuning heating and cooling • Fine tuning heating Tuning for heating is only possible if the heating output is activated (Config.ActivateHeating = TRUE). This parameter is not automatically reset by the PID_Temp instruction.
Cool.EnableTuning	BOOL	FALSE	Enabling of tuning for cooling Cool.EnableTuning must be set for the following tuning (at the same time or prior to the start with Mode and ModeActivate): • Pretuning cooling • Pretuning heating and cooling • Fine tuning cooling The tuning for cooling is only possible when the heating output and the cooling output with the PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. This parameter is not automatically reset by the PID_Temp instruction.

Tag	Data type	Default	Description
Config.InputPerOn(1)	BOOL	TRUE	If InputPerOn = TRUE, the Input_PER parameter is used for detecting the process value. If InputPerOn = FALSE, the Input parameter is used.
Config.InputUpperLimit(1)	REAL	120.0	High limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is exceeded, an error is output and the reaction is determined by ActivateRecoverMode. At the I/O input, the process value can be a maximum of 18% higher than the nominal range (overrange). This means the limit cannot be exceeded when you use an I/O input with the pre-setting for high limit and process value scaling. When pretuning is started, the difference between high and low limit of the process value is checked to determine whether the distance between setpoint and process value meets the necessary requirements. InputUpperLimit > InputLowerLimit
Config.InputLowerLimit(1)	REAL	0.0	Low limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is undershot, an error is output and the reaction is determined by ActivateRecoverMode. InputLowerLimit < InputUpperLimit
Config.InputUpperWarning(1)	REAL	3.402822e+-38	Warning high limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is exceeded, a warning is output at the Warning parameter. • If you set InputUpperWarning outside the process value limits, the configured absolute process value high limit is used as the warning high limit. • If you configure InputUpperWarning within the process value limits, this value is used as the warning high limit. InputUpperWarning > InputLowerWarning
Config.InputLowerWarning(1)	REAL	-3.402822e+38	Warning low limit of the process value Input and Input_PER are monitored to ensure adherence to this limit. If the limit is undershot, a warning is output at the Warning parameter. • If you set InputLowerWarning outside the process value limits, the configured absolute process value low limit is used as the warning low limit. • If you configure InputLowerWarning within the process value limits, this value is used as the warning low limit. InputLowerWarning < InputUpperWarning
Config.SetpointUpperLimit(1)	REAL	3.402822e+-38	High limit of setpoint Setpoint and SubstituteSetpoint are monitored to ensure adherence to this limit. If the limit is exceeded, a warning is output at the Warning parameter. • If you configure SetpointUpperLimit outside the process value limits, the configured process value absolute high limit is used as the setpoint high limit. • If you configure SetpointUpperLimit within the process value limits, this value is used as the setpoint high limit. SetpointUpperLimit > SetpointLowerLimit

Tag	Data type	Default	Description
Config.SetpointLowerLimit(1)	REAL	-3.402822e+38	Low limit of the setpoint Setpoint and SubstituteSetpoint are monitored to ensure adherence to this limit. If the limit is undershot, a warning is output at the Warning parameter. • If you set SetpointLowerLimit outside the process value limits, the configured process value absolute low limit is used as the setpoint low limit. • If you set SetpointLowerLimit within the process value limits, this value is used as the setpoint low limit. SetpointLowerLimit < SetpointUpperLimit
Config.ActivateHeating(1)	BOOL	TRUE	Activate heating output Config.ActivateHeating is available as of PID_Temp V2.0. • Config.ActivateHeating = FALSE Heating output deactivated • Config.ActivateHeating = TRUE Heating output activated If you are using the heating and cooling output, the controller must not be configured as master controller (Config.Cascade.IsMaster must be FALSE) . PID_Temp V1.x always behaves like Config.ActivateHeating = TRUE.
Config.ActivateCooling(1)	BOOL	FALSE	Activate cooling output • Config.ActivateCooling = FALSE Cooling output deactivated • Config.ActivateCooling = TRUE Cooling output activated If you are using the heating and cooling output, the controller must not be configured as master controller (Config.Cascade.IsMaster must be FALSE) .
Config.AdvancedCooling(1)	BOOL	TRUE	Method for heating/cooling • Cooling factor (Config.AdvancedCooling = FALSE) The output value calculation for cooling takes place with the PID parameters for heating (Retain.CtrlParams.Heat structure) taking into consideration the configurable cooling factor Config.CoolFactor. This method is suitable if the heating and cooling actuators have a similar time response but different gains. Pretuning and fine tuning for cooling are not available when you select this method. You can only execute the tuning for heating. • PID parameter switching (Config.AdvancedCooling = TRUE) The output value calculation for cooling takes place by means of a separate PID parameter set (Retain.CtrlParams.Cool structure). This method is suitable if the heating and cooling actuators have different time responses and different gains. Tuning for heating and cooling is available if this method is selected. Config.AdvancedCooling only takes effect if the heating output and cooling output are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE).

Tag	Data type	Default	Description
Config.CoolFactor(1)	REAL	1.0	Cooling factor If Config.AdvancedCooling = FALSE, Config.CoolFactor is considered as factor in the calculation of the output value for cooling. This allows different gains of heating and cooling actuators to be taken into account. Config.CoolFactor is not set automatically or adjusted during tuning. You must correctly configure Config.CoolFactor manually with the ratio "heating actuator gain/cooling actuator gain". Example: Config.CoolFactor = 2.0 means that the gain of the heating actuator is twice as high as the gain of the cooling actuator. Config.CoolFactor only takes effect if the heating output and cooling output are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) and cooling factor is selected as method for heating/cooling (Config.AdvancedCooling = FALSE). Config.CoolFactor > 0.0
Config.InputScaling.UpperPointIn(1)	REAL	27648.0	Scaling Input_PER high Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). UpperPointIn > LowerPointIn
Config.InputScaling.LowerPointIn(1)	REAL	0.0	Scaling Input_PER low Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). LowerPointIn < UpperPointIn
Config.InputScaling.UpperPointOut (1)	REAL	100.0	Scaled high process value Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). UpperPointOut > LowerPointOut
Config.InputScaling.LowerPointOut (1)	REAL	0.0	Scaled low process value Input_PER is scaled based on the two value pairs UpperPointOut, UpperPointIn and LowerPointOut, LowerPointIn. Only takes effect if Input_PER is used for process value acquisition (Config.InputPerOn = TRUE). LowerPointOut < UpperPointOut
Config.Output.Heat.Select(1)	INT	1	Selecting the output value for heating Config.Output.Heat.Select specifies which outputs are used for heating: • Heat.Select = 0 - OutputHeat is used • Heat.Select = 1 - OutputHeat and OutputHeat_PWM are used • Heat.Select = 2 - OutputHeat and OutputHeat_PER are used Outputs that are not used are not calculated and remain at their default value.

Tag	Data type	Default	Description
			Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE).
Config.Output.Heat.PwmPeriode(1)	REAL	0.0	Period duration of the pulse width modulation (PWM) for heating (OutputHeat_PWM output) in seconds: • Heat.PwmPeriode = 0.0 The sampling time of the PID algorithm for heating (Retain.CtrlParams.Heat.Cycle) is used as period duration of the PWM. • Heat.PwmPeriode > 0.0 The value is rounded off to an integer multiple of the PID_Temp sampling time (CycleTime.Value) and used as period duration of the PWM. This setting can be used to improve the smoothing of the process value with a long sampling time of the PID algorithm. The value must meet the following conditions: – Heat.PwmPeriode ≤ Retain.CtrlParams.Heat.Cycle, – Heat.PwmPeriode > Config.Output.Heat.MinimumOnTime – Heat.PwmPeriode > Config.Output.Heat.MinimumOffTime Heat.PwmPeriode only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and OutputHeat_PWM is selected as output for heating (Heat.Select = 1). See also PwmPeriode tag (Page 428).
Config.Output.Heat.PidUpperLimit	REAL	100.0	PID output value high limit for heating For controllers with activated heating output (Config.ActivateHeating = TRUE), the PID output value (PidOutputSum) is restricted to this high limit. Heat.PidUpperLimit forms a value pair together with the following parameters for scaling of the PID output value (PidOutputSum) to the outputs for heating: • Heat.UpperScaling for OutputHeat • Heat.PwmUpperScaling for OutputHeat_PWM • Heat.PerUpperScaling for OutputHeat_PER If you want to limit the value at the associated output, you must also adjust these scaling values. As of Version 2.0, PID_Temp supports the change of the output value limits in automatic mode. Up to Version 1.1, these may only be changed in the inactive or manual modes. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.PidUpperLimit > Heat.PidLowerLimit
Config.Output.Heat.PidLowerLimit	REAL	0.0	PID output value low limit for heating For controllers with activated heating output (Config.ActivateHeating = TRUE) and deactivated cooling output (Config.ActivateCooling = FALSE), the PID output value (PidOutputSum) is restricted to this low limit. For controllers with activated heating output (Config.ActivateHeating = TRUE) and activated cooling output (Config.ActivateCooling = TRUE), the value must be 0.0.

Tag	Data type	Default	Description
			Heat.PidLowerLimit forms a value pair together with the following parameters for scaling of the PID output value (PidOutputSum) to the outputs for heating: • Heat.LowerScaling for OutputHeat • Heat.PwmLowerScaling for OutputHeat_PWM • Heat.PerLowerScaling for OutputHeat_PER If you want to limit the value at the associated output, you must also adjust these scaling values. As of Version 2.0, PID_Temp supports the change of the output value limits in automatic mode. Up to Version 1.1, these may only be changed in the inactive or manual modes. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). The permitted value range is determined by the configuration. • Heating output activated and cooling output deactivated (Config.ActivateHeating = TRUE, Config.ActivateCooling = FALSE): Heat.PidLowerLimit < Heat.PidUpperLimit • Heating output and cooling output activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE): Heat.PidLowerLimit = 0.0
Config.Output.Heat.UpperScaling	REAL	100.0	Scaled high output value for heating Heat.UpperScaling and Heat.PidUpperLimit form a value pair for scaling of the PID output value (PidOutputSum) to the output value for heating (OutputHeat). The OutputHeat value is always located between Heat.UpperScaling and Heat.LowerScaling. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.UpperScaling ≠ Heat.LowerScaling
Config.Output.Heat.LowerScaling	REAL	0.0	Scaled low output value for heating Heat.LowerScaling and Heat.PidLowerLimit form a value pair for scaling of the PID output value (PidOutputSum) to the output value for heating (OutputHeat). The OutputHeat value is always located between Heat.UpperScaling and Heat.LowerScaling. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.UpperScaling ≠ Heat.LowerScaling
Config.Output.Heat.PwmUpperScaling	REAL	100.0	Scaled high PWM output value for heating Heat.PwmUpperScaling and Heat.PidUpperLimit form a value pair for scaling of the PID output value (PidOutputSum) to the pulse-width modulated output for heating (OutputHeat_PWM). The OutputHeat_PWM value is always located between Heat.PwmUpperScaling and Heat.PWMLowerScaling. Heat.PwmUpperScaling only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and OutputHeat_PWM is selected as output for heating (Heat.Select = 1). 100.0 ≥ Heat.PwmUpperScaling ≥ 0.0 Heat.PwmUpperScaling ≠ Heat.PwmLowerScaling

Tag	Data type	Default	Description
Config.Output.Heat.PwmLowerScaling	REAL	0.0	Scaled low PWM output value for heating Heat.PwmLowerScaling and Heat.PidLowerLimit form a value pair for scaling of the PID output value (PidOutputSum) to the pulse-width modulated output for heating (OutputHeat_PWM). The OutputHeat_PWM value is always located between Heat.PwmUpperScaling and Heat.PwmLowerScaling. Heat.PwmLowerScaling only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and OutputHeat_PWM is selected as output for heating (Heat.Select = 1). 100.0 ≥ Heat.PwmLowerScaling ≥ 0.0 Heat.PwmUpperScaling ≠ Heat.PwmLowerScaling
Config.Output.Heat.PerUpperScaling	REAL	27648.0	Scaled high analog output value for heating Heat.PerUpperScaling and Heat.PidUpperLimit form a value pair for scaling of the PID output value (PidOutputSum) to the analog output value for heating (OutputHeat_PER). The OutputHeat_PER value is always located between Heat.PerUpperScaling and Heat.PerLowerScaling. Heat.PerUpperScaling only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and OutputHeat_PER is selected as output for heating (Heat.Select = 2). 32511.0 ≥ Heat.PerUpperScaling ≥ -32512.0 Heat.PerUpperScaling ≠ Heat.PerLowerScaling
Config.Output.Heat.PerLowerScaling	REAL	0.0	Scaled low analog output value for heating Heat.PerLowerScaling and Heat.PidLowerLimit form a value pair for scaling of the PID output value (PidOutputSum) to the analog output value for heating (OutputHeat_PER). The OutputHeat_PER value is always located between Heat.PerUpperScaling and Heat.PerLowerScaling. Heat.PerLowerScaling only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and OutputHeat_PER is selected as output for heating (Heat.Select = 2). 32511.0 ≥ Heat.PerLowerScaling ≥ -32512.0 Heat.PerUpperScaling ≠ Heat.PerLowerScaling
Config.Output.Heat.MinimumOnTime[1]	REAL	0.0	Minimum on time of the pulse width modulation for heating (OutputHeat_PWM output) A PWM pulse is never shorter than this value. The value is rounded off to: Heat.MinimumOnTime = n × CycleTime.Value Heat.MinimumOnTime only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and OutputHeat_PWM is selected as output for heating (Heat.Select = 1). 100000.0 ≥ Heat.MinimumOnTime ≥ 0.0
Config.Output.Heat.MinimumOffTime[1]	REAL	0.0	Minimum off time of the pulse width modulation for heating (OutputHeat_PWM output) A PWM pause is never shorter than this value. The value is rounded off to: Heat.MinimumOffTime = n × CycleTime.Value Heat.MinimumOffTime only takes effect if the heating output is activated (Config.ActivateHeating = TRUE) and

Tag	Data type	Default	Description
			OutputHeat_PWM is selected as output for heating (Heat.Select = 1). 100000.0 ≥ Heat.MinimumOffTime ≥ 0.0
Config.Output.Cool.Select(1)	INT	1	Selecting the output value for cooling Config.Output.Cool.Select specifies which outputs are used for cooling: • Cool.Select = 0 - OutputCool is used • Cool.Select = 1 - OutputCool and OutputCool_PWM are used • Cool.Select = 2 - OutputCool and OutputCool_PER are used Outputs that are not used are not calculated and remain at their default value. Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE).
Config.Output.Cool.PwmPeriode(1)	REAL	0.0	Period duration of the pulse width modulation for cooling (OutputCool_PWM output) in seconds: • Cool.PwmPeriode = 0.0, Config.ActivateHeating = TRUE and Config.AdvancedCooling = FALSE: The sampling time of the PID algorithm for heating (Retain.CtrlParams.Heat.Cycle) is used as period duration of the PWM. • Cool.PwmPeriode = 0.0 and Config.ActivateHeating = FALSE or Cool.PwmPeriode = 0.0 and Config.AdvancedCooling = TRUE: The sampling time of the PID algorithm for cooling (Retain.CtrlParams.Cool.Cycle) is used as period duration of the PWM. • Cool.PwmPeriode > 0.0: The value is rounded off to an integer multiple of the PID_Temp sampling time (CycleTime.Value) and used as period duration of the PWM. This setting can be used to improve the smoothing of the process value with a long sampling time of the PID algorithm. The value must meet the following conditions: – Cool.PwmPeriode ≤ Retain.CtrlParams.Cool.Cycle or Retain.CtrlParams.Heat.Cycle – Cool.PwmPeriode > Config.Output.Cool.MinimumOnTime – Cool.PwmPeriode > Config.Output.Cool.MinimumOffTime Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PWM is selected as output for cooling (Cool.Select = 1). See also PwmPeriode tag (Page 425).

Tag	Data type	Default	Description
Config.Output.Cool.PidUpperLimit	REAL	0.0	PID output value high limit for cooling For controllers with activated heating output and cooling output (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the value must be 0.0. For controllers with deactivated heating output (Config.ActivateHeating = FALSE) and activated cooling output (Config.ActivateCooling = TRUE), the PID output value (PidOutputSum) is restricted to this high limit. Cool.PidUpperLimit forms a value pair together with the following parameters for scaling of the PID output value (PidOutputSum) to the outputs for cooling: • Cool.LowerScaling for OutputCool • Cool.PwmLowerScaling for OutputCool_PWM • Cool.PerLowerScaling for OutputCool_PER If you want to limit the value at the associated output, you must also adjust these scaling values. As of Version 2.0, PID_Temp supports the change of the output value limits in automatic mode. Up to Version 1.1, these may only be changed in the inactive or manual modes. Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE). The permitted value range is determined by the configuration. • Heating output and cooling output activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE): Cool.PidUpperLimit = 0.0 • Heating output deactivated and cooling output activated (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE): Cool.PidUpperLimit > Cool.PidLowerLimit
Config.Output.Cool.PidLowerLimit	REAL	-100.0	PID output value low limit for cooling For controllers with activated cooling output (Config.ActivateCooling = TRUE), the PID output value (PidOutputSum) is restricted to this low limit. Cool.PidLowerLimit forms a value pair together with the following parameters for scaling of the PID output value (PidOutputSum) to the outputs for cooling: • Cool.UpperScaling for OutputCool • Cool.PwmUpperScaling for OutputCool_PWM • Cool.PerUpperScaling for OutputCool_PER If you want to limit the value at the associated output, you must also adjust these scaling values. As of Version 2.0, PID_Temp supports the change of the output value limits in automatic mode. Up to Version 1.1, these may only be changed in the inactive or manual modes. Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE). Cool.PidLowerLimit < Cool.PidUpperLimit

Tag	Data type	Default	Description
Config.Output.Cool.UpperScaling	REAL	100.0	Scaled high output value for cooling Cool.UpperScaling and Cool.PidLowerLimit form a value pair for scaling of the PID output value (PidOutputSum) to the output value for cooling (OutputCool). The OutputCool value is always located between Cool.UpperScaling and Cool.LowerScaling. Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE). Cool.UpperScaling ≠ Cool.LowerScaling
Config.Output.Cool.LowerScaling	REAL	0.0	Scaled low output value for cooling Cool.LowerScaling and Cool.PidUpperLimit form a value pair for scaling of the PID output value (PidOutputSum) to the output value for cooling (OutputCool). The OutputCool value is always located between Cool.UpperScaling and Cool.LowerScaling. Only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE). Cool.UpperScaling ≠ Cool.LowerScaling
Config.Output.Cool.PwmUpperScaling	REAL	100.0	Scaled high PWM output value for cooling Cool.PwmUpperScaling and Cool.PidLowerLimit form a value pair for scaling of the PID output value (PidOutputSum) to the pulse-width modulated output for cooling (OutputCool_PWM). The OutputCool_PWM value is always located between Cool.PwmUpperScaling and Cool.PwmLowerScaling. Cool.PwmUpperScaling only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PWM is selected as output for cooling (Cool.Select = 1). 100.0 ≥ Cool.PwmUpperScaling ≥ 0.0 Cool.PwmUpperScaling ≠ Cool.PwmLowerScaling
Config.Output.Cool.PwmLowerScaling	REAL	0.0	Scaled low PWM output value for cooling Cool.PwmLowerScaling and Cool.PidUpperLimit form a value pair for scaling of the PID output value (PidOutputSum) to the pulse-width modulated output for cooling (OutputCool_PWM). The OutputCool_PWM value is always located between Cool.PwmUpperScaling and CoolPwm.LowerScaling. Cool.PwmLowerScaling only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PWM is selected as output for cooling (Cool.Select = 1). 100.0 ≥ Cool.PwmLowerScaling ≥ 0.0 Cool.PwmUpperScaling ≠ Cool.PwmLowerScaling
Config.Output.Cool.PerUpperScaling	REAL	27648.0	Scaled high analog output value for cooling Cool.PerUpperScaling and Cool.PidLowerLimit form a value pair for scaling of the PID output value (PidOutputSum) to the analog output value for cooling (OutputCool_PER). The OutputCool_PER value is always located between Cool.PerUpperScaling and Cool.PerLowerScaling. Cool.PerUpperScaling only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PER is selected as output for cooling (Cool.Select = 2). 32511.0 ≥ Cool.PerUpperScaling ≥ -32512.0 Cool.PerUpperScaling ≠ Cool.PerLowerScaling

Tag	Data type	Default	Description
Config.Output.Cool.PerLowerScaling	REAL	0.0	Scaled low analog output value for cooling Cool.PerLowerScaling and Cool.PidUpperLimit form a value pair for scaling of the PID output value (PidOutputSum) to the analog output value for cooling (OutputCool_PER). The OutputCool_PER value is always located between Cool.PerUpperScaling and Cool.PerLowerScaling. Cool.PerLowerScaling only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PER is selected as output for cooling (Cool.Select = 2). 32511.0 ≥ Cool.PerLowerScaling ≥ -32512.0 Cool.PerUpperScaling ≠ Cool.PerLowerScaling
Config.Output.Cool.MinimumOnTime(1)	REAL	0.0	Minimum on time of the pulse width modulation for cooling (OutputCool_PWM output) A PWM pulse is never shorter than this value. The value is rounded off to: Cool.MinimumOnTime = n × CycleTime.Value Cool.MinimumOnTime only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PWM is selected as output for cooling (Cool.Select = 1). 100000.0 ≥ Cool.MinimumOnTime ≥ 0.0
Config.Output.Cool.MinimumOffTime(1)	REAL	0.0	Minimum off time of the pulse width modulation for cooling (OutputCool_PWM output) A PWM pause is never shorter than this value. The value is rounded off to: Cool.MinimumOffTime = n × CycleTime.Value Cool.MinimumOffTime only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PWM is selected as output for cooling (Cool.Select = 1). 100000.0 ≥ Cool.MinimumOffTime ≥ 0.0
If you are using PID_Temp in a cascade (Page 196), the master controller and slave controller exchange information via the Master and Slave parameters. You need to make the interconnection. For details, see the Master parameter.			
Config.Cascade.IsMaster(1)	BOOL	FALSE	The controller is master in a cascade and provides the slave setpoint. Set IsMaster = TRUE if you are using this PID_Temp instance as master controller in a cascade. A master controller defines the setpoint of a slave controller with its output. A PID_Temp instance can be master controller and slave controller at the same time. If the controller is used as a master controller, only the heating output (Config.ActivateHeating = TRUE, Config.ActivateCooling = FALSE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) may be activated.

Tag	Data type	Default	Description
Config.Cascade.IsSlave(1)	BOOL	FALSE	The controller is slave in a cascade and receives its setpoint from the master. Set IsSlave = TRUE if you are using this PID_Temp instance as slave controller in a cascade. A slave controller receives its setpoint (Setpoint parameter) from the output of its master controller (OutputHeat or OutputCool parameter). A PID_Temp instance can be master controller and slave controller at the same time.
Config.Cascade.AntiWindUpMode(1)	INT	1	Anti-Windup behavior in the cascade Options are: • AntiWindUpMode = 0 The anti-windup functionality is deactivated. The master controller does not respond to the limit of its slave controllers. • AntiWindUpMode = 1 The integral action of the master controller is reduced in the ratio "Slaves in limit" to "Number of slaves" ("CountSlaves" parameter). This reduces the effects of the limitation on the control behavior. • AntiWindUpMode = 2 The integral action of the master controller is held as soon as a slave controller is in the limit. Only takes effect if the controller is configured as master controller (Config.Cascade.IsMaster = TRUE).
Config.Cascade.CountSlaves(1)	INT	1	Number of subordinate slaves Here you enter the number of directly subordinate slave controllers which receive their setpoint from this master controller. Only takes effect if the controller is configured as master controller (Config.Cascade.IsMaster = TRUE). 255 ≥ CountSlaves ≥ 1
CycleTime.StartEstimation	BOOL	TRUE	If CycleTime.EnEstimation = TRUE, CycleTime.StartEstimation = TRUE starts automatic determination of the PID_Temp sampling time (cycle time of the calling OB). CycleTime.StartEstimation = FALSE is set once measurement is complete.
CycleTime.EnEstimation	BOOL	TRUE	If CycleTime.EnEstimation = TRUE, the PID_Temp sampling time is determined automatically. If CycleTime.EnEstimation = FALSE, the sampling time PID_Temp is not determined automatically and must be configured correctly manually with CycleTime.Value.
CycleTime.EnMonitoring	BOOL	TRUE	If CycleTime.EnMonitoring = FALSE, the PID_Temp sampling time is not monitored. If PID_Temp cannot be executed within the sampling time, no error (ErrorBits = 16#0000_0800) is output and PID_Temp does not respond as configured with ActivateRecoverMode.
CycleTime.Value(1)	REAL	0.1	PID_Temp sampling time (cycle time of the calling OB) in seconds CycleTime.Value is determined automatically and is usually equivalent to the cycle time of the calling OB.
You can reload values from the CtrlParamsBackUp structure with LoadBackUp = TRUE.			
CtrlParamsBackUp.SetByUser	BOOL	FALSE	Saved value of Retain.CtrlParams.SetByUser

Tag	Data type	Default	Description
CtrlParamsBackUp.Heat.Gain	REAL	1.0	Saved proportional gain for heating
CtrlParamsBackUp.Heat.Ti	REAL	20.0	Saved integration time for heating in seconds
CtrlParamsBackUp.Heat.Td	REAL	0.0	Saved derivative action time for heating in seconds
CtrlParamsBackUp.Heat.TdFiltRatio	REAL	0.2	Saved derivative delay coefficient for heating
CtrlParamsBackUp.Heat.PWeighting	REAL	1.0	Saved weighting of the proportional action for heating
CtrlParamsBackUp.Heat.DWeighting	REAL	1.0	Saved weighting of the derivative action for heating
CtrlParamsBackUp.Heat.Cycle	REAL	1.0	Saved sampling time of the PID algorithm for heating in seconds
CtrlParamsBackUp.Heat.ControlZone	REAL	3.402822e+-38	Saved control zone width for heating
CtrlParamsBackUp.Heat.DeadZone	REAL	0.0	Saved dead zone width for heating
CtrlParamsBackUp.Cool.Gain	REAL	1.0	Saved proportional gain for cooling
CtrlParamsBackUp.Cool.Ti	REAL	20.0	Saved integration time for cooling in seconds
CtrlParamsBackUp.Cool.Td	REAL	0.0	Saved derivative action time for cooling in seconds
CtrlParamsBackUp.Cool.TdFiltRatio	REAL	0.2	Saved derivative delay coefficient for cooling
CtrlParamsBackUp.Cool.PWeighting	REAL	1.0	Saved proportional action weighting factor for cooling
CtrlParamsBackUp.Cool.DWeighting	REAL	1.0	Saved derivative action weighting factor for cooling
CtrlParamsBackUp.Cool.Cycle	REAL	1.0	Saved sampling time of the PID algorithm for cooling in seconds
CtrlParamsBackUp.Cool.ControlZone	REAL	3.402822e+-38	Saved control zone width for cooling
CtrlParamsBackUp.Cool.DeadZone	REAL	0.0	Saved dead zone width for cooling
PIDSelfTune.SUT.CalculateParamsHeat	BOOL	FALSE	The properties of the heating branch of the controlled system are saved during pretuning for heating. If SUT.CalculateParamsHeat = TRUE, the PID parameters for heating (Retain.CtrlParams.Heat structure) are recalculated on the basis of these properties. This enables you to change the parameter calculation method (PIDSelfTune.SUT.TuneRuleHeat parameter) and recalculate the PID parameters, without having to repeat the tuning. SUT.CalculateParamsHeat is set to FALSE after the calculation. Only possible if the pretuning was successful (SUT.ProcParHeatOk = TRUE).
PIDSelfTune.SUT.CalculateParamsCool	BOOL	FALSE	The properties of the cooling branch of the controlled system are saved during tuning for cooling. If SUT.CalculateParamsCool = TRUE, the PID parameters for cooling (Retain.CtrlParams.Cool structure) are recalculated on the basis of these properties. This enables you to change the parameter calculation method (PIDSelfTune.SUT.TuneRuleCool parameter) and recalculate the PID parameters, without having to repeat the tuning. SUT.CalculateParamsCool is set to FALSE after the calculation. Only possible if the pretuning was successful (SUT.ProcParCoolOk = TRUE). Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRU-

Tag	Data type	Default	Description
			E, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated.
PIDSelfTune.SUT.TuneRuleHeat	INT	2	Method for PID parameter calculation with pretuning for heating Options are: • SUT.TuneRuleHeat = 0: PID according to CHR • SUT.TuneRuleHeat = 1: PI according to CHR • SUT.TuneRuleHeat = 2: PID for temperature processes according to CHR (results in a slower and rather asymptomatic control response with lower overshoot than SUT.TuneRuleHeat = 0) (CHR = Chien, Hrones and Reswick) Only with SUT.TuneRuleHeat = 2 is the control zone Retain.CtrlParams.Heat.ControlZone automatically set during pretuning for heating.
PIDSelfTune.SUT.TuneRuleCool	INT	2	Method for PID parameter calculation with pretuning for cooling Options are: • SUT.TuneRuleCool = 0: PID according to CHR • SUT.TuneRuleCool = 1: PI according to CHR • SUT.TuneRuleCool = 2: PID for temperature processes according to CHR (results in a slower and rather asymptomatic control response with lower overshoot than SUT.TuneRuleCool = 0) (CHR = Chien, Hrones and Reswick) Only with SUT.TuneRuleCool = 2 is the control zone Retain.CtrlParams.Cool.ControlZone automatically set during pretuning for cooling. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated.
PIDSelfTune.SUT.State	INT	0	The SUT.State tag indicates the current phase of pretuning: • State = 0: Initialize pretuning • State = 100: Calculate standard deviation for heating • State = 200: Calculate standard deviation for cooling • State = 250: Calculate standard deviation for cooling • State = 300: Determine point of inflection for heating • State = 400: Determine point of inflection for cooling • State = 450: Determine point of inflection for cooling • State = 500: Heat to setpoint after point of inflection for heating • State = 600: Heat to setpoint after point of inflection for cooling • State = 700: Compare efficiency of the heating actuator and cooling actuator • State = 800: Heating and cooling activated • State = 900: Cooling activated • State = 1000: Determine delay time after switch-off of heating.

Tag	Data type	Default	Description
			• State = 1100: Cool to setpoint after point of inflection for cooling • State = 1200: Determine delay time after switch-off of cooling. • State = 9900: Pretuning successful • State = 1: Pretuning not successful
PIDSelfTune.SUT.ProcParHeatOk	BOOL	FALSE	TRUE: The calculation of the process parameters for pretuning heating was successful. The PID parameters can be recalculated with PIDSelfTune.SUT.CalculateParamsHeat = TRUE. FALSE: No pretuning for heating has been performed or the calculation of the process parameters has failed. The PID parameters can only be recalculated after successful tuning. PID_Temp sets this tag automatically during tuning.
PIDSelfTune.SUT.ProcParCoolOk	BOOL	FALSE	TRUE: The calculation of the process parameters for pretuning cooling was successful. The PID parameters can be recalculated with PIDSelfTune.SUT.CalculateParamsCool = TRUE. FALSE: No pretuning for cooling has been performed or the calculation of the process parameters has failed. The PID parameters can only be recalculated after successful tuning. PID_Temp sets this tag automatically during tuning.
PIDSelfTune.SUT.AdaptDelayTime	INT	0	The AdaptDelayTime tag determines the adjustment of the delay time at the operating point (only for pretuning that is started with a distance between the setpoint and process value). Options are: • SUT.AdaptDelayTime = 0: No adaptation of delay time. The phase SUT.State = 1000 or SUT.State = 1200 is skipped. This option results in a shorter tuning time than with SUT.AdaptDelayTime = 1. • SUT.AdaptDelayTime = 1: Adaptation of the delay time to the setpoint in phase SUT.State = 1000 or SUT.State = 1200 by temporarily switching off the heating or cooling. This option results in a longer tuning time than withSUT.AdaptDelayTime = 0. It can improve the control response if the process behavior depends significantly on the operating point (non-linearity). This option should not be used for multi-zone applications with strong thermal connections.
PIDSelfTune.SUT.CoolingMode	INT	0	The CoolingMode tag determines the manipulated variable output to determine the cooling parameters for pretuning heating and cooling. Options are: • SUT.CoolingMode = 0: Switch off heating and switch on cooling after reaching the setpoint. The SUT.State = 700 phase is skipped. Phase SUT.State = 500 is followed by phase SUT.State = 900. This option can improve the control response if the gain of the cooling actuator is low compared to the gain of the heating actuator. It results in a shorter tuning time than with SUT.CoolingMode = 1 or 2.

Tag	Data type	Default	Description
			• SUT.CoolingMode = 1: Switch on cooling in addition to heating after reaching the setpoint. The SUT.State = 700 phase is skipped. Phase SUT.State = 500 is followed by phase SUT.State = 800. This option can improve the control response if the gain of the cooling actuator is high compared to the gain of the heating actuator. • SUT.CoolingMode = 2: After heating up to the setpoint, a decision is automatically made in phase SUT.State = 700 as to whether heating is switched off. Phase SUT.State = 500 is followed by phase SUT.State = 700 and then SUT.State = 800 or SUT.State = 900. This option requires more time than options 0 and 1.
PIDSelfTune.TIR.RunIn	BOOL	FALSE	Use the RunIn tag to specify the sequence of fine tuning during start from automatic mode. • RunIn = FALSE If fine tuning is started from automatic mode, the system uses the existing PID parameters to control to the setpoint (TIR.State = 500 or 600). Only then will fine tuning start. • RunIn = TRUE PID_Temp tries to reach the setpoint with minimum or maximum output value (TIR.State = 300 or 400). This can produce increased overshoot. Fine tuning then starts automatically. RunIn is set to FALSE after fine tuning. When fine tuning starts from inactive or manual mode, PID_Temp reacts as described under RunIn = TRUE.
PIDSelfTune.TIR.CalculateParamsHeat	BOOL	FALSE	The properties of the heating branch of the controlled system are saved during fine tuning for heating. If TIR.CalculateParamsHeat = TRUE, the PID parameters for heating (Retain.CtrlParams.Heat structure) are recalculated on the basis of these properties. This enables you to change the parameter calculation method (PIDSelfTune.TIR.TuneRuleHeat parameter) and recalculate the PID parameters, without having to repeat the tuning. TIR.CalculateParamsHeat is set to FALSE after the calculation. Only possible if fine tuning heating was successful beforehand (TIR.ProcParHeatOk = TRUE).
PIDSelfTune.TIR.CalculateParamsCool	BOOL	FALSE	The properties of the cooling branch of the controlled system are saved during fine tuning for cooling. If TIR.CalculateParamsCool = TRUE, the PID parameters for cooling (Retain.CtrlParams.Cool structure) are recalculated on the basis of these properties. This enables you to change the parameter calculation method (PIDSelfTune.TIR.TuneRuleCool parameter) and recalculate the PID parameters, without having to repeat the tuning. TIR.CalculateParamsCool is set to FALSE after the calculation. Only possible if fine tuning cooling was successful beforehand (TIR.ProcParCoolOk = TRUE). Only takes effect when the heating output and the cooling output with PID parameter switching

Tag	Data type	Default	Description
			(Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated.
PIDSelfTune.TIR.TuneRuleHeat	INT	0	Method for parameter calculation during fine tuning for heating Options are: • TIR.TuneRuleHeat = 0: PID automatic • TIR.TuneRuleHeat = 1: PID fast (faster control response with higher amplitudes of the output value than with TIR.TuneRuleHeat = 2) • TIR.TuneRuleHeat = 2: PID slow (slower control response with lower amplitudes of the output value than with TIR.TuneRuleHeat = 1) • TIR.TuneRuleHeat = 3: ZN PID • TIR.TuneRuleHeat = 4: ZN PI • TIR.TuneRuleHeat = 5: ZN P (ZN=Ziegler-Nichols) To be able to repeat the calculation of the PID parameters for heating with TIR.CalculateParamsHeat and TIR.TuneRuleHeat = 0, 1 or 2, the previous fine tuning also has to have been executed with TIR.TuneRuleHeat = 0, 1 or 2. If this is not the case, TIR.TuneRuleHeat = 3 is used. The recalculation of the PID parameters for heating with TIR.CalculateParamsHeat and TIR.TuneRuleHeat = 3, 4 or 5 is always possible.
PIDSelfTune.TIR.TuneRuleCool	INT	0	Method for parameter calculation during fine tuning for cooling Options are: • TIR.TuneRuleCool = 0: PID automatic • TIR.TuneRuleCool = 1: PID fast (faster control response with higher amplitudes of the output value than with TIR.TuneRuleCool = 2) • TIR.TuneRuleCool = 2: PID slow (slower control response with lower amplitudes of the output value than with TIR.TuneRuleCool = 1) • TIR.TuneRuleCool = 3: ZN PID • TIR.TuneRuleCool = 4: ZN PI • TIR.TuneRuleCool = 5: ZN P (ZN=Ziegler-Nichols) To be able to repeat the calculation of the PID parameters for cooling with TIR.CalculateParamsCool and TIR.TuneRuleCool = 0, 1 or 2, the previous fine tuning also has to have been executed with TIR.TuneRuleCool = 0, 1 or 2. If this is not the case, TIR.TuneRuleCool = 3 is used. The recalculation of the PID parameters for cooling with TIR.CalculateParamsCool and TIR.TuneRuleCool = 3, 4 or 5 is always possible. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated.

Tag	Data type	Default	Description
PIDSelfTune.TIR.State	INT	0	The TIR.State tag indicates the current phase of "fine tuning": • State = 0: Initialize fine tuning • State = 100: Calculate standard deviation for heating • State = 200: Calculate standard deviation for cooling • State = 300: Attempting to reach setpoint for heating with two-step control using heating • State = 400: Attempting to reach setpoint for cooling with two-step control using cooling • State = 500: Attempting to reach setpoint for heating with PID control • State = 600: Attempting to reach setpoint for cooling with PID control • State = 700: Calculate standard deviation for heating • State = 800: Calculate standard deviation for cooling • State = 900: Determine oscillation and calculate parameters for heating • State = 1000: Determine oscillation and calculate parameters for cooling • State = 9900: Fine tuning successful • State = 1: Fine tuning not successful If the fine tuning of a heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) stops for a longer period of time at TIR.State = 900 or 1000 and Progress = 1.0 without change, note the information about the tuning offset under PID_Temp state and mode parameters (Page 416)
PIDSelfTune.TIR.ProcParHeatOk	BOOL	FALSE	TRUE: The calculation of the process parameters for fine tuning heating was successful. The PID parameters can be recalculated with PIDSelfTune.TIR.CalculateParamsHeat = TRUE. FALSE: No fine tuning for heating has been performed or the calculation of the process parameters has failed. The PID parameters can only be recalculated after successful tuning. PID_Temp sets this tag automatically during tuning.
PIDSelfTune.TIR.ProcParCoolOk	BOOL	FALSE	TRUE: The calculation of the process parameters for fine tuning cooling was successful. The PID parameters can be recalculated with PIDSelfTune.TIR.CalculateParamsCool = TRUE. FALSE: No fine tuning for cooling has been performed or the calculation of the process parameters has failed. The PID parameters can only be recalculated after successful tuning. PID_Temp sets this tag automatically during tuning.
PIDSelfTune.TIR.OutputOffsetHeat	REAL	0.0	Tuning offset heating of the PID output value TIR.OutputOffsetHeat is added to the value that results from PidOutputSum for the heating branch. To receive a positive offset at the outputs for heating, define a positive value for TIR.OutputOffsetHeat. The resulting values at the outputs for heating are the result of the configured output scaling (Config.Output.Heat structure). This tuning offset can be used in controllers with activated heating and cooling output and PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) for fine tuning cooling. If the outputs for cooling are not active at the setpoint that is to be tuned (PidOutputSum > 0.0), fine tuning cooling is not possible. In this case, enter a positive tuning offset heating which

Tag	Data type	Default	Description
			is higher than the PID output value (PidOutputSum) at the setpoint in the steady state before you start tuning. This step increases the values at the outputs for heating and activates the outputs for cooling (PidOutputSum < 0.0). Fine tuning cooling is now possible. When fine tuning is complete, TIR.OutputOffsetHeat is reset to 0.0. Major changes at TIR.OutputOffsetHeat in one step can result in temporary overshoots. Config.Output.Heat.PidUpperLimit ≥ PIDSelfTune.TIR.OutputOffsetHeat ≥ Config.Output.Heat.PidLowerLimit
PIDSelfTune.TIR.OutputOffsetCool	REAL	0.0	Tuning offset cooling of the PID output value TIR.OutputOffsetCool is added to the value that results from PidOutputSum for the cooling branch. To receive a positive offset at the outputs for cooling, define a negative value for TIR.OutputOffsetCool. The resulting values at the outputs for cooling are the result of the configured output scaling (Config.Output.Cool structure). This tuning offset can be used in controllers with activated heating and cooling output (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) for fine tuning heating. If the outputs for heating are not active at the setpoint that is to be tuned (PidOutputSum < 0.0), fine tuning heating is not possible. In this case, enter a negative tuning offset cooling which is lower than the PID output value (PidOutputSum) at the setpoint in the steady state before you start tuning. This step increases the values at the outputs for cooling and activates the outputs for heating (PidOutputSum > 0.0). Fine tuning heating is now possible. When fine tuning is complete, TIR.OutputOffsetCool is reset to 0.0. Major changes at TIR.OutputOffsetCool in one step can result in temporary overshoots. Config.Output.Cool.PidUpperLimit ≥ PIDSelfTune.TIR.OutputOffsetCool ≥ Config.Output.Cool.PidLowerLimit
PIDSelfTune.TIR.WaitForControlIn	BOOL	FALSE	Waiting with fine tuning after reaching the setpoint If TIR.WaitForControlIn = TRUE, fine tuning waits in between reaching the setpoint (TIR.State = 500 or 600) and calculation of the standard deviation (TIR.State = 700 or 800) until a FALSE -> TRUE edge is given at TIR.FinishControlIn. TIR.WaitForControlIn can be used for simultaneous fine tuning of several controllers in multi-zone applications (Page 203) to synchronize tuning of the individual zones. It ensures that all zones have reached their setpoints before the actual tuning starts. The influence of thermal connections between the zones on tuning can be reduced in this way. TIR.WaitForControlIn only takes effect if fine tuning is started from automatic mode with PIDSelfTune.TIR.RunIn = FALSE.

Tag	Data type	Default	Description
PIDSelfTune.TIR.ControlInReady	BOOL	FALSE	If the setpoint is reached during fine tuning, PID_Temp sets TIR.ControlInReady = TRUE. If TIR.WaitForControlIn = TRUE has been set before, PID_Temp waits for additional tuning steps until an edge FALSE -> TRUE is given at TIR.FinishControlIn. If TIR.WaitForControlIn = FALSE, PID_Temp continues the tuning directly and TIR.ControlInReady is not relevant.
PIDSelfTune.TIR.FinishControlIn	BOOL	FALSE	If TIR.WaitForControlIn = TRUE and TIR.ControlInReady = TRUE, a FALSE -> TRUE edge at TIR.FinishControlIn stops the wait and fine tuning resumes.
PIDCtrl.PIDInit	BOOL	FALSE	PIDCtrl.PIDInit is available as of PID_Temp version 1.1. If PIDCtrl.PIDInit = TRUE in "Automatic mode", the integral action PIDCtrl.IOutputOld is preassigned automatically as if PidOutputSum = OverwriteInitialOutputValue in the previous cycle. This can be used for a Override control with PID_Temp (Page 205).
PIDCtrl.IntegralHoldPositive	BOOL	FALSE	Manual stop of the integral action in the positive direction PIDCtrl.IntegralHoldPositive is available as of PID_Temp Version 2.0.
PIDCtrl.IntegralHoldNegative	BOOL	FALSE	Manual stop of the integral action in the negative direction PIDCtrl.IntegralHoldNegative is available as of PID_Temp Version 2.0.
PIDCtrl.IOutputOld(1)	REAL	0.0	Integral action in last cycle
Retain.CtrlParams.SetByUser(1)	BOOL	FALSE	Enable manual input of PID parameters If Retain.CtrlParams.SetByUser = TRUE, the PID parameters are editable. Retain.CtrlParams.SetByUser is used for configuring the controller in the TIA Portal and has no influence on the behavior of the control algorithm in the CPU. SetByUser is retentive.
Retain.CtrlParams.Heat.Gain(1)	REAL	1.0	Active proportional gain for heating Heat.Gain is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.Gain ≥ 0.0
Retain.CtrlParams.Heat.Ti(1)	REAL	20.0	Active integration time for heating in seconds The integral action for heating is switched off with Heat.CtrlParams.Ti = 0.0. Heat.Ti is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). 100000.0 ≥ Heat.Ti ≥ 0.0
Retain.CtrlParams.Heat.Td(1)	REAL	0.0	Active derivative action time for heating in seconds The derivative action for heating is switched off with Heat.CtrlParams.Td = 0.0. Heat.Td is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). 100000.0 ≥ Heat.Td ≥ 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.Heat.TdFiltRatio(1)	REAL	0.2	Active derivative delay coefficient for heating The derivative delay coefficient delays the effect of the derivative action. Derivative delay = derivative action time × derivative delay coefficient • 0.0: Derivative action is effective for one cycle only and therefore almost not effective. • 0.5: This value has proved useful in practice for controlled systems with **one** dominant time constant. • > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed. Heat.TdFiltRatio is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.TdFiltRatio ≥ 0.0
Retain.CtrlParams.Heat.PWeighting(1)	REAL	1.0	Active weighting of the proportional action for heating The proportional action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Proportional action for setpoint change is fully effective • 0.0: Proportional action for setpoint change is not effective The proportional action is always fully effective when the process value is changed. Heat.PWeighting is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). 1.0 ≥ Heat.PWeighting ≥ 0.0
Retain.CtrlParams.Heat.DWeighting (1)	REAL	1.0	Active weighting of the derivative action for heating The derivative action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Derivative action is fully effective upon setpoint change • 0.0: Derivative action is not effective upon setpoint change The derivative action is always fully effective when the process value is changed. Heat.DWeighting is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). 1.0 ≥ Heat.DWeighting ≥ 0.0
Retain.CtrlParams.Heat.Cycle(1)	REAL	1.0	Active sampling time of the PID algorithm for heating in seconds CtrlParams.Heat.Cycle is calculated during tuning and rounded to an integer multiple of CycleTime.Value. If Config.Output.Heat.PwmPeriode = 0.0, Heat.Cycle is also used as period duration of the pulse width modulation for heating. If Config.Output.Cool.PwmPeriode = 0.0 and Config.ActivateCooling = TRUE and Config.AdvancedCooling = FALSE, Heat.Cycle is also used as period duration of the pulse width modulation for cooling. Heat.Cycle is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). 100000.0 ≥ Heat.Cycle > 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.Heat.ControlZone (1)	REAL	3.402822e+-38	Active control zone width for heating The control zone for heating is switched off with Heat.ControlZone = 3.402822e+38. Heat.ControlZone is only set automatically during pretuning heating or pretuning heating and cooling if PIDSelfTune.SUT.TuneRuleHeat = 2 is selected as method of the parameter calculation. For controllers with activated heating output (Config.ActivateHeating = TRUE) and deactivated cooling output (Config.ActivateCooling = FALSE) or controllers with activated heating and cooling output and cooling factor (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = FALSE) the control zone is located symmetrically between Setpoint − Heat.ControlZone and Setpoint + Heat.ControlZone. For controllers with activated heating output and cooling output and PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE), the control zone is located between Setpoint − Heat.ControlZone and Setpoint + Cool.ControlZone. Heat.ControlZone is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.ControlZone > 0.0
Retain.CtrlParams.Heat.DeadZone(1)	REAL	0.0	Active dead zone width for heating (see PID parameters (Page 177)) The dead zone for heating is switched off with Heat.DeadZone = 0.0. Heat.DeadZone is not set automatically or adjusted during tuning. You must correctly configure Heat.DeadZone manually. When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning. For controllers with activated heating output (Config.ActivateHeating = TRUE) and deactivated cooling output (Config.ActivateCooling = FALSE) or controllers with activated heating and cooling output and cooling factor (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = FALSE), the dead zone is located symmetrically between Setpoint − Heat.DeadZone and Setpoint + Heat.DeadZone. For controllers with activated heating output and cooling output and PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE), the dead zone is located between Setpoint − Heat.DeadZone and Setpoint + Cool.DeadZone. Heat.DeadZone is retentive. Only takes effect if the heating output is activated (Config.ActivateHeating = TRUE). Heat.DeadZone ≥ 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.Cool.Gain(1)	REAL	1.0	Active proportional gain for cooling Cool.Gain is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. Cool.Gain ≥ 0.0
Retain.CtrlParams.Cool.Ti(1)	REAL	20.0	Active integration time for cooling in seconds The integral action for cooling is switched off with Cool.CtrlParams.Ti = 0.0. Cool.Ti is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. 100000.0 ≥ Cool.Ti ≥ 0.0
Retain.CtrlParams.Cool.Td(1)	REAL	0.0	Active derivative action time for cooling in seconds The derivative action for cooling is switched off with Cool.CtrlParams.Td = 0.0. Cool.Td is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. 100000.0 ≥ Cool.Td ≥ 0.0
Retain.CtrlParams.Cool.TdFiltRatio(1)	REAL	0.2	Active derivative delay coefficient for cooling The derivative delay coefficient delays the effect of the derivative action. Derivative delay = derivative action time × derivative delay coefficient • 0.0: Derivative action is effective for one cycle only and therefore almost not effective. • 0.5: This value has proved useful in practice for controlled systems with one dominant time constant. • > 1.0: The greater the coefficient, the longer the effect of the derivative action is delayed. Cool.TdFiltRatio is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. Cool.TdFiltRatio ≥ 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.Cool.PWeighting(-1)	REAL	1.0	Active weighting of the proportional action for cooling The proportional action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Proportional action for setpoint change is fully effective • 0.0: Proportional action for setpoint change is not effective The proportional action is always fully effective when the process value is changed. Cool.PWeighting is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. 1.0 ≥ Cool.PWeighting ≥ 0.0
Retain.CtrlParams.Cool.DWeighting(1)	REAL	1.0	Active weighting of the derivative action for cooling The derivative action may weaken with changes to the setpoint. Values from 0.0 to 1.0 are applicable. • 1.0: Derivative action is fully effective upon setpoint change • 0.0: Derivative action is not effective upon setpoint change The derivative action is always fully effective when the process value is changed. Cool.DWeighting is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. 1.0 ≥ Cool.DWeighting ≥ 0.0
Retain.CtrlParams.Cool.Cycle(1)	REAL	1.0	Active sampling time of the PID algorithm for cooling in seconds CtrlParams.Cool.Cycle is calculated during tuning and rounded to an integer multiple of CycleTime.Value. If Config.Output.Cool.PwmPeriode = 0.0 and also Config.ActivateHeating = FALSE or Config.AdvancedCooling = TRUE, Cool.Cycle is also used as period duration of the pulse width modulation for cooling. If Config.Output.Cool.PwmPeriode = 0.0, Config.ActivateHeating = TRUE and Config.AdvancedCooling = FALSE, Heat.Cycle is used as period duration of the pulse width modulation for cooling. Cool.Cycle is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. 100000.0 ≥ Cool.Cycle > 0.0

Tag	Data type	Default	Description
Retain.CtrlParams.Cool.ControlZone (1)	REAL	3.402822e+-38	Active control zone width for cooling The control zone for cooling is switched off with Cool.ControlZone = 3.402822e+38. Cool.ControlZone is only set automatically during pretuning cooling or pretuning heating and cooling if PIDSelfTune.SUT.TuneRuleCool = 2 is selected as method of the parameter calculation. For controllers with activated heating output and cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE), the control zone is located between Setpoint - Heat.ControlZone and Setpoint + Cool.ControlZone. For controllers with deactivated heating output (Config.ActivateHeating = FALSE) and activated cooling output (Config.ActivateCooling = TRUE), the control zone is located symmetrically between Setpoint - Cool.ControlZone and Setpoint + Cool.ControlZone. Cool.ControlZone is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. Cool.ControlZone > 0.0
Retain.CtrlParams.Cool.DeadZone(1)	REAL	0.0	Active dead zone width for cooling (see PID parameters (Page 177)) The dead zone for cooling is switched off with Cool.DeadZone = 0.0. Cool.DeadZone is not set automatically or adjusted during tuning. You must correctly configure Cool.DeadZone manually. When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning. For controllers with activated heating output and cooling output and PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE), the dead zone is located between Setpoint - Heat.DeadZone and Setpoint + Cool.DeadZone. For controllers with deactivated heating output (Config.ActivateHeating = FALSE) and activated cooling output (Config.ActivateCooling = TRUE), the dead zone is located symmetrically between Setpoint - Cool.DeadZone and Setpoint + Cool.DeadZone. Cool.DeadZone is retentive. Only takes effect when the heating output and the cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE) or only the cooling output (Config.ActivateHeating = FALSE, Config.ActivateCooling = TRUE) is activated. Cool.DeadZone ≥ 0.0

11.3.4.7 PID_Temp state and mode parameters

Correlation of the parameters

The State parameter shows the current operating mode of the PID controller. You cannot change the State parameter.

With a rising edge at ModeActivate, PID_Temp switches to the operating mode saved in the Mode in-out parameter.

Heat.EnableTuning and Cool.EnableTuning specify for pretuning and fine tuning, if tuning takes place for heating or cooling.

When the CPU is switched on or switches from Stop to RUN mode, PID_Temp starts in the operating mode saved in the Mode parameter. To retain PID_Temp in "Inactive" mode, set RunModeByStartup = FALSE.

Meaning of values

State / Mode	Description of operating mode
0	**Inactive** The following output values are output in "Inactive" mode: • 0.0 as PID output value (PidOutputSum) • 0.0 as output value for heating (OutputHeat) and output value for cooling (OutputCool) • 0 as analog output value for heating (OutputHeat_PER) and analog output value for cooling (OutputCool_PER) • FALSE as PWM output value for heating (OutputHeat_PWM) and PWM output value for cooling (OutputCool_PWM) This does not depend on the configured output value limits and scaling in the structures Config.Output.Heat and Config.Output.Cool.
1	**Pretuning** The pretuning determines the process response to a jump change of the output value and searches for the point of inflection. The PID parameters are calculated from the maximum rate of rise and dead time of the controlled system. You obtain the best PID parameters when you perform pretuning and fine tuning. PID_Temp offers different pretuning types depending on the configuration: • Pretuning heating: A jump change is output at the output value heating, the PID parameters for heating are calculated (Retain.CtrlParams.Heat structure), and control to the setpoint then takes place in automatic mode. If the process behavior strongly depends on the operating point, an adaptation of the delay time can be activated at the setpoint with PIDSelfTune.SUT.AdaptDelayTime. • Pretuning heating and cooling: A jump is output at the output value heating. As soon as the process value is close to the setpoint, a jump change is output at the output value cooling. The PID parameters for heating (Retain.CtrlParams.Heat structure) and cooling (Retain.CtrlParams.Cool structure) are calculated. Then, control to the setpoint takes place in automatic mode. If the process behavior strongly depends on the operating point, an adaptation of the delay time can be activated at the setpoint with PIDSelfTune.SUT.AdaptDelayTime. Depending on the effect of the cooling actuator compared to the heating actuator, the quality of tuning can be influenced by whether or not the heating and cooling outputs are operated simultaneously during tuning. You can specify this with PIDSelfTune.SUT.CoolingMode. • Pretuning cooling: A jump change is output at the output value cooling and the PID parameters for cooling are calculated (Retain.CtrlParams.Cool structure). Then, control to the setpoint takes place in automatic mode.

State / Mode	Description of operating mode
	Depending on the configuration, the pretuning cooling can be started from two different operating states: – After pretuning for heating and with process value close to the setpoint: This option is available for all versions of PID_Temp, for controllers with activated heating output and cooling output with PID parameter switching (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE, Config.AdvancedCooling = TRUE). – Process value with sufficient distance to the setpoint: This option is also available for PID_Temp from V2.0 for controllers with activated cooling output (Config.ActivateCooling = TRUE) regardless of the activation of the heating output (Config.ActivateHeating). If the process behavior is heavily dependent on the operating point, setting PIDSelfTune.SUT.AdaptDelayTime for this option can be used to adapt the delay time to the setpoint. If you want to tune the PID parameters for heating and cooling, you can expect improved control response by carrying out "Pretuning heating" and subsequently "Pretuning cooling" than by carrying out "Pretuning heating and cooling". However, carrying out pretuning in two steps takes more time. **General requirements for pretuning:** • The PID_Temp instruction is called in a cyclic interrupt OB. • Inactive (State = 0), manual mode (State = 4), or automatic mode (State = 3) • ManualEnable = FALSE • Reset = FALSE • The setpoint and the process value lie within the configured limits. **Requirements for pretuning heating:** • Heat.EnableTuning = TRUE • Cool.EnableTuning = FALSE • The heating output is activated (Config.ActivateHeating = TRUE). • The process value must not be too close to the setpoint. |Setpoint - Input| > 0.3 * |Config.InputUpperLimit - Config.InputLowerLimit| and |Setpoint - Input| > 0.5 * |Setpoint| • The setpoint is greater than the process value. Setpoint > Input **Requirements for pretuning heating and cooling:** • Heat.EnableTuning = TRUE • Cool.EnableTuning = TRUE • The heating output and cooling output are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE). • The PID parameter switching is activated (Config.AdvancedCooling = TRUE). • The process value must not be too close to the setpoint. |Setpoint - Input| > 0.3 * |Config.InputUpperLimit - Config.InputLowerLimit| and |Setpoint - Input| > 0.5 * |Setpoint| • The setpoint is greater than the process value. Setpoint > Input **Requirements for pretuning cooling with process value close to the setpoint:** • Heat.EnableTuning = FALSE • Cool.EnableTuning = TRUE • The heating output and cooling output are activated (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE). • The PID parameter switching is activated (Config.AdvancedCooling = TRUE). • "Pretuning heating" or "Pretuning heating and cooling" has been carried out successfully, if possible at the same setpoint. Successful execution is indicated by PIDSelfTune.SUT.ProcParHeatOk = TRUE. • The process value must be close to the setpoint. |Setpoint - Input| < 0.05 * |Config.InputUpperLimit - Config.InputLowerLimit|

State / Mode	Description of operating mode
	Requirements for pretuning cooling with distance between process value and setpoint • PID_Temp as of V2.0 • Heat.EnableTuning = FALSE • Cool.EnableTuning = TRUE • The cooling output is activated (Config.ActivateCooling = TRUE). • If the heating output is activated (Config.ActivateHeating = TRUE), PID parameter switching must also be activated (Config.AdvancedCooling = TRUE). • The process value must not be too close to the setpoint. |Setpoint - Input| > 0.3 * |Config.InputUpperLimit - Config.InputLowerLimit| and |Setpoint - Input| > 0.5 * |Setpoint| • The setpoint is less than the process value. Setpoint < Input The more stable the process value is, the easier it is to calculate the PID parameters and the more precise the result will be. Noise on the process value can be tolerated as long as the rate of rise of the process value is significantly higher compared to the noise. This is most likely the case in operating modes "Inactive" or "Manual mode". The setpoint is frozen in the CurrentSetpoint tag. Tuning is canceled when: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel The method for calculation of the PID parameters can be specified separately for heating and cooling with PIDSelfTune.SUT.TuneRuleHeat and PIDSelfTune.SUT.TuneRuleCool. Before the PID parameters are recalculated, they are backed up in the CtrlParamsBackUp structure and can be reactivated with LoadBackUp. After successful pretuning, the switch is made to automatic mode. After unsuccessful pretuning, the switch to the mode is determined by ActivateRecoverMode. The phase of pretuning is indicated with PIDSelfTune.SUT.State. For starting pretuning in automatic mode, it is recommended to perform the required setpoint change simultaneously with the rising edge at ModeActivate. If the setpoint is changed first and the pretuning is started later, the output value in automatic mode is adjusted accordingly and causes a change to the process value. This can have a negative effect on the subsequent pretuning or prevent it from starting.
2	**Fine tuning** Fine tuning generates a constant, limited oscillation of the process value. The PID parameters are tuned for the operating point from the amplitude and frequency of this oscillation. PID parameters from fine tuning usually have better master control and disturbance characteristics than PID parameters from pretuning. You obtain the best PID parameters when you perform pretuning and fine tuning. PID_Temp automatically attempts to generate an oscillation greater than the noise of the process value. Fine tuning is only minimally influenced by the stability of the process value. PID_Temp offers different fine tuning types depending on the configuration: • Fine tuning heating: PID_Temp generates an oscillation of the process value with periodic changes at the output value heating and calculates the PID parameters for heating (Retain.CtrlParams.Heat structure). • Fine tuning cooling: PID_Temp generates an oscillation of the process value with periodic changes at the output value cooling and calculates the PID parameters for cooling (Retain.CtrlParams.Cool structure). **Temporary tuning offset for heating/cooling controllers** If PID_Temp is used as a heating/cooling controller (Config.AcitvateHeating = TRUE, Config.ActivateCooling = TRUE), the PID output value (PidOutputSum) at the setpoint has to fulfill the following requirements so that process value oscillation can be generated and fine tuning can be carried out successfully: • Positive PID output value for fine tuning heating • Negative PID output value for fine tuning cooling

State / Mode	Description of operating mode
	If this requirement is not met, you can define a temporary offset for fine tuning which is output at the output with the opposite effect: • Offset for cooling output (PIDSelfTune.TIR.OutputOffsetCool) with fine tuning heating. Before starting tuning, enter a negative tuning offset cooling that is lower than the PID output value (PidOutputSum) at the setpoint in the stationary state. • Offset for heating output (PIDSelfTune.TIR.OutputOffsetHeat) with fine tuning cooling. Before starting tuning, enter a positive tuning offset heating that is higher than the PID output value (PidOutputSum) at the setpoint in the stationary state. The defined offset is balanced by the PID algorithm so that the process value remains at the setpoint. The height of the offset allows the PID output value to be adapted correspondingly so that it fulfills the requirement mentioned above. To avoid larger overshoots of the process value when defining the offset, it can also be increased in several steps. If PID_Temp exits the fine tuning mode, the tuning offset is reset. Example for definition of an offset for fine tuning cooling: • Without offset: – Setpoint = Process value (ScaledInput) = 80 °C – PID output value (PidOutputSum) = 30.0 – Output value heating (OutputHeat) = 30.0 – Output value cooling (OutputCool) = 0.0 Oscillation of the process value around the setpoint cannot be generated with the cooling output alone. Fine tuning would fail here. • With definition of an offset for heating output (PIDSelfTune.TIR.OutputOffsetHeat) = 80.0 – Setpoint = Process value (ScaledInput) = 80 °C – PID output value (PidOutputSum) = -50.0 – Output value heating (OutputHeat) = 80.0 – Output value cooling (OutputCool) = -50.0 By defining an offset for the heating output, the cooling output can now create an oscillation of the process value around the setpoint. Fine tuning can now be carried out successfully. **General requirements for fine tuning:** • The PID_Temp instruction is called in a cyclic interrupt OB. • No disturbances are expected. • The setpoint and the process value lie within the configured limits. • The control loop has stabilized at the operating point. The operating point is reached when the process value corresponds to the setpoint. When the dead zone is switched on, the result can be a permanent control deviation (deviation between setpoint and process value). This can have a negative effect on fine tuning. • ManualEnable = FALSE • Reset = FALSE • Automatic (State = 3), inactive (State = 0) or manual (State = 4) mode **Requirements for fine tuning heating:** • Heat.EnableTuning = TRUE • Cool.EnableTuning = FALSE • The heating output is activated (Config.ActivateHeating = TRUE). • If PID_Temp is configured as heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the heating output must be active at the operating point at which tuning is to take place (PidOutputSum > 0.0 - see Tuning offset). **Requirements for fine tuning cooling:** • Heat.EnableTuning = FALSE • Cool.EnableTuning = TRUE

State / Mode	Description of operating mode
	• The cooling output is activated (Config.ActivateCooling = TRUE). • If the heating output is activated (Config.ActivateHeating = TRUE), PID parameter switching must also be activated (Config.AdvancedCooling = TRUE). • If PID_Temp is configured as heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), the cooling output must be active at the operating point at which tuning is to take place (PidOutputSum < 0.0 - see Tuning offset). **The course of fine tuning is determined by the mode from which it is started:** • Automatic mode (State = 3) with PIDSelfTune.TIR.RunIn = FALSE (default) Start fine tuning from automatic mode if you wish to improve the existing PID parameters through tuning. PID_Temp controls the system using the existing PID parameters until the control loop has stabilized and the requirements for fine tuning have been met. Only then will fine tuning start. • Inactive (State = 0), manual mode (State = 4), or automatic mode (State = 3) with PIDSelfTune.TIR.RunIn = TRUE Attempts are made to reach the setpoint with the minimum or maximum output value: – with minimum or maximum output value heating for fine tuning heating – With minimum or maximum output value cooling for fine tuning cooling. This can produce increased overshoot. When the setpoint is reached, fine tuning is started. If the setpoint cannot be reached, PID_Temp does not abort tuning automatically. The setpoint is frozen in the CurrentSetpoint tag. Tuning is canceled when: • Setpoint > CurrentSetpoint + CancelTuningLevel or • Setpoint < CurrentSetpoint - CancelTuningLevel The method for calculation of the PID parameters can be specified separately for heating and cooling with PIDSelfTune.TIR.TuneRuleHeat and PIDSelfTune.TIR.TuneRuleCool. Before the PID parameters are recalculated, they are backed up in the CtrlParamsBackUp structure and can be reactivated with LoadBackUp. The controller changes to automatic mode after successful fine tuning. After unsuccessful fine tuning, the switch to the mode is determined by ActivateRecoverMode. The "Fine tuning" phase is indicated with PIDSelfTune.TIR.State.
3	**Automatic mode** In automatic mode, PID_Temp corrects the controlled system in accordance with the parameters specified. The controller switches to automatic mode if one the following requirements is fulfilled: • Pretuning successfully completed • Fine tuning successfully completed • Changing of the Mode in-out parameter to the value 3 and a rising edge at ModeActivate. The switchover from automatic mode to manual mode is only bumpless if carried out in the commissioning editor. The ActivateRecoverMode tag is taken into consideration in automatic mode.
4	**Manual mode** In manual mode, you specify a manual PID output value in the ManualValue parameter. The values at the outputs for heating and cooling resulting from this manual value are the result of the configured output scaling. With the preset output scaling, specify a negative manual value to obtain a positive value at the outputs for cooling. Example with default setting: ManualValue = -50.0 -> OutputCool = 50.0, ManualValue = -100.0 -> OutputCool = 100.0 You can also activate this operating mode using ManualEnable = TRUE. We recommend that you change the operating mode using Mode and ModeActivate only. The switchover from manual mode to automatic mode is bumpless. The ActivateRecoverMode tag is taken into consideration in manual mode.

State / Mode	Description of operating mode
5	**Substitute output value with error monitoring** The control algorithm is deactivated. The SetSubstituteOutput tag determines which PID output value (PidOutputSum) is output in this operating mode. • SetSubstituteOutput = FALSE: Last valid PID output value • SetSubstituteOutput = TRUE: Substitute output value (SubstituteOutput) You cannot activate this operating mode using Mode = 5. In the event of an error, it is activated instead of "Inactive" operating mode if all the following conditions are met: • Automatic mode (State = 3) • ActivateRecoverMode = TRUE • One or more errors have occurred in which ActivateRecoverMode (Page 425) is effective. As soon as the errors are no longer pending, PID_Temp switches back to automatic mode. With the preset output scaling, specify a negative substitute output value to obtain a positive value at the outputs for cooling. Example with default setting: SubstituteOutput = -50.0 -> OutputCool = 50.0, SubstituteOutput = -100.0 -> OutputCool = 100.0.

ENO characteristics

If State = 0, then ENO = FALSE.

If State ≠ 0, then ENO = TRUE.

Automatic switchover of operating mode during commissioning

Automatic mode is activated following successful pretuning or fine tuning. The following table shows how Mode and State change during successful pretuning.

Cycle no.	Mode	State	Action
0	4	4	Set Mode = 1
1	1	4	Set ModeActivate = TRUE
1	4	1	Value of State is saved in Mode parameter Pretuning is started
n	4	1	Pretuning successfully completed
n	3	3	Automatic mode is started

PID_Temp automatically switches the operating mode in the event of an error.

The following table shows how Mode and State change during pretuning with errors.

Cycle no.	Mode	State	Action
0	4	4	Set Mode = 1
1	1	4	Set ModeActivate = TRUE
1	4	1	Value of State is saved in Mode parameter Pretuning is started
n	4	1	Pretuning canceled
n	4	4	Manual mode is started

If ActivateRecoverMode = TRUE, the operating mode saved in the Mode parameter is activated. When you start pretuning or fine tuning, PID_Temp has saved the value of State in the Mode in-out parameter. This means PID_Temp switches to the mode from which tuning was started.

If ActivateRecoverMode = FALSE, the system switches to "Inactive" operating mode.

See also

Output parameters of PID_Temp (Page 384)

In/out parameters of PID_Temp V2 (Page 386)

11.3.4.8 PID_Temp ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

ErrorBits (DW#16#...)	Description
0000_0000	There is no error.
0000_0001	The "Input" parameter is outside the process value limits. • Input > Config.InputUpperLimit or • Input < Config.InputLowerLimit If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in automatic mode. If manual mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in manual mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter.
0000_0002	Invalid value at "Input_PER" parameter. Check whether an error is pending at the analog input. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp outputs the configured substitute output value. As soon as the error is no longer pending, PID_Temp switches back to automatic mode. If manual mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in manual mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter.
0000_0004	Error during fine tuning. The oscillation of the process value could not be maintained. If PID_Temp is used as a heating/cooling controller (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE), then in order to generate a process value oscillation and successfully carry out the fine tuning, the PID output value (PidOutputSum) at the setpoint must be • positive for fine tuning heating • negative for fine tuning cooling If this requirement is not met, use the tuning offsets (PIDSelfTune.TIR.OutputOffsetCool and PIDSelfTune.TIR.OutputOffsetHeat tags), see Fine tuning (Page 189). If there was ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.

ErrorBits (DW#16#...)	Description
0000_0008	Error at start of pretuning heating/cooling. The process value is too close to the setpoint or greater/less than the setpoint. Start fine tuning. The tuning requirements are described under parameters State and Mode PID_Temp (Page 416). If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0010	The setpoint was changed during tuning. You can set the permitted fluctuation of the setpoint at the CancelTuningLevel tag. If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0020	Pretuning is not permitted during fine tuning. If ActivateRecoverMode = TRUE before the error occurred, PID_Temp remains in fine tuning mode.
0000_0040	Error during pretuning. Cooling could not reduce the process value. If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0100	Error during fine tuning resulted in invalid parameters. If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0000_0200	Invalid value at "Input" parameter: Value has an invalid number format. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp outputs the configured substitute output value. As soon as the error is no longer pending, PID_Temp switches back to automatic mode. If manual mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in manual mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter.
0000_0400	Calculation of output value failed. Check the PID parameters. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp outputs the configured substitute output value. As soon as the error is no longer pending, PID_Temp switches back to automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter.
0000_0800	Sampling time error: PID_Temp is not called within the sampling time of the cyclic interrupt OB. It is recommended to call PID_Temp in a cyclic interrupt OB without conditions and to activate or deactivate it via the operating mode at the Mode parameter. Conditional calls or the call in OB1 can have a negative effect on the control quality. Monitoring of the sampling time can be disabled with CycleTime.EnMonitoring = FALSE. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in automatic mode. If manual mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in manual mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter. If this error occurred during simulation with PLCSIM, see the notes under Simulating PID_Temp with PLCSIM (Page 209).
0000_1000	Invalid value at "Setpoint" parameter or "SubstituteSetpoint": Value has an invalid number format. If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp outputs the configured substitute output value. As soon as the error is no longer pending, PID_Temp switches back to automatic mode. If manual mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in manual mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter.

ErrorBits (DW#16#...)	Description
0001_0000	Invalid value at ManualValue parameter. Value has an invalid number format. If ActivateRecoverMode = TRUE before the error occurred, PID_Temp remains in manual mode and uses SubstituteOutput as PID output value. As soon as you specify a valid value in ManualValue, PID_Temp uses it as the PID output value.
0002_0000	Invalid value at SubstituteOutput tag. Value has an invalid number format. PID_Temp remains in the "Substitute output value with error monitoring" mode or manual mode and uses Config.Output.Heat.PidLowerLimit or Config.Output.Cool.PidUpperLimit as PID output value. As soon as you specify a valid value in SubstituteOutput, PID_Temp uses it as the PID output value.
0004_0000	Invalid value at Disturbance parameter. Value has an invalid number format. If automatic mode was active and ActivateRecoverMode = TRUE before the error occurred, Disturbance is set to zero. PID_Temp remains in automatic mode. If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred , PID_Temp switches to the operating mode saved in the Mode parameter. If Disturbance in the current phase has no effect on the output value, tuning is not be canceled.
0020_0000	Error in master in the cascade (Page 196): Slaves are not in automatic mode or have enabled a substitute setpoint and are preventing tuning of the master. If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0040_0000	Pretuning heating is not permitted while cooling is active. The tuning requirements are described under parameters State and Mode PID_Temp (Page 416). If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0080_0000	The process value must be close to the setpoint or have sufficient distance to the setpoint to start pretuning cooling. The tuning requirements are described under parameters State and Mode PID_Temp (Page 416). If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0100_0000	Error at start of tuning: Heat.EnableTuning and Cool.EnableTuning are not set or do not match the configuration. The tuning requirements are described under parameters State and Mode PID_Temp (Page 416). If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0200_0000	Pretuning of cooling with process value close to the setpoint requires successful pretuning heating. The tuning requirements are described under parameters State and Mode PID_Temp (Page 416). If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0400_0000	Error at start of fine tuning: Heat.EnableTuning and Cool.EnableTuning must not be set simultaneously. The tuning requirements are described under parameters State and Mode PID_Temp (Page 416). If ActivateRecoverMode = TRUE before the error occurred, PID_Temp cancels the tuning and switches to the operating mode saved in the Mode parameter.
0800_0000	Error during calculation of the PID parameters resulted in invalid parameters. The invalid parameters are discarded and the original PID parameters are retained unchanged. If this error occurs during pretuning, make sure that: • Pretuning heating or pretuning heating and cooling: The PID output value is not already limited by the high limit for heating before the start of the pretuning. • Pretuning cooling: The PID output value is not already limited by the low limit for cooling before the start of the pretuning. For starting a pretuning in automatic mode, it is recommended to perform the required setpoint change simultaneously with the rising edge at ModeActivate. This prevents the PID output value from running into the limitation between the setpoint change and the start of the pretuning. Alternatively, this can also be achieved by starting from manual mode or "Inactive" mode.

ErrorBits (DW#16#...)	Description
	A distinction is made between the following scenarios: • If automatic mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in automatic mode. • If manual mode was active before the error occurred and ActivateRecoverMode = TRUE, PID_Temp remains in manual mode. • If pretuning or fine tuning mode was active and ActivateRecoverMode = TRUE before the error occurred, PID_Temp switches to the operating mode saved in the Mode parameter.

11.3.4.9 PID_Temp ActivateRecoverMode tag

The ActivateRecoverMode tag determines the response in the event of an error. The Error parameter indicates if an error is pending. When the error is no longer pending, Error = FALSE. The ErrorBits parameter shows which errors have occurred.

Automatic mode and manual mode

NOTICE
Your system may be damaged. If ActivateRecoverMode = TRUE, PID_Temp remains in automatic mode or in manual mode even if there is an error and the process value limits are exceeded. This may damage your system. It is essential to configure how your controlled system reacts in the event of an error to protect your system from damage.

ActivateRecover-Mode	Description
FALSE	PID_Temp switches to "Inactive" mode in the event of an error. The controller is only activated by a falling edge at Reset or a rising edge at ModeActivate.
TRUE	**Automatic mode** If errors occur frequently in automatic mode, this setting has a negative effect on the control response, because PID_Temp switches between the calculated PID output value and the substitute output value at each error. In this case, check the ErrorBits parameter and eliminate the cause of the error. If one or several of the following errors occur and automatic mode was active before the error occurred, PID_Temp remains in automatic mode: • 0000001h: The "Input" parameter is outside the process value limits. • 0000800h: Sampling time error • 0040000h: Invalid value at Disturbance parameter. • 8000000h: Error during calculation of the PID parameters If one or several of the following errors occur and automatic mode was active before the error occurred, PID_Temp switches to "Substitute output value with error monitoring" mode: • 0000002h: Invalid value at Input_PER parameter. • 0000200h: Invalid value at Input parameter. • 0000400h: Calculation of output value failed. • 0001000h: Invalid value at Setpoint parameter or SubstituteSetpoint. As soon as the errors are no longer pending, PID_Temp switches back to automatic mode.

ActivateRecover-Mode	Description
TRUE	If the following error occurs in "Substitute output value with error monitoring" mode, PID_Temp sets the PID output value to Config.Output.Heat.PidLowerLimit as long as this error is pending: • 0020000h: Invalid value at SubstituteOutput tag. Value has an invalid number format. This behavior is independent of SetSubstituteOutput.
	Manual mode If one or several errors occur and manual mode was active before the error occurred, PID_Temp remains in manual mode. If the following error occurs in manual mode, as long as this error is pending, PID_Temp sets the PID output value to SubstituteOutput: • 0010000h: Invalid value at ManualValue parameter. Value has an invalid number format. If the error 0010000h is pending in manual mode and the following error occurs, PID_Temp sets the PID output value to Config.Output.Heat.PidLowerLimit as long as this error is pending: • 0020000h: Invalid value at SubstituteOutput tag. Value has an invalid number format. This behavior is independent of SetSubstituteOutput.

Pretuning and fine tuning

ActivateRecover-Mode	Description
FALSE	PID_Temp switches to "Inactive" mode in the event of an error. The controller is only activated by a falling edge at Reset or a rising edge at ModeActivate.
TRUE	If the following error occurs, PID_Temp remains in the active mode: • 0000020h: Pretuning is not permitted during fine tuning. The following errors are ignored: • 0010000h: Invalid value at ManualValue parameter. • 0020000h: Invalid value at SubstituteOutput tag. When any other error occurs, PID_Temp cancels the tuning and switches to the mode from which tuning was started.

11.3.4.10 PID_Temp Warning tag

If several warnings are pending simultaneously, the values of the Warning tag are displayed with binary addition. The display of warning 16#0000_0003, for example, indicates that the warnings 16#0000_0001 and 16#0000_0002 are pending simultaneously.

Warning (DW#16#....)	Description
0000_0000	No warning pending.
0000_0001	The point of inflection was not found during pretuning.
0000_0004	The setpoint was limited to the configured limits.
0000_0008	Not all the necessary controlled system properties were defined for the selected method of calculation. Instead, the PID parameters were calculated using the method TIR.TuneRuleHeat = 3 or TIR.TuneRuleCool = 3.
0000_0010	The operating mode could not be changed because Reset = TRUE or ManualEnable = TRUE.

Warning (DW#16#....)	Description
0000_0020	The cycle time of the calling OB limits the sampling time of the PID algorithm. Improve results by using shorter OB cycle times.
0000_0040	The process value exceeded one of its warning limits.
0000_0080	Invalid value at Mode. The operating mode is not switched.
0000_0100	The manual value was restricted to the limits of the PID output value.
0000_0200	The specified rule for tuning is not supported. No PID parameters are calculated.
0000_1000	The substitute output value cannot be reached because it is outside the output value limits.
0000_4000	The specified selection of the output value for heating and/or cooling is not supported. Only the output OutputHeat or OutputCool is used.
0000_8000	Invalid value at PIDSelfTune.SUT.AdaptDelayTime. The default value 0 is used.
0001_0000	Invalid value at PIDSelfTune.SUT.CoolingMode. The default value 0 is used.
0002_0000	The simultaneous activation of heating and cooling (Config.ActivateHeating = TRUE, Config.ActivateCooling = TRUE) is not supported for a controller that is used as a master (Config.Cascade.IsMaster = TRUE). PID_Temp works as a heating controller. Deactivate the heating or cooling by setting Config.ActivateHeating or Config.ActivateCooling to FALSE.
0004_0000	Invalid value at Retain.CtrlParams.Heat.Gain, Retain.CtrlParams.Cool.Gain or Config.CoolFactor. PID_Temp supports only positive values for proportional gain (heating and cooling) and cooling factor. Automatic mode remains active with PID output value 0.0. The integral component is stopped.

The following warnings are deleted as soon as the cause has been remedied or you repeat the action with valid parameters:

- 16#0000_0001
- 16#0000_0004
- 16#0000_0008
- 16#0000_0040
- 16#0000_0100

All other warnings are cleared with a rising edge at Reset or ErrorAck.

11.3.4.11 PwmPeriode tag

If the PID algorithm sampling time (Retain.CtrlParams.Heat.Cycle or Retain.CtrlParams.Heat.Cycle) and thus the time period of the pulse width modulation is very high when OutputHeat_PWM or OutputCool_PWM is used, you can specify a deviating shorter period duration with the Config.Output.Heat.PwmPeriode or Config.Output.Cool.PwmPeriode parameters in order to improve smoothing of the process value.

Time period of the pulse width modulation at OutputHeat_PWM

Time period of the PWM at output OutputHeat_PWM depending on Config.Output.Heat.PwmPeriode:

- Heat.PwmPeriode = 0.0 (default)

  The sampling time of the PID algorithm for heating (Retain.CtrlParams.Heat.Cycle) is used as period duration of the PWM.

- Heat.PwmPeriode > 0.0

  The value is rounded off to an integer multiple of the PID_Temp sampling time (CycleTime.Value) and used as period duration of the PWM.

  The value must meet the following conditions:

  – Heat.PwmPeriode ≤ Retain.CtrlParams.Heat.Cycle
  – Heat.PwmPeriode > Config.Output.Heat.MinimumOnTime
  – Heat.PwmPeriode > Config.Output.Heat.MinimumOffTime

Time period of the pulse width modulation at OutputCool_PWM

Time period of the PWM at output OutputCool_PWM depending on Config.Output.Cool.PwmPeriode and the method for heating/cooling:

- Cool.PwmPeriode = 0.0, Config.ActivateHeating = TRUE and Config.AdvancedCooling = FALSE:

  The sampling time of the PID algorithm for heating (Retain.CtrlParams.Heat.Cycle) is used as period duration of the PWM.

- Cool.PwmPeriode = 0.0 and Config.ActivateHeating = FALSE

  or

  Cool.PwmPeriode = 0.0 and Config.AdvancedCooling = TRUE:

  The sampling time of the PID algorithm for cooling (Retain.CtrlParams.Cool.Cycle) is used as period duration of the PWM.

- Cool.PwmPeriode > 0.0:

  The value is rounded off to an integer multiple of the PID_Temp sampling time (CycleTime.Value) and used as period duration of the PWM.

  The value must meet the following conditions:

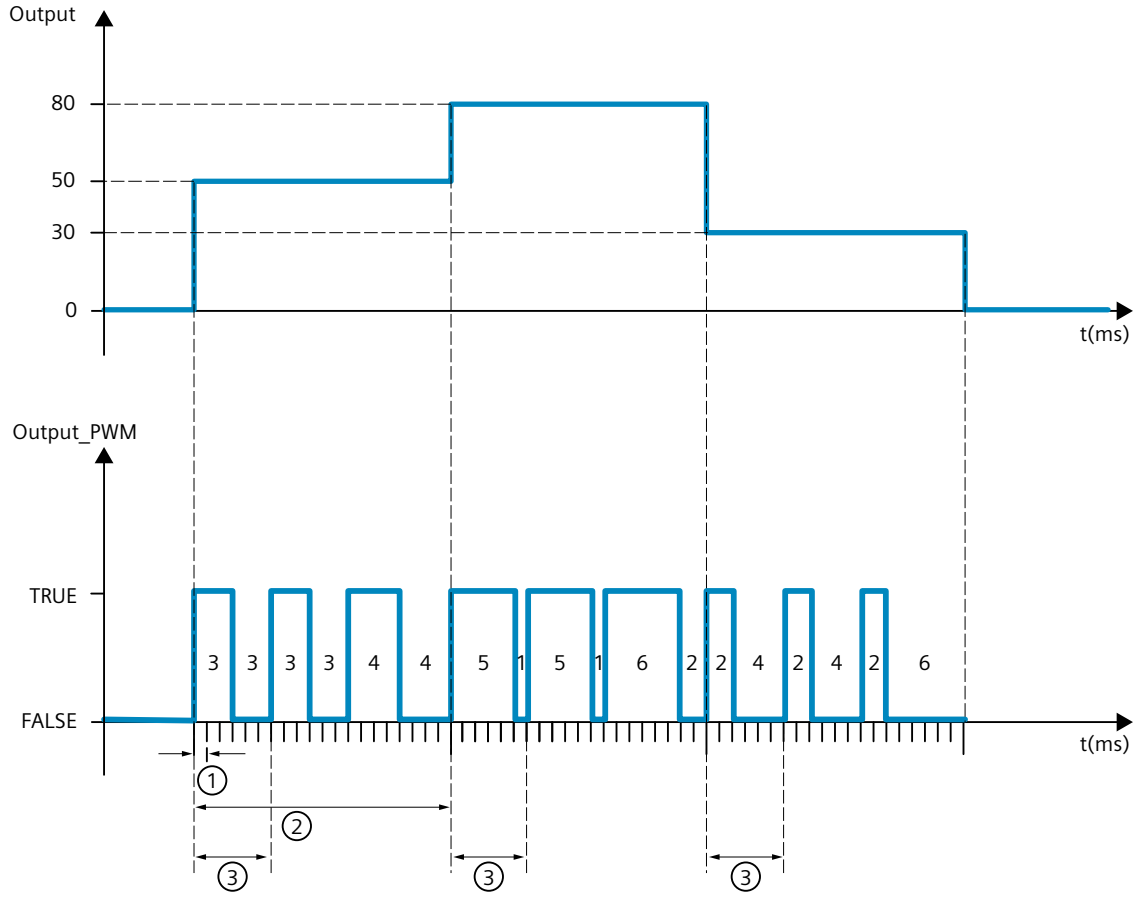
  – Cool.PwmPeriode ≤ Retain.CtrlParams.Cool.Cycle or Retain.CtrlParams.Heat.Cycle
  – Cool.PwmPeriode > Config.Output.Cool.MinimumOnTime
  – Cool.PwmPeriode > Config.Output.Cool.MinimumOffTime

Config.Output.Cool.PwmPeriode only takes effect if the cooling output is activated (Config.ActivateCooling = TRUE) and OutputCool_PWM is selected as output for cooling (Config.Output.Cool.Select = 1).

When you use PwmPeriode, the accuracy of the PWM output signal is determined by the ratio of PwmPeriode to the PID_Temp sampling time (cycle time of the OB). PwmPeriode should be at least 10 times the PID_Temp sampling time.

If the sampling time of the PID algorithm is not an integer multiple of PwmPeriode, each last period of the PWM within the sampling time of the PID algorithm is extended accordingly.

Example for OutputHeat_PWM



① PID_Temp sampling time = 100.0 ms (cycle time of the calling cyclic interrupt OB, CycleTime.Value tag)

② PID algorithm sampling time = 2000.0 ms (Retain.CtrlParams.Heat.Cycle tag)

③ Time period of the PWM for heating = 600.0 ms (Config.Output.Heat.PwmPeriode tag)

11.3.4.12 IntegralResetMode tag

The IntegralResetMode tag determines how the integral action PIDCtrl.IOutputOld is preassigned:

- When switching from "Inactive" operating mode to "Automatic mode"
- With edge TRUE -> FALSE at parameter Reset and parameter Mode = 3

This setting only works for one cycle and only takes effect if the integral action is activated (Retain.CtrlParams.Heat.Ti and Retain.CtrlParams.Cool.Ti > 0.0 tags).

IntegralReset-Mode	**Description**
0	Smooth The value of PIDCtrl.IOutputOld is preassigned so that the switchover is bumpless, which means "Automatic mode" starts with the output value = 0.0 (PidOutputSum parameter) and there is no jump of the output value regardless of the control deviation (setpoint – process value).
1	Delete We recommend setting the weighting of the proportional action (Retain.CtrlParams.Heat.PWeighting and Retain.CtrlParams.Cool.PWeighting tags) to 1.0 when this option is used. The value of PIDCtrl.IOutputOld is deleted. Any control deviation will cause the PID output value to jump. The direction of the output value jump depends on the active weighting of the proportional action (Retain.CtrlParams.Heat.PWeighting and Retain.CtrlParams.Cool.PWeighting tags) and the control deviation: • Active proportional action weighting = 1.0: Output value jump and control deviation have identical signs. Example: If the process value is less than the setpoint (positive control deviation), the PID output value jumps to a positive value. • Active proportional action weighting < 1.0: For large system deviations, the PID output value jump and control deviation have identical signs. Example: If the process value is much less than the setpoint (positive control deviation), the PID output value jumps to a positive value. For small system deviations, the PID output value jump and control deviation have different signs. Example: If the process value is just below the setpoint (positive control deviation), the PID output value jumps to a negative value. This is usually not desirable, because it results in a temporary increase in the control deviation. The smaller the configured weighting of the proportional action, the greater the control deviation must be to receive a PID output value jump with identical sign. We recommend setting the weighting of the proportional action (Retain.CtrlParams.Heat.PWeighting and Retain.CtrlParams.Cool.PWeighting tags) to 1.0 when this option is used. Otherwise, you may experience the undesirable behavior described for small control deviations. Alternatively, you can also use IntegralResetMode = 4. This option guarantees identical signs of the PID output value jump and control deviation independent of the configured weighting of the proportional action and the control deviation.
2	Hold The value of PIDCtrl.IOutputOld is not changed. You can define a new value using the user program.
3	Preassign The value of PIDCtrl.IOutputOld is automatically preassigned as if PidOutputSum = OverwriteInitialOutputValue in the last cycle.
4	Like setpoint change (only for PID_Temp with version ≥ 1.1) The value of PIDCtrl.IOutputOld is automatically preassigned so that a similar PID output value jump results as for a PI controller in automatic mode in case of a setpoint change from the current process value to the current setpoint. Any control deviation will cause the PID output value to jump. The PID output value jump and control deviation have identical signs.

IntegralReset-Mode	Description
	Example: If the process value is less than the setpoint (positive control deviation), the PID output value jumps to a positive value. This is independent of the configured weighting of the proportional action and the control deviation.

If IntegralResetMode is assigned a value outside the valid value range, PID_Temp behaves as with the preassignment of IntegralResetMode:

- PID_Temp up to V1.0: IntegralResetMode = 1
- PID_Temp as of V1.1: IntegralResetMode = 4

11.4 PID basic functions

11.4.1 CONT_C

11.4.1.1 Description CONT_C

The CONT_C instruction is used on SIMATIC S7 automation systems to control technical processes with continuous input and output variables. You can assign parameters to enable or disable sub-functions of the PID controller and adapt it to the process. In addition to the functions in the setpoint and process value branches, the instruction implements a complete PID controller with continuous output value output and the option of manually influencing the value of the output value.

Application

You can use the controller as a PID fixed setpoint controller, or in multi-loop control systems, also as a cascade, blending or ratio controller. The functions of the controller are based on the PID control algorithm of the sampling controller with an analog signal, if necessary extended by including a pulse shaper stage to generate pulse-width modulated output signals for two or three step controllers with proportional actuators.

Call

The CONT_C instruction has an initialization routine that is run through when input parameter COM_RST = TRUE is set. During initialization, the integral action is set to the initialization value I_ITVAL. All the signal outputs are set to zero. COM_RST = FALSE has to be set after the initialization routine has been completed.

The calculation of the values in the control blocks is only correct if the block is called at regular intervals. You should therefore call the control blocks in a cyclic interrupt OB (OB 30 to OB 38). Enter the sampling time in the CYCLE parameter.

Error information

The error message word RET_VAL is not evaluated by the block.

11.4.1.2 How CONT_C works

Setpoint branch

The setpoint is entered in floating-point format at the SP_INT input.

Process value branch

The process value can be input in I/O or floating-point format. The function CRP_IN converts the I/O value PV_PER to a floating-point format -100 to +100 % in accordance with the following rule:

Output of CRP_IN = PV_PER * 100 / 27648

The PV_NORM function scales the output of CRP_IN according to the following rule:

Output of PV_NORM = (output of CRP_IN) *PV_FAC + PV_OFF

PV_FAC has a default of 1 and PV_OFF a default of 0.

Forming the error signal

The difference between the setpoint and process value is the error signal. To suppress a minor sustained oscillation due to manipulated variable quantization (e.g. with a pulse width modulation with PULSEGEN), the error signal is applied to a dead band (DEADBAND). With DEADB_W = 0, the dead band is switched off.

PID Algorithm

The PID algorithm operates as a position algorithm. The proportional, integral (INT), and differential (DIF) actions are connected in parallel and can be activated or deactivated individually. This allows P, PI, PD, and PID controllers to be configured. Pure I controllers are also possible.

Manual value processing

It is possible to switch over between manual and automatic mode. In manual mode, the manipulated variable is corrected to a manually selected value.

The integral action (INT) is set internally to LMN - LMN_P - DISV and the derivative action (DIF) is set to 0 and synchronized internally. Changeover to automatic mode is therefore bumpless.

Manipulated value processing

You can use the LMNLIMIT function to limit the manipulated value to selected values. Alarm bits indicate when a limit is exceeded by the input variable.

The LMN_NORM function normalizes the output of LMNLIMIT according to the following rule:

LMN = (output of LMNLIMIT) * LMN_FAC + LMN_OFF

LMN_FAC has a default of 1 and LMN_OFF a default of 0.

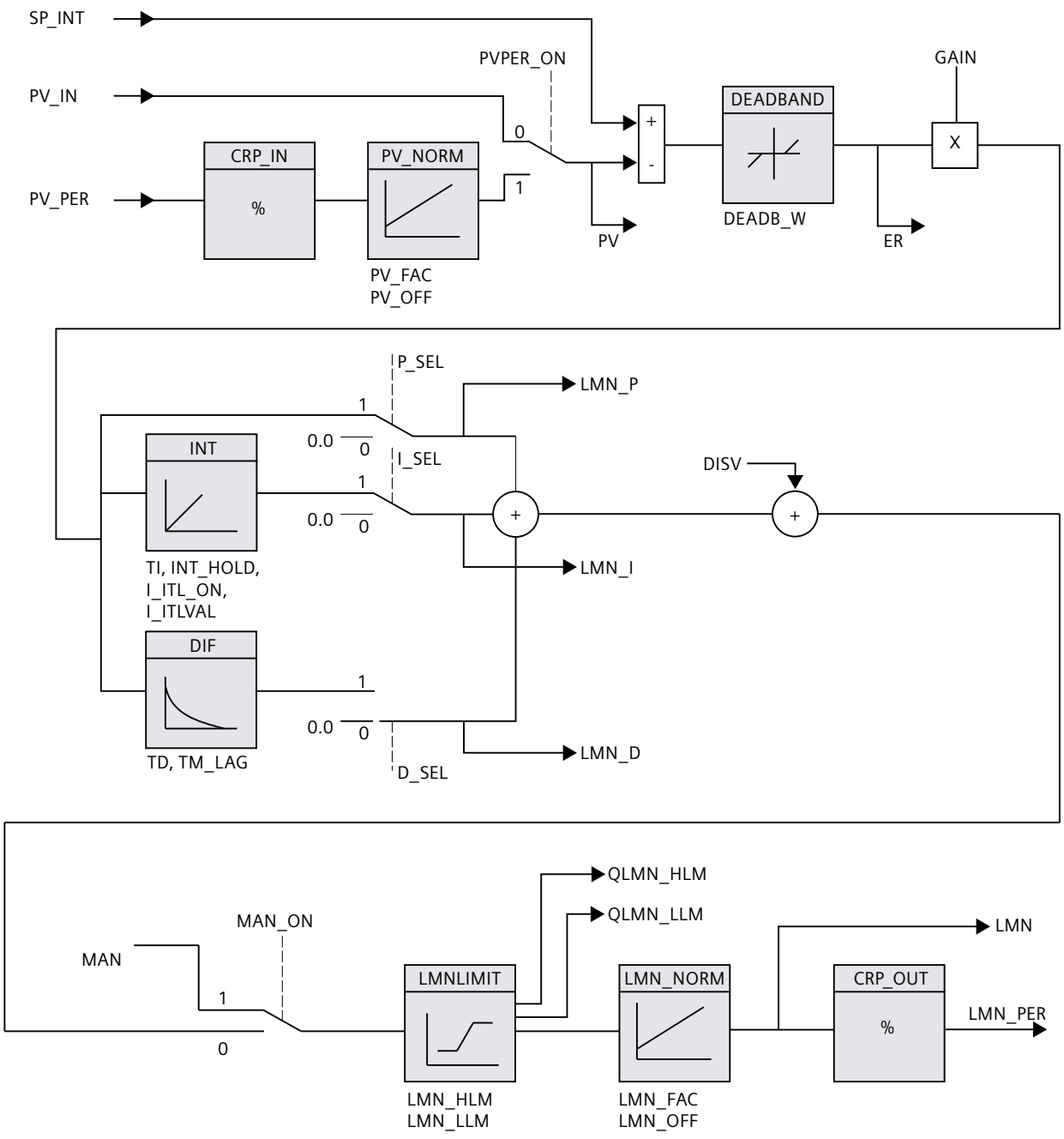
The manipulated value is also available in I/O format. The CRP_OUT function converts the LMN floating-point value to a I/O value according to the following rule:

LMN_PER = LMN * 27648 / 100

Feedforward control

A disturbance variable can be added at the DISV input.

11.4.1.3 CONT_C block diagram



11.4.1.4 Input parameter CONT_C

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-13

Parameters	Data type	Default	Description
COM_RST	BOOL	FALSE	The instruction has an initialization routine that is processed when the "Restart" input is set.
MAN_ON	BOOL	TRUE	If the input "Enable manual mode" is set then the control loop is interrupted. A manual value is set as the manipulated value.
PVPER_ON	BOOL	FALSE	If the process value is to be read in from the I/Os, the PV_PER input must be interconnected with the I/Os and the "Enable process value I/Os" input must be set.
P_SEL	BOOL	TRUE	The PID actions can be switched on and off individually in the PID algorithm. P-action is on when the "Enable P-action" input is set.
I_SEL	BOOL	TRUE	The PID actions can be switched on and off individually in the PID algorithm. I action is on when the input "I-action on" is set.
INT_HOLD	BOOL	FALSE	The output of the integral action can be frozen. For this the input "I-action hold" must be set.
I_ITL_ON	BOOL	FALSE	The output of the integral action can be set at the I_ITLVAL input. For this the input "Set I-action" must be set.
D_SEL	BOOL	FALSE	The PID actions can be switched on and off individually in the PID algorithm. D-action is on when the input "Enable D-action" is set.
CYCLE	TIME	T#1s	The time between block calls must be constant. The "Sampling time" input specifies the time between block calls. CYCLE >= 1ms
SP_INT	REAL	0.0	The input "Internal setpoint" is used to specify a setpoint. Permissible are values from -100 to 100 % or a physical variable 1).
PV_IN	REAL	0.0	At the "Process value input" you can assign parameters to a commissioning value or you can interconnect an external process value in floating-point format. Permissible are values from -100 to 100 % or a physical variable 1).
PV_PER	WORD	W#16#0000	The process value in I/O format is interconnected with the controller at the "Process value I/0" input.
MAN	REAL	0.0	The "Manual value" input is used to set a manual value using the operator interface functions. Permissible are values from -100 to 100 % or a physical variable 2).
GAIN	REAL	2.0	The "Proportional gain" input specifies controller amplification.
TI	TIME	T#20s	The "Integration time" input determines the time response of the integral action. TI >= CYCLE
TD	TIME	T#10s	The "Derivative action time" input determines the time response of the derivative action. TD >= CYCLE
TM_LAG	TIME	T#2s	Time lag of the D-action The algorithm of the D-action contains a delay for which parameters can be assigned at the input "Time lag of the D-action". TM_LAG >= CYCLE/2
DEADB_W	REAL	0.0	A dead band is applied to the system deviation. The "Dead band width" input determines the size of the dead band. DEADB_W >= 0.0 (%) or a physical variable 1)

Parameters	Data type	Default	Description
LMN_HLM	REAL	100.0	The manipulated value is always restricted to a high limit and low limit. The "High limit of manipulated value" input specifies the high limit. Permissible are real values starting at LMN_LLM (%) or a physical variable 2).
LMN_LLM	REAL	0.0	The manipulated value is always restricted to a high limit and low limit. The "Low limit of manipulated value" input specifies the low limit. Permissible are real values up to LMN_HLM (%) or a physical variable 2).
PV_FAC	REAL	1.0	The "Process value factor" input is multiplied by the process value. The input is used to scale the process value range.
PV_OFF	REAL	0.0	The input "Process value offset" is added to the process value. The input is used to scale the process value range.
LMN_FAC	REAL	1.0	The "Manipulated value factor" input is multiplied with the manipulated value. The input is used to scale the manipulated value range.
LMN_OFF	REAL	0.0	The input "Manipulated value offset" is added to the process value. The input is used to scale the manipulated value range.
I_ITLVAL	REAL	0.0	The output of the integral action can be set at the I_ITL_ON input. The initialization value is indicated at the input "Initialization value of the integral-action." Permissible are values of -100.0 to 100.0 (%) or a physical variable 2).
DISV	REAL	0.0	For feedforward control, the disturbance variable is interconnected to the "Disturbance variable" input. Permissible are values of -100.0 to 100.0 (%) or a physical variable 2).

1) Parameters in the setpoint and process value branches with the same unit

2) Parameters in the manipulated value branch with the same unit

11.4.1.5 Output parameters CONT_C

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-14

Parameter	Data type	Default	Description
LMN	REAL	0.0	The effective "Manipulated value" is output in floating point format at the "Manipulated value" output.
LMN_PER	WORD	W#16#0000	The manipulated value in I/O format is interconnected on the input "Manipulated value I/O" with the controller.
QLMN_HLM	BOOL	FALSE	The manipulated value is always restricted to a high limit and low limit. The output "High limit of manipulated value reached" indicates that the high limit has been reached.
QLMN_LLM	BOOL	FALSE	The manipulated value is always restricted to a high limit and low limit. The output "Low limit of manipulated value reached" indicates that the low limit has been reached.
LMN_P	REAL	0.0	The "P-action" output contains the proportional action of the manipulated variable.
LMN_I	REAL	0.0	The "I-action" output contains the integral action of the manipulated variable.
LMN_D	REAL	0.0	The "D-action" output contains the derivative action of the manipulated variable.
PV	REAL	0.0	The effective process value is output at the "Process value" output.
ER	REAL	0.0	The effective system deviation is output at the "Error signal" output.

11.4.2 CONT_S

11.4.2.1 Description CONT_S

The CONT_S instruction is used on SIMATIC S7 automation systems to control technical processes with binary output value output signals for actuators with integrating behavior. During parameter assignment, you can activate or deactivate sub-functions of the PI step controller to adapt the controller to the controlled system. In addition to the functions in the process value branch, the instruction implements a complete proportional-plus-integral-action controller with binary output value output and the option of manually influencing the value of the output value. The step controller operates without a position feedback signal.

Application

You can use the controller as a PI fixed setpoint controller or in secondary control loops in cascade, blending or ratio controllers, however you cannot use it as the primary controller. The functions of the controller are based on the PI control algorithm of the sampling controller supplemented by the functions for generating the binary output signal from the analog actuating signal.

Call

The CONT_S instruction has an initialization routine that is run through when input parameter COM_RST = TRUE is set. All the signal outputs are set to zero. COM_RST = FALSE has to be set after the initialization routine has been completed.

The calculation of the values in the control blocks is only correct if the block is called at regular intervals. You should therefore call the control blocks in a cyclic interrupt OB (OB 30 to OB 38). Enter the sampling time in the CYCLE parameter.

Error information

The error message word RET_VAL is not evaluated by the block.

11.4.2.2 Mode of operation CONT_S

Setpoint branch

The setpoint is entered in floating-point format at the SP_INT input.

Process value branch

The process value can be input in I/O or floating-point format. The function CRP_IN converts the I/O value PV_PER to a floating-point format -100 to +100 % in accordance with the following rule:

Output of CRP_IN = PV_PER * 100 / 27648

The PV_NORM function normalizes the output of CRP_IN according to the following rule:

Output of PV_NORM = (output of CRP_IN) * PV_FAC + PV_OFF

PV_FAC has a default of 1 and PV_OFF a default of 0.

Forming the error signal

The difference between the setpoint and process value is the error signal. To suppress a small constant oscillation due to the manipulated variable quantization (for example, due to a limited resolution of the manipulated value by the control valve), a dead band is applied to the error signal (DEADBAND). With DEADB_W = 0, the dead band is switched off.

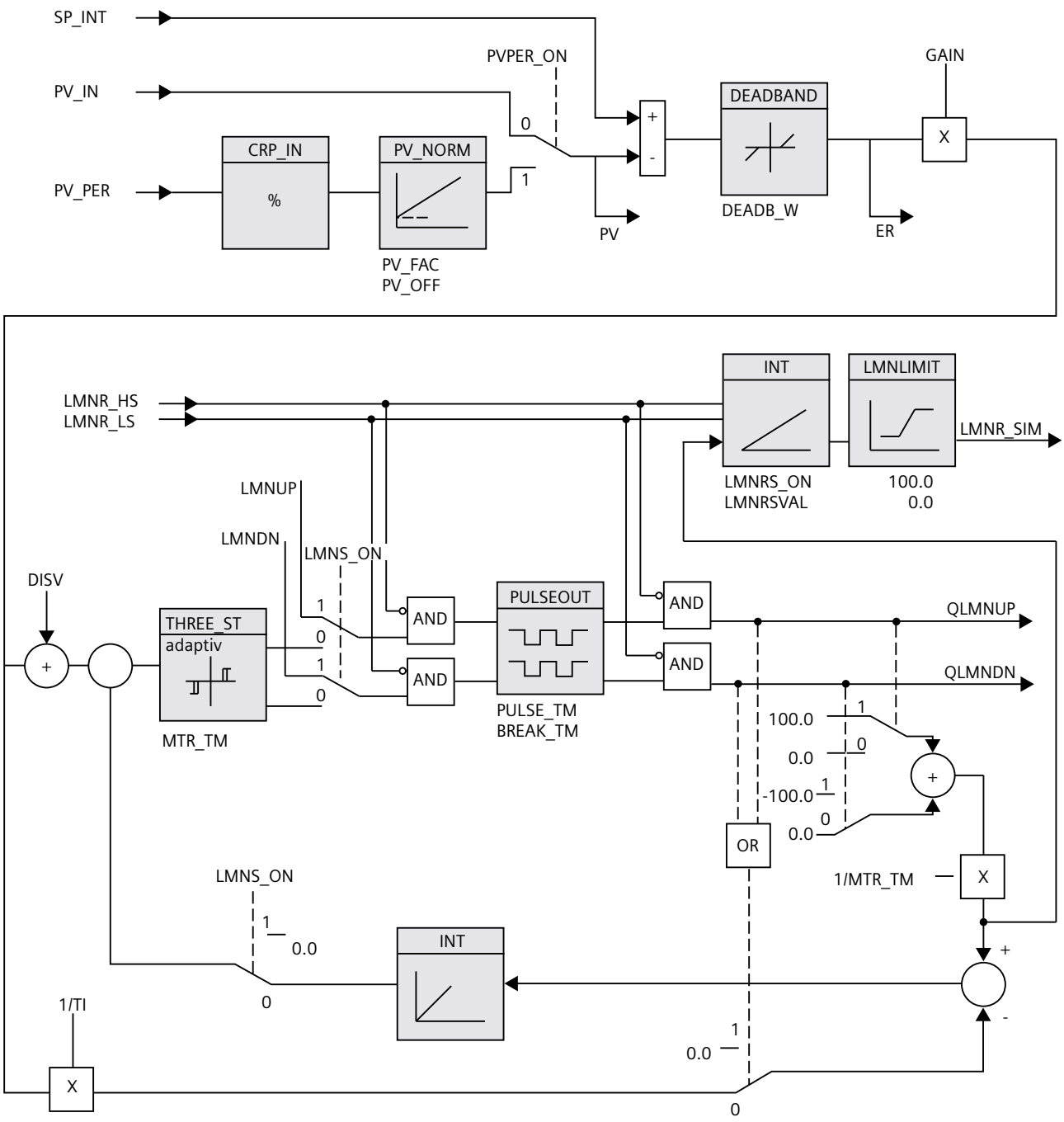
PI step algorithm

The instruction operates without position feedback. The I-action of the PI algorithm and the assumed position feedback signal are calculated in **one** integral action (INT) and compared with the remaining P-action as a feedback value. The difference is applied to a three-step element (THREE_ST) and a pulse shaper (PULSEOUT) that generates the pulses for the control valve. The switching frequency of the controller can be reduced by adapting the response threshold of the three-step element.

Feedforward control

A disturbance variable can be added at the DISV input.

11.4.2.3 Block diagram CONT_S



11.4.2.4 Input parameters CONT_S

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-15

Parameters	Data type	Default	Description
COM_RST	BOOL	FALSE	The block has an initialization routine that is processed when the "Restart" input is set.
LMNR_HS	BOOL	FALSE	The signal "Control valve at high endstop" is interconnected at the input "High endstop signal of position feedback". LMNR_HS=TRUE means: The control valve is at high end-stop.
LMNR_LS	BOOL	FALSE	The signal "Control valve at low endstop" is interconnected on the input "Low endstop signal of position feedback". LMNR_LS=TRUE means The control valve is at low endstop.
LMNS_ON	BOOL	FALSE	Manipulated value signal processing is switched to manual mode at the "Enable manual mode of manipulated signal".
LMNUP	BOOL	FALSE	The output signal QLMNUP is operated in manual mode of the manipulated value signals at the input "Manipulated value signal up".
LMNDN	BOOL	FALSE	The output signal QLMNDN is operated in manual mode of the manipulated value signals at the input "Manipulated value signal down"
PVPER_ON	BOOL	FALSE	If the process value is to be read from the I/O then the input PV_PER must be interconnected with the I/O and the input "Enable process value I/O" must be set.
CYCLE	TIME	T#1s	The time between block calls must be constant. The "Sampling time" input specifies the time between block calls. CYCLE >= 1ms
SP_INT	REAL	0.0	The input "Internal setpoint" is used to specify a setpoint. Permissible are values from -100 to 100 % or a physical variable [1].
PV_IN	REAL	0.0	At the "Process value input" you can assign parameters to a commissioning value or you can interconnect an external process value in floating-point format. Permissible are values from -100 to 100 % or a physical variable [1].
PV_PER	WORD	W#16#0-000	The process value in I/O format is interconnected with the controller at the "Process value I/O" input.
GAIN	REAL	2.0	The "Proportional gain" input specifies controller amplification.
TI	TIME	T#20s	The "Integration time" input determines the time response of the integral action. TI >= CYCLE
DEADB_W	REAL	1.0	A dead band is applied to the system deviation. The "Dead band width" input determines the size of the dead band. Permissible are values from 0 to 100 % or a physical variable [1].
PV_FAC	REAL	1.0	The "Process value factor" input is multiplied by the process value. The input is used to scale the process value range.
PV_OFF	REAL	0.0	The input "Process value offset" is added to the process value. The input is used to scale the process value range.
PULSE_TM	TIME	T#3s	You can assign a minimum pulse time at the parameter "Minimum pulse time". PULSE_TM >= CYCLE

Parameters	Data type	Default	Description
BREAK_TM	TIME	T#3s	You can assign a minimum break time at the parameter "Minimum break time". BREAK_TM >= CYCLE
MTR_TM	TIME	T#30s	The time required by the actuator to move from limit stop to limit stop is entered at the "Motor actuating time" parameter. MTR_TM >= CYCLE
DISV	REAL	0.0	For feedforward control, the disturbance variable is interconnected to the "Disturbance variable" input. Permissible are values from -100 to 100 % or a physical variable [2].

[1] Parameters in setpoint and process value branches with identical unit

[2] Parameters in the manipulated value branch with same unit

11.4.2.5 Output parameters CONT_S

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-16

Parameters	Data type	Default	Description
QLMNUP	BOOL	FALSE	If the output "Manipulated value signal up" is set then the control valve should be open.
QLMNDN	BOOL	FALSE	If the output "Manipulated value signal down" is set then the control valve should be closed.
PV	REAL	0.0	The effective process value is output at the "Process value" output.
ER	REAL	0.0	The effective system deviation is output at the "Error signal" output.

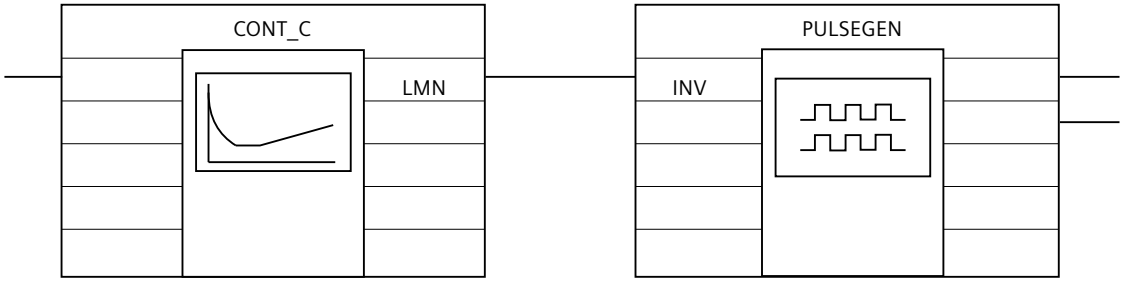
11.4.3 PULSEGEN

11.4.3.1 Description PULSEGEN

The instruction PULSEGEN serves as the structure of a PID controller with impulse output for proportional actuators. PULSEGEN transforms the input value INV (= LMN of the PID controller) through modulation of the impulse width in an impulse sequence with a constant period duration, which corresponds with the cycle time with which the input value is updated.

Application

You can use the PULSEGEN instruction to configure two- or three-step PID controllers with pulse width modulation. The function is normally used in conjunction with the continuous controller CONT_C.



Call

The PULSEGEN instruction has an initialization routine that is run through when input parameter COM_RST = TRUE is set. All the signal outputs are set to zero. COM_RST = FALSE has to be set after the initialization routine has been completed.

The calculation of the values in the control blocks is only correct if the block is called at regular intervals. You should therefore call the control blocks in a cyclic interrupt OB (OB 30 to OB 38). Enter the sampling time in the CYCLE parameter.

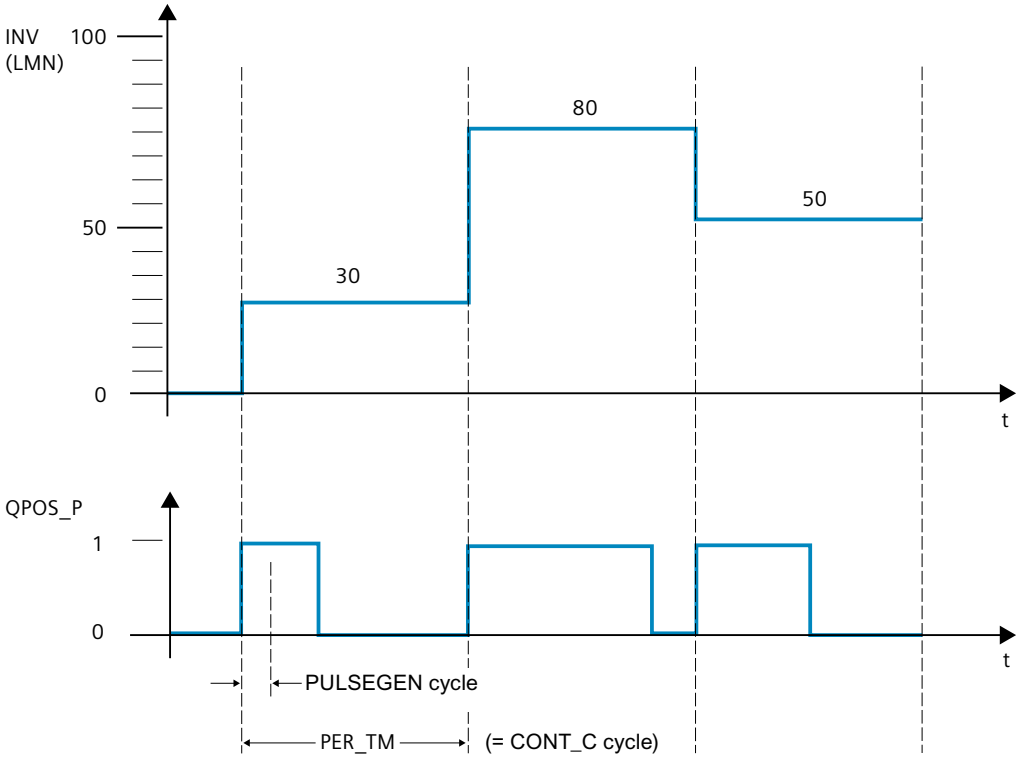
Responses in the event of an error

The error message word RET_VAL is not evaluated by the block.

11.4.3.2 Mode of operation PULSEGEN

Impulse width modulation

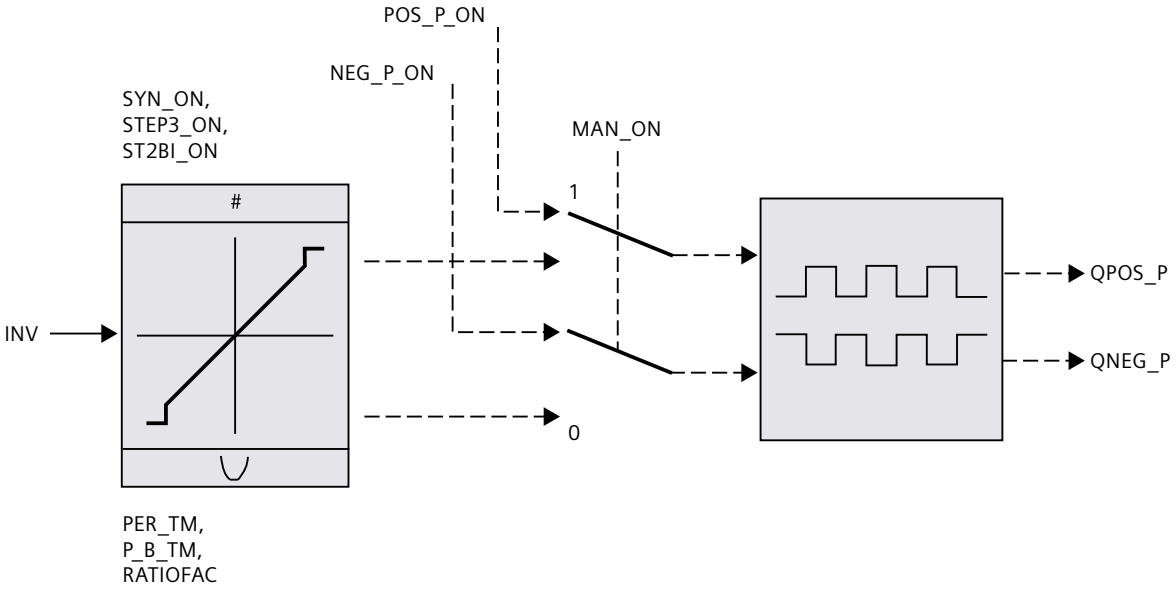
The duration of a pulse per period duration is proportional to the input variable. The cycle assigned via PER_TM is not identical to the processing cycle of the PULSEGEN instruction. Rather, a PER_TM cycle is made up of several processing cycles of the PULSEGEN instruction, whereby the number of PULSEGEN calls per PER_TM cycle determines the accuracy of the pulse width.



An input variable of 30% and 10 PULSEGEN calls per PER_TM mean the following:

- "One" at the QPOS_P output for the first three calls of PULSEGEN (30% of 10 calls)
- "Zero" at the QPOS_P output for seven further calls of PULSEGEN (70% of 10 calls)

Block diagram



Accuracy of the manipulated value

With a "Sampling ratio" of 1:10 (CONT_C calls to PULSEGEN calls) the accuracy of the manipulated value in this example is restricted to 10%, in other words, set input values INV can only be simulated by a pulse duration at the QPOS_P output in steps of 10 %.

The accuracy is increased as the number of PULSEGEN calls per CONT_C call is increased.

If PULSEGEN is called, for example, 100 times more often than CONT_C, a resolution of 1 % of the manipulated value range is achieved.

NOTE

The reduction ratio of the call frequency must be programmed by the user.

Automatic synchronization

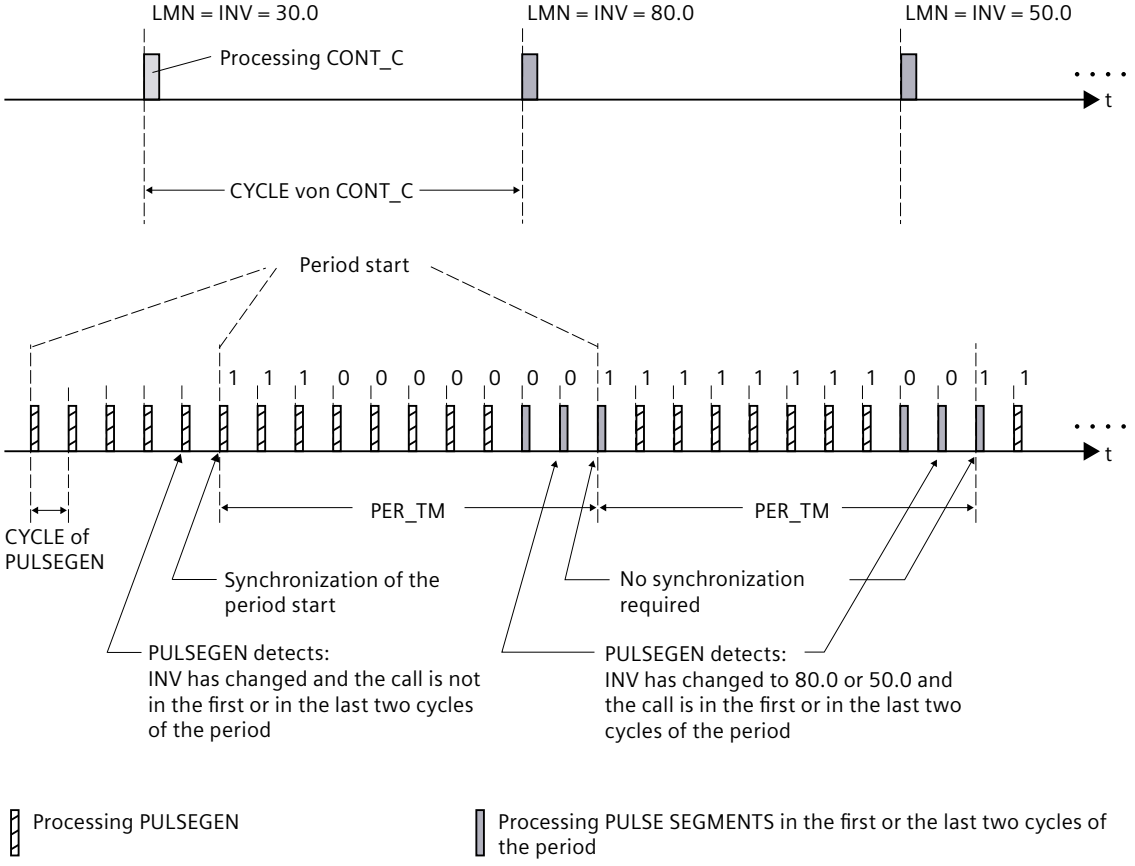
It is possible to automatically synchronize the pulse output with the instruction that updates the input variable INV (e.g. CONT_C). This ensures that a change in the input variable is output as quickly as possible as a pulse.

The pulse shaper evaluates the input value INV at intervals corresponding to the period duration PER_TM and converts the value into a pulse signal of corresponding length.

Since, however, INV is usually calculated in a slower cyclic interrupt class, the pulse shaper should start the conversion of the discrete value into a pulse signal as soon as possible after the updating of INV.

To allow this, the block can synchronize the start of the period using the following procedure:

If INV changes and if the block call is not in the first or last two call cycles of a period, a synchronization is performed. The pulse duration is recalculated and in the next cycle is output with a new period.



The automatic synchronization is switched off, if SYN_ON = FALSE.

NOTE

The start of a new period and subsequent synchronization usually leads to a certain imprecision when the old value of INV (i.e. of LMN) is mapped to the pulse signal.

11.4.3.3 Mode of operation PULSEGEN

Modes

Depending on the parameters assigned to the pulse shaper, PID controllers with a three-step output or with a bipolar or unipolar two-step output can be configured. The following table illustrates the setting of the switch combinations for the possible modes.

Mode	MAN_ON	STEP3_ON	ST2BI_ON
Three-step control	FALSE	TRUE	Any
Two-step control with bi-polar Manipulating range (-100 % to 100 %)	FALSE	FALSE	TRUE
Two-step control with unipolar Manipulating range (0 % to 100 %)	FALSE	FALSE	FALSE
Manual mode	TRUE	Any	Any

Manual mode in two/three-step control

In the manual mode (MAN_ON = TRUE), the binary outputs of the three-step or two-step controller can be set using the signals POS_P_ON and NEG_P_ON regardless of INV.

Control	POS_P_ON	NEG_P_ON	QPOS_P	QNEG_P
Three-step control	FALSE	FALSE	FALSE	FALSE
	TRUE	FALSE	TRUE	FALSE
	FALSE	TRUE	FALSE	TRUE
	TRUE	TRUE	FALSE	FALSE
Two-step control	FALSE	Any	FALSE	TRUE
	TRUE	Any	TRUE	FALSE

11.4.3.4 Three-step control

Three-step control

In "Three-step control" mode, it is possible to generate three statuses of the actuating signal. For this, the status values of the binary output signals QPOS_P and QNEG_P are assigned to the respective operating statuses of the actuator. The table shows the example of a temperature control:

Output signals	Heat	Off	Cool
QPOS_P	TRUE	FALSE	FALSE
QNEG_P	FALSE	FALSE	TRUE

The pulse duration is calculated from the input variable via a characteristic curve. The form of the characteristic curve is defined by the minimum pulse duration or minimum interval and the ratio factor. The normal value for the ratio factor is 1.

The "doglegs" in the curves are caused by the minimum pulse duration or minimum interval.

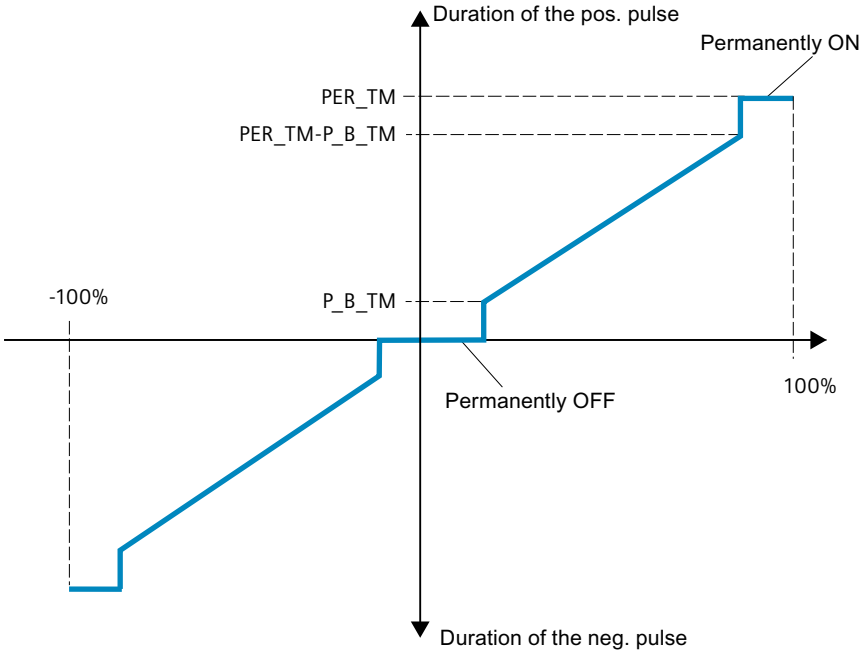
Minimum pulse duration or minimum interval

A correctly assigned minimum pulse duration or minimum interval P_B_TM can prevent short on/off times, which reduce the working life of switching elements and actuators. Small absolute values of input variable LMN that could otherwise generate a pulse duration shorter than P_B_TM are suppressed. Large input values that would generate a pulse duration longer than PER_TM - P_B_TM are set to 100% or -100%.

The duration of positive or negative pulses is calculated by multiplying the input variable (in %) by the period duration:

Pulse duration = INV / 100 * PER_TM

The following figure shows a symmetrical characteristic curve of the three-step controller (ratio factor = 1).



Asymmetrical three-step control

Using the ratio factor RATIOFAC, the ratio of the duration of positive to negative pulses can be changed. In a thermal process, for example, this would allow different system time constants for heating and cooling.

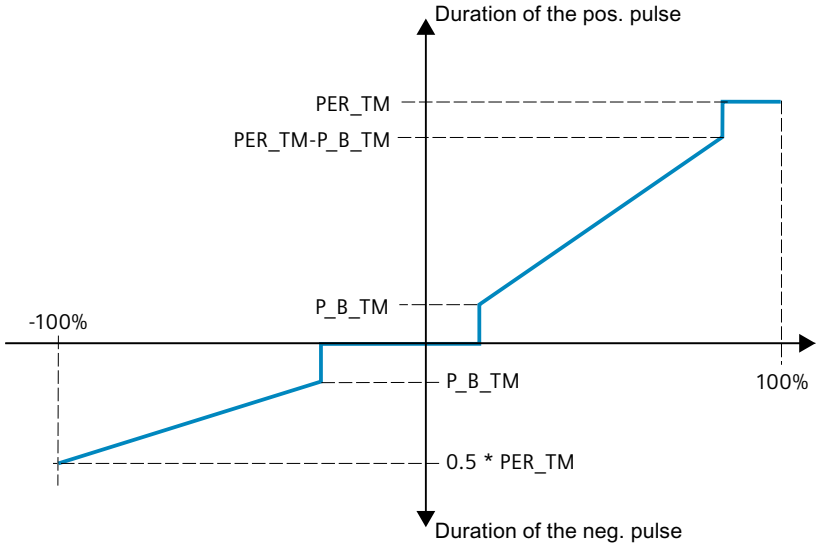
Ratio factor < 1

The pulse duration at the negative pulse output, calculated by multiplying the input variable by the period duration, is multiplied by the ratio factor.

Positive pulse duration = INV /100 * PER_TM

Negative pulse duration = INV / 100 * PER_TM * RATIOFAC

The following figure shows the asymmetrical characteristic curve of the three-step controller (ratio factor = 0.5):



Ratio factor > 1

The pulse duration at the positive pulse output, calculated by multiplying the input variable by the period duration, is divided by the ratio factor.

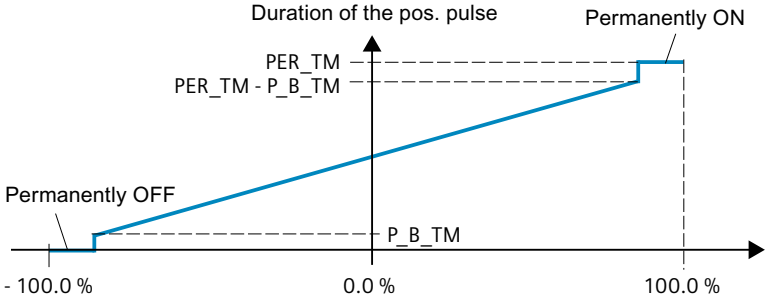
Positive pulse duration = INV / 100 * PER_TM / RATIOFAC

Negative pulse duration = INV / 100 * PER_TM

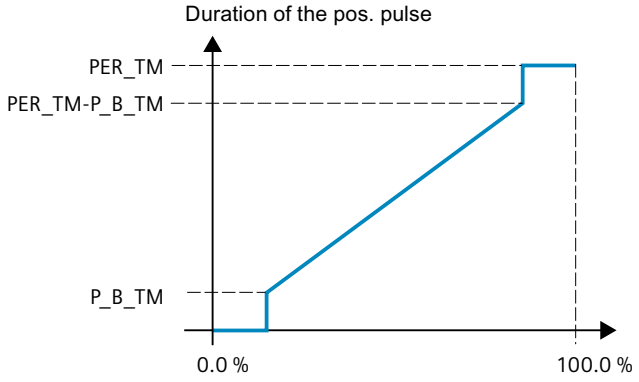
11.4.3.5 Two-step control

In two-step control, only the positive pulse output QPOS_P of PULSEGEN is connected to the on/off actuator. Depending on the manipulated value range used, the two-step controller has a bipolar or a unipolar manipulated value range.

Two-step control with bipolar manipulated variable range (-100% to 100%)



Two-step control with unipolar manipulated variable range (0% to 100%)



The negated output signal is available at QNEG_P if the connection of the two-step controller in the control loop requires a logically inverted binary signal for the actuating pulses.

Pulse	Actuator On	Actuator Off
QPOS_P	TRUE	FALSE
QNEG_P	FALSE	TRUE

11.4.3.6 Input parameters PULSEGEN

The values of the input parameters are not limited in the block. There is no parameter check.

Table 11-17

Parameters	Data type	Default	Description
INV	REAL	0.0	At the input parameter "Input variable" an analog manipulated variable is connected. Values from -100 to 100 % are permitted.
PER_TM	TIME	T#1s	At the parameter "Period duration" the constant period duration of the pulse width modulation is entered. This corresponds to the sampling time of the controller. The ratio between the sampling time of the pulse shaper and the sampling time of the controller determines the accuracy of the pulse width modulation. PER_TM >=20*CYCLE
P_B_TM	TIME	T#50 ms	You can assign a minimum pulse/break time at the parameter "Minimum pulse/break time". P_B_TM >= CYCLE
RATIOFAC	REAL	1.0	Using the "Ratio factor" input parameter the ratio of the duration of positive to negative pulses can be changed. In a thermal process, this would, for example, allow different time constants for heating and cooling to be compensated (for example, in a process with electrical heating and water cooling). Values from 0.1 to 10.0 are permitted.
STEP3_ON	BOOL	TRUE	At the input parameter "Enable three-step control" the appropriate mode is activated. In three-step control both output signals are active.
ST2BI_ON	BOOL	FALSE	At the input parameter "Enable two-step control for bipolar manipulated value range" you can select from the modes "Two-step control for bipolar manipulated value range" and "Two-step control for unipolar manipulated value range". STEP3_ON = FALSE is required.
MAN_ON	BOOL	FALSE	Setting the input parameter "Enable manual mode" allows the output signals to be set manually.

Parameters	Data type	Default	Description
POS_P_ON	BOOL	FALSE	For manual mode three-step control, the output signal QPOS_P can be operated on the input parameter "Positive pulse on". In manual mode with two-step control, QNEG_P is always set inversely to QPOS_P.
NEG_P_ON	BOOL	FALSE	For manual mode three-step control, the output signal QNEG_P can be operated on the input parameter "Negative pulse on". In manual mode with two-step control, QNEG_P is always set inversely to QPOS_P.
SYN_ON	BOOL	TRUE	By setting the input parameter "Enable synchronization", it is possible to synchronize the pulse output automatically with the block that updates the input variable INV. This ensures that a change in the input variable is output as quickly as possible as a pulse.
COM_RST	BOOL	FALSE	The block has an initialization routine that is processed when the input "Restart" is set.
CYCLE	TIME	T#10ms	The time between block calls must be constant. The "Sampling time" input specifies the time between block calls. CYCLE >= 1ms

11.4.3.7 Output parameter PULSEGEN

Table 11-18

Parameters	Data type	Default	Description
QPOS_P	BOOL	FALSE	The output parameter "Output signal positive pulse" is set if a pulse will be output. In three-step control, this is always the positive pulse. In two-step control, the QNEG_P is always set inversely to QPOS_P.
QNEG_P	BOOL	FALSE	The output parameter "Output signal negative pulse" is set if a pulse will be output. In three-step control, this is always the negative pulse. In two-step control, QNEG_P is always set inversely to QPOS_P.

11.4.4 TCONT_CP

11.4.4.1 Description TCONT_CP

The instruction TCONT_CP is used to control temperature processes with continuous or pulsed control signals. The controller functionality is based on the PID control algorithm with additional functions for temperature processes. To improve the control response with temperature processes, the block includes a control zone and reduction of the proportional component if there is a setpoint step change.

The instruction can set the PI/PID parameters itself using the controller optimization function.

Application

The controller controls one actuator; in other words, with one controller you can either heat or cool but not both. If you use the block for cooling, GAIN must be assigned a negative value. This inversion of the controller means that if the temperature rises, for example, the manipulated variable LMN and with it the cooling action is increased.

Call

The instruction TCONT_CP must be called with a constant bus cycle time. To achieve this, use a cyclic interrupt priority class (for example, OB35 for an S7-300).

The TCONT_CP instruction has an initialization routine that is run through when input parameter COM_RST = TRUE is set. During initialization, the integral action is set to the initialization value I_ITVAL. All the signal outputs are set to zero. Following execution of the initialization routine, the block sets COM_RST back to FALSE. If you require initialization when the CPU restarts, call the block in OB100 with COM_RST = TRUE.

See also

Operating principle of the pulse generator (Page 460)

Block diagram TCONT_CP (Page 463)

11.4.4.2 Mode of operation TCONT_CP

Setpoint branch

The setpoint is entered at input SP_INT in floating-point format as a physical value or percentage. The setpoint and process value used to form the control deviation must have the same unit.

Process value options (PVPER_ON)

Depending on PVPER_ON, the process value can be read in, in the I/O or floating-point format.

PVPER_ON	Process Value Input
TRUE	The process value is read in via the analog I/Os (PIW xxx) at input PV_PER.
FALSE	The process value is acquired in floating-point format at input PV_IN.

Process value format conversion CRP_IN (PER_MODE)

The CRP_IN function converts the I/O value PV_PER to floating-point format depending on the PER_MODE switch according to the following rules:

PER_MODE	Output of CRP_IN	Analog Input Type	Unit
0	PV_PER * 0.1	Thermoelements; PT100/NI100; standard	°C;°F
1	PV_PER * 0.01	PT100/NI100; climate;	°C;°F
2	PV_PER * 100/27648	Voltage/current	%

Process value scaling PV_NORM (PF_FAC, PV_OFFS)

The PV_NORM function calculates the output of CRP_IN according to the following rule:

"Output of PV_NORM" = "Output of CRP_IN" * PV_FAC + PV_OFFS

It can be used for the following purposes:

- Process value adjustment with PV_FAC as process value factor and PV_OFFS as process value offset.
- Scaling of temperature to percentage

  You want to enter the setpoint as a percentage and must now convert the measured temperature value to a percentage.
- Scaling of percentage to temperature

  You want to enter the setpoint in the physical temperature unit and must now convert the measured voltage/current value to a temperature.

Calculation of the parameters:

- PV_FAC = range of PV_NORM/range of CRP_IN;
- PV_OFFS = LL (PV_NORM) - PV_FAC * LL(CRP_IN);

  where LL: Low limit

The scaling is switched off with the default values (PV_FAC = 1.0 and PV_OFFS = 0.0). The effective process value is output at the PV output.

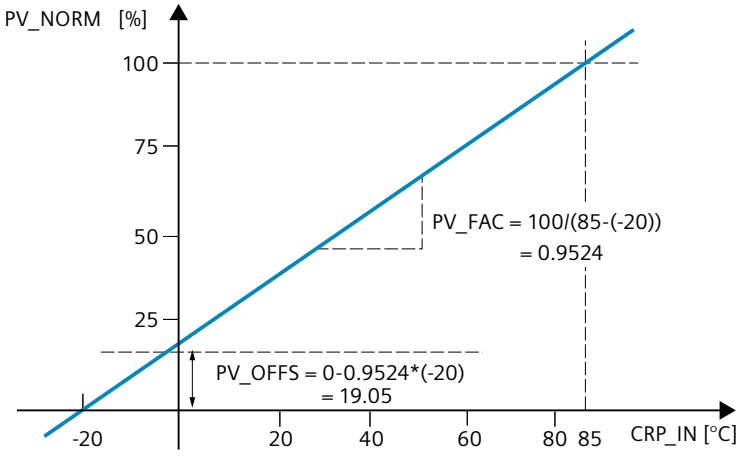
NOTE

With pulse control, the process value must be transferred to the block in the fast pulse call (reason: mean value filtering). Otherwise, the control quality can deteriorate.

Example of Process Value Scaling

If you want to enter the setpoint as a percentage, and you have a temperature range of -20 to 85 °C applied to , CRP_IN you must normalize the temperature range as a percentage.

The diagram below shows an example of adapting the temperature range -20 to 85 °C to an internal scale of 0 to 100 %:



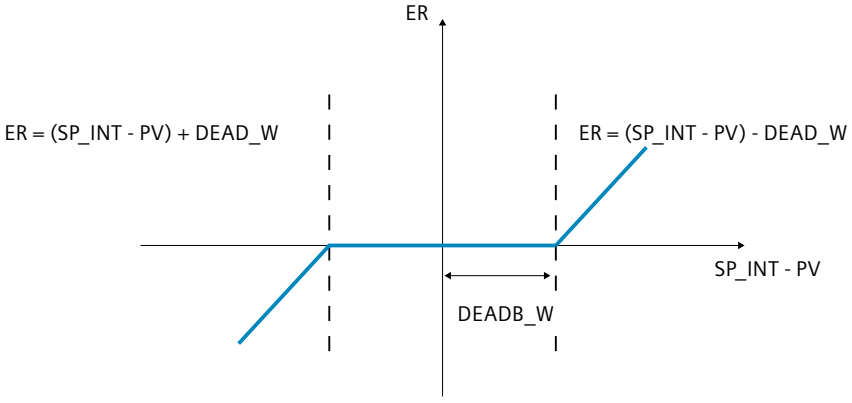
Forming the control deviation

The difference between the setpoint and process value is the control deviation before the dead zone.

The setpoint and process value must exist in the same unit.

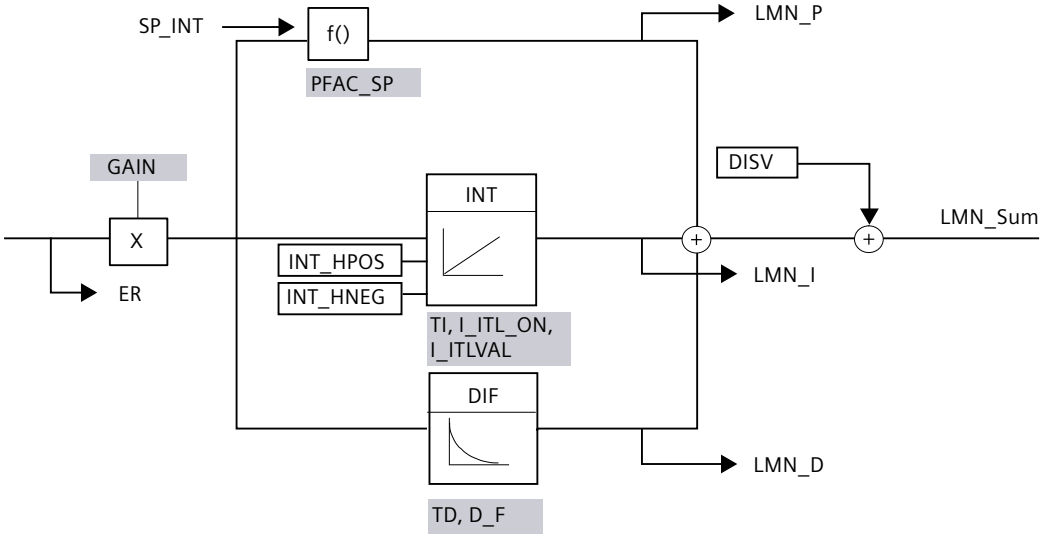
Dead zone (DEADB_W)

To suppress a minor sustained oscillation due to the manipulated variable quantization (for example, in pulse width modulation with PULSEGEN) a dead zone is applied to the (DEADBAND) control deviation. With DEADB_W = 0.0, the dead zone is disabled. The effective control deviation is indicated by the ER parameter.



PID algorithm

The following figure shows the block diagram of the PID algorithm.



PID algorithm (GAIN, TI, TD, D_F)

The PID algorithm operates as a position algorithm. The proportional, integral (INT), and derivative (DIF) actions are connected in parallel and can be activated or deactivated individually. This allows P, PI, PD, and PID controllers to be configured.

Controller tuning supports PI and PID controllers. Controller inversion is implemented using a negative GAIN (cooling controller).

If you set TI and TD to 0.0, you obtain a pure P controller at the operating point.

The step response in the time range is:

$$LMN_Sum(t) = GAIN \cdot ER(0) \cdot \left(1 + \frac{1}{TI} \cdot t + D_F \cdot e^{\frac{-t}{TD\ /\ D_F}}\right)$$

Where:

LMN_Sum(t) the manipulated variable in the controller's automatic mode

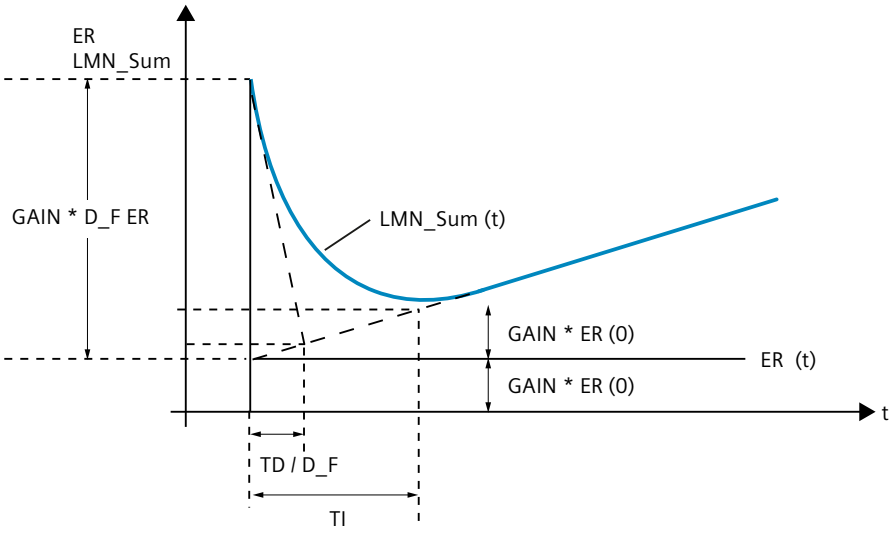
ER (0) is the step height of the normalized control deviation

GAIN is the controller gain

TI is the integration time

TD is the derivative action time

D_F is the derivative factor



Integral action (TI, I_ITL_ON, I_ITLVAL)

In manual mode, it is corrected as follows: LMN_I = LMN - LMN_P - DISV.

If the output value is limited, the integral action is halted. If the control deviation moves the integral action back in the direction of the output range, the integral action is enabled again.

The integral action is also modified by the following measures:

- The integral action of the controller is deactivated by TI = 0.0
- Weakening of the proportional action when setpoint changes occur
- Control zone
- The output value limits can be modified online

Weakening of the proportional action when setpoint changes occur (PFAC_SP)

To prevent overshoot, you can weaken the proportional action using the "Proportional factor for setpoint changes" parameter (PFAC_SP). Using PFAC_SP, you can select continuously between 0.0 and 1.0 to decide the effect of the proportional action when the setpoint changes:

- PFAC_SP = 1.0: Proportional action for setpoint change is fully effective
- PFAC_SP = 0.0: Proportional action for setpoint change is not effective

The weakening of the proportional action is achieved by compensating the integral action.

Derivative action (TD, D_F)

- The derivative action of the controller is deactivated by TD = 0.0
- If the derivative action is active, the following relationship should apply:

  TD = 0.5 * CYCLE * D_F

Parameter Settings of a P or PD Controller with Operating Point

In the user interface, deactivate the integral action (TI = 0.0) and possibly also the derivative action (TD = 0.0). Then make the following parameter settings:

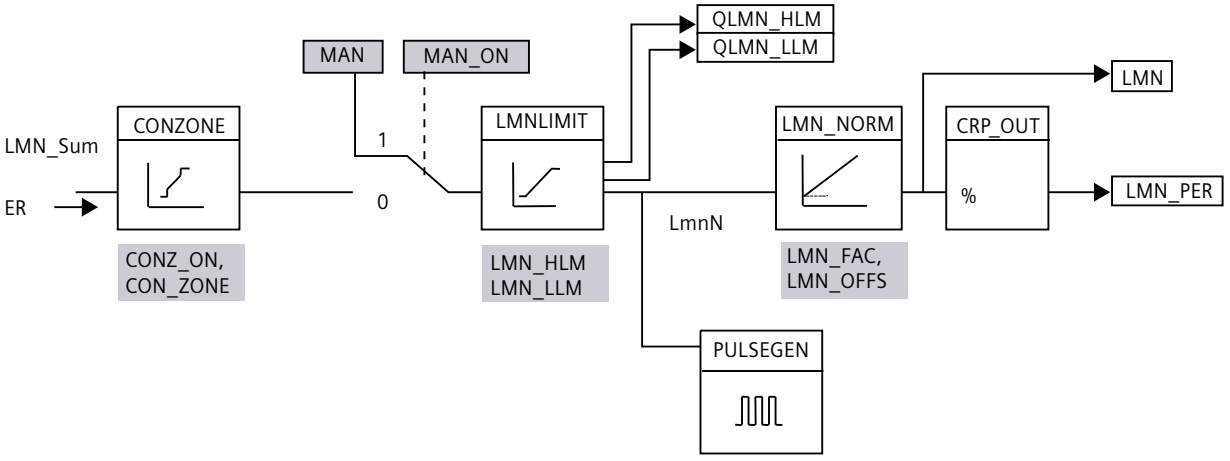
- I_ITL_ON = TRUE
- I_ITLVAL = operating point;

Feedforward control (DISV)

A disturbance variable can be added at the DISV input.

Calculating the output value

The diagram below is the block diagram of the output value calculation:



Parameter configuration interface

Instruction call interface

Parameter configuration interface, call interface

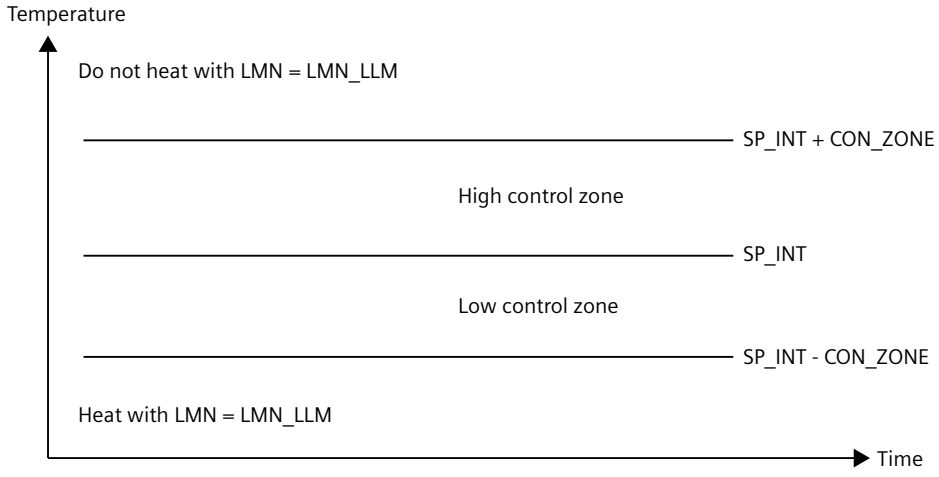
Control zone (CONZ_ON, CON_ZONE)

If CONZ_ON = TRUE, the controller operates with a control zone. This means that the controller operates according to the following algorithm:

- If process value PV exceeds the setpoint SP_INT by more than CON_ZONE, the value LMN_LLM is output as the manipulated variable.
- If the process value PV falls below setpoint SP_INT by more than CON_ZONE, LMN_HLM is output.
- If the process value PV is within the control zone (CON_ZONE), the output value takes its value from the PID algorithm LMN_Sum.

NOTE

Changing the manipulated variable from LMN_LLM or LMN_HLM to LMN_Sum occurs under compliance of a hysteresis of 20% of the control zone.



NOTE

Before enabling the control zone manually, make sure that the control zone band is not too narrow. If the control zone band is too small, oscillations will occur in the manipulated variable and process value.

Advantage of the Control Zone

When the process value enters the control zone, the D-action causes an extremely fast reduction of the manipulated variable. This means that the control zone is only useful when the D-action is activated. Without a control zone, only the reducing proportional action would essentially reduce the manipulated variable. The control zone leads to faster settling without overshoot or undershoot if the output minimum or maximum manipulated variable is a long way from the manipulated variable required for the new operating point.

Manual value processing (MAN_ON, MAN)

You can change over between manual and automatic mode. In manual mode, the manipulated variable is corrected to a manually selected value.

The integral action (INT) is set internally to LMN - LMN_P - DISV and the derivative action (DIF) is set to 0 and synchronized internally. Changeover to automatic mode is therefore bumpless.

NOTE

The MAN_ON parameter has no effect during tuning.

Output value limit LMNLIMIT (LMN_HLM, LMN_LLM)

The LMNLIMIT function is used to limit the output value to the limits LMN_HLM and LMN_LLM. If these limits are reached, this is indicated by the message bits QLMN_HLM and QLMN_LLM.

If the output value is limited, the integral action is halted. If the control deviation moves the integral action back in the direction of the output range, the integral action is enabled again.

Changing the Manipulated Value Limits Online

If the range of the output value is reduced and the new unlimited value of the output value is outside the limits, the integral action and therefore the output value shifts.

The output value is reduced by the same amount as the output value limit changed. If the output value was unlimited prior to the change, it is set exactly to the new limit (described here for the high output value limit).

Scaling of output value LMN_NORM (LMN_FAC, LMN_OFFS)

The LMN_NORM function normalizes the output value according to the following rule:

LMN = LmnN * LMN_FAC + LMN_OFFS

It can be used for the following purposes:

- Output value scaling with LMN_FAC as output value factor and LMN_OFFS as output value offset.

The output value is also available in I/O format. The CRP_OUT function converts the LMN floating-point value to an I/O value according to the following rule:

LMN_PER = LMN * 27648/100

The scaling is switched off with the default values (LMN_FAC = 1.0 and LMN_OFFS = 0.0). The effective output value is sent to output LMN.

Save controller parameters SAVE_PAR

If you classify the current controller parameters as utilizable, you can save these before a manual change in structure parameters provided specifically for this in the instance DB of the instruction TCONT_CP. If you optimize the controller, the saved parameters are overwritten by the values that were valid prior to tuning.

PFAC_SP, GAIN, TI, TD, D_F, CONZ_ON and CONZONE are written to the structure PAR_SAVE.

Reloading Saved Controller Parameters UNDO_PAR

The last controller parameter settings you saved can be activated for the controller again using this function (in manual mode only).

Change between PI and PID parameters LOAD_PID (PID_ON)

Following tuning, the PI and PID parameters are stored in the PI_CON and PID_CON structures. Depending on PID_ON, you can use LOAD_PID in manual mode to write the PI or PID parameters to the effective controller parameters.

PID parameters PID_ON = TRUE	PI parameters PID_ON = FALSE
• GAIN = PID_CON.GAIN • TI = PID_CON.TI • TD = PID_CON.TD	• GAIN = PI_CON.GAIN • TI = PI_CON.TI

NOTE

The controller parameters are only written back to the controller with UNDO_PAR or LOAD_PID, if the controller gain is not equal to 0:

With LOAD_PID, the parameters are only copied if the corresponding GAIN <> 0 is (either the PI or PID parameters). This strategy takes into account the situation that no tuning has yet been made or that PID parameters are missing. If PID_ON = TRUE and PID.GAIN = FALSE, PID_ON is set to FALSE and the PI parameter is copied.

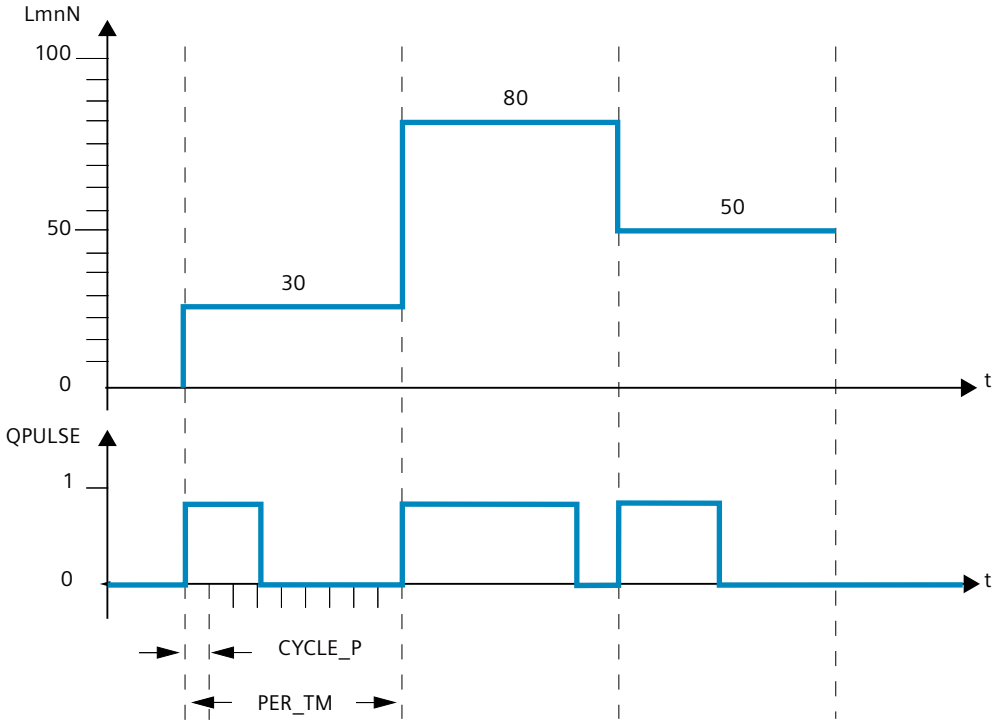
- D_F, PFAC_SP are preset by the tuning. These can then be modified by the user. LOAD_PID does not change these parameters.
- With LOAD_PID, the control zone is always recalculated (CON_ZONE = 250/GAIN), even if CONZ_ON = FALSE.

See also

Operating principle of the pulse generator (Page 460)
Block diagram TCONT_CP (Page 463)

11.4.4.3 Operating principle of the pulse generator

The function PULSEGEN transforms the analog manipulated value LmnN through pulse width module into an impulse sequence with the period duration PER_TM. PULSEGEN is switched on with PULSE_ON = TRUE and is processed in the cycle CYCLE_P.



A manipulated value of LmnN = 30% and 10 PULSEGEN calls per PER_TM therefore means:

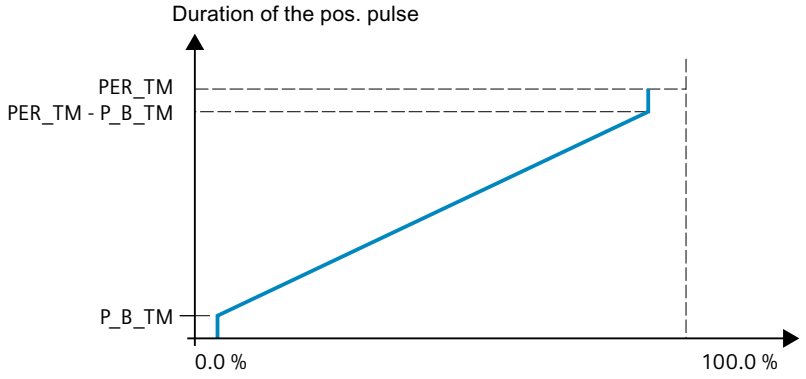
- TRUE at output QPULSE for the first three PULSEGEN calls
  (30% of 10 calls)
- FALSE at output QPULSE for seven further PULSEGEN calls
  (70% of 10 calls)

The duration of a pulse per pulse repetition period is proportional to the manipulated variable and is calculated as follows:

Pulse duration = PER_TM * LmnN /100

By suppressing the minimum pulse or break time, the characteristic curve of the conversion develops "knees" in the start and end regions.

The following diagram illustrates two-step control with a unipolar manipulated variable range (0% to 100%):



Minimum pulse or minimum break time (P_B_TM)

Short on or off times hinder the lifespan of actuators and fine controlling units. These can be avoided by setting a minimum pulse duration or minimum break time P_B_TM.

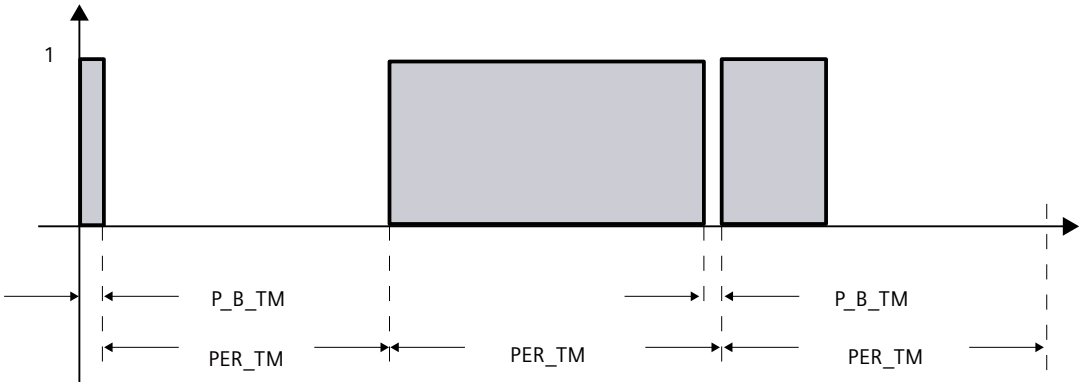
Small absolute values of input variable LmnN that could otherwise generate a pulse duration shorter than P_B_TM are suppressed.

Large input values that would generate a pulse duration greater than PER_TM - P_B_TM are set to 100%. This reduces the dynamic response of pulse generation.

Set values of P_B_TM ≤ 0,1 * PER_TM are recommended for the minimum pulse duration and the minimum break duration.

The "knees" in the curves in the diagram above are caused by the minimum pulse or minimum break times.

The following schematic illustrates the switching response of the pulse output:



Accuracy of pulse generation

The smaller the pulse generator CYCLE_P is compared to the period duration PER_TM, the more precise the pulse width modulation is. To achieve sufficiently accurate control, the following relationship should apply:

CYCLE_P ≤ PER_TM/50

The manipulated value is transformed with a resolution of ≤ 2 % into an impulse.

NOTE

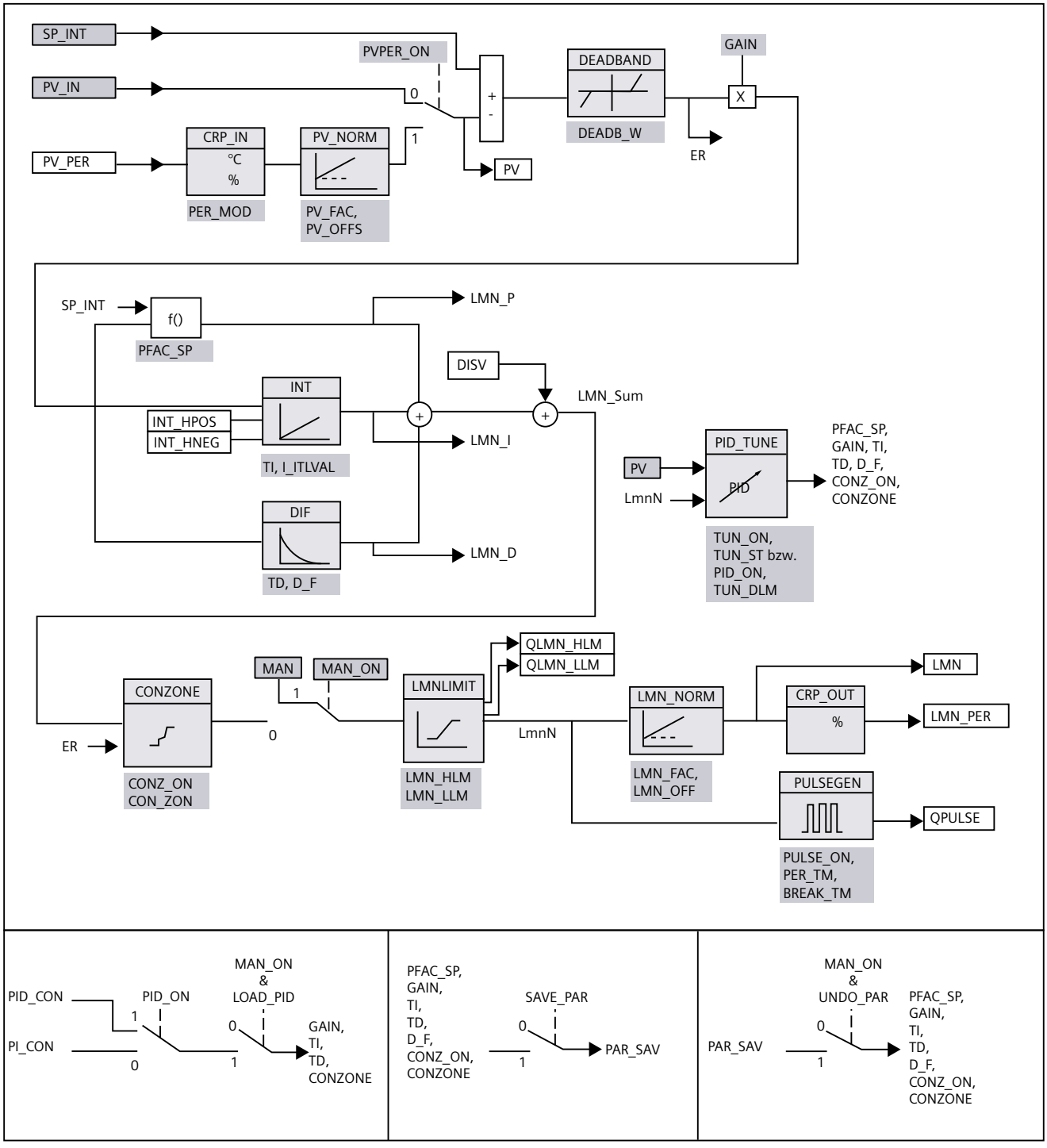
When calling the controller in the pulse shaper cycle, you must note the following:

Calling the controller in the pulse shaper cycle will cause the process value to be averaged. As a result, at output PV, different values may be at input PV_IN and PV_PER. If you want to track the setpoint value, you must save the process value at input parameter PV_IN at the call times for complete controller processing (QC_ACT = TRUE). For pulse shaper calls occurring between these times, you must supply the input parameters PV_IN and SP_INT with the saved process value.

See also

Description TCONT_CP (Page 450)
Mode of operation TCONT_CP (Page 451)
Block diagram TCONT_CP (Page 463)
Input parameters TCONT_CP (Page 464)
Output parameters TCONT_CP (Page 465)
In/out parameters TCONT_CP (Page 465)
Static variables TCONT_CP (Page 466)
Parameter STATUS_H (Page 470)
Parameters STATUS_D (Page 471)

11.4.4.4 Block diagram TCONT_CP



See also

Description TCONT_CP (Page 450)
Mode of operation TCONT_CP (Page 451)
Operating principle of the pulse generator (Page 460)
Input parameters TCONT_CP (Page 464)
Output parameters TCONT_CP (Page 465)
In/out parameters TCONT_CP (Page 465)
Static variables TCONT_CP (Page 466)
Parameter STATUS_H (Page 470)
Parameters STATUS_D (Page 471)

11.4.4.5 Input parameters TCONT_CP

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-19

Parameters	Address	Data type	Default	Description
PV_IN	0.0	REAL	0.0	At the "Process value input" you can assign parameters to a commissioning value or you can interconnect an external process value in floating-point format. The valid values depend on the sensors used.
PV_PER	4.0	INT	0	The process value in I/O format is interconnected with the controller at the "Process value I/O" input.
DISV	6.0	REAL	0.0	For feedforward control, the disturbance variable is interconnected to the "Disturbance variable" input.
INT_HPOS	10.0	BOOL	FALSE	The output of the integral action can be held in the positive direction. For this, the input INT_HPOS must be set to TRUE. In a cascade control, INT_HPOS of the primary controller is connected to QLMN_HLM of the secondary controller.
INT_HNEG	10.1	BOOL	FALSE	The output of the integral action can be held in the negative direction. For this, the input INT_HNEG must be set to TRUE. In a cascade control, INT_HNEG of the primary controller is connected to QLMN_LLM of the secondary controller.
SELECT	12.0	INT	0	If the pulse shaper is on, there are several ways of calling the PID algorithm and pulse shaper: • SELECT = 0: The controller is called in a fast cyclic interrupt priority class and the PID algorithm and pulse shaper are processed. • SELECT = 1: The controller is called in OB1 and only the PID algorithm is processed. • SELECT = 2: The controller is called in a fast cyclic interrupt priority class and only the pulse shaper is processed. • SELECT = 3: The controller is called a slow cyclic interrupt priority class and only the PID algorithm is processed.

See also

Operating principle of the pulse generator (Page 460)

Block diagram TCONT_CP (Page 463)

11.4.4.6 Output parameters TCONT_CP

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-20

Parameter	Address	Data type	Default	Description
PV	14.0	REAL	0.0	The effective process value is output at the "Process value" output. The valid values depend on the sensors used.
LMN	18.0	REAL	0.0	The effective "Manipulated value" is output in floating point format at the "Manipulated value" output.
LMN_PER	22.0	INT	0	The manipulated value in I/O format is interconnected with the controller on the output "Manipulated value I/O".
QPULSE	24.0	BOOL	FALSE	The manipulated value is pulse-width-modulated at the QPULSE output.
QLMN_HLM	24.1	BOOL	FALSE	The manipulated value is always restricted to a high limit and low limit. The output QLMN_HLM signals that the high limit has been reached.
QLMN_LLM	24.2	BOOL	FALSE	The manipulated value is always restricted to a high limit and low limit. The output QLMN_LLM signals that the low limit has been reached.
QC_ACT	24.3	BOOL	TRUE	This parameter indicates whether continuous control component will be processed the next time the block is called (relevant only when SELECT has the value 0 or 1).

See also

Operating principle of the pulse generator (Page 460)

Block diagram TCONT_CP (Page 463)

Parameter STATUS_H (Page 470)

Parameters STATUS_D (Page 471)

11.4.4.7 In/out parameters TCONT_CP

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-21

Parameters	Address	Data type	Default	Description
CYCLE	26.0	REAL	0.1 s	Sets the sampling time for the PID algorithm. In phase 1, the tuner calculates the sampling time and enters it in CYCLE. CYCLE > 0.001 s
CYCLE_P	30.0	REAL	0.02 s	At this input, you set the sampling time for the pulse shaper action. In phase 1, the TCONT_CP instruction calculates the sampling time and enters it in CYCLE_P. CYCLE_P > 0.001 s

Parameters	Address	Data type	Default	Description
SP_INT	34.0	REAL	0.0	The input "Internal setpoint" is used to specify a setpoint. The valid values depend on the sensors used.
MAN	38.0	REAL	0.0	The "Manual value" input is used to set a manual value. In automatic mode, it tracks the manipulated value.
COM_RST	42.0	BOOL	FALSE	The block has an initialization routine that is processed when the COM_RST input is set.
MAN_ON	42.1	BOOL	TRUE	If the input "Enable manual mode" is set then the control loop is interrupted. The manual value MAN is set as manipulated value.

See also

Operating principle of the pulse generator (Page 460)
Block diagram TCONT_CP (Page 463)

11.4.4.8 Static variables TCONT_CP

The names of the following variables apply both to the data block and to access via the Openness API.

Table 11-22

Parameters	Address	Data type	Default	Description
DEADB_W	44.0	REAL	0.0	A deadband is applied to the control deviation. The "Deadband width" input determines the size of the deadband. The valid values depend on the sensors used.
I_ITLVAL	48.0	REAL	0.0	The output of the integrator can be set at the I_ITL_ON input. The initialization value is applied to the "Initialization value of the I-action" input. During a restart COM_RST = TRUE, the I-action is set to the initialization value. Values from -100 to 100 % are permitted.
LMN_HLM	52.0	REAL	100.0	The output value is always restricted to a high limit and low limit. The "Manipulated value high limit" input specifies the high limit. LMN_HLM > LMN_LLM
LMN_LLM	56.0	REAL	0.0	The output value is always restricted to a high limit and low limit. The "Manipulated value low limit" input specifies the low limit. LMN_LLM < LMN_HLM
PV_FAC	60.0	REAL	1.0	The "Process value factor" input is multiplied by the "Process value I/O". The input is used to scale the process value range.
PV_OFFS	64.0	REAL	0.0	The "Process value offset" input is added to the "Process value I/O". The input is used to scale the process value range.
LMN_FAC	68.0	REAL	1.0	The "Output value factor" input is multiplied with the output value. The input is used to scale the output value range.
LMN_OFFS	72.0	REAL	0.0	The "Output value offset" input is added to the output value. The input is used to scale the output value range.
PER_TM	76.0	REAL	1.0 s	The period duration of the pulse width modulation is entered at the PER_TM parameter. The relationship of the period duration to the sampling time of the pulse shaper determines the accuracy of the pulse width modulation. PER_TM ≥ CYCLE

Parameters	Address	Data type	Default	Description
P_B_TM	80.0	REAL	0.02 s	You can assign a minimum pulse or break time at the parameter "Minimum pulse/break time". P_B_TM is internally limited to > CYCLE_P.
TUN_DLMN	84.0	REAL	20.0	Process excitation for controller tuning results from a output value step change at TUN_DLMN. Values from -100 to 100 % are permitted.
PER_MODE	88.0	INT	0	You can use this switch to enter the type of I/O module. The process value at input PV_PER is then scaled as follows at the PV output. • PER_MODE = 0: Thermocouples; PT100/NI100; standard PV_PER * 0.1 Unit: C, °F • PER_MODE = 1: PT100/NI100; climate PV_PER * 0.01 Unit: C, °F • PER_MODE = 2: Current/voltage PV_PER * 100/27648 Unit: %
PVPER_ON	90.0	BOOL	FALSE	If the process value is to be read in from the I/Os, the PV_PER input must be interconnected with the I/Os and the "Enable process value I/Os" input must be set.
I_ITL_ON	90.1	BOOL	FALSE	The output of the integrator can be set at the I_ITLVAL input. The "Set I-action" input must be set for this.
PULSE_ON	90.2	BOOL	FALSE	If PULSE_ON = TRUE is set, the pulse shaper is activated.
TUN_KEEP	90.3	BOOL	FALSE	The mode changes to automatic only when TUN_KEEP changes to FALSE.
ER	92.0	REAL	0.0	The effective control deviation is output at the "Control deviation" output. The valid values depend on the sensors used.
LMN_P	96.0	REAL	0.0	The "P-action" output contains the proportional action of the manipulated tag.
LMN_I	100.0	REAL	0.0	The "integral action" output contains the integral action of the manipulated tag.
LMN_D	104.0	REAL	0.0	The "D-action" output contains the derivative action of the manipulated tag.
PHASE	108.0	INT	0	The current phase of controller tuning is indicated at the PHASE output. • PHASE = 0: No optimization mode; automatic or manual mode • PHASE = 1: Ready to start tuning; check parameters, wait for excitation, measure the sampling times • PHASE = 2: Actual tuning: Searching for point of inflection with constant output value. Entering the sampling time in instance DB. • PHASE = 3: Calculating the process parameters. Saving valid controller parameters prior to tuning. • PHASE = 4: Controller design • PHASE = 5: Following up the controller to the new manipulated variable • PHASE = 7: Validating the process type
STATUS_H	110.0	INT	0	STATUS_H indicates the diagnostic value via the search for the point of inflection during the heating process.
STATUS_D	112.0	INT	0	STATUS_D indicates the diagnostic value via the controller design during the heating process.
QTUN_RUN	114.0	BOOL	0	The tuning manipulated tag has been applied, tuning has started and is still in phase 2 (searching for point of inflection).
PI_CON	116.0	STRUCT		PI controller parameters
GAIN	+0.0	REAL	0.0	PI controller gain %/phys. Unit

Parameters	Address	Data type	Default	Description
TI	+4.0	REAL	0.0 s	PI integration time [s]
PID_CON	124.0	STRUCT		PID controller parameters
GAIN	+0.0	REAL	0.0	PID controller gain
TI	+4.0	REAL	0.0s	PID integration time [s]
TD	+8.0	REAL	0.0s	PID derivative action time [s]
PAR_SAVE	136.0	STRUCT		The PID parameters are saved in this structure.
PFAC_SP	+0.0	REAL	1.0	Proportional factor for setpoint changes Values from 0.0 to 1.0 are permitted.
GAIN	+4.0	REAL	0.0	Controller gain %/phys. Unit
TI	+8.0	REAL	40.0 s	Integration time [s]
TD	+12.0	REAL	10.0 s	Derivative action time (s)
D_F	+16.0	REAL	5.0	Derivative factor Values from 5.0 to 10.0 are permitted.
CON_ZONE	+20.0	REAL	100.0	Control zone band If the control deviation is greater than the control zone band, the high output value limit is output as output value. If the control deviation is less than the negative control zone band, the low output value limit is output as the output value. CON_ZONE ≥ 0.0
CONZ_ON	+24.0	BOOL	FALSE	Enable control zone
PFAC_SP	162.0	REAL	1.0	PFAC_SP specifies the effective P-action when there is a setpoint change. This is set between 0 and 1. • 1: P-action has full effect if the setpoint changes. • 0: P-action has no effect if the setpoint changes. Values from 0.0 to 1.0 are permitted.
GAIN	166.0	REAL	2.0	The "Proportional gain" input specifies controller amplification. The direction of control can be reversed by giving GAIN a negative sign. %/phys. Unit
TI	170.0	REAL	40.0 s	The "Integration time" (integral-action time) input defines the integrator's time response.
TD	174.0	REAL	10.0 s	The "Derivative-action time" (rate time) input decides the time response of the differentiator.
D_F	178.0	REAL	5.0	The derivative factor decides the lag of the D-action. D_F = derivative-action time/"Lag of the D-action" Values from 5.0 to 10.0 are permitted.
CON_ZONE	182.0	REAL	100.0	If the control deviation is greater than the control zone band, the high output value limit is output as output value. If the control deviation is less than the negative control zone band, the low output value limit is output as the output value. The valid values depend on the sensors used.
CONZ_ON	186.0	BOOL	FALSE	You can use CONZ_ON =TRUE to enable the control zone.
TUN_ON	186.1	BOOL	FALSE	If TUN_ON=TRUE, the output value is averaged until the output value excitation TUN_DLMN is enabled either by a setpoint step-change or by TUN_ST=TRUE.
TUN_ST	186.2	BOOL	FALSE	If the setpoint is to remain constant during controller tuning at the operating point, a output value step-change by the amount of TUN_DLMN is activated by TUN_ST=1.

Parameters	Address	Data type	Default	Description
UNDO_PAR	186.3	BOOL	FALSE	Loads the controller parametersPFAC_SP, GAIN, TI, TD, D_FCONZ_ON and CON_ZONE from the data structure PAR_SAVE (only in manual mode).
SAVE_PAR	186.4	BOOL	FALSE	Saves the controller parameters PFAC_SP, GAIN, TI, TD, D_F, CONZ_ON and CON_ZONE in the data structure PAR_SAVE.
LOAD_PID	186.5	BOOL	FALSE	Loads the controller parametersGAIN, TI,TD depending on PID_ON from the data structure PI_CON or PID_CON (only in manual mode)
PID_ON	186.6	BOOL	TRUE	At the PID_ON input, you can specify whether or not the tuned controller will operate as a PI or PID controller. • PID controller: PID_ON = TRUE • PI controller: PID_ON = FALSE With certain process types it is nevertheless possible that only a PI controller will be designed despite PID_ON = TRUE.
GAIN_P	188.0	REAL	0.0	Identified process gain. In the case of process type I, GAIN_P tends to be estimated too low.
TU	192.0	REAL	0.0	Identified time lag of the process. TU ≥ 3*CYCLE
TA	196.0	REAL	0.0	Identified recovery time of the process. In the case of process type I, TA tends to be estimated too low.
KIG	200.0	REAL	0.0	Maximum process value rise at manipulated tag excitation from 0 to 100 % [1/s] GAIN_P = 0.01 * KIG * TA
N_PTN	204.0	REAL	0.0	The parameter specifies the order of the process. "Non-integer values" are also possible. Values from 1.01 to 10.0 are permitted.
TM_LAG_P	208.0	REAL	0.0	Time constants of a PTN model (practical values only for N_PTN >= 2).
T_P_INF	212.0	REAL	0.0	Time from process excitation until the point of inflection.
P_INF	216.0	REAL	0.0	Process value change from process excitation until the point of inflection. The valid values depend on the sensors used.
LMN0	220.0	REAL	0.0	Output value at the start of tuning Detected in phase 1 (mean value). Values from 0 to 100 % are permitted.
PV0	224.0	REAL	0.0	Process value at the start of tuning
PVDT0	228.0	REAL	0.0	Process value slew rate at start of tuning [1/s] Sign adapted.
PVDT	232.0	REAL	0.0	Current process value slew rate [1/s] Sign adapted.
PVDT_MAX	236.0	REAL	0.0	Max. change in the process value per second [1/s] Maximum derivative of the process value at the point of inflection (sign adapted, always > 0); is used to calculate TU and KIG.
NOI_PVDT	240.0	REAL	0.0	Noise action in PVDT_MAX in % The higher the noise action, the less accurate (less aggressive) the control parameters.
NOISE_PV	244.0	REAL	0.0	Absolute noise in process value Difference between maximum and minimum process value in phase 1.

Parameters	Address	Data type	Default	Description
FIL_CYC	248.0	INT	1	Number of cycles of the mean value filter The process value is determined through FIL_CYC cycles. FIL_CYC is increased from 1 to a max. of 1024 if needed.
POI_CMAX	250.0	INT	2	Maximum number of cycles after point of inflection This time is used to find another (i.e. better) inflection point for measuring noise. The tuning is completed only after this time.
POI_CYCL	252.0	INT	0	Number of cycles after inflection point

See also

Operating principle of the pulse generator (Page 460)
Block diagram TCONT_CP (Page 463)

11.4.4.9 Parameter STATUS_H

STATUS_H	Description	Remedy
0	Default, or no/no new controller parameters	
10000	Tuning completed + suitable controller parameters found	
2xxxx	Tuning completed + controller parameters uncertain	
2xx2x	Point of inflection not reached (only if excited via setpoint step-change)	If the controller oscillates, weaken the controller parameters, or repeat the test with a smaller manipulated value difference TUN_DLMN.
2x1xx	Estimation error (TU < 3*CYCLE)	Reduce CYCLE and repeat attempt. Special case for PT1-only process: Do not repeat test, if necessary reduce controller parameters.
2x3xx	Estimation error TU too high	Repeat test under better conditions.
21xxx	Estimation error N_PTN < 1	Repeat test under better conditions.
22xxx	Estimation error N_PTN > 10	Repeat test under better conditions.
3xxxx	Tuning canceled in phase 1 owing to faulty parameter assignment:	
30002	Effective manipulated value differential < 5%	Correct manipulated value differential TUN_DLMN.
30005	The sampling times CYCLE and CYCLE_P differ by more than 5% of the measured values.	Compare CYCLE and CYCLE_P with the cycle time of the cyclic interrupt priority class and note any loop scheduler. Check CPU load. An excessively loaded CPU can result in prolonged sampling times that are inconsistent with CYCLE or CYCLE_P.

NOTE

If you cancel tuning in phase 1 or 2, STATUS_H = 0 is set. However, STATUS_D still displays the status of the last controller calculation.

The higher the value of STATUS_D, the higher the order of the control process, the greater the TU/TA ratio and the gentler the controller parameters will be.

See also

Operating principle of the pulse generator (Page 460)

Block diagram TCONT_CP (Page 463)

11.4.4.10 Parameters STATUS_D

STATUS_D	Description
0	No controller parameters were calculated.
110	N_PTN <= 1.5 Process type I fast
121	N_PTN > 1.5 Process type I
200	N_PTN > 1.9 Process type II (transition range)
310	N_PTN >= 2.1 Process type III fast
320	N_PTN > 2.6 Process type III
111, 122, 201, 311, 321	Parameters have been corrected from phase 7.

NOTE

The higher the value of STATUS_D, the higher the order of the control process, the greater the TU/TA ratio and the gentler the controller parameters will be.

See also

Operating principle of the pulse generator (Page 460)

Block diagram TCONT_CP (Page 463)

11.4.5 TCONT_S

11.4.5.1 Description TCONT_S

The TCONT_S instruction is used on SIMATIC S7 automation systems to control technical temperature processes with binary manipulated value output signals for actuators with integrating behavior. The functionality is based on the PI control algorithm of the sampling controller. The step controller operates without a position feedback signal.

Application

You can also use the controller in a cascade control as a secondary position controller. You specify the actuator position via the setpoint input SP_INT. In this case, you must set the process value input and the parameter TI (integration time) to zero. An application might be, for example, temperature control with heating power control using pulse-break activation and cooling control using a butterfly valve. To close the valve completely, the manipulated variable (ER*GAIN) should be negative.

Call

The instruction TCONT_S must be called with a constant bus cycle time. To achieve this, use a cyclic interrupt level (e.g. OB35 with S7-300). The sampling time is specified at the CYCLE parameter.

CYCLE sampling time

The CYCLE sampling time match the time difference between two calls (cycle time of the cyclic interrupt OB taking into account the reduction ratios).

The controller sampling time should not exceed 10% of the calculated integration time of the controller (TI). Generally, you must set the sampling time to a much lower value to achieve the required accuracy of the step controller.

Required accuracy G	MTR_TM	CYCLE = MTR_TM*G	Comment
0.5%	10 s	0.05 s	The sampling time is determined by the required accuracy of the step controller.

Start-up

The TCONT_S instruction has an initialization routine that is run through when input parameter COM_RST = TRUE is set. Following execution of the initialization routine, the block sets COM_RST back to FALSE. All outputs are set to their initial values. If you require initialization when the CPU restarts, call the block in OB100 with COM_RST = TRUE.

See also

Block diagram TCONT_S (Page 477)

11.4.5.2 Mode of operation TCONT_S

Setpoint branch

The setpoint is entered at input SP_INT in floating-point format as a physical value or percentage. The setpoint and process value used to form the control deviation must have the same unit.

Process value options (PVPER_ON)

Depending on PVPER_ON, the process value can be read in, in the I/O or floating-point format.

PVPER_ON	Process Value Input
TRUE	The process value is read in via the analog I/Os (PIW xxx) at input PV_PER.
FALSE	The process value is acquired in floating-point format at input PV_IN.

Process value format conversion CRP_IN (PER_MODE)

The CRP_IN function converts the I/O value PV_PER to floating-point format depending on the PER_MODE switch according to the following rules:

PER_MODE	Output of CRP_IN	Analog Input Type	Unit
0	PV_PER * 0.1	Thermoelements; PT100/NI100; standard	°C;°F
1	PV_PER * 0.01	PT100/NI100; climate;	°C;°F
2	PV_PER * 100/27648	Voltage/current	%

Process value scaling PV_NORM (PF_FAC, PV_OFFS)

The PV_NORM function calculates the output of CRP_IN according to the following rule:

"Output of PV_NORM" = "Output of CRP_IN" * PV_FAC + PV_OFFS

It can be used for the following purposes:

- Process value adjustment with PV_FAC as process value factor and PV_OFFS as process value offset.
- Scaling of temperature to percentage

  You want to enter the setpoint as a percentage and must now convert the measured temperature value to a percentage.
- Scaling of percentage to temperature

  You want to enter the setpoint in the physical temperature unit and must now convert the measured voltage/current value to a temperature.

Calculation of the parameters:

- PV_FAC = range of PV_NORM/range of CRP_IN;
- PV_OFFS = LL (PV_NORM) - PV_FAC * LL(CRP_IN);

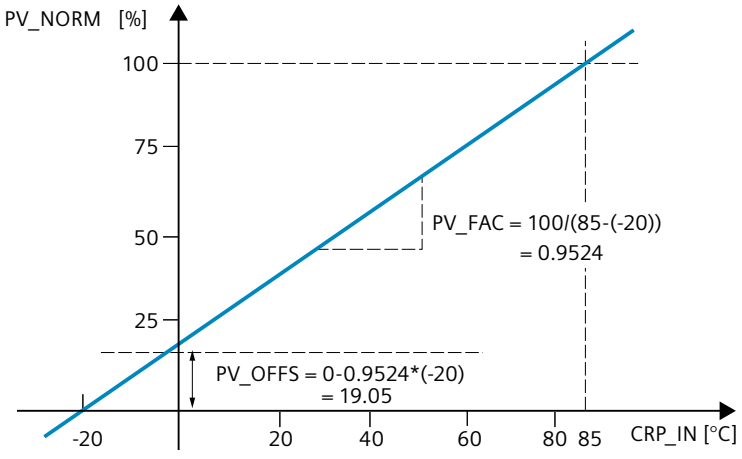
  where LL: low limit

The scaling is switched off with the default values (PV_FAC = 1.0 and PV_OFFS = 0.0). The effective process value is output at the PV output.

Example of Process Value Scaling

If you want to enter the setpoint as a percentage, and you have a temperature range of -20 to 85 °C applied to , CRP_IN you must normalize the temperature range as a percentage.

The diagram below shows an example of adapting the temperature range -20 to 85 °C to an internal scale of 0 to 100 %:



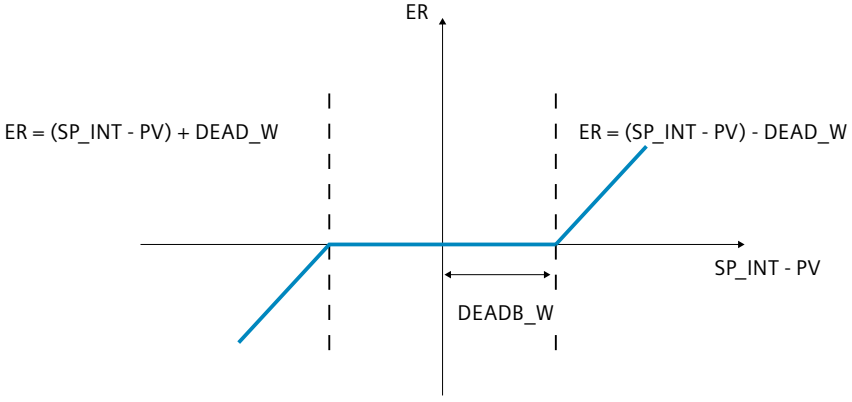
Forming the control deviation

The difference between the setpoint and process value is the control deviation before the dead zone.

The setpoint and process value must exist in the same unit.

Dead zone (DEADB_W)

To suppress a minor sustained oscillation due to the manipulated variable quantization (for example, in pulse width modulation with PULSEGEN) a dead zone is applied to the (DEADBAND) control deviation. With DEADB_W = 0.0, the dead zone is disabled.



PI step controller algorithm

The instruction TCONT_S operates without position feedback. The I-action of the PI algorithm and the assumed position feedback signal are calculated in an integrator (INT) and compared as a feedback value with the remaining proportional action. The difference is applied to a three-step element (THREE_ST) and a pulse shaper (PULSEOUT) that generates the pulses for the control valve. Adapting the response threshold of the three-step element reduces the switching frequency of the controller.

Weakening of the proportional action when setpoint changes occur

To prevent overshoot, you can weaken the proportional action using the "Proportional factor for setpoint changes" parameter (PFAC_SP). Using PFAC_SP, you can now select continuously between 0.0 and 1.0 to decide the effect of the proportional action when the setpoint changes:

- PFAC_SP = 1.0: Proportional action for setpoint change is fully effective
- PFAC_SP = 0.0: Proportional action has no effect in the setpoint change

As in the case of the continuous controller, a value of PFAC_SP < 1.0 can reduce the overshoot if the motor run time MTR_TM is small compared with the recovery time TA and the ratio is TU/TA < 0.2. If MTR_TM reaches 20% of TA, only a slight improvement can still be achieved.

Feedforward control

A disturbance variable can be added at the DISV input.

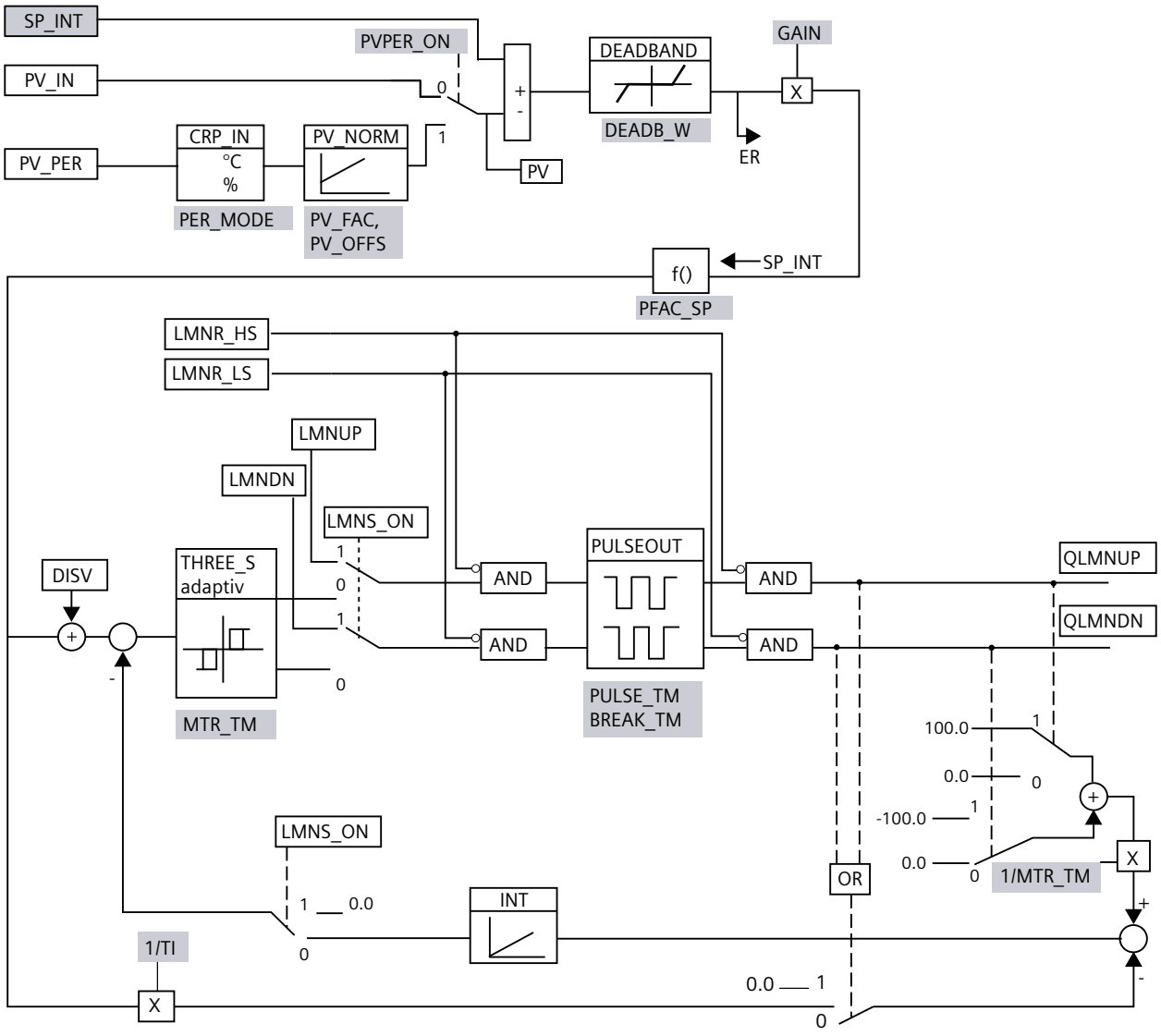
Manual value processing (LMNS_ON, LMNUP, LMNDN)

With LMNS_ON, you can change between manual and automatic mode. In manual mode, the actuator is halted and the integral action (INT) is set to 0 internally. Using LMNUP and LMNDN, the actuator can be adjusted to OPEN and CLOSED. Switching over to automatic mode therefore involves a bump. As a result of the GAIN, the existing control deviation leads to a step change in the internal manipulated variable. The integral component of the actuator, however, results in a ramp-shaped excitation of the process.

See also

Block diagram TCONT_S (Page 477)

11.4.5.3 Block diagram TCONT_S



Parameter configuration interface

Instruction call interface

Parameter configuration interface, call interface

See also

Description TCONT_S (Page 472)

Mode of operation TCONT_S (Page 473)

Input paramters TCONT_S (Page 478)

Output parameters TCONT_S (Page 479)

In/out parameters TCONT_S (Page 479)

Static variables TCONT_S (Page 479)

11.4.5.4 Input paramters TCONT_S

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-23

Parameters	Address	Data type	Default	Description
CYCLE	0.0	REAL	0.1 s	At this input, you enter the sampling time for the controller. CYCLE ≥ 0.001
SP_INT	4.0	REAL	0.0	The input "Internal setpoint" is used to specify a setpoint. The valid values depend on the sensors used.
PV_IN	8.0	REAL	0.0	At the "Process variable input" you can assign parameters to a commissioning value or you can interconnect an external process value in floating-point format. The valid values depend on the sensors used.
PV_PER	12.0	INT	0	The process value in I/O format is interconnected with the controller at the "Process value I/O" input.
DISV	14.0	REAL	0.0	For feedforward control, the disturbance variable is interconnected to the "Disturbance variable" input.
LMNR_HS	18.0	BOOL	FALSE	The signal "Control valve at high endstop" is interconnected on the input "High endstop signal of position feedback". • LMNR_HS=TRUE: The control valve is located at the high endstop.
LMNR_LS	18.1	BOOL	FALSE	The signal "Control valve at low endstop" is interconnected on the input "Low endstop signal of position feedback". • LMNR_LS=TRUE: The control valve is located at the low endstop.
LMNS_ON	18.2	BOOL	TRUE	Manipulated value signal processing is switched to manual mode at the "Enable manual mode of manipulated signal".
LMNUP	18.3	BOOL	FALSE	In manual mode of manipulated signals, the output parameter QLMNUP is operated at the input parameter "Manipulated signal up".
LMNDN	18.4	BOOL	FALSE	In manual mode of the manipulated signals, the output parameter QLMNDN is operated at the input parameter "Manipulated signal down".

See also

Block diagram TCONT_S (Page 477)

11.4.5.5 Output parameters TCONT_S

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-24

Parameters	Address	Data type	Default	Description
QLMNUP	20.0	BOOL	FALSE	If the output "Manipulated value signal up" is set then the control valve should be open.
QLMNDN	20.1	BOOL	FALSE	If the output "Manipulated value signal down" is set then the control valve should be closed.
PV	22.0	REAL	0.0	The effective process value is output at the "Process value" output.
ER	26.0	REAL	0.0	The effective system deviation is output at the "Error signal" output.

See also

Block diagram TCONT_S (Page 477)

11.4.5.6 In/out parameters TCONT_S

The names of the following parameters apply both to the data block and to access via the Openness API.

Table 11-25

Parameters	Address	Data type	Default	Description
COM_RST	30.0	BOOL	FALSE	The block has an initialization routine that is processed when the COM_RST input is set.

See also

Block diagram TCONT_S (Page 477)

11.4.5.7 Static variables TCONT_S

The names of the following variables apply both to the data block and to access via the Openness API.

Table 11-26

Parameters	Address	Data type	Default	Description
PV_FAC	32.0	REAL	1.0	The "Process value factor" input is multiplied by the process value. The input is used to scale the process value range.
PV_OFFS	36.0	REAL	0.0	The input "Process value offset" is added to the process value. The input is used to scale the process value range. The valid values depend on the sensors used.
DEADB_W	40.0	REAL	0.0	A deadband is applied to the control deviation. The "Deadband width" input determines the size of the deadband. DEADB_W ≥ 0.0

Parameters	Addre-ss	Data type	Default	Description
PFAC_SP	44.4	REAL	1.0	PFAC_SP specifies the effective P-action when there is a setpoint change. • 1: P-action has full effect if the setpoint changes. • 0: P-action has no effect if the setpoint changes. Values from 0.0 to 1.0 are permitted.
GAIN	48.0	REAL	2.0	The "Proportional gain" input specifies controller amplification. The direction of control can be reversed by giving GAIN a negative sign. %/phys. Unit
TI	52.0	REAL	40.0 s	The "Integration time" (integral-action time) input defines the integrator's time response.
MTR_TM	56.0	REAL	30 s	The runtime from endstop to endstop of the control valve is entered at the "Motor actuating time" parameter. MTR_TM ≥ CYCLE
PULSE_TM	60.0	REAL	0.0 s	A minimum pulse time can be configured at the "Minimum pulse time" parameter.
BREAK_TM	64.0	REAL	0.0 s	You can assign a minimum break time at the parameter "Minimum break time".
PER_MODE	68.0	INT	0	You can use this switch to enter the type of I/O module. The process value at input PV_PER is then scaled as follows at the PV output. • PER_MODE = 0: Thermocouples; PT100/NI100; standard PV_PER * 0.1 Unit: C, °F • PER_MODE = 1: PT100/NI100; climate PV_PER * 0.01 Unit: C, °F • PER_MODE = 2: Current/voltage PV_PER * 100/27648 Unit: %
PVPER_ON	70.0	BOOL	FALSE	If the process value is to be read in from the I/Os, the PV_PER input must be interconnected with the I/Os and the "Enable process value I/Os" input must be set.

See also

Block diagram TCONT_S (Page 477)

11.4.6 Integrated system functions

11.4.6.1 CONT_C_SF

CONT_C_SF

The instruction CONT_C_SF is integrated in the S7-300 compact CPUs. The instruction must not be transmitted to the S7-300 CPU during loading. The scope of function corresponds with the instruction CONT_C.

See also

Description CONT_C (Page 431)
How CONT_C works (Page 432)
CONT_C block diagram (Page 434)
Input parameter CONT_C (Page 435)
Output parameters CONT_C (Page 436)

11.4.6.2 CONT_S_SF

CONT_S_SF

The instruction CONT_S_SF is integrated in the S7-300 compact CPUs. The instruction must not be transmitted to the S7-300 CPU during loading. The scope of function corresponds with the instruction CONT_S.

See also

Description CONT_S (Page 437)
Mode of operation CONT_S (Page 438)
Block diagram CONT_S (Page 439)
Input parameters CONT_S (Page 440)
Output parameters CONT_S (Page 441)

11.4.6.3 PULSEGEN_SF

PULSEGEN_SF

The instruction PULSEGEN_SF is integrated in the S7-300 compact CPUs. The instruction must not be transmitted to the S7-300 CPU during loading. The scope of function corresponds with the instruction PULSEGEN.

See also

Description PULSEGEN (Page 442)
Mode of operation PULSEGEN (Page 443)
Mode of operation PULSEGEN (Page 446)
Three-step control (Page 446)
Two-step control (Page 448)
Input parameters PULSEGEN (Page 449)
Output parameter PULSEGEN (Page 450)

11.5 Polyline

11.5.1 Compatibility with CPU and FW

The following table shows which version of Polyline can be used on which CPU:

CPU	FW	Polyline
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.5.2 Description Polyline

Description

The Polyline instruction maps input value Input onto output value Output using a characteristic curve. The characteristic curve is defined as a polyline with maximum 50 points. Linear interpolation is performed between the points. You can fit the polyline to the desired characteristic curve using the number and configuration of the points.

The Polyline instruction can be used, for example, to linearize non-linear characteristics of sensors or actuators.

Interpolation calculation

Polyline calculates the output value at the Output parameter for the input value at the Input parameter that lies between point values x_i and x_{i+1} with a linear interpolation. The linear interpolation is calculated according to the following formula:

$$Output = \frac{(Input - x_i)}{(x_{i+1} - x_i)} (y_{i+1} - y_i) + y_i$$

With parameter Reset = TRUE, an alternative output value can also be specified using the SubstituteOutput parameter.

Polyline data

The value pairs for the polyline are contained in the Static area of the instruction.

NOTE

- The minimum number of value pairs to be configured is 2.
- The maximum number of value pairs to be configured is 50.
- For a valid configuration, the x values must be specified in ascending order.

To allow the polyline data to be changed without the changes taking effect immediately, the value pairs of the polyline are duplicated and contained in the following structures:

- UserData

  The polyline data in this structure can be edited.

  Make use of this structure to specify or change the polyline data. Changes in this structure do not affect the interpolation calculation until the check and duplication of the data to the WorkingData structure is initiated. This happens by setting Validate = TRUE or automatically during the first processing of Polyline after the operating state transition of the CPU from STOP to RUN.

  The preassignment of values in this structure does not represent a valid configuration. To use the values for the interpolation calculation, change the tags to valid values.

- WorkingData

  The polyline data in this structure cannot be edited. This data is used for the interpolation calculation. Do not manually change the data in this structure.

Both structures have the same data type and thus the same content:

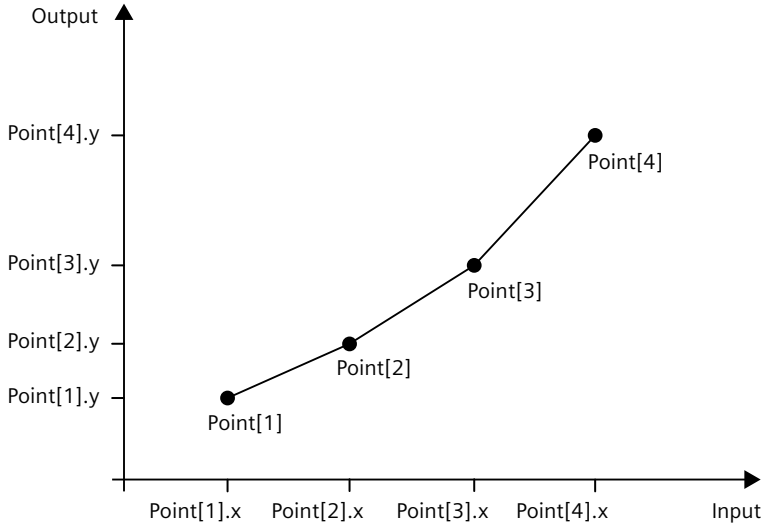
- NumberOfUsedPoints

  Number of points used for the interpolation calculation.

- Point

  The array with 50 elements contains value pairs of points Point[i].x and Point[i].y with index "i" from 1 to 50.

The following figure shows a polyline with four points:



Call

Polyline is called in an OB as a single-instance DB, Polyline is called in an FC as a single-instance DB or parameter instance DB; Polyline can be called as a single-instance DB, as a multi-instance DB and as a parameter instance DB in an FB.

When the instruction is called, no technology object is created. Polyline configuration is available for individual instances in the Inspector window of the programming editor.

Startup

The tags in the UserData and WorkingData structures are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

If you change the actual values in the UserData structure in online mode and these values are to be retained after the operating state transition of the CPU from STOP to RUN, back up these values in the start values of the data block.

At the first call of the Polyline instruction after the operating state transition of the CPU from STOP to RUN, the data in the UserData structure is automatically checked for validity. If the check is successful, the data is transferred to the WorkingData structure.

Response to errors

The Polyline instruction detects different errors that may occur during interpolation calculation. The result of the interpolation calculation can be output at the output despite a pending error. If an error prevents correct calculation of the interpolation result, a substitute output value is output at the output.

You specify the substitute output value that is output if an error occurs that prevents correct calculation of the interpolation result as follows at the ErrorMode tag:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter
2	The last valid result of interpolation calculation 0.0 if there is no valid result

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.5.3 Operating principle Polyline

Polyline data

To change the polyline, you edit the values in the UserData structure. The values are then checked for validity and transferred to the WorkingData structure. Only in the WorkingData structure are the values used for the interpolation calculation.

The values are checked and transferred when

- You set the Validate parameter to TRUE while the Reset parameter is set to FALSE.
- Polyline is called for the first time after the change of operating state of the CPU from STOP to RUN while the Reset parameter is set to FALSE.

  If Polyline has already been called, for example in OB100, another automatic check of the values is not performed at the subsequent calls.

If the polyline data in the UserData structure is invalid, the previous polyline data in the WorkingData structure remains unchanged and a corresponding error message is output. If the check was performed for the first time, no valid values are available in the WorkingData structure and a corresponding error message is output. In this case, the Output parameter is specified with the substitute output value that you configure with the ErrorMode tag.

The check and transfer of the values from the UserData structure requires more CPU processing time than the interpolation calculation. In time-critical applications, the first

execution of Polyline can be in startup OB 100. In this way, the time-consuming one-time check and transfer of the polyline data can be completed before the cyclic application program sections.

Validity of the polyline data

When the values in the UserData structure are checked, they must meet the following conditions so that a valid polyline is available for the interpolation calculation:

- 2 ≤ UserData.NumberOfUsedPoints ≤ 50
- UserData.Point[j].x < UserData.Point[j+1].x with index j = 1..(UserData.NumberOfUsedPoints – 1)
- -3.402823e+38 ≤ UserData.Point[i].x ≤ 3.402823e+38 with index i = 1..UserData.NumberOfUsedPoints
- -3.402823e+38 ≤ UserData.Point[i].y ≤ 3.402823e+38 with index i = 1..UserData.NumberOfUsedPoints
- UserData.Point[i].x and UserData.Point[i].y are valid REAL values (≠ NaN) with index i = 1..UserData.NumberOfUsedPoints

If one or more conditions are not met during the check, the values in the UserData structure are not transferred to the WorkingData structure. A corresponding error message is output at the ErrorBits (Page 491) parameter.

The preassignment of values in the UserData structure does not represent a valid configuration. Change the tags to valid values so that the tags can be used for the interpolation calculation.

NOTE

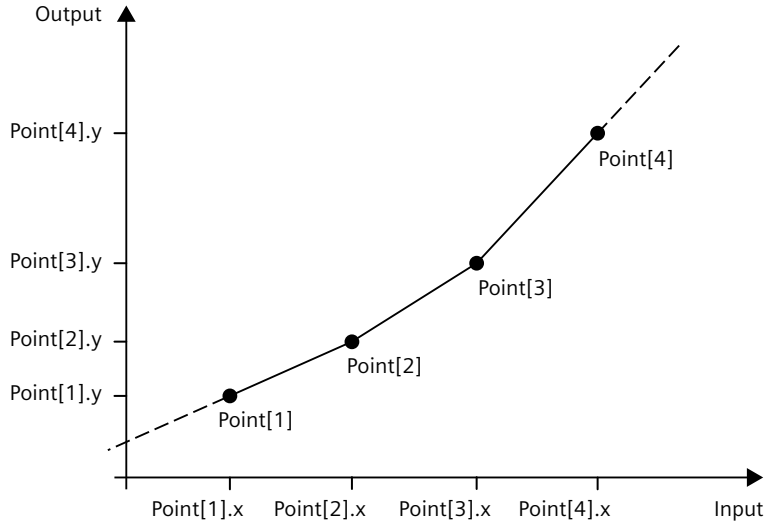
If more than the maximum number of 50 points are needed for your application, use two or more instances of Polyline.

Calculating the output value

If the input value at the Input parameter is below the first x-value or above the last x-value of the utilized points, configure the preassignment of the Output parameter with the following settings at the OutOfRangeMode tag:

- OutOfRangeMode = 0

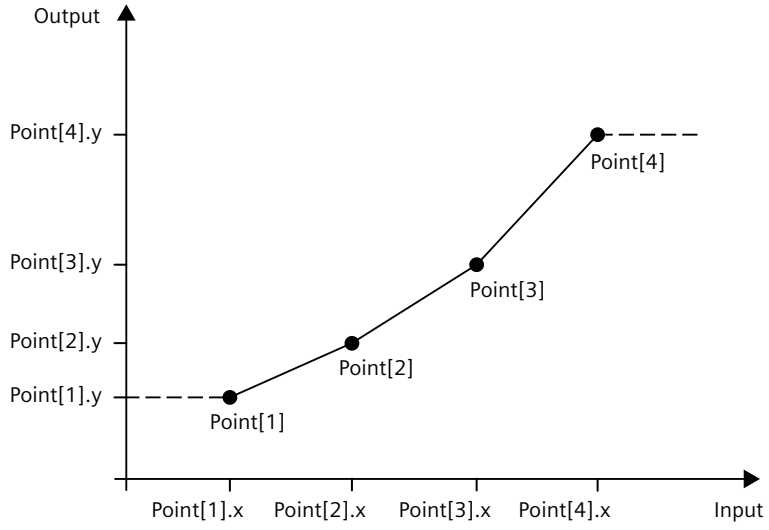
  The output value is extrapolated with the slope of the first or last two points.



  If the OutOfRangeMode tag lies outside the permissible value range of 0 to 1, the default preassignment 0 becomes effective.

- OutOfRangeMode = 1

  The output value is limited to the y-value of the first or last point.



The Output parameter has a permissible value range of a REAL data type of -3.402823e+38 to 3.402823e+38. The output value at the Output parameter is checked for validity each time the Polyline instruction is executed. If the interpolation calculation yields an invalid REAL value, the output value is replaced with the setting at the ErrorMode tag.

Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

Currently utilized points

The NextXIndex index outputs the index of the next higher x-value for the current input value. You can use this to determine the points that are being used for the current interpolation calculation.

WorkingData.Point[NextXIndex-1].x < Input ≤ WorkingData.Point[NextXIndex].x

Example:

- If the value of the Input parameter is between WorkingData.Point[3].x and WorkingData.Point[4].x, the NextXIndex tag has the value 4.
- If the value of the Input parameter is less than WorkingData.Point[1].x, the NextXIndex tag has the value 1.
- If the value of the Input parameter is greater than WorkingData.Point[WorkingData.NumberOfUsedPoints].x and is thus greater than the last x-value of the polyline, the NextXIndex tag has the value of the WorkingData.NumberOfUsedPoints + 1 tag. Consequently, maximum permissible value of the NextXIndex tag is 51.

11.5.4 Input parameters of Polyline

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
Substitu-teOutput	REAL	0.0	SubstituteOutput is used as the substitute output value when • Reset = TRUE or • An error with error message ErrorBits ≥ 16#0001_0000 prevents correct calculation of the interpolation result, and the configured value of ErrorMode is 1 .
Validate	BOOL	FALSE	If Validate is set to TRUE, the polyline data in UserData is checked for validity and transferred to WorkingData.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset
Reset	BOOL	FALSE	Performs a restart of the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. • As long as Reset is set to FALSE, the interpolation calculation is performed.

11.5.5 Output parameters of Polyline

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 491) shows which error messages are pending. ErrorBits is retentive and is reset at a positive edge at Reset or ErrorAck .

11.5.6 Static tags of Polyline

Tag	Data type	Default	Description
UserData	AuxFct_Point-Table	-	Input area for polyline data The polyline data in the UserData structure can be edited. Changes in this structure do not affect the interpolation calculation until the check and duplication of the data to the WorkingData structure is initiated.
UserData.NumberOfUsedPoints	INT	0	Number of points used for the interpolation calculation Permissible value range: 2 to 50
UserData.Point	Array[1..50] of AuxFct_Point	-	Points for the interpolation calculation The array with 50 elements of data type AuxFct_Point contains the value pairs of the points.

Tag	Data type	Default	Description
UserData.Point[i]	AuxFct_Point	-	Point for the interpolation calculation An element with index "i" from the "Point" array.
UserData.Point[i].x	REAL	0.0	x-value of the point Permissible value range: Point[i].x < Point[i+1].x
UserData.Point[i].y	REAL	0.0	y-value of the point
WorkingData	AuxFct_Point-Table	-	Display area of the currently active polyline data The polyline data in the WorkingData structure cannot be edited. It is used for the interpolation calculation.
WorkingData.NumberOfUsedPoints	INT	0	Number of points used for the interpolation calculation Permissible value range: 2 to 50
WorkingData.Point	Array[1..50] of AuxFct_Point	-	Points for the interpolation calculation The array with 50 elements of type AuxFct_Point contains the value pairs of the points.
WorkingData.Point[i]	AuxFct_Point	-	Point for the interpolation calculation An element with index "i" from the "Point" array.
WorkingData.Point[i].x	REAL	0.0	x-value of the point Permissible value range: Point[i].x < Point[i+1].x
WorkingData.Point[i].y	REAL	0.0	y-value of the point
ErrorMode	INT	0	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid output value Permissible value range: 0 to 2
OutOfRangeMode	INT	0	Selection of the output value if the input value lies outside the defined x-values • 0 = Maintain slope • 1 = y-value of the first/last point Permissible value range: 0 to 1
NextXIndex	INT	2	Index of the next x-value Used for monitoring the index of the breakpoints that are being used for the current interpolation calculation. The following condition applies: WorkingData.Point[NextXIndex-1].x < Input ≤ WorkingData.Point[NextXIndex].x Do not change this value.

11.5.7 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

For Polyline, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
- Errors with error messages ErrorBits ≥ 16#0001_0000

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 are pending, Polyline reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, interpolation calculation
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:** If the interpolation value is output at the output (Reset = FALSE and ErrorBits < 16#0001_0000), check the following tags used in the interpolation calculation: • Input • WorkingData.Point[i].x • WorkingData.Point[i].y When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the ErrorMode tag: • Input • SubstituteOutput When Reset = TRUE, check the SubstituteOutput parameter.
0000_0002	**Cause of error:** One or more tags in the UserData structure have invalid values while the polyline data is checked (Validate = TRUE and Reset = FALSE). **Response to error:** The polyline data in the UserData structure is not transferred to the WorkingData structure so that the changes made in the UserData structure will not become effective. The Polyline FB continues the interpolation calculation with the unchanged and valid polyline data in the WorkingData structure. **Solution:**

ErrorBits (DW#16#...)	Description
	Ensure that the following conditions are met when the Validate parameter is set to TRUE: • 2 ≤ UserData.NumberOfUsedPoints ≤ 50 • UserData.Point[j].x < UserData.Point[j+1].x with index j = 1..(UserData.NumberOfUsedPoints - 1) • -3.402823e+38 ≤ UserData.Point[i].x ≤ 3.402823e+38 with index i = 1..UserData.NumberOfUsedPoints • -3.402823e+38 ≤ UserData.Point[i].y ≤ 3.402823e+38 with index i = 1..UserData.NumberOfUsedPoints • UserData.Point[i].x and UserData.Point[i].y are valid REAL values (≠ NaN) with index i = 1..UserData.NumberOfUsedPoints

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 are pending, Polyline reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, Polyline reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, interpolation calculation
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th colspan="3">Description</th></tr>
<tr><td>0001_0000</td><td colspan="3">Cause of error:
The SubstituteOutput or Input parameter that is being used as the output value has no valid REAL value.
Response to error:
The output is set to 0.0.
Solution:
Make sure that the parameter used as output value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). The parameter that is used as output value depends on Reset and ErrorMode:</td></tr>
<tr><td></td><td>Reset</td><td>ErrorMode</td><td>Output value</td></tr>
<tr><td></td><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td></td><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td></td><td>TRUE</td><td>-</td><td>SubstituteOutput</td></tr>
</table>

ErrorBits (DW#16#...)	Description
0002_0000	**Cause of error:** The Input parameter has no valid REAL value, while the interpolation calculation is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. When ErrorMode = 0, 0.0 is used as output value. The NextXIndex tag is not updated as long as the Input parameter has an invalid REAL value **Solution:** Make sure that the parameter Input is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF).
0004_0000	**Cause of error:** The interpolation calculation yields an invalid REAL value for the Output parameter. **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. The NextXIndex tag can have an invalid value as long as this error is pending. **Solution:** Check the REAL values in the WorkingData structure for validity. **Additional information:** If you want to change the polyline data, first edit the UserData structure and then set parameter Validate = TRUE. Do not manually change the data of the WorkingData structure.
0008_0000	**Cause of error:** One or more tags in the UserData structure have invalid values while the polyline data is checked. **Response to error:** The polyline data in the UserData structure is not transferred to the WorkingData structure so that the values in the UserData structure do not become effective. FB Polyline does not output the interpolation value at the Output parameter because no valid polyline data is contained in the WorkingData structure. The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions are met when the polyline data is checked: • 2 ≤ UserData.NumberOfUsedPoints ≤ 50 • UserData.Point[j].x < UserData.Point[j+1].x with index j = 1..(UserData.NumberOfUsedPoints – 1) • -3.402823e+38 ≤ UserData.Point[i].x ≤ 3.402823e+38 with index i = 1..UserData.NumberOfUsedPoints • -3.402823e+38 ≤ UserData.Point[i].y ≤ 3.402823e+38 with index i = 1..UserData.NumberOfUsedPoints • UserData.Point[i].x and UserData.Point[i].y are valid REAL values (≠ NaN) with index i = 1..UserData.NumberOfUsedPoints **Additional information:** The polyline data in the UserData structure is checked when • The Validate parameter is set to TRUE while the Reset parameter is set to FALSE or • Polyline is called for the first time with parameter Reset = FALSE after the operating state transition of the CPU from STOP to RUN. Note that all tags in the UserData and WorkingData structures are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

11.6 SplitRange

11.6.1 Compatibility with CPU and FW

The following table shows which version of SplitRange can be used on which CPU:

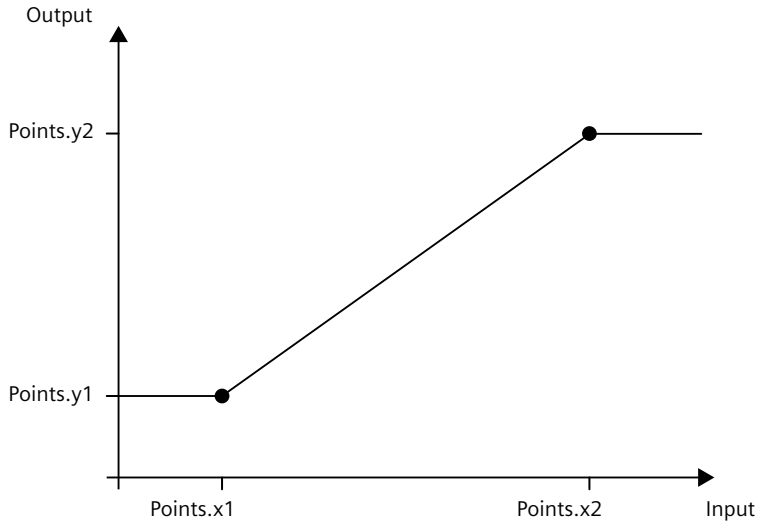
CPU	FW	SplitRange
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.6.2 SplitRange description

Description

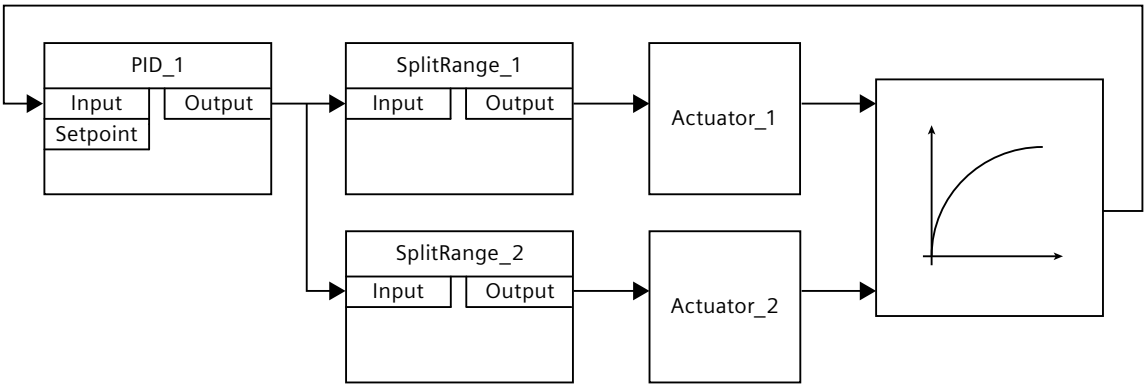
The SplitRange instruction converts the input value into an output value. The input value is located in the value range that is limited by Points.x1 and Points.x2. The output value is located in the value range that is limited by Points.y1 and Points.y2.

The following figure shows the relevant characteristic of an example configuration of the SplitRange instruction:



Use SplitRange when you need to control a process that is influenced by multiple actuators. SplitRange splits the output value range of the PID controller into multiple subranges. Assign a subrange to each actuator. The user program calls the block once per subrange. The input value of each SplitRange instance is connected to the output value of the PID controller.

The figure below shows an example of a control loop with two SplitRange instances and two actuators:



Validity of the SplitRange data

The value pairs in the Points structure define the input and output value range of SplitRange. The two value pairs are located in the static area of the block SplitRange.

SplitRange checks whether the following conditions are met for each call so that valid values are available for the calculation of the output value:

- Points.x1 < Points.x2
- Points.x1, Points.y1, Points.x2 and Points.y2 are within the permitted value range from -3.402823e+38 to 3.402823e+38
- Points.x1, Points.y1, Points.x2 and Points.y2 are valid REAL values (≠ NaN e.g. 16#7FFF_FFFF)

If one or more of these conditions are not met, correct calculation of the output value is not possible. A corresponding error message is output at the ErrorBits parameter.

The preassignment of the x and y values with 0.0 does not represent a valid configuration. Change the tags to valid values so that the tags can be used for the calculation of the output value.

Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

Call

In an OB or FC, SplitRange is called as single-instance DB. In an FB, SplitRange can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. No parameter assignment interface or commissioning interface is available. You assign the SplitRange parameters directly using the instance DB and commission SplitRange using a watch table of the user program in the CPU or HMI.

Startup

The tags in the static area of SplitRange are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

If you change the actual values in the Points structure in online mode and these values are to be retained after the operating state transition of the CPU from STOP to RUN, back up these values in the start values of the data block.

Response to errors

The SplitRange instruction detects different errors that can occur during the calculation of the output value. The result of the calculation can be output at the output despite a pending error. If an error prevents correct calculation of the output value, a substitute output value is output at the output.

You specify the substitute output value that is output if an error occurs that prevents correct calculation of the output value as follows at the ErrorMode tag:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter
2	The last valid result of output value calculation 0.0 if there is no valid result

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.6.3 SplitRange input parameters

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
SubstituteOutput	REAL	0.0	SubstituteOutput is used as the substitute output value when • Reset = TRUE or • An error with error message ErrorBits ≥ 16#0001_0000 prevents correct calculation of the output value, and the configured value of ErrorMode is 1.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset
Reset	BOOL	FALSE	Performs a restart of the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. • As long as Reset is set to FALSE, the calculation of the output value is performed.

11.6.4 SplitRange output parameters

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 498) shows which error messages are pending. ErrorBits is retentive and is reset at a positive edge at Reset or ErrorAck .
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.

11.6.5 SplitRange static tags

Tag	Data type	Default	Description
Points	AuxFct_SplitRange_Points	-	Points data
Points.x1	REAL	0.0	x-value of point 1 Permissible value range: Points.x1 < Points.x2
Points.y1	REAL	0.0	y-value of point 1
Points.x2	REAL	0.0	x-value of point 2 Permissible value range: Points.x1 < Points.x2
Points.y2	REAL	0.0	y-value of point 2
ErrorMode	INT	0	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid output value Permissible value range: 0 to 2

11.6.6 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

For SplitRange, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
- Errors with error messages ErrorBits ≥ 16#0001_0000

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 are pending, SplitRange reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, output value calculation
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:** When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the ErrorMode tag: • Input • SubstituteOutput When Reset = TRUE, check the SubstituteOutput parameter.

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 are pending, SplitRange reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, SplitRange reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, output value calculation
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th>Description</th></tr>
<tr><td>0001_0000</td><td>Cause of error:
The SubstituteOutput or Input parameter that is being used as the output value has no valid REAL value.
Response to error:
The output is set to 0.0.
Solution:
Make sure that the parameter used as output value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). The parameter that is used as output value depends on Reset and ErrorMode:
<table>
<tr><td>Reset</td><td>ErrorMode</td><td>Output value</td></tr>
<tr><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td>TRUE</td><td>-</td><td>SubstituteOutput</td></tr>
</table></td></tr>
<tr><td>0002_0000</td><td>Cause of error:
The Input parameter has no valid REAL value while the calculation of the output value is being performed (Reset = FALSE).
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. When ErrorMode = 0, 0.0 is used as output value.
Solution:
Make sure that the parameter Input is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF).</td></tr>
<tr><td>0004_0000</td><td>Possible causes of error:
• One or more tags in the Points structure have invalid values.
• The calculation of the output value yields an invalid REAL value for the Output parameter.
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter.
Solution:
Ensure that the following conditions are met:
1. Points.x1 < Points.x2
2. Points.x1, Points.y1, Points.x2 and Points.y2 are within the permitted value range from -3.402823e+38 to 3.402823e+38
3. Points.x1, Points.y1, Points.x2 and Points.y2 are valid REAL values (≠ NaN e.g. 16#7FFF_FFFF)
Additional information:</td></tr>
</table>

ErrorBits (DW#16#...)	Description
	Note that all tags in the Points structure are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

11.7 RampFunction

11.7.1 Compatibility with CPU and FW

The following table shows which version of RampFunction can be used on which CPU:

CPU	FW	RampFunction
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.7.2 RampFunction description

Description

The RampFunction instruction limits the slew rate of a signal. RampFunction outputs a signal jump at the input as ramp function of the output value.

Use the RampFunction to prevent signal jumps, for example, in the following cases:

- Between setpoint source and setpoint input of the controller to achieve a smoother response without influencing the disturbance reaction.
- Between the controller output and the actuator input to preserve the actuator, for example, a motor with gears or the process.

The following limits can be set for the slew rate:

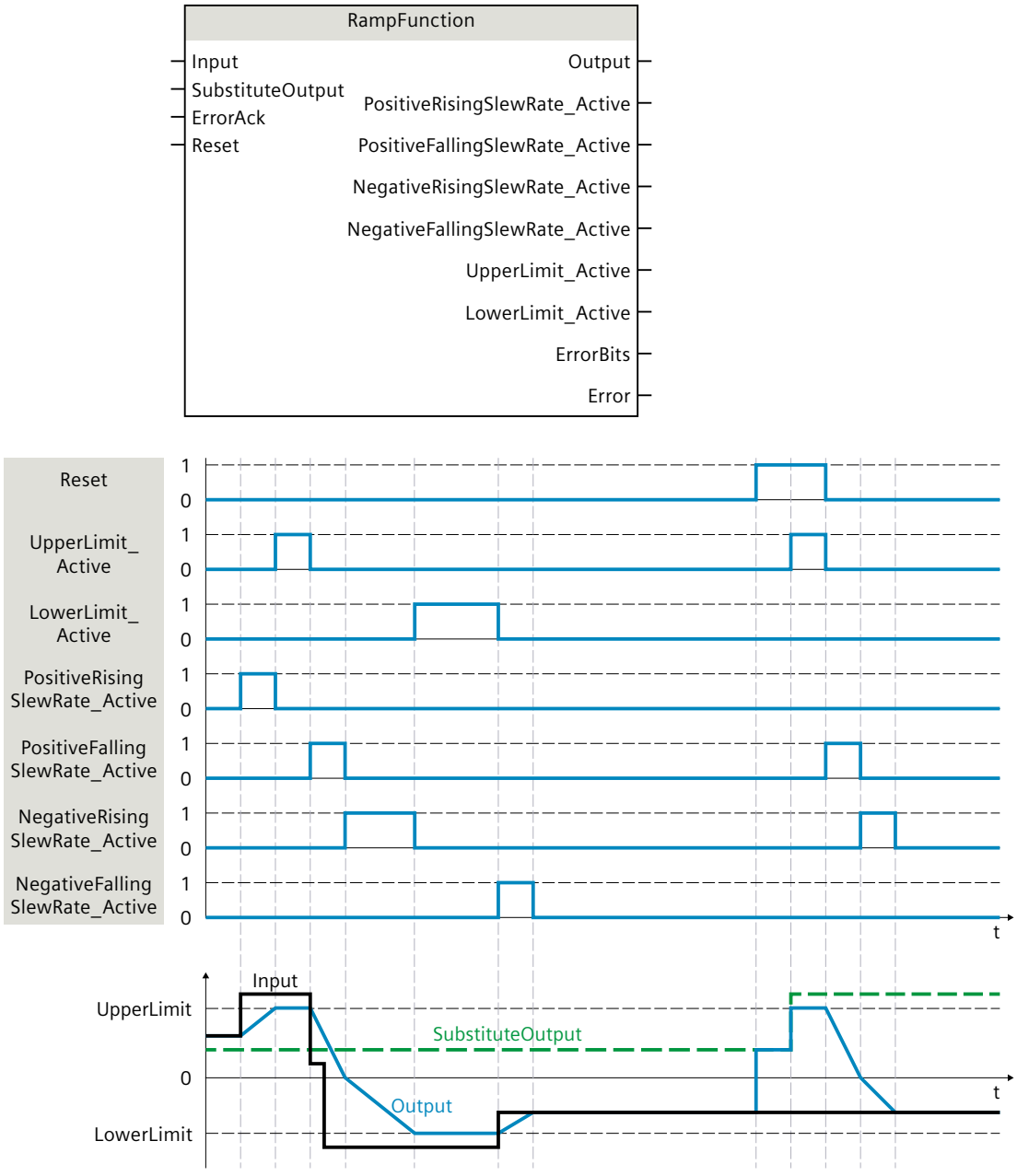
- Increasing slew rate in positive value range
- Decreasing slew rate in positive value range
- Increasing slew rate in negative value range
- Decreasing slew rate in negative value range

In addition, the RampFunction instruction limits the output value to the high and low limit.

When the slew rate limit or the low or high limit are reached, RampFunction sets the associated output bit to TRUE.

Function chart

The following figure shows the RampFunction instruction and a function chart as an example:



Call

In an OB or FC, RampFunction is called as single-instance DB. In an FB, RampFunction can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. No parameter assignment interface or commissioning interface is available. You assign the RampFunction parameters directly using the instance DB and commission RampFunction using a watch table of the user program in the CPU or HMI.

Startup

The tags in the static area of RampFunction are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

If you change the actual values of the limits in online mode and these values are to be retained after the operating state transition of the CPU, back up these values in the start values of the data block.

Specify the initialization value for the Output parameter at the StartMode tag.

During the first call of RampFunction after the

- Operating state transition of the CPU

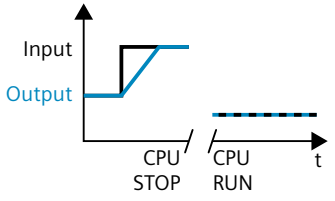
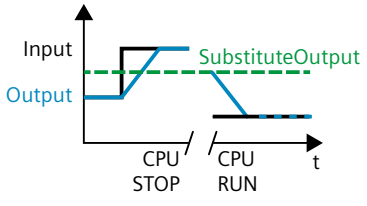
or

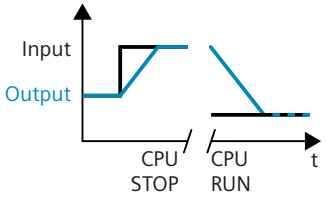
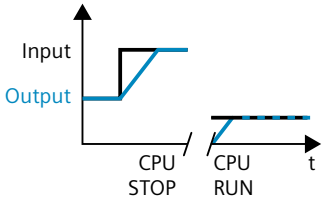
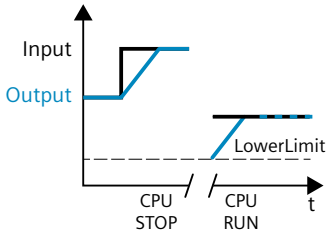
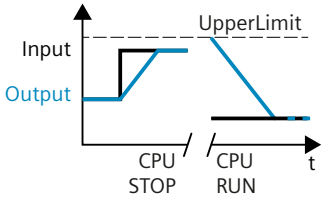
- Execution of "Load start values as actual values" (only with "All values" option, not with "Only setpoints" option)

the initialization value is output at the Output parameter.

For subsequent calls, RampFunction calculates the output value, starting from this initialization value, based on the input value and the slew rate limits.

The following table shows the dependency between the StartMode tag and the Output parameter. The values in the Output column are output at the Output parameter after the operating state transition of the CPU.

StartMode	Output	Example
0	Value of the Input parameter	
1	Value of the SubstituteOutput parameter	

StartMode	Output	Example
2	Remains unchanged. Output parameter is retentive.	
3	0.0	
4	Value of the LowerLimit tag	
5	Value of the UpperLimit tag	

The following applies in addition for all values of the StartMode tag:

- When the values of the UpperLimit and LowerLimit tags are valid, the initialization value is limited to the value range of these tags. Only then is the initialization value output at the Output parameter.
- If the initialization value is not a valid REAL value, the substitute output value is output at the Output parameter. The substitute output value is configured by the ErrorMode tag. The substitute output value is limited by the value range of the tags UpperLimit and LowerLimit. If the substitute output value is also not a valid REAL value, 0.0 is output at the Output parameter. For subsequent calls, the instruction calculates the output value starting from this substitute output value.
- The StartMode tag only takes effect when the Reset = FALSE parameter is set at the first call of the instruction and at the same time no error with error message ErrorBits ≥ 16#0002_0000 is pending. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

Response to errors

The RampFunction instruction detects different errors that can occur during the calculation of the output value. The result of this calculation can be output at the output despite a pending error. If an error prevents correct calculation of the output value, a substitute output value is output at the output.

Specify the substitute output value that is output if an error occurs that prevents correct calculation of the output value at the ErrorMode tag.

The following table shows the dependency between the ErrorMode tag and the substitute output value that is output by the RampFunction at the Output parameter:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter
2	The last valid output value at the Output parameter
3	0.0
4	Value of the LowerLimit tag
5	Value of the UpperLimit tag

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- When the values of the UpperLimit and LowerLimit tags are valid, the substitute output value is limited to the value range of these tags. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.
- If an error is pending that prevents correct calculation of the output value, RampFunction changes at the Output parameter from the calculated output value to the substitute output value. A jump of the output value can occur, depending on the value of the ErrorMode tag.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.7.3 RampFunction mode of operation

Limiting the slew rate

You can configure four limits for the slew rate of the input signal. The following factors determine which limit is currently in effect:

- Sign of the output value at the Output parameter
- Change of direction of the absolute value of the output value at the Output parameter

The following table shows the effective tags for the slew rate limit depending on the Output parameter:

Output	Effective tag
Output ≥ 0 and |Output| rising	PositiveRisingSlewRate
Output ≥ 0 and |Output| falling	PositiveFallingSlewRate
Output < 0 and |Output| rising	NegativeRisingSlewRate
Output < 0 and |Output| falling	NegativeFallingSlewRate

The absolute value of the slew rate limits defines the maximum change of the output value per second.

Example:

The following scenario applies for the example:

- PositiveRisingSlewRate = 10.0
- Call time of RampFunction = 0.1 s
- Input > Output ≥ 0.0

Result:

The output value Output increases by 1.0 per call (10.0 per second) until the value at the Input parameter has been reached.

To disable the slew rate limit for one or more areas, set the corresponding tag to the value 3.402823e+38.

When the output value Output is currently limited by a slew rate limit, RampFunction sets the associated output bit to TRUE:

- PositiveRisingSlewRate_Active
- PositiveFallingSlewRate_Active
- NegativeRisingSlewRate_Active
- NegativeFallingSlewRate_Active

When the Reset parameter is set to TRUE, the slew rate limits are not in effect. This means jumps at the SubstituteOutput parameter result in jumps at the Output parameter.

RampFunction checks whether the following conditions for the tags PositiveRisingSlewRate, PositiveFallingSlewRate, NegativeRisingSlewRate and NegativeFallingSlewRate are met for each call:

- Values are within the permitted value range greater than 0.0 up to 3.402823e+38
- Values are valid REAL values (≠ NaN e.g. 16#7FFF_FFFF)

If one or more conditions are not met, the substitute output value is output at the Output parameter. A corresponding error message is output at the ErrorBits parameter.

Limiting the output value

The output value Output is always limited to the value range of the tags UpperLimit and LowerLimit as long as these tags have valid values.

When the output value Output is currently limited by this value range, RampFunction sets the associated output bit to TRUE:

- UpperLimit_Active
- LowerLimit_Active

The limit of the output value has a higher priority than the limit of the slew rate. Changes of the tags UpperLimit and LowerLimit therefore result in jumps of the output value Output, if this is required to observe the limits of the tags UpperLimit and LowerLimit. The limiting of the slew rate is not taken into account in this case.

Example:

If the UpperLimit is reduced from 100.0 to 80.0 while the values of the parameters Input and Output are 90.0, the output value Output jumps to 80.0. The output value Output jumps to 80.0 regardless whether or not it violates the configured limit for the slew rate.

RampFunction checks whether the following conditions are met for each call:

- LowerLimit < UpperLimit
- LowerLimit and UpperLimit are within the permitted value range from -3.402823e+38 to 3.402823e+38
- LowerLimit and UpperLimit are valid REAL values (≠ NaN e.g. 16#7FFF_FFFF)

If one or more conditions are not met, the substitute output value is output at the Output parameter. A corresponding error message is output at the ErrorBits parameter.

In addition, RampFunction checks for each call whether the output value Output has the permitted value range of a REAL data type from -3.402823e+38 to 3.402823e+38. If the calculation of the output value yields an invalid REAL value, the substitute output value is output at the Output parameter. You configure the substitute output value at the ErrorMode tag.

Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

Measuring the cycle time automatically

To calculate the slew rate of the output value RampFunction needs the time that has expired since the last call of RampFunction.

By default, the cycle time is measured automatically and output as of the second call at the CycleTime.Value tag. RampFunction measures the cycle time for each call of the instruction and can therefore be used in non-isochronous call cycles, e.g. in OB1.

Note that conditional calls of the instruction, active breakpoints, or the loading of snapshots as actual values during automatic measurement of the cycle time will extend the cycle time value.

If measurement of the cycle time returns no valid result, RampFunction calculates the current output value with the last valid cycle time. In addition, RampFunction outputs an error message at the ErrorBits parameter.

When you disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement tag = FALSE, you must enter the cycle time manually at the CycleTime.Value tag. RampFunction checks the CycleTime.Value tag for validity at each call.

Automatic measurement of the cycle time with breakpoints

When breakpoints are active between two calls of RampFunction, automatic measurement of the cycle time results in the actual time that has elapsed between two calls. When one breakpoint is active, the CPU is in HOLD operating state.

NOTE

The active breakpoints extend the time period between two calls of RampFunction.

The longer the time period between two calls, the greater the maximum permitted change of the output value at the Output parameter.

Example:

The following scenario applies for the example:

- PositiveRisingSlewRate = 10.0
- Call time of RampFunction = 0.1 s
- Input > Output ≥ 0.0

Result without breakpoints:

The output value Output increases by 1.0 per call until the value at the Input parameter has been reached.

Result with an active breakpoint of ten seconds:

With the next call, the output value Output increases by 100.0.

If you do not need the calculation of the output value based on the actual time with active breakpoints, follow these steps:

- Disable automatic measurement of the cycle time by setting the tag CycleTime.EnableMeasurement = FALSE.
- Enter the cycle time manually at the CycleTime.Value tag.

11.7.4 RampFunction input parameters

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
SubstituteOutput	REAL	0.0	SubstituteOutput is used as the substitute output value when • Reset = TRUE or • An error with error message ErrorBits ≥ 16#0001_0000 prevents correct calculation of the output value, and the configured value of ErrorMode is 1.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset
Reset	BOOL	FALSE	Performs a restart of the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. • As long as Reset is set to FALSE, the calculation of the output value is performed.

11.7.5 RampFunction output parameters

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value
PositiveRisingSlewRate_Active	BOOL	FALSE	When PositiveRisingSlewRate_Active = TRUE, the output value is currently limited by PositiveRisingSlewRate .
PositiveFallingSlewRate_Active	BOOL	FALSE	When PositiveFallingSlewRate_Active = TRUE, the output value is currently limited by PositiveFallingSlewRate.
NegativeRisingSlewRate_Active	BOOL	FALSE	When NegativeRisingSlewRate_Active = TRUE, the output value is currently limited by NegativeRisingSlewRate.
NegativeFallingSlewRate_Active	BOOL	FALSE	When NegativeFallingSlewRate_Active = TRUE, the output value is currently limited by NegativeFallingSlewRate.
UpperLimit_Active	BOOL	FALSE	When UpperLimit_Active = TRUE, the output value is currently limited by UpperLimit.
LowerLimit_Active	BOOL	FALSE	When LowerLimit_Active = TRUE, the output value is currently limited by LowerLimit.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 510) shows which error messages are pending. ErrorBits is retentive and is reset at a positive edge at Reset or ErrorAck .
Error	BOOL	FALSE	When Error = TRUE, at least one error is currently pending.

11.7.6 RampFunction static tags

Tag	Data type	Default	Description
PositiveRisingSlewRate	REAL	10.0	Limit for slew rate of the output value per second in positive range with rising absolute value With PositiveRisingSlewRate = 3.402823e+38, this slew rate limit is disabled. Permissible value range: > 0.0
PositiveFallingSlewRate	REAL	10.0	Limit for slew rate of the output value per second in positive range with falling absolute value With PositiveFallingSlewRate = 3.402823e+38, this slew rate limit is disabled. Permissible value range: > 0.0
NegativeRisingSlewRate	REAL	10.0	Limit for slew rate of the output value per second in negative range with rising absolute value With NegativeRisingSlewRate = 3.402823e+38, this slew rate limit is disabled. Permissible value range: > 0.0
NegativeFallingSlewRate	REAL	10.0	Limit for slew rate of the output value per second in negative range with falling absolute value With NegativeFallingSlewRate = 3.402823e+38, this slew rate limit is disabled. Permissible value range: > 0.0
UpperLimit	REAL	100.0	High limit of output value Permissible value range: > LowerLimit
LowerLimit	REAL	0.0	Low limit of output value Permissible value range: < UpperLimit
ErrorMode	INT	2	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid output value • 3 = 0.0 • 4 = LowerLimit • 5 = UpperLimit Permissible value range: 0 to 5
StartMode	INT	2	Selecting the output value for the first call of the instruction • 0 = Input • 1 = SubstituteOutput • 2 = Last output value • 3 = 0.0 • 4 = LowerLimit • 5 = UpperLimit Permissible value range: 0 to 5
CycleTime	AuxFct_CycleTime	-	Cycle time data
CycleTime.Value	REAL	0.1	Time interval between two calls of the instruction in seconds Permissible value range: > 0.0
CycleTime.EnableMeasurement	BOOL	TRUE	Automatic measurement of the cycle time • FALSE = Deactivated • TRUE = Activated

11.7.7 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

For RampFunction, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
- Errors with error messages ErrorBits ≥ 16#0001_0000

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 are pending, RampFunction reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, output value calculation
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0002	**Cause of error:** The measurement of the cycle time yields in an invalid value while the output value is being calculated (Reset = FALSE). **Response to error:** If a valid value of the cycle time has already been measured, RampFunction calculates the output value based on the last value of the CycleTime.Value tag. If no valid value of the cycle time was previously measured, RampFunction still outputs the output value configured with the StartMode tag at the Output parameter.

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 are pending, RampFunction reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.
- The output value limit remains active as long as the tags LowerLimit and UpperLimit have valid values.

- The slew rate limit is no longer active. Jumps at the output value can occur in one of the following scenarios:
  - When the error is detected, RampFunction switches from the calculated output value to the replacement output value. Whether a jump occurs depends on the value of the tag ErrorMode.
  - The substitute output value is changed while it is active.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, RampFunction reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, output value calculation
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th>Description</th></tr>
<tr><td>0001_0000</td><td>Cause of error:
The SubstituteOutput parameter or a different tag that is being used as output value has no valid REAL value.
Response to error:
The output is set to 0.0 and limited by the tags LowerLimit and UpperLimit.
Solution:
Make sure that the tag used as output value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). The tag that is used as output value depends on Reset and ErrorMode:
<table>
<tr><th>Reset</th><th>ErrorMode</th><th>Output value</th></tr>
<tr><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td>FALSE</td><td>4</td><td>LowerLimit</td></tr>
<tr><td>FALSE</td><td>5</td><td>UpperLimit</td></tr>
<tr><td>TRUE</td><td>-</td><td>SubstituteOutput</td></tr>
</table></td></tr>
<tr><td>0002_0000</td><td>Cause of error:
The Input parameter has no valid REAL value while the calculation of the output value is being performed (Reset = FALSE).
Response to error:
The substitute output value is output at the Output parameter that is configured at the ErrorMode tag and is limited by the tags UpperLimit and LowerLimit.
When ErrorMode = 0, 0.0 is used as output value.
Solution:
Make sure that the parameter Input is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF).</td></tr>
<tr><td>0004_0000</td><td>Cause of error:
The calculation of the output value yields an invalid REAL value for the Output parameter.
Response to error:
The substitute output value is output at the Output parameter that is configured at the ErrorMode tag and is limited by the tags UpperLimit and LowerLimit.
Solution:</td></tr>
</table>

ErrorBits (DW#16#...)	Description
	Check all tags involved in the calculation of the output value: • Input • PositiveRisingSlewRate • PositiveFallingSlewRate • NegativeRisingSlewRate • NegativeFallingSlewRate • CycleTime.Value These tags have valid values. The calculation of the output value fails in this combination of tags.
0008_0000	**Cause of error:** The LowerLimit or UpperLimit tag has an invalid value. **Response to error:** The following value is output at the Output parameter, depending on the Reset parameter: • Reset = FALSE The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. • Reset = TRUE The value of the SubstituteOutput parameter is output at the Output parameter. In both cases, the Ouput parameter is limited to the value range of the REAL data type from -3.402823e+38 to 3.402823e+38. **Solution:** Ensure that the following conditions are met: 1. LowerLimit < UpperLimit 2. LowerLimit and UpperLimit are within the permitted value range from -3.402823e+38 to 3.402823e+38 3. LowerLimit and UpperLimit are valid REAL values (≠ NaN e.g. 16#7FFF_FFFF)
0010_0000	**Cause of error:** At least one of the following tags has invalid values while the calculation of the output value is being performed (Reset = FALSE): 1. PositiveRisingSlewRate 2. PositiveFallingSlewRate 3. NegativeRisingSlewRate 4. NegativeFallingSlewRate **Response to error:** The substitute output value is output at the Output parameter that is configured at the ErrorMode tag and is limited by the tags UpperLimit and LowerLimit. **Solution:** Ensure that the following conditions are met for all four tags listed above: • The values are within the permitted value range greater than 0.0 up to 3.402823e+38 • The values are valid REAL values (≠ NaN e.g. 16#7FFF_FFFF)
0020_0000	**Cause of error:** The tag (configured with StartMode) for the initialization of the Output parameter at the first call of the instruction does not have a valid REAL value. **Response to error:** The substitute output value is output with the first call of the instruction at the Output parameter that is configured at the ErrorMode tag and is limited by the tags LowerLimit and UpperLimit. For subsequent calls, RampFunction calculates the output value starting from this substitute output value. **Solution:** Make sure that the tag for initializing the parameter Output is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). When Reset = FALSE is set, the initialization takes effect with the first call of the instruction after the operating state transition of the CPU from STOP to RUN. The tag that is used for the initialization of the Output parameter depends on StartMode: • StartMode = 1: Substitute Output • StartMode = 2: Output

ErrorBits (DW#16#...)	Description
0040_0000	**Cause of error:** The CycleTime.Value tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value is output at the Output parameter that is configured at the ErrorMode tag and is limited by the tags UpperLimit and LowerLimit. **Solution:** Ensure that the following conditions are met: • 0.0 < CycleTime.Value ≤ 3.402823e+38 • CycleTime.Value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF) **Additional information:** To automatically calculate the value of the CycleTime.Value tag, set the CycleTime.EnableMeasurement tag to TRUE.

11.8 RampSoak

11.8.1 Compatibility with CPU and FW

The following table shows which version of RampSoak can be used on which CPU:

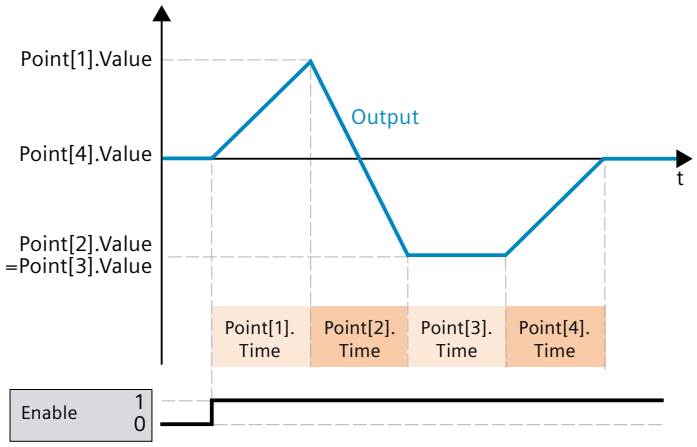
CPU	FW	RampSoak
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.8.2 Description of RampSoak

Description

You can use the RampSoak instruction to generate an output value that follows a configurable profile on a time-dependent basis. Every point of this profile has a target value and a time value. When the profile is executed, the target value of the current point is reached within the time value.

The following figure shows a profile with 4 points:



The RampSoak instruction can be used, for example, to provide a setpoint value profile for regulating a temperature process.

Calculation of the output value

The output value is calculated with an interpolation between the current point and the previous point according to the following formula:

$$\text{Output}(t) = \text{Point}[i].\text{Value} - \frac{\text{RemainingTime_Point}}{\text{Point}[i].\text{Time}} (\text{Point}[i].\text{Value} - \text{Point}[i-1].\text{Value})$$

The *i* represents the value of the CurrentPoint parameter.

On the basis of the time that has elapsed, a determination is made as to which points from the profile are currently used for calculating the output value.

Call

In an OB or FC, RampSoak is called as single-instance DB. In an FB, RampSoak can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. No parameter assignment interface or commissioning interface is available. You assign the RampSoak parameters directly using the instance DB and commission RampSoak using a watch table of the user program in the CPU or HMI.

Startup

The tags in the static area of RampSoak and hence also the profile data in the UserData and WorkingData structures are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

If you change the actual values in the UserData structure in online mode and these values are to be retained after the operating state transition of the CPU from STOP to RUN, back up these values in the start values of the data block.

At the first call of the RampSoak instruction after the operating state transition of the CPU from STOP to RUN, the data in the UserData structure is automatically validated. If the check is successful, the data is transferred to the WorkingData structure.

With the tag StartMode (Page 524), you can define the starting behavior of the RampSoak instruction at the first call after the operating state transition of the CPU from STOP to RUN.

Response to errors

If the output value cannot be correctly calculated, the RampSoak instruction instead outputs a substitute output value and an error with an error message ErrorBits >= 16#0002_0000. You can use the tag ErrorMode (Page 533) to define the substitute output value as follows:

Error-Mode	Output
0	Value of the WorkingData.StartValue tag Make sure that the profile data in UserData is validated with the Validate parameter and accepted after WorkingData. If the profile data has never been verified and accepted, the default value 0.0 of WorkingData.StartValue is used.
1	Value of the SubstituteOutput parameter
2	The last valid output value of the profile execution 0.0, if no valid output value of the profile execution is available.
3	0.0

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range -3.402823e+38 .. +3.402823e+38 of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter or 0.0 is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.8.3 Operating principle RampSoak

11.8.3.1 Configuring and validating profile data

Configuring profile data

You can configure the profile in the static structure UserData.

It contains the following elements:

- NumberOfUsedPoints

  Number of points used for the profile.

- StartValue

  Optional output value when the profile execution is started (Page 524), stopped (Page 527) or ended.

- Point

  The array with 50 elements contains value pairs of the points Point[i].Value and Point[i].Time:

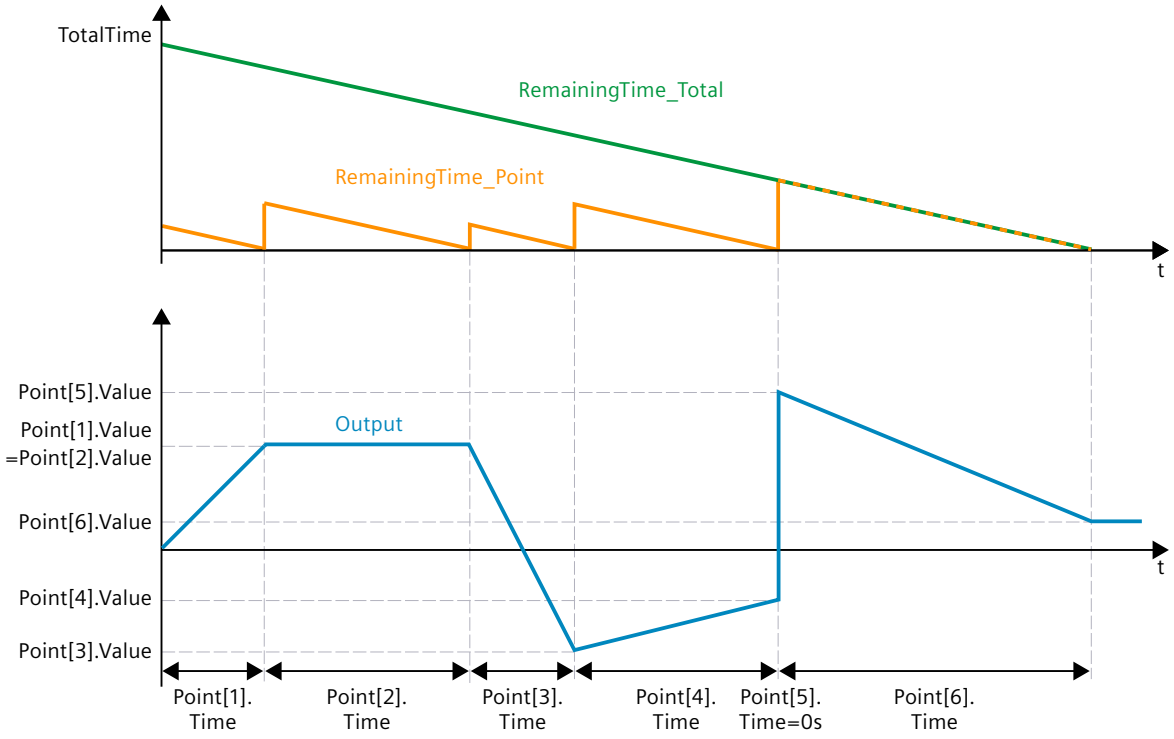
  – Point[i].Value

    The output value is changed to this value in steps as long as the point is active, and reaches this value within the time Point[i].Time.

  – Point[i].Time

    This value defines the duration of the point in seconds.

The following figure shows a profile with 6 points. Point number 5 has a duration of 0 seconds, which results in skipping of the output value.



Validating the profile data

Before the profile data is used for the profile execution, a validation of the profile data in the UserData structure is necessary.

The validation is triggered as follows:

- When you set the Validate parameter to TRUE.
- When the parameter Enable is set to TRUE for the first time after the operating state change of the CPU from STOP to RUN and no validation of the profile data has been carried out previously.

The following conditions are checked for the profile data in the UserData structure:

- 1 ≤ UserData.NumberOfUsedPoints ≤ 50
- NextPoint ≤ UserData.NumberOfUsedPoints
- When the profile execution is activated (Enable = TRUE):
  - CurrentPoint ≤ UserData.NumberOfUsedPoints
- -3.402823e+38 ≤ UserData.StartValue ≤ 3.402823e+38
- -3.402823e+38 ≤ UserData.Point[i].Value ≤ 3.402823e+38 with index *i* = 1..UserData.NumberOfUsedPoints

- 0.0 ≤ UserData.Point[i].Time ≤ 3.402823e+38 with index *i* = 1..UserData.NumberOfUsedPoints
- 0.0 < UserData.Point[1].Time + UserData.Point[2].Time +...+ UserData.Point[UserData.NumberOfUsedPoints].Time ≤ 3.402823e+38

Effects of the profile data validation and possible error messages

When the conditions are fulfilled, the new profile data in the UserData structure is transferred to the WorkingData structure and used for the profile execution. The TotalTime parameter is updated. The RemainingTime_Total parameter is updated when the profile is executed.

NOTE

The value and duration of the current point are temporarily stored and also remain unchanged after a successful validation of the new profile data until the current point is completed. The new profile data is used from the start of the next point.

If one of the conditions is not fulfilled, the existing profile data in the WorkingData structure remains unchanged. An error with the error message ErrorBits = 16#0000_0004 (Page 533) is pending.

If the Enable parameter or the Next parameter is set to TRUE, but there is no valid profile data present in the WorkingData structure, then an error with the error message ErrorBits = 16#0008_0000 (Page 533) will be pending.

NOTE

If you do not change the default values in the UserData structure, the validation of the profile data fails.

NOTE

You cannot change the offline values of the WorkingData structure. If you want to change the profile data, first edit the UserData structure and then set parameter Validate = TRUE.

11.8.3.2 Executing a profile

To execute a profile and calculate the output value, you need validated profile data and a positive edge at the Enable parameter.

Starting and stopping profile execution - Enable parameter

You can start the profile execution and calculation of the output value with a positive edge at the Enable parameter. The profile execution starts with the point that is specified at the in-out parameter NextPoint.

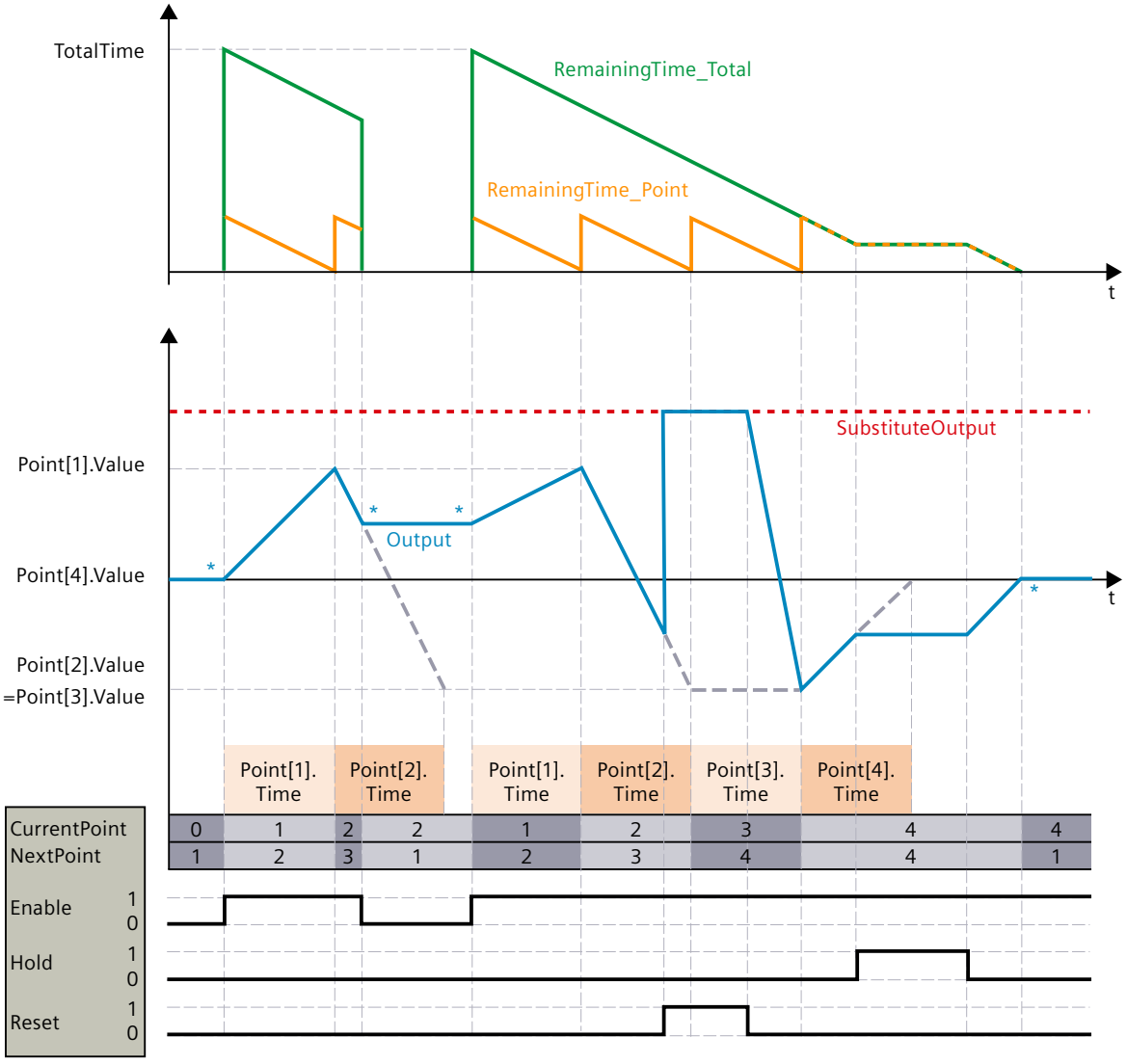
You can stop the profile execution with a negative edge at the parameter Enable.

If the profile is stopped or completely run, the in-out parameter NextPoint is automatically set to 1. Thus, the next profile execution starts from the first point of the profile if the in-out parameter NextPoint is not changed.

You can configure the behavior at the start, stop and completion of the profile execution with the static tags StartMode (Page 524) and StopMode (Page 527).

The profile execution only determines the output value at the Output parameter, if Reset = FALSE. If RESET = TRUE is set, then an activated profile execution is continued in the background.

The following graphic shows how the input parameters Enable, Reset and Hold determine the execution of the profile:



In this example, the starting and stopping behavior of the profile execution (marked with an *) is shown with the default StartMode = StopMode = 2 (start from last output value / keep last output value).

Holding profile execution - Hold parameter

You can use the parameter Hold = TRUE to pause the activated profile execution.

The Hold = TRUE parameter has the following effect:

- The Output, CurrentPoint, NextPoint, RemainingTime_Total, and RemainingTime_Point parameters remain unchanged.
- An edge at the parameters Enable or Next is delayed and only becomes effective when Hold = FALSE.
- If the Reset parameter changes from TRUE to FALSE, the Hold parameter influences the changes at the Output parameter. You can find more information in the description of the Reset parameter.

The Hold parameter has no effect on the processing of the Validate and ErrorAck parameters.

Overwrite output value - Reset parameter

With the parameter Reset = TRUE, you can reset the instruction and overwrite the output value at the Output parameter with the value of the SubstituteOutput parameter.

An activated profile execution is continued in the background. Using the parameters Enable, Hold and Next continues to be possible.

If the profile execution is still active (Enable=TRUE and the profile not yet fully run through) and the parameter Reset changes from TRUE to FALSE, the behavior depends on the Hold parameter:

- Hold = FALSE

  The Output parameter is changed in increments from the SubstituteOutput to the value of the current point and reaches it within the remaining time of the current point (RemainingTime_Point).

- Hold = TRUE

  The Output parameter jumps from the SubstituteOutput to the value of the paused profile execution.

If the profile execution is no longer active (Enable=FALSE or the profile fully run through) and the Reset parameter changes from TRUE to FALSE, the Output parameter jumps to the last value of the profile execution.

Continuing the profile execution with a certain point - Next parameter

With a positive edge at the Next parameter, you can continue the profile execution with Point[NextPoint].

When the profile execution is deactivated, the parameter Next = TRUE has the following effect:

- The Output parameter assumes the value of Point[NextPoint].Value.
- The CurrentPoint parameter assumes the value of NextPoint.
- The NextPoint parameter is increased. If NextPoint is the last point of the profile, then the value of NextPoint becomes 1.

When the profile execution is activated, the parameter Next = TRUE has the following effect:

- The Output parameter is changed in increments from its current value to the value of Point[NextPoint].Value and reaches it during Point[NextPoint].Time.
- The RemainingTime_Point parameter assumes the value of Point[NextPoint].Time.
- The RemainingTime_Total parameter is updated accordingly.
- The CurrentPoint parameter assumes the value of NextPoint.
- The NextPoint parameter is increased. If NextPoint is the last point of the profile, then the new value is dependent on StopMode. You can find more information in the description of the NextPoint parameter.

NOTE

At the first call of the RampSoak instruction after the operating state transition of the CPU from STOP to RUN, the behavior is determined by StartMode. The Next parameter is only effective with the following calls.

An example profile with the Next parameter is available in the following section "Continuing the profile execution with a certain point - NextPoint parameter".

Continuing the profile execution with a certain point - NextPoint parameter

The NextPoint parameter determines with which point the profile execution is continued.
If the current point has been completed, the RampSoak instruction automatically updates the value of the NextPoint parameter to the next point of the profile.
Through a change in the value of the NextPoint parameter, you can determine that the profile execution should be continued with another point.

The NextPoint parameter can influence the behavior of the profile execution in the following manner, if it is deactivated:

- If there is a positive edge at parameter Next then parameter Output assumes the value of Point[NextPoint].Value.
- When the profile execution is started, NextPoint represents the first CurrentPoint. The Output parameter is changed in increments from the value that is defined by StartMode to the value of Point[NextPoint].Value and reaches it during Point[NextPoint].Time.

The NextPoint parameter can influence the behavior of the profile execution in the following manner, if it is activated:

- Without positive edge at parameter Next:

  When the current point has been completed, the process continues with NextPoint.
- With positive edge at parameter Next:

  The process continues with NextPoint.

While the last point of the profile execution is active (CurrentPoint = WorkingData.NumberOfUsedPoints), StopMode determines, in the following manner, how the value of NextPoint is updated automatically:

- StopMode <> 4

  While the last point is active: NextPoint = CurrentPoint = WorkingData.NumberOfUsedPoints.

  The profile execution finished after the last point.

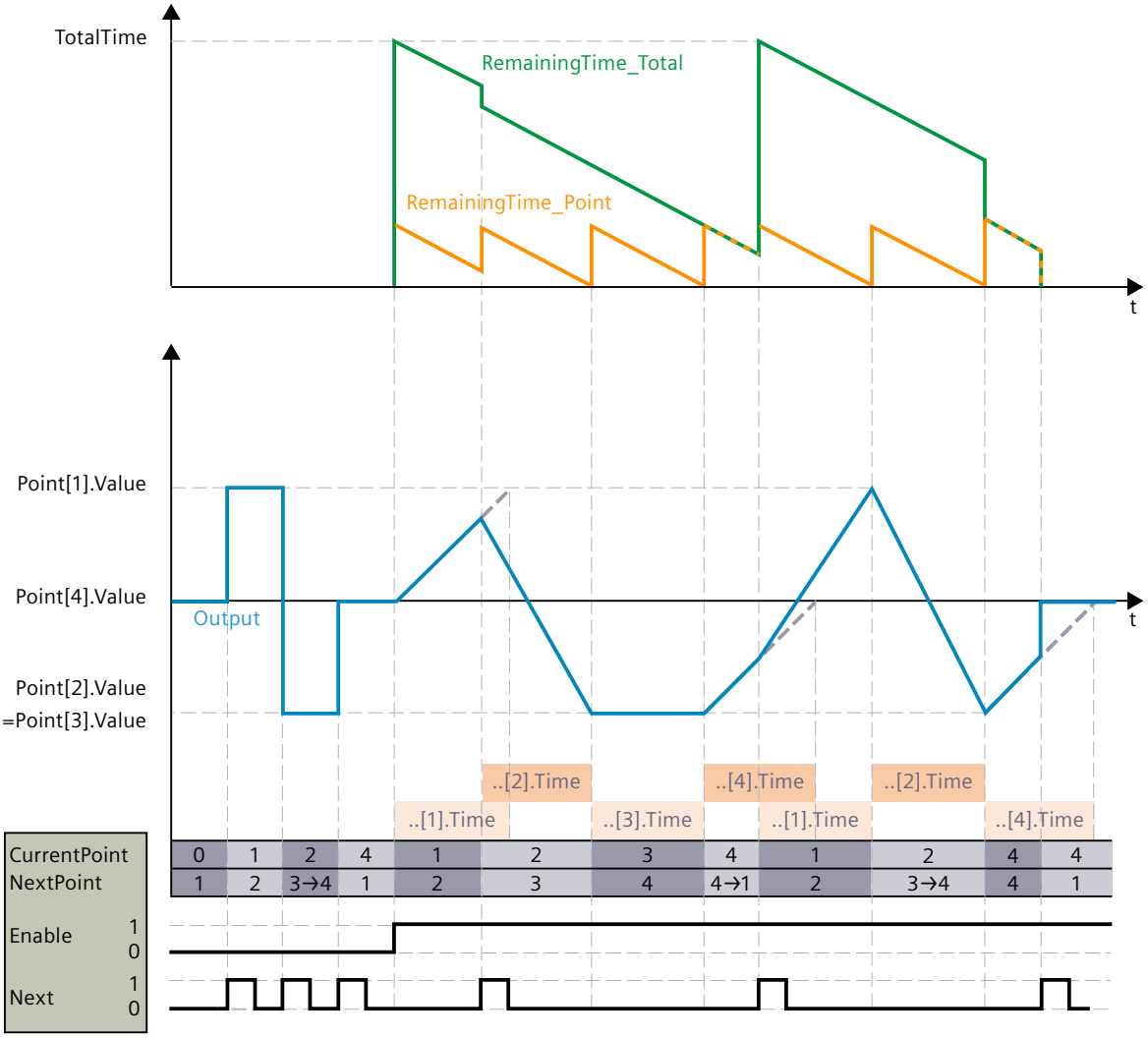
- StopMode = 4

  While the last point is active: NextPoint = 1.

  The profile execution restarts after the last point.

If the profile is stopped or completely run, the in-out parameter NextPoint is automatically set to 1. Thus, the next profile execution starts from the first point of the profile if the in-out parameter NextPoint is not changed.

The following graphic shows how the Next and NextPoint parameters determine the profile execution: If the automatic change of NextPoint is subsequently overwritten by a user input, this is marked with →:



In this example, the stopping behavior of the profile execution is shown with StopMode <> 4.

11.8.3.3 Configuring the starting behavior - static tag StartMode

With the StartMode tag, you can define the behavior of the RampSoak instruction in the following cases.

- When the RampSoak instruction is executed after the operating state transition of the CPU from STOP to RUN (restart).
- The profile execution is started.
- Execution of "Load start values as actual values" (only with "All values" option, not with "Only setpoints" option).

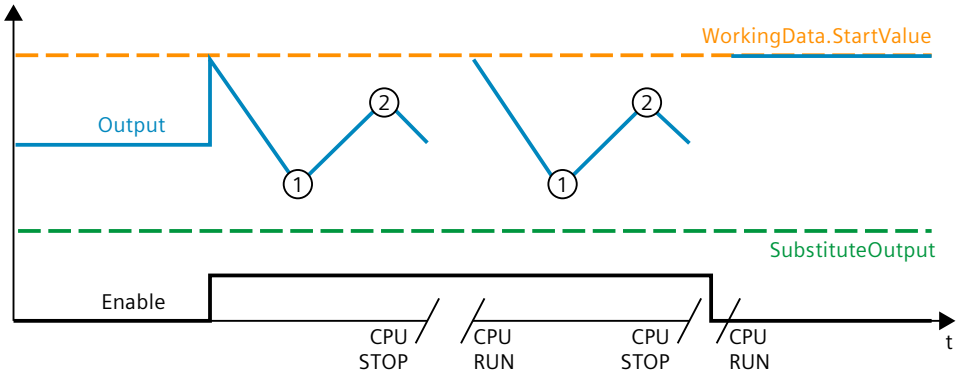
The following settings of the StartMode tag are possible:

- StartMode = 0

  The Output parameter assumes the value of WorkingData.StartValue.

  The profile execution starts from this value if, after a restart of the CPU, Enable = TRUE is set or if Enable changes from FALSE to TRUE.

  The following graphic shows the start of the profile execution and restart of the CPU with StartMode = 0:



NOTE

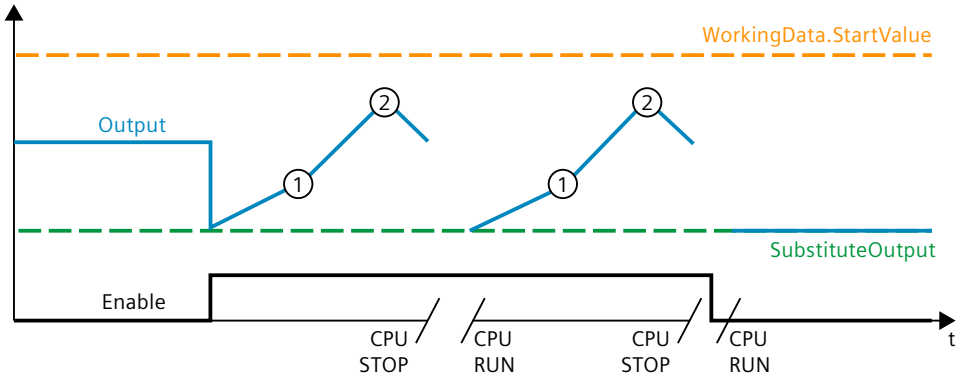
With this setting, the profile data must be validated with the first call of the instruction after the CPU restart and assumed by the WorkingData. Otherwise, the default value 0.0 of WorkingData.StartValue is used.

- StartMode = 1

  The Output parameter assumes the value of SubstituteOutput.

  The profile execution starts from this value if, after a restart of the CPU, Enable = TRUE is set or if Enable changes from FALSE to TRUE.

The following graphic shows the start of the profile execution and restart of the CPU with StartMode = 1:

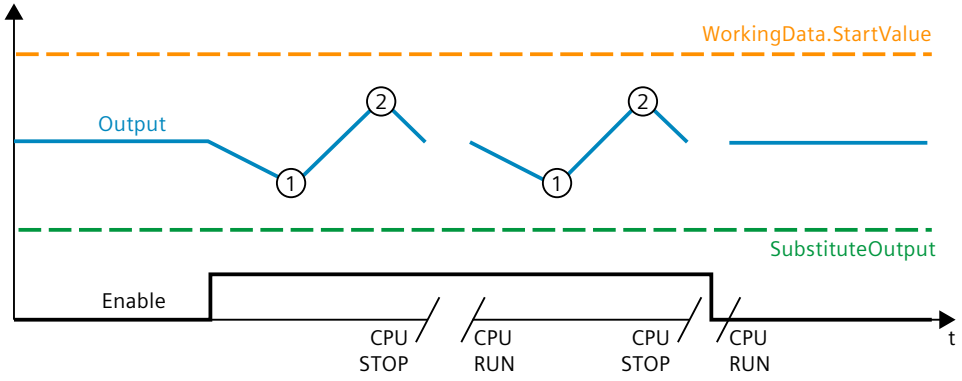


- StartMode = 2

  The Output parameter remains unchanged.

  The profile execution starts from the unchanged value of the Output parameter, if, after a restart of the CPU, Enable = TRUE is set or if Enable changes from FALSE to TRUE.

  The following graphic shows the start of the profile execution and restart of the CPU with StartMode = 2:

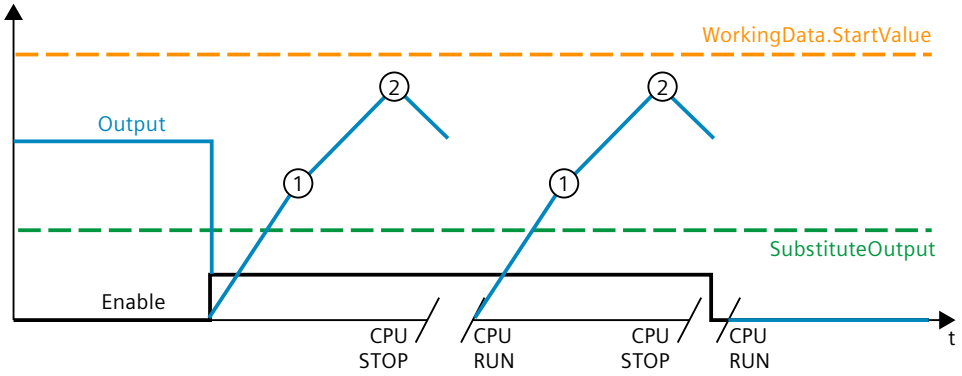


- StartMode = 3

  The Output parameter adopts the value 0.0.

  The profile execution starts from this value if, after a restart of the CPU, Enable = TRUE is set or if Enable changes from FALSE to TRUE.

The following graphic shows the start of the profile execution and restart of the CPU with StartMode = 3:



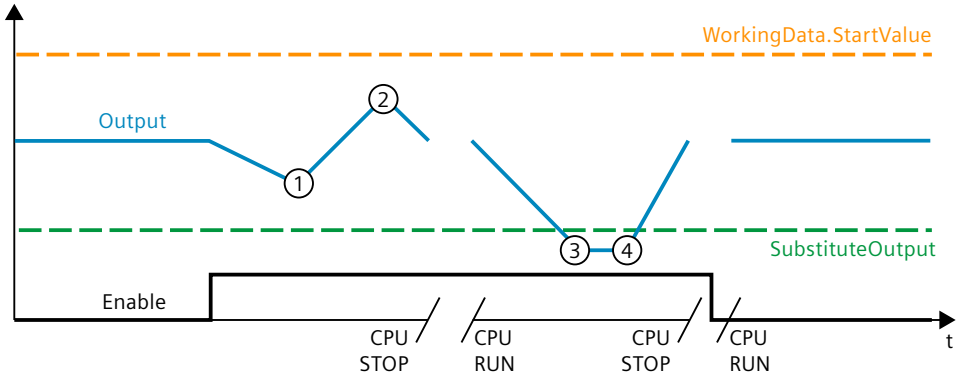
- StartMode = 4

  The Output parameter remains unchanged.

  The profile execution continues if, after the restart of the CPU, Enable = TRUE remains set and the profile execution was activated before the restart.

  The profile execution starts from the unchanged value of the Output parameter, if, after a restart of the CPU, Enable = TRUE is set and the profile execution was deactivated before the restart or if Enable changes from FALSE to TRUE.

  The following graphic shows the start of the profile execution and restart of the CPU with StartMode = 4:



The following applies in addition for all values of the StartMode tag:

- The Enable parameter, the StartMode tag and the profile data in the UserData and WorkingData structures are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN. Make sure that at the first call of the RampSoak instruction, after the operating status transition of the CPU from STOP to RUN, these tags have suitable values to achieve the desired behavior.
- The value selected through StartMode is limited to the value range of the REAL data type. Only then is it output at the Output parameter.
- If the value selected through StartMode is not a valid REAL value, the substitute output value is output at the Output parameter. The substitute output value is configured by means of the ErrorMode tag and is limited to the value range of the REAL data type. If the profile execution is activated, it starts from this substitute output value.

- Only if the parameter Reset = FALSE has been set and, at the same time, there is no error pending with an error message ErrorBits ≥ 16#0002_0000, does the StartMode tag act on the Output parameter. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

11.8.3.4 Configuring the stopping behavior - static tag StopMode

With the StopMode tag, you can define the behavior of the RampSoak instruction in the following cases.

- The profile execution is finished in that the last point has been reached.
- The profile execution is stopped by resetting Enable.

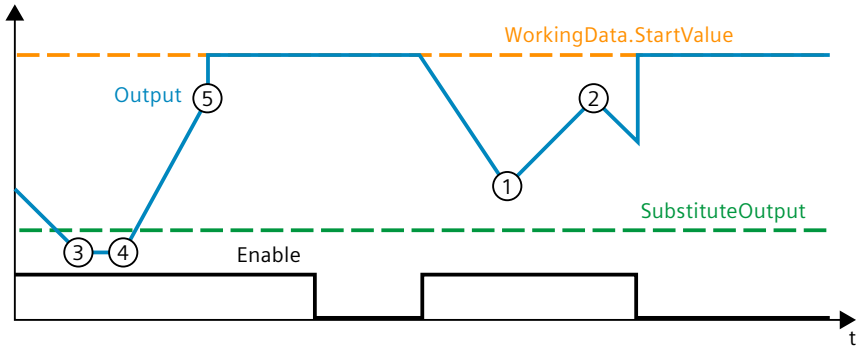
The value that is set through StopMode is used as the output value until a new action, for example the start of the profile execution, is triggered.

The following settings of the StopMode tag are possible:

- StopMode = 0

  The Output parameter assumes the value of WorkingData.StartValue.

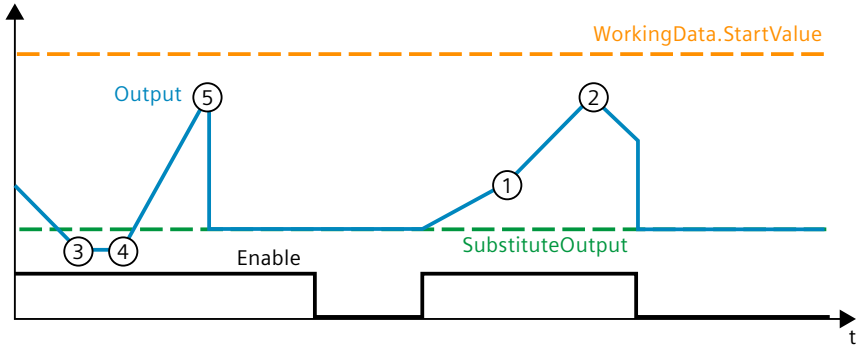
  The following graphic shows how the execution of a profile with 5 points is ended and stopped with StopMode = 0:



- StopMode = 1

  The Output parameter assumes the value of SubstituteOutput.

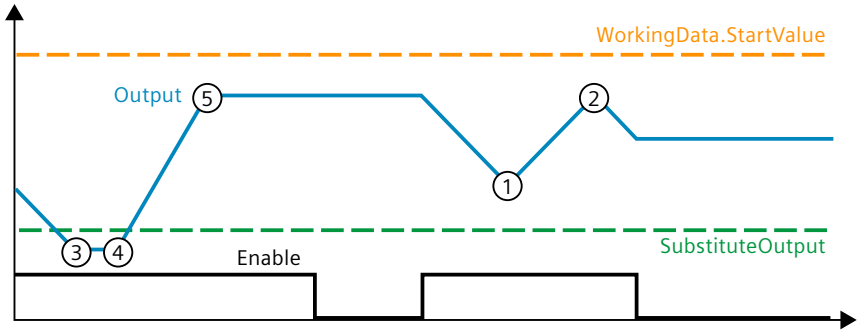
  The following graphic shows how the execution of a profile with 5 points is ended and stopped with StopMode = 1:



- StopMode = 2

  The Output parameter assumes the last valid value of the profile execution.

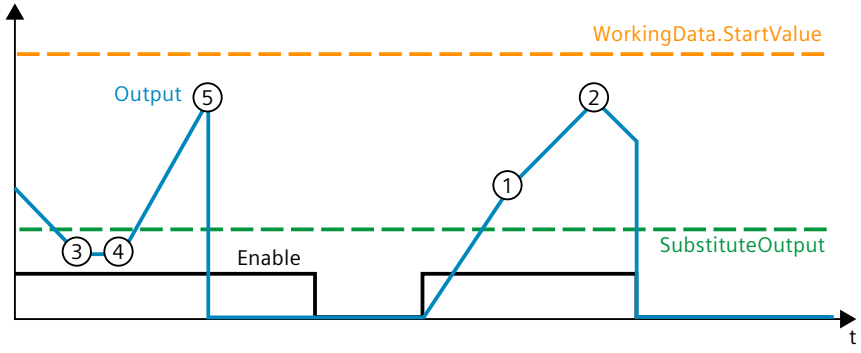
  The following graphic shows how the execution of a profile with 5 points is ended and stopped with StopMode = 2:



- StopMode = 3

  The Output parameter adopts the value 0.0.

  The following graphic shows how the execution of a profile with 5 points is ended and stopped with StopMode = 3:

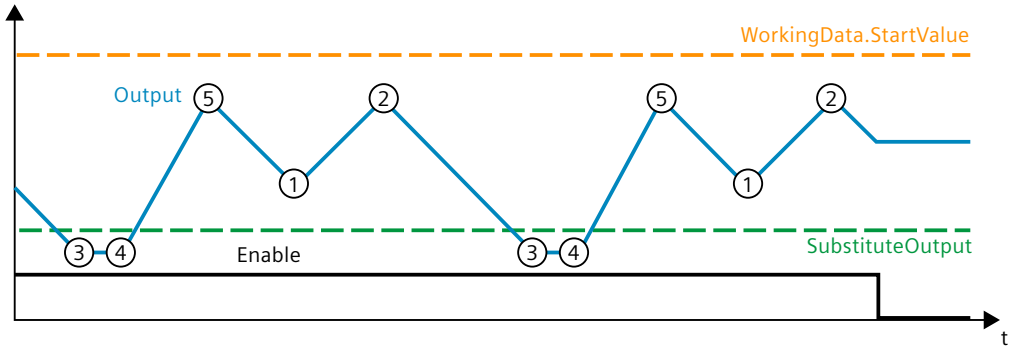


- StopMode = 4

  If the profile execution has ended with the last point, it is automatically restarted and it is continued with WorkingData.Point[1]. As long as Enable is not reset, the profile execution is repeated.

  If the profile execution is stopped with Enable = FALSE, then the Output parameter assumes the last valid value of the profile execution.

The following graphic shows how the execution of a profile with 5 points is ended and stopped with StopMode = 4:



The following applies in addition for all values of the StopMode tag:

- The value selected through StopMode is limited to the value range of the REAL data type. Only then is it output at the Output parameter.
- If the value selected through StopMode is not a valid REAL value, the substitute output value is output at the Output parameter and then retained. The substitute output value is configured by means of the ErrorMode tag and is limited to the value range of the REAL data type.
- Only if the parameter Reset = FALSE has been set and, at the same time, there is no error pending with an error message ErrorBits ≥ 16#0002_0000, does the StopMode tag act on the Output parameter. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

11.8.3.5 Measuring the cycle time

Measuring the cycle time automatically

To calculate the output value, RampSoak needs the time that has expired since the last call of RampSoak.

By default, the cycle time is measured automatically and output as of the second call at the CycleTime.Value tag. RampSoak measures the cycle time for each call of the instruction and can therefore be used in non-isochronous call cycles, e.g. in OB1.

Note that conditional calls of the instruction, active breakpoints, or the loading of snapshots as actual values during automatic measurement of the cycle time will extend the cycle time value.

If measurement of the cycle time does not return a valid result, RampSoak calculates the current output value with the last valid cycle time. In addition, RampSoak outputs an error message at the ErrorBits parameter.

When you disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement = FALSE tag, you must enter the cycle time manually at the CycleTime.Value tag. RampSoak checks the CycleTime.Value tag for validity at each call.

Automatic measurement of the cycle time with breakpoints

When breakpoints are active between two calls of RampSoak, automatic measurement of the cycle time gives the actual time that has elapsed between two calls. When one breakpoint is active, the CPU is in the HOLD operating state.

NOTE

The active breakpoints extend the time period between two calls of RampSoak.

The longer the time period between two calls, the greater the change of the output value at the Output parameter. Points can be skipped depending on the elapsed time and the configured profile data.

If you do not need the calculation of the output value based on the actual time with active breakpoints, follow these steps:

- Disable automatic measurement of the cycle time by setting the tag CycleTime.EnableMeasurement = FALSE.
- Enter the cycle time manually for the CycleTime.Value tag.

11.8.3.6 Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and an error with the error message ErrorBits ≥ 16#0001_0000 is pending.
- Enable input EN is set to FALSE.

In all other cases the enable output ENO is set to TRUE.

11.8.4 Input parameter RampSoak

Parameter	Data type	Default	Description
Enable	BOOL	FALSE	The profile execution and calculation of the output value is started with a positive edge at the Enable parameter. The profile execution is stopped with a negative edge at the Enable parameter.
Hold	BOOL	FALSE	If Hold is set to TRUE, the execution of the profile is paused. The output value remains constant.
Next	BOOL	FALSE	With a positive edge at the Next parameter the profile execution is continued with Point[NextPoint].
SubstituteOutput	REAL	0.0	SubstituteOutput is used as a substitute output value when Reset = TRUE or one of the following modes is currently in effect: • ErrorMode = 1 • StartMode = 1 • StopMode = 1

Parameter	Data type	Default	Description
Validate	BOOL	FALSE	If Validate is set to TRUE, the profile data in UserData is checked for validity and transferred to WorkingData.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset.
Reset	BOOL	FALSE	Resets the instruction. • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. If the profile is executed at the same time, then that process runs in the background. • As long as Reset is set to FALSE, the output value is determined by the profile execution.

11.8.5 Output parameter RampSoak

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value The output value is retentive.
CurrentPoint	INT	0	Number of the point that is currently being used for the profile execution and calculation of the output value.
TotalTime	REAL	0.0	Total time of the profile (summation of the times of all the points used) in seconds
Remaining-Time_Total	REAL	0.0	Remaining time of the profile in seconds
Remaining-Time_Point	REAL	0.0	Remaining time of the current point in seconds
ErrorBits	DWORD	16#0	The ErrorBits (Page 533) parameter shows which error messages are present. ErrorBits is retentive and is reset when there is a positive edge at Reset or ErrorAck.
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.

11.8.6 In-out parameter RampSoak

Parameter	Data type	Default	Description
NextPoint	Int	1	Number of the point that will be used next. Permissible value range: 1 to WorkingData.NumberOfUsedPoints

11.8.7 Static tags RampSoak

Tag	Data type	Default	Description
UserData	AuxFct_RampSoak_Profile	-	The profile data is input in the UserData structure. The profile data in the UserData structure can be edited. Changes in this structure affect the execution of the profile only when the validation and copying of the data into the WorkingData structure are initiated.
UserData.NumberOfUsedPoints	INT	0	Number of points of the profile used Permissible value range: 1 to 50
UserData.StartValue	REAL	0.0	StartValue is used as an optional output value if one of the following modes is currently in effect: • ErrorMode = 0 • StartMode = 0 • StopMode = 0
UserData.Point	Array[1..50] of AuxFct_RampSoak_Point	-	Points of the profile
UserData.Point[i].Value	REAL	0.0	Output value of this point
UserData.Point[i].Time	REAL	0.0	Duration of this point in seconds Permissible value range: Point[i].Time ≥ 0.0
WorkingData	AuxFct_RampSoak_Profile	-	The profile data currently in effect is displayed in the WorkingData structure. The profile data in the WorkingData structure cannot be edited.
WorkingData.NumberOfUsedPoints	INT	0	Number of points of the profile used Permissible value range: 1 to 50
WorkingData.StartValue	REAL	0.0	WorkingData.StartValue is used as an optional output value if one of the following modes is currently in effect: • ErrorMode = 0 • StartMode = 0 • StopMode = 0
WorkingData.Point	Array[1..50] of AuxFct_RampSoak_Point	-	Points of the profile
WorkingData.Point[i].Value	REAL	0.0	Output value of this point
WorkingData.Point[i].Time	REAL	0.0	Duration of this point in seconds Permissible value range: Point[i].Time ≥ 0.0
ErrorMode	INT	2	Selection of the substitute output value following an error • 0 = WorkingData.StartValue • 1 = SubstituteOutput • 2 = last valid output value of the profile execution • 3 = 0.0 Permissible value range: 0 to 3 If the value of ErrorMode does not correspond to the permissible range of values, then ErrorMode = 2.

Tag	Data type	Default	Description
StartMode	INT	2	Selection of the starting behavior • 0 = WorkingData.StartValue • 1 = SubstituteOutput • 2 = start from the last output value • 3 = 0.0 • 4 = continue from the last output value Permissible value range: 0 to 4 If the value of StartMode does not correspond to the permissible range of values, then StartMode = 2.
StopMode		2	Selection of the stopping behavior • 0 = WorkingData.StartValue • 1 = SubstituteOutput • 2 = last valid output value of the profile execution • 3 = 0.0 • 4 = cyclical operation Permissible value range: 0 to 4 If the value of StopMode does not correspond to the permissible range of values, then StopMode = 2.
CycleTime	AuxFct_CycleTime	-	Cycle time data
CycleTime.Value	REAL	0.1	Cycle time in seconds (time interval between two calls) Permissible value range: CycleTime.Value > 0.0
CycleTime.Enable Measurement	BOOL	TRUE	Automatic measurement of the cycle time • FALSE = Deactivated • TRUE = Activated

11.8.8 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

With RampSoak, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000

  The output value can be calculated despite the error.
- Errors with error messages ErrorBits ≥ 16#0001_0000

  The error prevents a calculation of the output value. A substitute output value is output.

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 is/are pending, RampSoak reacts as follows:

- The output value is determined as follows despite this error:
  - If Reset = FALSE output value calculation through the execution of the profile
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:** If ErrorBits < 16#0001_0000 and Reset = FALSE, the output value is limited, while it is determined through StartMode or StopMode. In this case, check the following parameters depending on the set value at the StartMode or StopMode tags: • WorkingData.StartValue • SubstituteOutput When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the tag ErrorMode: • WorkingData.StartValue • SubstituteOutput When Reset = TRUE, check the SubstituteOutput parameter. **Additional information:** If you want to change the WorkingData.StartValue, first edit the UserData.StartValue and then set the parameter Validate = TRUE. Do not manually change the data of the WorkingData structure.
0000_0002	**Cause of error:** The measurement of the cycle time yields an invalid value while the execution of the profile is activated (Enable = TRUE). **Response to error:** If a valid value of the cycle time has already been measured, RampSoak continues execution of the profile based on this last value of the CycleTime.Value tag. If no valid value of the cycle time was previously measured, RampSoak still outputs the output value configured with the tag StartMode at the Output parameter.
0000_0004	**Cause of error:** One or more tags in the UserData structure have invalid values while the profile data is checked. **Response to error:** The profile data in the UserData structure is not transferred to the WorkingData structure, so the changes made in the UserData structure do not become effective. **Solution:** Ensure that the following conditions are met when the profile data is checked: • 1 ≤ UserData.NumberOfUsedPoints ≤ 50 • -3.402823e+38 ≤ UserData.Point[i].Value ≤ 3.402823e+38 with index *i* = 1..UserData.NumberOfUsedPoints • 0.0 ≤ UserData.Point[i].Time ≤ 3.402823e+38 with index *i* = 1..UserData.NumberOfUsedPoints • -3.402823e+38 ≤ UserData.StartValue ≤ 3.402823e+38 • NextPoint ≤ UserData.NumberOfUsedPoints • 0.0 < UserData.Point[1].Time + UserData.Point[2].Time +...+ UserData.Point[UserData.NumberOfUsedPoints].Time ≤ 3.402823e+38 • With execution of the profile activated: CurrentPoint ≤ UserData.NumberOfUsedPoints **Additional information:** The profile data in the UserData structure are checked in the following cases: • If the Validate parameter is set to TRUE. • Or if RampSoak is called after the operating state transition of the CPU from STOP to RUN for the first time with the parameter Enable = TRUE and there was no validation of the profile data carried out previously. Note that all tags in the UserData and WorkingData structures are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.

ErrorBits (DW#16#...)	Description
0000_0008	**Cause of error:** The NextPoint parameter has an invalid value. **Response to error:** NextPoint is reset to the last valid value. **Solution:** Ensure that the following condition is met: • 1 ≤ NextPoint ≤ WorkingData.NumberOfUsedPoints

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 is/are pending, RampSoak reacts as follows:

- The output value cannot be determined as expected. The table below shows the reaction of the Output parameter and the execution of the profile.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, RampSoak reacts as follows:

- The output value is determined as follows:
  - If Reset = FALSE, output value through the execution of the profile
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th>Description</th></tr>
<tr><td>0001_0000</td><td>Cause of error:
The SubstituteOutput parameter or the WorkingData.StartValue tag is currently used for determining the output value, but does not have any valid REAL value.
Response to error:
If Reset = TRUE and SubstituteOutput is a valid REAL value, then SubstituteOutput continues to be output at the parameter Output.
In all other cases, parameter Output is set to 0.0.
Solution:
Make sure that the SubstituteOutput parameter and the WorkingData.StartValue tag are valid REAL values (≠NaN, e.g. 16#7FFF_FFFF). The tag that is used depends on Reset the pending errors and ErrorMode:
<table>
<tr><th>Reset</th><th>ErrorBits</th><th>ErrorMode</th><th>Tag used</th></tr>
<tr><td>-</td><td>>= 16#0002_0000</td><td>0</td><td>WorkingData.StartValue</td></tr>
<tr><td>-</td><td>>= 16#0002_0000</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td>TRUE</td><td>-</td><td>-</td><td>SubstituteOutput</td></tr>
</table>
Additional information:
If you want to change the WorkingData.StartValue, first edit the UserData.StartValue and then set the parameter Validate = TRUE. Do not manually change the data of the WorkingData structure.</td></tr>
</table>

ErrorBits (DW#16#...)	Description
0004_0000	**Cause of error:** The calculation during the execution of the profile yields an invalid REAL value. **Response to error:** Execution of the profile is aborted. If Reset = FALSE, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter and then retained. If Reset = TRUE, then SubstituteOutput continues to be output at the Output parameter. **Solution:** Validate the REAL values in the WorkingData structure and, if required, start execution of the profile once again. **Additional information:** If you want to change the profile data, first edit the UserData structure and then set parameter Validate = TRUE. Do not manually change the data of the Struktur WorkingData.
0008_0000	**Cause of error:** The Enable parameter or the Next parameter is set to TRUE, but there is no valid profile data present in the WorkingData structure. **Response to error:** Parameter Enable and parameter Next are not effective. If Reset = FALSE, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter. If Reset = TRUE, then SubstituteOutput continues to be output at the Output parameter. **Solution:** Input valid profile data in the UserData structure and then set the parameter Validate = TRUE. In this manner, the profile data is transferred after validation to the WorkingData structure. **Additional information:** If parameter Enable or parameter Next is still set to TRUE, they become effective as soon as valid profile data is present in the WorkingData structure. A fresh positive edge is not required. Note that all tags in the UserData and WorkingData structures are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN.
0010_0000	**Cause of error:** The tag (configured with StopMode) which determines the output value when the execution of the profile has ended or been stopped does not have any valid REAL value. **Response to error:** If Reset = FALSE, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter and then retained. If Reset = TRUE, then SubstituteOutput continues to be output at the Output parameter. **Solution:** Make sure that the tag is a valid REAL value (≠ NaN for example, 16#7FFF_FFFF). The tag that is used depends on StopMode: • StopMode = 0: WorkingData.StartValue • StopMode = 1: SubstituteOutput **Additional information:** If you want to change the WorkingData.StartValue, first edit the UserData.StartValue and then set the parameter Validate = TRUE. Do not manually change the data of the WorkingData structure.
0020_0000	**Cause of error:** The tag (configured with StartMode), which determines the output value when the instruction is called for the first time, or the execution of the profile is started, does not have a valid REAL value. **Response to error:** If Reset = FALSE, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter and then retained. If the execution of the profile is activated (Enable = TRUE), it starts initially from this substitute output value. If Reset = TRUE, then SubstituteOutput continues to be output at the Output parameter. **Solution:**

ErrorBits (DW#16#...)	Description
	Make sure that the tag is a valid REAL value (≠ NaN for example, 16#7FFF_FFFF). The tag that is used depends on StartMode: • StartMode = 0: WorkingData.StartValue • StartMode = 1: SubstituteOutput • StartMode = 2: Output **Additional information:** If you want to change the WorkingData.StartValue, first edit the UserData.StartValue and then set the parameter Validate = TRUE. Do not manually change the data of the WorkingData structure.
0040_0000	**Cause of error:** The CycleTime.Value tag has an invalid value while the execution of the profile is activated (Enable = TRUE). **Response to error:** Execution of the profile is paused. If Reset = FALSE, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter. If Reset = TRUE, then SubstituteOutput continues to be output at the Output parameter. Execution of the profile is continued as soon as this error is not present any more. If execution of the profile is stopped beforehand, the substitute output value is retained. **Solution:** Ensure that the following conditions are met: • 0.0 < CycleTime.Value ≤ 3.402823e+38 • CycleTime.Value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF) **Additional information:** To automatically calculate the value of the tag CycleTime.Value, set the tag CycleTime.EnableMeasurement to TRUE.

11.9 Filter_PT1

11.9.1 Compatibility with CPU and FW

The following table shows which version of Filter_PT1 can be used on which CPU:

CPU	FW	Filter_PT1
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.9.2 Description of Filter_PT1

Description

The instruction Filter_PT1 is a proportional transfer element with a first-order lag, also referred to as PT1 element.

You can use Filter_PT1 for the following purposes:

- Low-pass filter to attenuate high frequency components, such as noise, in a signal.
- Delay element to smooth signal step changes, for example, from the setpoint or the output value of a controller.
- Process simulation block to implement a closed control loop within the CPU. This means, for example, that you can test controllers before commissioning.

You can specify the following filter parameters:

- Proportional gain (Gain)
- Lag time constant (Lag)

NOTE

Differences between a continuous-time PT1 element and Filter_PT1

Because Filter_PT1 is executed in a PLC program, Filter_PT1 is a discrete-time implementation of a PT1 element. Discrete-time systems cannot have the same properties as the corresponding continuous-time model. Depending on the cycle time, discrete-time systems can emulate a continuous-time system well: The smaller and more constant the cycle time, the smaller the conformity error between the properties of Filter_PT1 and the properties of a continuous-time PT1 element. The properties of a continuous-time PT1 element are the transfer function, the time response and the frequency response which are described below.

For a good simulation of the frequency response, a maximum cycle time of one-tenth of the shortest period duration of the input signal components is recommended. For example, a signal with frequency components of up to 50 Hz has a minimum period duration of 20 ms. To achieve good simulation of the frequency response, a maximum cycle time of 2 ms is recommended for this example.

Transfer function of a PT1 element

The following formula shows the transfer function of a PT1 element, whereby s is equal to the Laplace operator:

$$G(s) = \frac{\text{Output}(s)}{\text{Input}(s)} = \frac{\text{Gain}}{1 + \text{Lag} \cdot s}$$

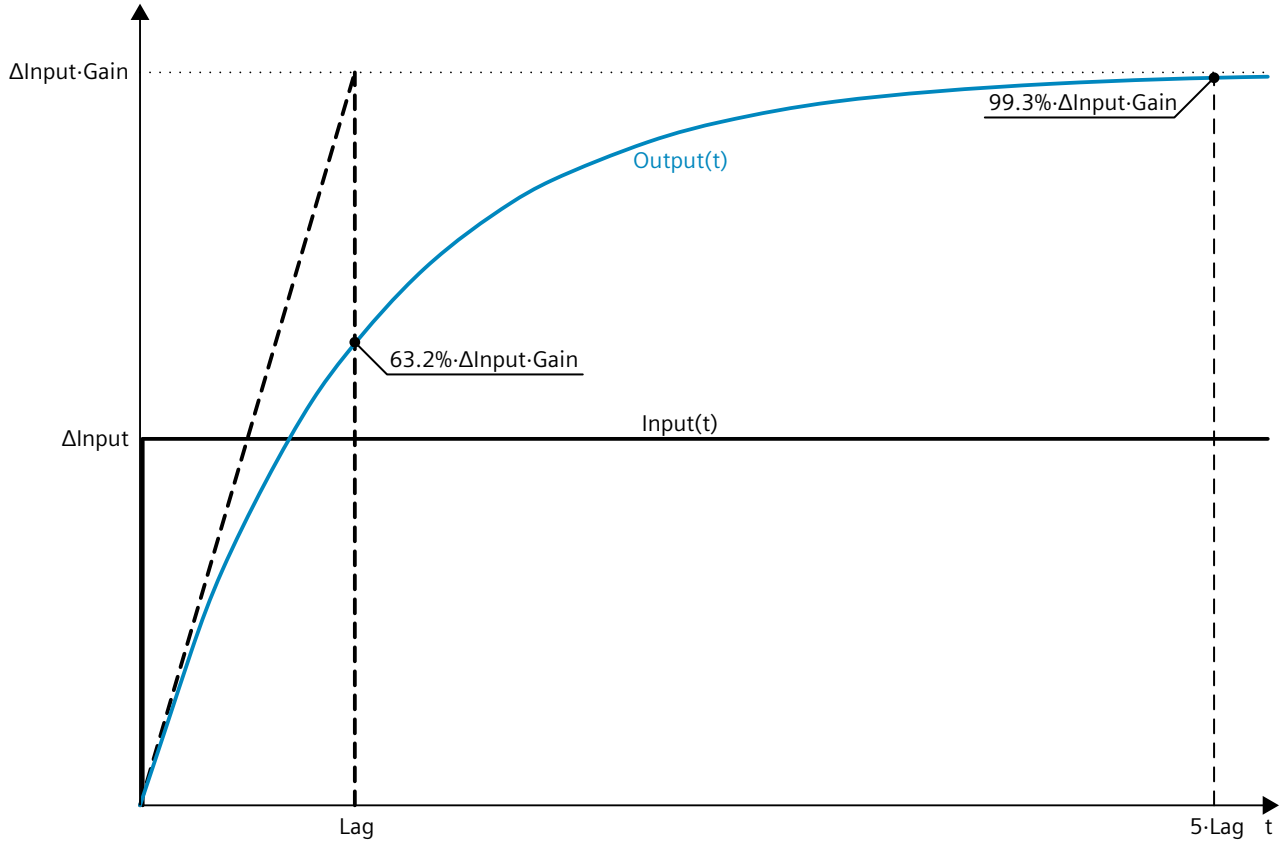
Time response of a PT1 element

The step response is the response of the output value to a step change of the input value.

The step response for a step change of the input value from 0 to ΔInput can be calculated using the following formula:

$$Output(t) = \Delta Input \cdot Gain \cdot (1 - e^{-\frac{t}{Lag}})$$

The following figure shows the step response of a PT1 element:



Frequency response of a PT1 element

The frequency response of a transfer element is described by the amplitude response and the phase response.

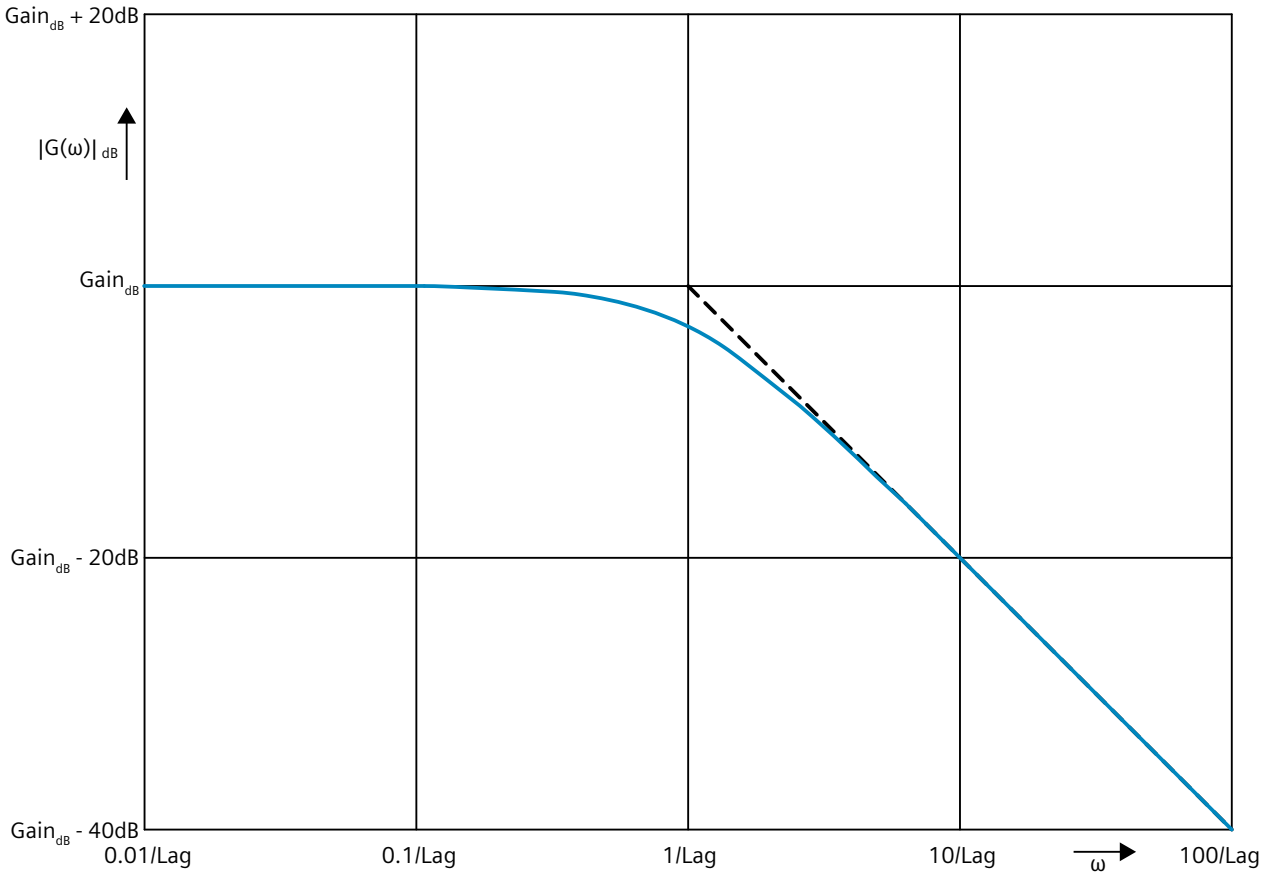
The amplitude response describes the gain of a signal through the transfer element depending on the angular frequency of the signal.

The following equation describes the amplitude response of a PT1 element:

$$|G(\omega)| = \frac{Gain}{\sqrt{1 + (\omega \cdot Lag)^2}}$$

|G(ω)|	Signal gain as a function of the angular frequency
ω	Angular frequency

The following figure shows the amplitude response of a PT1 element:



The phase response describes the phase offset of a signal through the transfer element depending on the angular frequency of the signal.

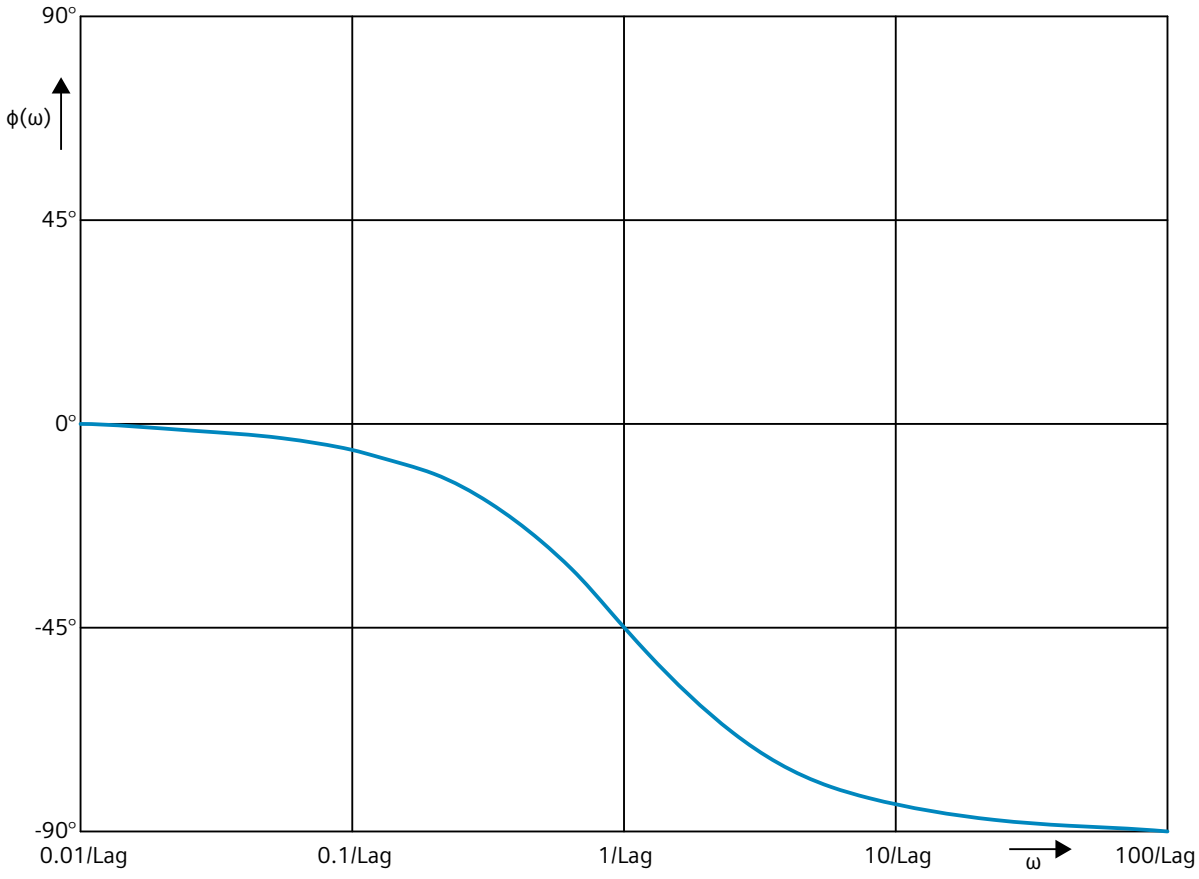
The following equation describes the phase response of a PT1 element:

$$\varphi(\omega) = -\tan^{-1}(\omega \cdot \text{Lag})$$

φ(ω) Phase offset as a function of the angular frequency

ω Angular frequency

The following figure shows the phase response of a PT1 element:



Call

In an OB or FC, Filter_PT1 is called as single-instance DB. In an FB, Filter_PT1 can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. No parameter assignment interface or commissioning interface is available. You assign the Filter_PT1 parameters directly using the instance DB and commission Filter_PT1 using a watch table of the user program in the CPU or HMI.

Startup

The tags in the static area of Filter_PT1 are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN. If you change the actual values in online mode and these values are to be retained after the operating state transition of the CPU, back up these values in the start values of the data block.

Specify the initialization value for the Output parameter at the StartMode tag.

During the first call of Filter_PT1 after the

- Operating state transition of the CPU

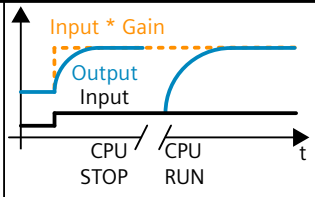
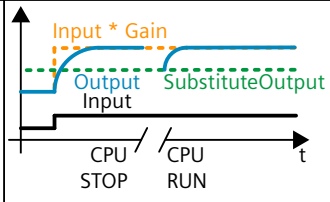
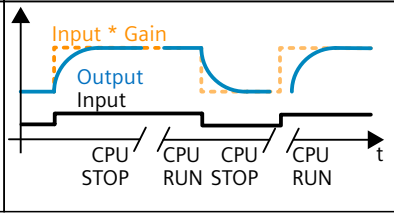
or

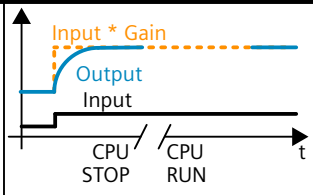
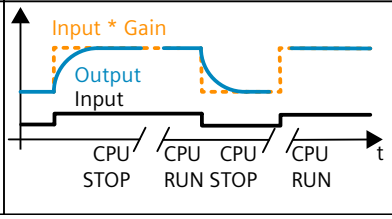
- Execution of "Load start values as actual values" (only with "All values" option, not with "Only setpoints" option)

the initialization value is output at the Output parameter.

For subsequent calls, Filter_PT1 calculates the output value, starting from this initialization value, based on the input value and the filter configuration.

The following table shows the dependency between the StartMode tag and the Output parameter. The values in the Output column are output at the Output parameter after the operating state transition of the CPU.

StartMode	Output	Example
0	Value of the Input parameter	
1	Value of the SubstituteOutput parameter	
2	Remains unchanged Output parameter is retentive Default setting Is used when StartMode is not in the range 0...4	

StartMode	Output	Example
3	0.0	
4	Value of the Input * Gain product	

The following applies in addition for all values of the StartMode tag:

- The initialization value is limited to the value range of the data type REAL. Only then is the initialization value output at the Output parameter.
- If the initialization value is not a valid REAL value, the substitute output value is output at the Output parameter. The substitute output value is configured by the ErrorMode tag. The substitute output value is limited to the value range of the data type REAL before it is output at the Output parameter. If the substitute output value is also not a valid REAL value, 0.0 is output at the Output parameter. For subsequent calls, the instruction calculates the output value starting from this substitute output value.
- The StartMode tag only takes effect when the Reset = FALSE parameter is set at the first call of the instruction and at the same time no error with error message ErrorBits ≥ 16#0002_0000 is pending. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

Response to errors

The Filter_PT1 instruction detects different errors that can occur during the calculation of the output value. The result of this calculation can be output at the output despite a pending error. If an error prevents correct calculation of the output value, a substitute output value is output at the output.

Specify the substitute output value that is output if an error occurs that prevents correct calculation of the output value at the ErrorMode tag.

The following table shows the dependency between the ErrorMode tag and the substitute output value that is output by the Filter_PT1 at the Output parameter:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter

ErrorMode	Output
2	The last valid filter output value 0.0 if no valid filter output value is available Default setting Is used when ErrorMode is not in the range 0...4
3	0.0
4	Value of the Input * Gain product

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.9.3 Operating principle Filter_PT1

Reset response

Filter_PT1 behaves as follows depending on the Reset parameter:

- If the Reset =TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.
- If the Reset = FALSE parameter is set, the value that is output at the Output parameter is calculated by the filter algorithm.
- When the Reset parameter is set from FALSE to TRUE, the value at the Output parameter changes directly to the value of the SubstituteOutput parameter. An output jump can occur during this transition. In addition, the ErrorBits parameter is reset.
- When the Reset parameter is set from TRUE to FALSE, the filtering algorithm is added so that the transition is bumpless.

Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

Measuring the cycle time automatically

To calculate the output value, Filter_PT1 needs the time that has expired since the last call of Filter_PT1.

By default, the cycle time is measured automatically and output as of the second call at the CycleTime.Value tag. Filter_PT1 measures the cycle time for each call of the instruction and can therefore be used in non-isochronous call cycles, e.g. in OB1.

Note that conditional calls of the instruction, active breakpoints, or the loading of snapshots as actual values during automatic measurement of the cycle time will extend the cycle time value. A cycle time that is too long is identified as error with error message ErrorBits = 16#0008_0000.

If measurement of the cycle time returns no valid result, Filter_PT1 calculates the current output value with the last valid cycle time. In addition, Filter_PT1 outputs an error message at the ErrorBits parameter.

When you disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement tag = FALSE, you must enter the cycle time manually at the CycleTime.Value tag. Filter_PT1 checks the CycleTime.Value tag for validity at each call.

Automatic measurement of the cycle time with breakpoints

When breakpoints are active between two calls of Filter_PT1, automatic measurement of the cycle time results in the actual time that has elapsed between two calls. When one breakpoint is active, the CPU is in HOLD operating state.

NOTE

The active breakpoints extend the time period between two calls of Filter_PT1.

The longer the time period between two calls, the greater the change of the output value at the Output parameter.

Furthermore, it is possible that the longer time intervals violate the condition Lag ≥ CycleTime.Value/2 and an error with the error message ErrorBits = 16#0008_0000 is therefore identified.

If you do not need the calculation of the output value based on the actual time with active breakpoints, follow these steps:

- Disable automatic measurement of the cycle time by setting the tag CycleTime.EnableMeasurement = FALSE.
- Enter the cycle time manually at the CycleTime.Value tag.

11.9.4 Input parameter Filter_PT1

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
Substitu-teOutput	REAL	0.0	SubstituteOutput is used as the substitute output value when • Reset = TRUE or • An error with error message ErrorBits ≥ 16#0001_0000 prevents the correct calculation of the output value, and ErrorMode is configured to the value 1.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset.
Reset	BOOL	FALSE	Performs a restart of the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. • As long as Reset is set to FALSE, the calculation of the output value is performed.

11.9.5 Output parameter Filter_PT1

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value The output value is retentive.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 547) shows which error messages are pending. ErrorBits is retentive and is reset upon a positive edge at Reset or ErrorAck.
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.

11.9.6 Static tags Filter_PT1

Tag	Data type	Default	Description
Gain	REAL	1.0	Proportional gain
Lag	REAL	25.0	Lag time constant in seconds Permissible value range: Lag ≥ CycleTime.Value/2
ErrorMode	INT	2	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid filter output value • 3 = 0.0 • 4 = Input * Gain Permissible value range: 0 to 4

Tag	Data type	Default	Description
StartMode	INT	2	Selecting the output value for the first call of the instruction • 0 = Input • 1 = SubstituteOutput • 2 = Last output value • 3 = 0.0 • 4 = Input * Gain Permissible value range: 0 to 4
CycleTime	AuxFct_CycleTime	-	Cycle time data
CycleTime.Value	REAL	0.1	Cycle time in seconds (time interval between two calls) Permissible value range: CycleTime.Value > 0.0
CycleTime.Enable Measurement	BOOL	TRUE	Automatic measurement of the cycle time • FALSE = Deactivated • TRUE = Activated

11.9.7 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

For Filter_PT1, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
- Errors with error messages ErrorBits ≥ 16#0001_0000

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 are pending, Filter_PT1 reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:** If the value determined by the filter function is output at the output (Reset = FALSE and ErrorBits < 16#0001_0000), check the following tags used in the filter calculation: • Input • Gain • Lag • CycleTime.Value

ErrorBits (DW#16#...)	Description
	When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the tag ErrorMode: • Input • SubstituteOutput • The product of Input and Gain When Reset = TRUE, check the SubstituteOutput parameter.
0000_0002	**Cause of error:** The measurement of the cycle time yields in an invalid value while the output value is being calculated (Reset = FALSE). **Response to error:** If a valid value of the cycle time has already been measured, Filter_PT1 calculates the output value based on the last value of the CycleTime.Value tag. If no valid value of the cycle time was previously measured, Filter_PT1 still outputs the output value configured with the StartMode tag at the Output parameter.

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 are pending, Filter_PT1 reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, Filter_PT1 reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th colspan="3">Description</th></tr>
<tr><td>0001_0000</td><td colspan="3">Cause of error:
The SubstituteOutput parameter or a different tag that is being used as output value has no valid REAL value.
Response to error:
The output is set to 0.0.
Solution:
Make sure that the tag used as output value is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF). The tag that is used as output value depends on Reset and ErrorMode:</td></tr>
<tr><td></td><td>Reset</td><td>ErrorMode</td><td>Output value</td></tr>
<tr><td></td><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td></td><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td></td><td>FALSE</td><td>4</td><td>Product of Input and Gain</td></tr>
</table>

ErrorBits (DW#16#...)	Description		
0001_0000	TRUE	-	SubstituteOutput
0002_0000	**Cause of error:** The Input parameter has no valid REAL value while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. When ErrorMode = 0, 0.0 is used as output value. **Solution:** Make sure that the parameter Input is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF).		
0004_0000	**Cause of error:** The calculation of the output value yields an invalid REAL value for the Output parameter. **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Check all tags involved in the calculation of the output value: • Input • Gain • Lag • CycleTime.Value These tags have valid values. The calculation of the output value fails in this combination of tags.		
0008_0000	**Cause of error:** The Lag or Gain tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions for the values of the Gain and Lag tags are met: • -3.402823e+38 ≤ Gain ≤ 3.402823e+38 • CycleTime.Value/2 ≤ Lag ≤ 3.402823e+38 • The values are valid REAL values (≠ NaN, for example 16#7FFF_FFFF) **Additional information:** Note that the condition CycleTime.Value/2 ≤ Lag may be violated in the following scenarios: • The time interval between two calls of Filter_PT1 is longer than 2 * Lag, for example, due to conditional calls in the program sequence or active breakpoints. • A snapshot of the Filter_PT1 instance DB is loaded into the CPU as actual values, and the snapshot was created more than 2 * Lag ago. In these scenarios, an error message ErrorBits = 16#0008_0000 is detected during automatic measurement of the cycle time.		
0020_0000	**Cause of error:** The tag (configured with StartMode) for the initialization of the Output parameter at the first call of the instruction does not have a valid REAL value. **Response to error:** The substitute output value is output with the first call of the instruction at the Output parameter that is configured at the ErrorMode tag. For subsequent calls, Filter_PT1 calculates the output value starting from this substitute output value. **Solution:** Make sure that the tag for initializing the parameter Output is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). When Reset = FALSE is set, the initialization takes effect with the first call of the instruction after the operating state transition of the CPU from STOP to RUN. The tag that is used for the initialization of the Output parameter depends on StartMode: • StartMode = 1: SubstituteOutput • StartMode = 2: Output • StartMode = 4: Product of Input and Gain		

ErrorBits (DW#16#...)	Description
0040_0000	**Cause of error:** The CycleTime.Value tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions are met: • 0.0 < CycleTime.Value ≤ 3.402823e+38 • CycleTime.Value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF) **Additional information:** To automatically calculate the value of the CycleTime.Value tag, set the CycleTime.EnableMeasurement tag to TRUE.

11.10 Filter_PT2

11.10.1 Compatibility with CPU and FW

The following table shows which version of Filter_PT2 can be used on which CPU:

CPU	FW	Filter_PT2
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.10.2 Description of Filter_PT2

Description

The instruction Filter_PT2 is a proportional transfer element with a second-order lag, also referred to as PT2 element.

You can use Filter_PT2 for the following purposes:

- Low-pass filter to attenuate high frequency components, such as noise, in a signal.
- Delay element to smooth signal step changes, for example, from the setpoint or the output value of a controller.
- Process simulation block to implement a closed control loop within the CPU. This means, for example, that you can test controllers before commissioning.

You can specify the following filter parameters:

- Proportional gain (Gain)
- Time constant (TimeConstant)
- Damping (Damping)

NOTE

Differences between a continuous-time PT2 element and Filter_PT2

Because Filter_PT2 is executed in a PLC program, Filter_PT2 is a discrete-time implementation of a PT2 element. Discrete-time systems cannot have the same properties as the corresponding continuous-time model. Depending on the cycle time, discrete-time systems can emulate a continuous-time system well: The smaller and more constant the cycle time, the smaller the conformity error between the properties of Filter_PT2 and the properties of a continuous-time PT2 element. The properties of a continuous-time PT2 element are the transfer function, the time response and the frequency response which are described below.

For a good simulation of the frequency response, a maximum cycle time of one-tenth of the shortest period duration of the input signal components is recommended. For example, a signal with frequency components of up to 50 Hz has a minimum period duration of 20 ms. To achieve good simulation of the frequency response, a maximum cycle time of 2 ms is recommended for this example.

Transfer function of a PT2 element

The following formula shows the transfer function of a PT2 element, whereby s is equal to the Laplace operator:

$$G(s) = \frac{\text{Output(s)}}{\text{Input(s)}} = \frac{\text{Gain}}{1 + 2 \cdot \text{Damping} \cdot \text{TimeConstant} \cdot s + \text{TimeConstant} \cdot s}$$

If Damping ≥ 1, the PT2 element can be described as two PT1 elements switched in series:

$$G(s) = \frac{\text{Output(s)}}{\text{Input(s)}} = \frac{\text{Gain}}{(1 + \text{Lag}_1 \cdot s) \cdot (1 + \text{Lag}_2 \cdot s)}$$

The lag time constants of the PT1 elements switched in series are calculated as follows:

$$Lag_{1/2} = TimeConstant \cdot \left(Damping \pm \sqrt{Damping^2 - 1}\right)$$

Time response of a PT2 element

The step response is the response of the output value to a step change of the input value.

The step response for a step change of the input value from 0 to ΔInput can be calculated using the following formulas:

The following formula applies to Damping < 1:

$$Output(t) = \Delta Input \cdot Gain \cdot \left(1 - e^{-\frac{Damping}{TimeConstant} \cdot t} \cdot \left[\cos\left(\frac{\sqrt{1 - Damping^2}}{TimeConstant} \cdot t\right) + \frac{Damping}{\sqrt{1 - Damping^2}} \cdot \sin\left(\frac{\sqrt{1 - Damping^2}}{TimeConstant} \cdot t\right)\right]\right)$$

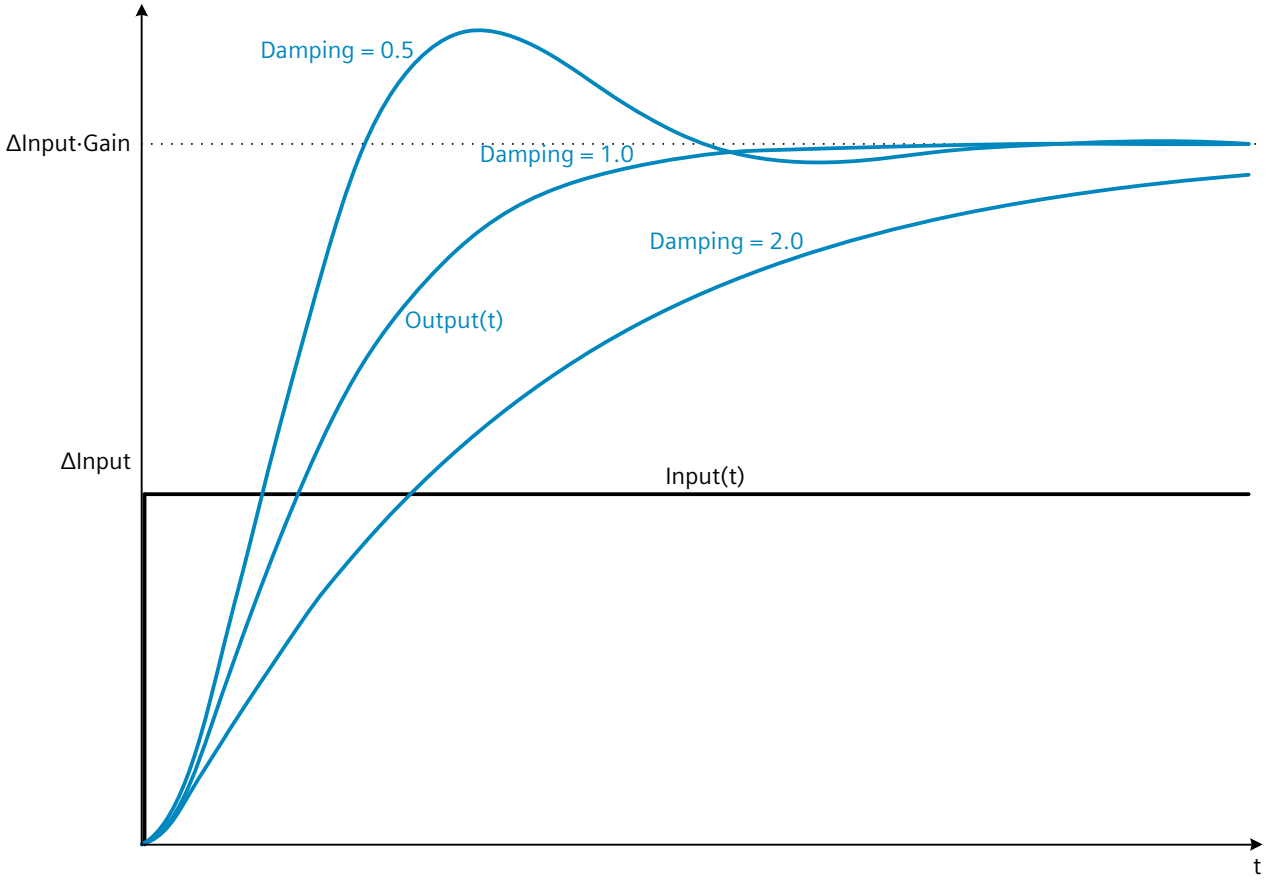
The following formula applies to Damping = 1:

$$Output(t) = \Delta Input \cdot Gain \cdot \left(1 - e^{-\frac{t}{TimeConstant}} - \frac{t}{TimeConstant} \cdot e^{-\frac{t}{TimeConstant}}\right)$$

The following formula with the above calculated Lag_1 and Lag_2 applies to Damping > 1:

$$Output(t) = \Delta Input \cdot Gain \cdot \left(1 - \frac{Lag_1}{Lag_1 - Lag_2} \cdot e^{-\frac{t}{Lag_1}} + \frac{Lag_2}{Lag_1 - Lag_2} \cdot e^{-\frac{t}{Lag_2}}\right)$$

The following figure shows the step response of a PT2 element with various values for the damping:



Frequency response of a PT2 element

The frequency response of a transfer element is described by the amplitude response and the phase response.

The amplitude response describes the gain of a signal through the transfer element depending on the angular frequency of the signal.

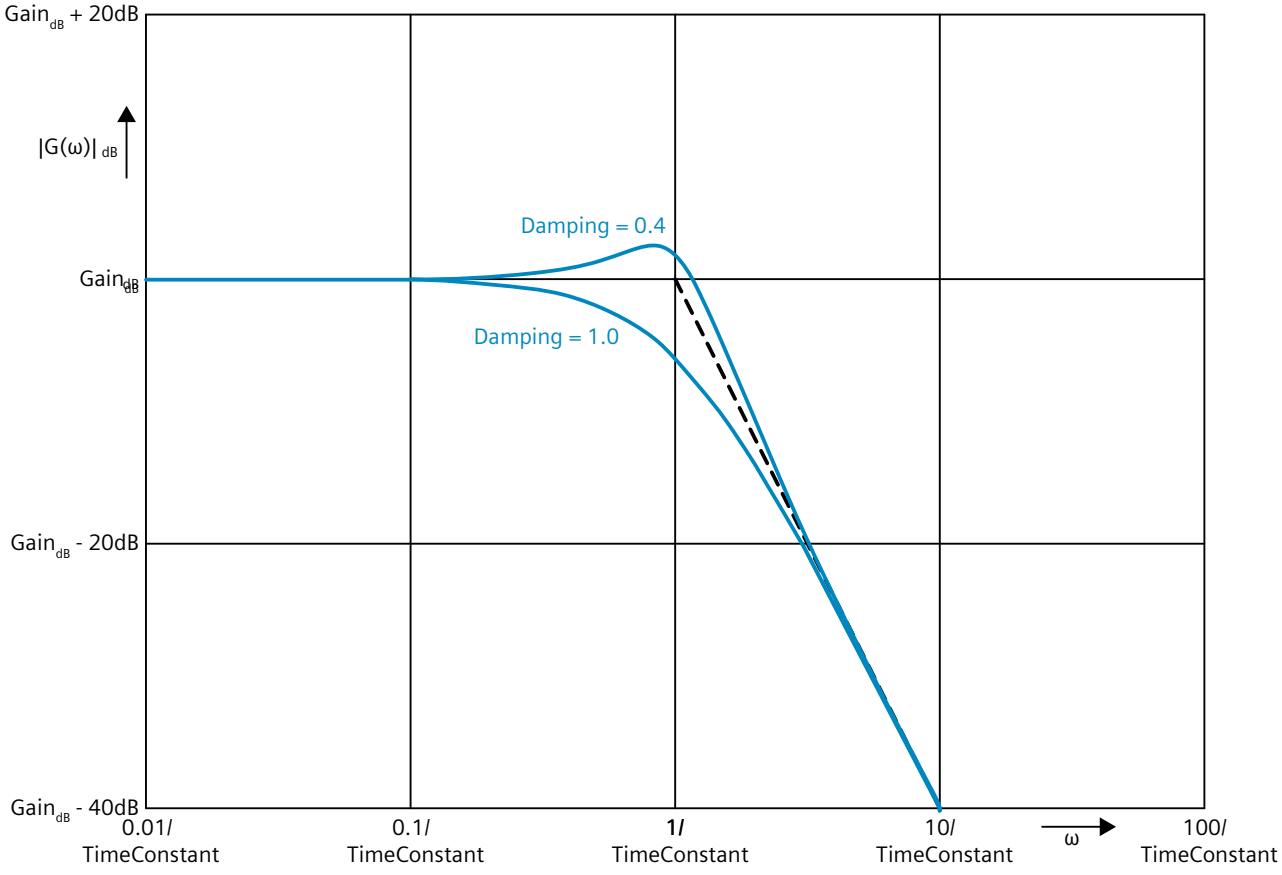
The following equation describes the amplitude response of a PT2 element:

$$|G(\omega)| = \frac{\text{Gain}}{\sqrt{(1 - [\omega \cdot \text{TimeConstant}]^2)^2 + (\omega \cdot 2 \cdot \text{Damping} \cdot \text{TimeConstant})^2}}$$

|G(ω)| Signal gain as a function of the angular frequency

ω Angular frequency

The following figure shows the amplitude response of a PT2 element with a damping of 0.4 and 1.0:



NOTE

When Damping < 1/√2, a resonance peak appears in the amplitude response.

The phase response describes the phase offset of a signal through the transfer element depending on the angular frequency of the signal.

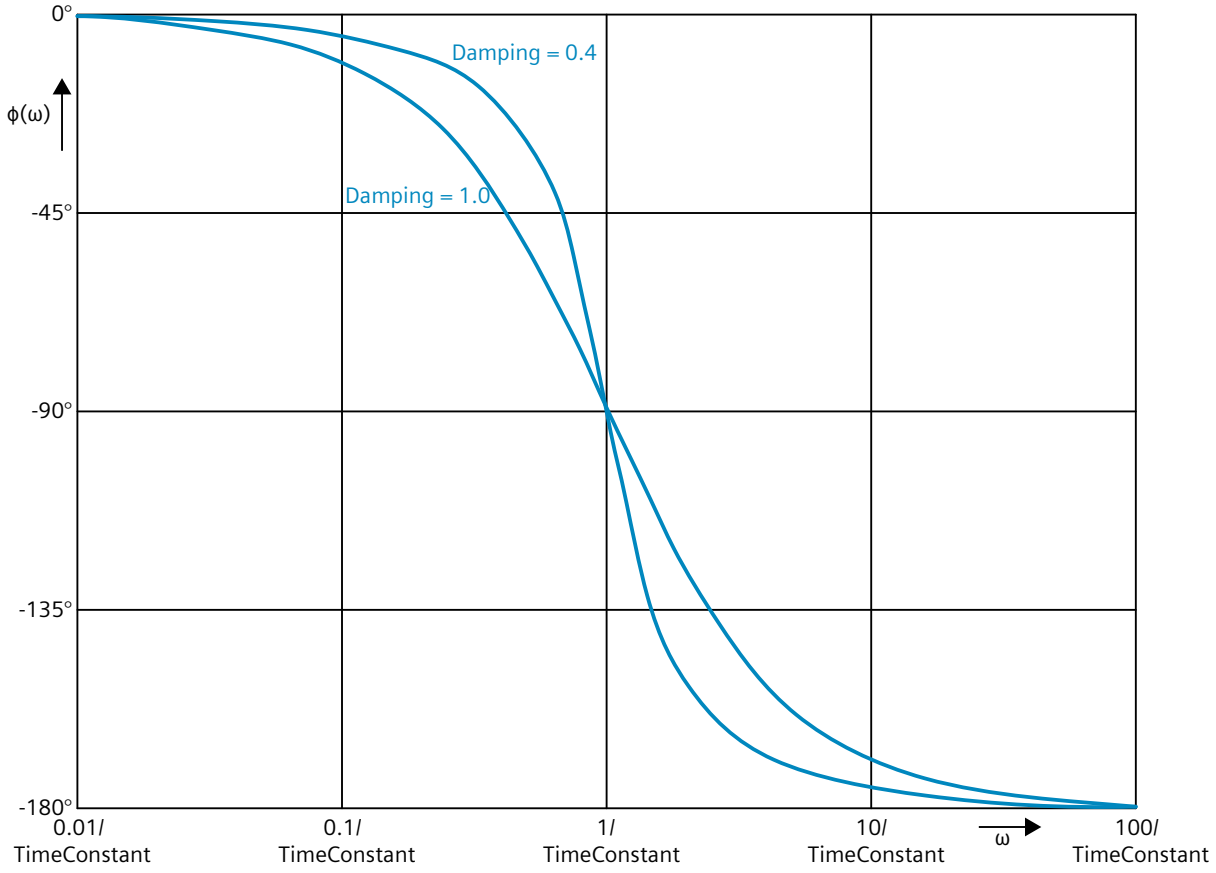
The following equation describes the phase response of a PT2 element:

$$\varphi(\omega) = -\tan^{-1}\left(\frac{\omega \cdot 2 \cdot \text{Damping} \cdot \text{TimeConstant}}{1 - (\omega \cdot \text{TimeConstant})^2}\right)$$

φ(ω) Phase offset as a function of the angular frequency

ω Angular frequency

The following figure shows the phase response of a PT2 element:



Call

In an OB or FC, Filter_PT2 is called as single-instance DB. In an FB, Filter_PT2 can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. No parameter assignment interface or commissioning interface is available. You assign the Filter_PT2 parameters directly using the instance DB and commission Filter_PT2 using a watch table of the user program in the CPU or HMI.

Startup

The tags in the static area of Filter_PT2 are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN. If you change the actual values in online mode and these values are to be retained after the operating state transition of the CPU, back up these values in the start values of the data block.

Specify the initialization value for the Output parameter at the StartMode tag.

During the first call of Filter_PT2 after the

- Operating state transition of the CPU

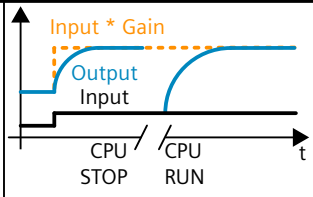
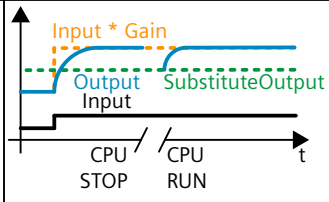
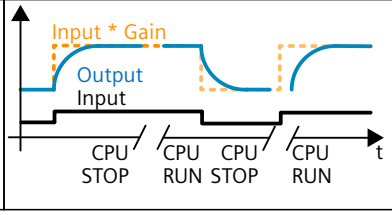
or

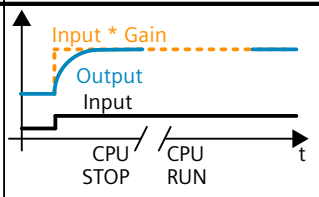
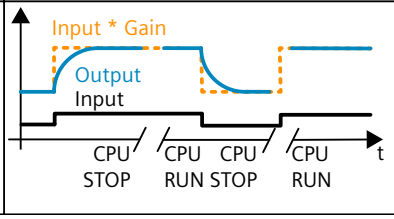
- Execution of "Load start values as actual values" (only with "All values" option, not with "Only setpoints" option)

the initialization value is output at the Output parameter.

For subsequent calls, Filter_PT2 calculates the output value, starting from this initialization value, based on the input value and the filter configuration.

The following table shows the dependency between the StartMode tag and the Output parameter. The values in the Output column are output at the Output parameter after the operating state transition of the CPU.

StartMode	Output	Example
0	Value of the Input parameter	
1	Value of the SubstituteOutput parameter	
2	Remains unchanged Output parameter is retentive Default setting Is used when StartMode is not in the range 0...4	

StartMode	Output	Example
3	0.0	
4	Value of the Input * Gain product	

The following applies in addition for all values of the StartMode tag:

- The initialization value is limited to the value range of the data type REAL. Only then is the initialization value output at the Output parameter.
- If the initialization value is not a valid REAL value, the substitute output value is output at the Output parameter. The substitute output value is configured by the ErrorMode tag. The substitute output value is limited to the value range of the data type REAL before it is output at the Output parameter. If the substitute output value is also not a valid REAL value, 0.0 is output at the Output parameter. For subsequent calls, the instruction calculates the output value starting from this substitute output value.
- The StartMode tag only takes effect when the Reset = FALSE parameter is set at the first call of the instruction and at the same time no error with error message ErrorBits ≥ 16#0002_0000 is pending. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

Response to errors

The Filter_PT2 instruction detects different errors that can occur during the calculation of the output value. The result of this calculation can be output at the output despite a pending error. If an error prevents correct calculation of the output value, a substitute output value is output at the output.

Specify the substitute output value that is output if an error occurs that prevents correct calculation of the output value at the ErrorMode tag.

The following table shows the dependency between the ErrorMode tag and the substitute output value that is output by the Filter_PT2 at the Output parameter:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter

ErrorMode	Output
2	The last valid filter output value 0.0 if no valid filter output value is available Default setting Is used when ErrorMode is not in the range 0...4
3	0.0
4	Value of the Input * Gain product

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.10.3 Operating principle Filter_PT2

Reset response

Filter_PT2 behaves as follows depending on the Reset parameter:

- If the Reset =TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.
- If the Reset = FALSE parameter is set, the value that is output at the Output parameter is calculated by the filter algorithm.
- When the Reset parameter is set from FALSE to TRUE, the value at the Output parameter changes directly to the value of the SubstituteOutput parameter. An output jump can occur during this transition. In addition, the ErrorBits parameter is reset.
- When the Reset parameter is set from TRUE to FALSE, the filtering algorithm is added so that the transition is bumpless.

Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

Measuring the cycle time automatically

To calculate the output value, Filter_PT2 needs the time that has expired since the last call of Filter_PT2.

By default, the cycle time is measured automatically and output as of the second call at the CycleTime.Value tag. Filter_PT2 measures the cycle time for each call of the instruction and can therefore be used in non-equidistant call cycles, e.g. in OB1.

Note that conditional calls of the instruction, active breakpoints, or the loading of snapshots as actual values during automatic measurement of the cycle time will extend the cycle time value. A cycle time that is too long is identified as error with error message ErrorBits = 16#0008_0000.

If measurement of the cycle time returns no valid result, Filter_PT2 calculates the current output value with the last valid cycle time. In addition, Filter_PT2 outputs an error message at the ErrorBits parameter.

When you disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement tag = FALSE, you must enter the cycle time manually at the CycleTime.Value tag. Filter_PT2 checks the CycleTime.Value tag for validity at each call.

Automatic measurement of the cycle time with breakpoints

When breakpoints are active between two calls of Filter_PT2, automatic measurement of the cycle time results in the actual time that has elapsed between two calls. When one breakpoint is active, the CPU is in HOLD operating state.

NOTE

The active breakpoints extend the time period between two calls of Filter_PT2.

The longer the time period between two calls, the greater the change of the output value at the Output parameter.

Furthermore, it is possible that the longer time intervals violate the condition TimeConstant ≥ CycleTime.Value/2 and an error with the error message ErrorBits = 16#0008_0000 is therefore identified.

If you do not need the calculation of the output value based on the actual time with active breakpoints, follow these steps:

- Disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement tag = FALSE.
- Enter the cycle time manually at the CycleTime.Value tag.

11.10.4 Input parameter Filter_PT2

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
Substitu-teOutput	REAL	0.0	SubstituteOutput is used as the substitute output value when • Reset = TRUE or • An error with error message ErrorBits ≥ 16#0001_0000 prevents the correct calculation of the output value, and ErrorMode is configured to the value 1.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset.
Reset	BOOL	FALSE	Performs a restart of the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. • As long as Reset is set to FALSE, the calculation of the output value is performed.

11.10.5 Output parameter Filter_PT2

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value The output value is retentive.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 560) shows which error messages are pending. ErrorBits is retentive and is reset upon a positive edge at Reset or ErrorAck.
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.

11.10.6 Static tags Filter_PT2

Tag	Data type	Default	Description
Gain	REAL	1.0	Proportional gain
TimeConstant	REAL	25.0	Time constant in seconds Permissible value range: TimeConstant ≥ CycleTime.Value/2
Damping	REAL	1.0	Damping Permissible value range: Damping > 0.0
ErrorMode	INT	2	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid filter output value • 3 = 0.0 • 4 = Input * Gain Permissible value range: 0 to 4

Tag	Data type	Default	Description
StartMode	INT	2	Selecting the output value for the first call of the instruction • 0 = Input • 1 = SubstituteOutput • 2 = Last output value • 3 = 0.0 • 4 = Input * Gain Permissible value range: 0 to 4
CycleTime	AuxFct_CycleTime	-	Cycle time data
CycleTime.Value	REAL	0.1	Cycle time in seconds (time interval between two calls) Permissible value range: CycleTime.Value > 0.0
CycleTime.Enable Measurement	BOOL	TRUE	Automatic measurement of the cycle time • FALSE = Deactivated • TRUE = Activated

11.10.7 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

For Filter_PT2, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
- Errors with error messages ErrorBits ≥ 16#0001_0000

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 are pending, Filter_PT2 reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:**

ErrorBits (DW#16#...)	Description
	If the value determined by the filter function is output at the output (Reset = FALSE and ErrorBits < 16#0001_0000), check the following tags used in the filter calculation: • Input • Gain • TimeConstant • Damping • CycleTime.Value When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the tag ErrorMode: • Input • SubstituteOutput • The product of Input and Gain When Reset = TRUE, check the SubstituteOutput parameter.
0000_0002	**Cause of error:** The measurement of the cycle time yields in an invalid value while the output value is being calculated (Reset = FALSE). **Response to error:** If a valid value of the cycle time has already been measured, Filter_PT2 calculates the output value based on the last value of the CycleTime.Value tag. If no valid value of the cycle time was previously measured, Filter_PT2 still outputs the output value configured with the StartMode tag at the Output parameter.

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 are pending, Filter_PT2 reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, Filter_PT2 reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th>Description</th></tr>
<tr><td>0001_0000</td><td>Cause of error:
The SubstituteOutput parameter or a different tag that is being used as output value has no valid REAL value.
Response to error:
The output is set to 0.0.
Solution:
Make sure that the tag used as output value is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF). The tag that is used as output value depends on Reset and ErrorMode:
<table>
<tr><th>Reset</th><th>ErrorMode</th><th>Output value</th></tr>
<tr><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td>FALSE</td><td>4</td><td>Product of Input and Gain</td></tr>
<tr><td>TRUE</td><td>-</td><td>SubstituteOutput</td></tr>
</table></td></tr>
<tr><td>0002_0000</td><td>Cause of error:
The Input parameter has no valid REAL value while the calculation of the output value is being performed (Reset = FALSE).
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. When ErrorMode = 0, 0.0 is used as output value.
Solution:
Make sure that the parameter Input is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF).</td></tr>
<tr><td>0004_0000</td><td>Cause of error:
The calculation of the output value yields an invalid REAL value for the Output parameter.
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter.
Solution:
Check all tags involved in the calculation of the output value:
• Input
• Gain
• TimeConstant
• Damping
• CycleTime.Value
These tags have valid values. The calculation of the output value fails in this combination of tags.</td></tr>
<tr><td>0008_0000</td><td>Cause of error:
The Gain, TimeConstant or Damping tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE).
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter.
Solution:
Ensure that the following conditions for the values of the Gain, TimeConstant and Damping tags are met:
• -3.402823e+38 ≤ Gain ≤ 3.402823e+38
• CycleTime.Value/2 ≤ TimeConstant ≤ 3.402823e+38
• 0.0 < Damping ≤ 3.402823e+38
• The values are valid REAL values (≠ NaN, for example 16#7FFF_FFFF)
Additional information:</td></tr>
</table>

ErrorBits (DW#16#...)	Description
	Note that the condition CycleTime.Value/2 ≤ TimeConstant may be violated in the following scenarios: • The time interval between two calls of Filter_PT2 is longer than 2 * TimeConstant, for example, due to conditional calls in the program sequence or active breakpoints. • A snapshot of the Filter_PT2 instance DB is loaded into the CPU as actual values, and the snapshot was created more than 2 * TimeConstant ago. In these scenarios, an error message ErrorBits = 16#0008_0000 is detected during automatic measurement of the cycle time.
0020_0000	**Cause of error:** The tag (configured with StartMode) for the initialization of the Output parameter at the first call of the instruction does not have a valid REAL value. **Response to error:** The substitute output value is output with the first call of the instruction at the Output parameter that is configured at the ErrorMode tag. For subsequent calls, Filter_PT2 calculates the output value starting from this substitute output value. **Solution:** Make sure that the tag for initializing the parameter Output is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). When Reset = FALSE is set, the initialization takes effect with the first call of the instruction after the operating state transition of the CPU from STOP to RUN. The tag that is used for the initialization of the Output parameter depends on StartMode: • StartMode = 1: SubstituteOutput • StartMode = 2: Output • StartMode = 4: Product of Input and Gain
0040_0000	**Cause of error:** The CycleTime.Value tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions are met: • 0.0 < CycleTime.Value ≤ 3.402823e+38 • CycleTime.Value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF) **Additional information:** To automatically calculate the value of the CycleTime.Value tag, set the CycleTime.EnableMeasurement tag to TRUE.

11.11 Filter_DT1

11.11.1 Compatibility with CPU and FW

The following table shows which version of Filter_DT1 can be used on which CPU:

CPU	FW	Filter_DT1
S7-1200	as of V4.2	V1.0
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.11.2 Description of Filter_DT1

Description

The instruction Filter_DT1 is a differentiator with a first-order lag, also referred to as DT1 element.

You can use Filter_DT1 for the following purposes:

- High-pass filter to attenuate low frequency components in a signal.
- Differentiator to calculate the derivation of a signal, such as the speed from position values.
- Feedforward control to lessen the effect of measurable disturbances on the process.

You can specify the following filter parameters:

- Derivative action time (Td)
- Lag time constant (Lag)

NOTE

Differences between a continuous-time DT1 element and Filter_DT1

Because Filter_DT1 is executed in a PLC program, Filter_DT1 is a discrete-time implementation of a DT1 element. Discrete-time systems cannot have the same properties as the corresponding continuous-time model. Depending on the cycle time, discrete-time systems can emulate a continuous-time system well: The smaller and more constant the cycle time, the smaller the conformity error between the properties of Filter_DT1 and the properties of a continuous-time DT1 element. The properties of a continuous-time DT1 element are the transfer function, the time response and the frequency response which are described below.

For a good simulation of the frequency response, a maximum cycle time of one-tenth of the shortest period duration of the input signal components is recommended. For example, a signal with frequency components of up to 50 Hz has a minimum period duration of 20 ms. To achieve good simulation of the frequency response, a maximum cycle time of 2 ms is recommended for this example.

Transfer function of a DT1 element

The following formula shows the transfer function of a DT1 element, whereby s is equal to the Laplace operator:

$$G(s) = \frac{\text{Output}(s)}{\text{Input}(s)} = \frac{\text{Td} \cdot s}{1 + \text{Lag} \cdot s}$$

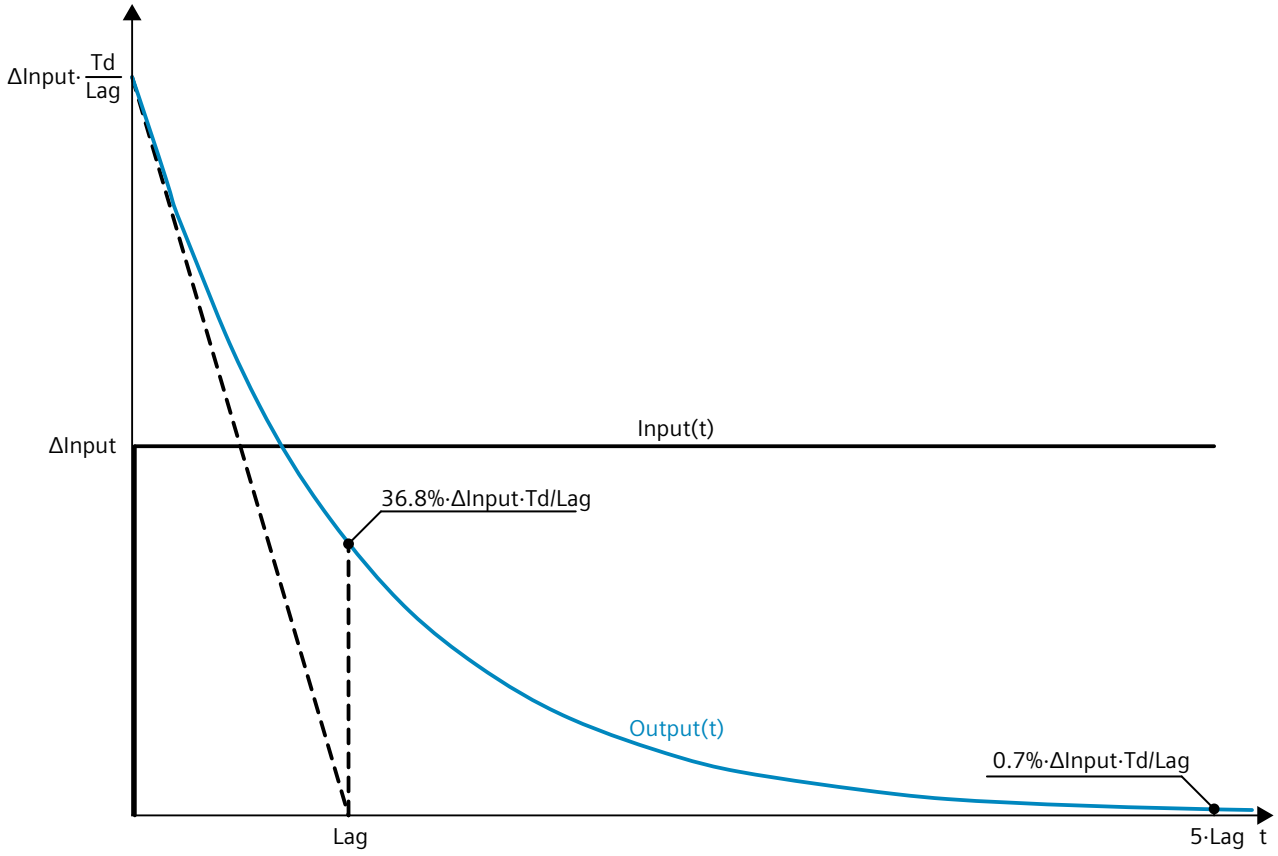
Time response of a DT1 element

The step response is the response of the output value to a step change of the input value.

The step response for a step change of the input value from 0 to ΔInput can be calculated using the following formula:

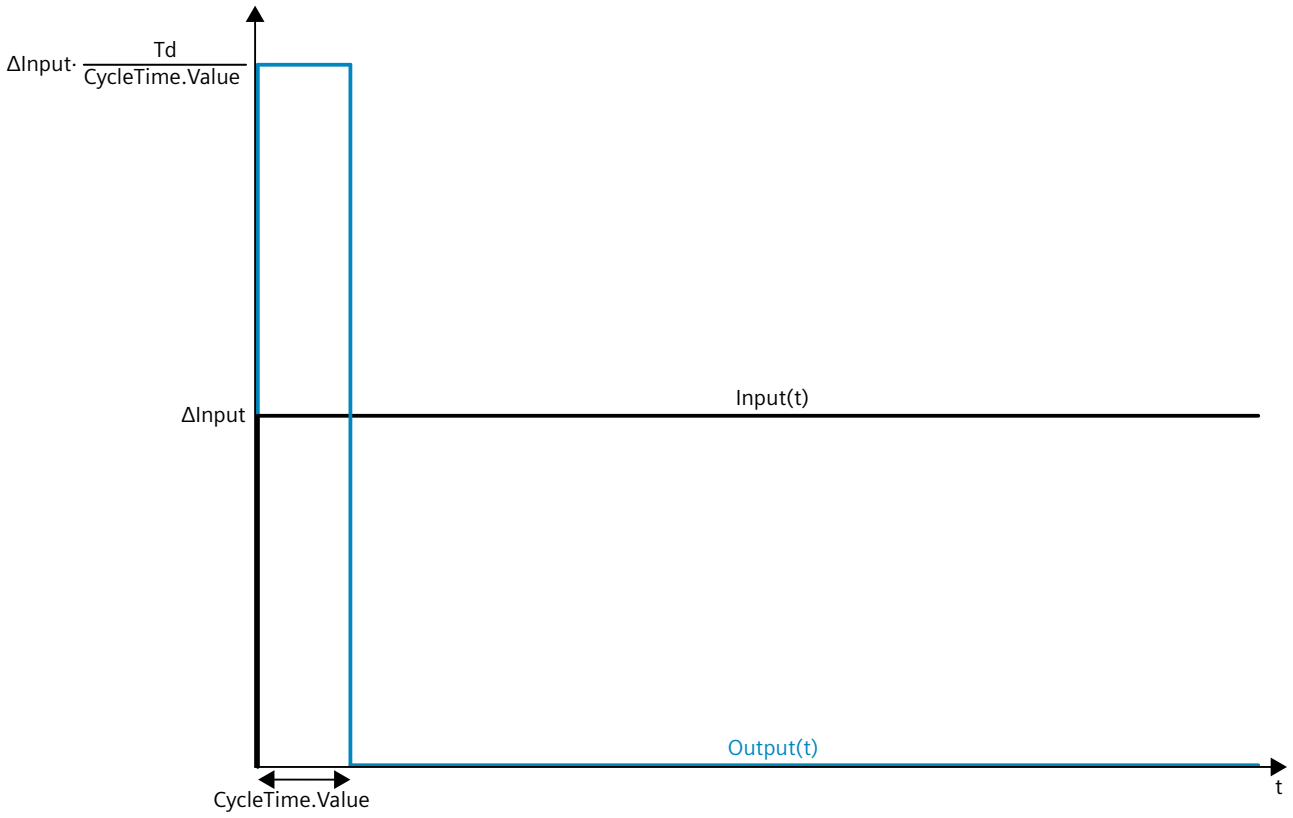
$$\text{Output}(t) = \Delta\text{Input} \cdot \frac{Td}{Lag} \cdot e^{-\frac{t}{Lag}}$$

The following figure shows the step response of a DT1 element:



To disable the lag, set the Lag parameter to the minimum value CycleTime.Value / 2. In this case, changes to the input value are multiplied by Td / CycleTime.Value and output at the Output parameter. After one cycle, the output value is 0.0.

The following figure shows the step response in case of Lag = CycleTime.Value / 2:



Frequency response of a DT1 element

The frequency response of a transfer element is described by the amplitude response and the phase response.

The amplitude response describes the gain of a signal through the transfer element depending on the angular frequency of the signal.

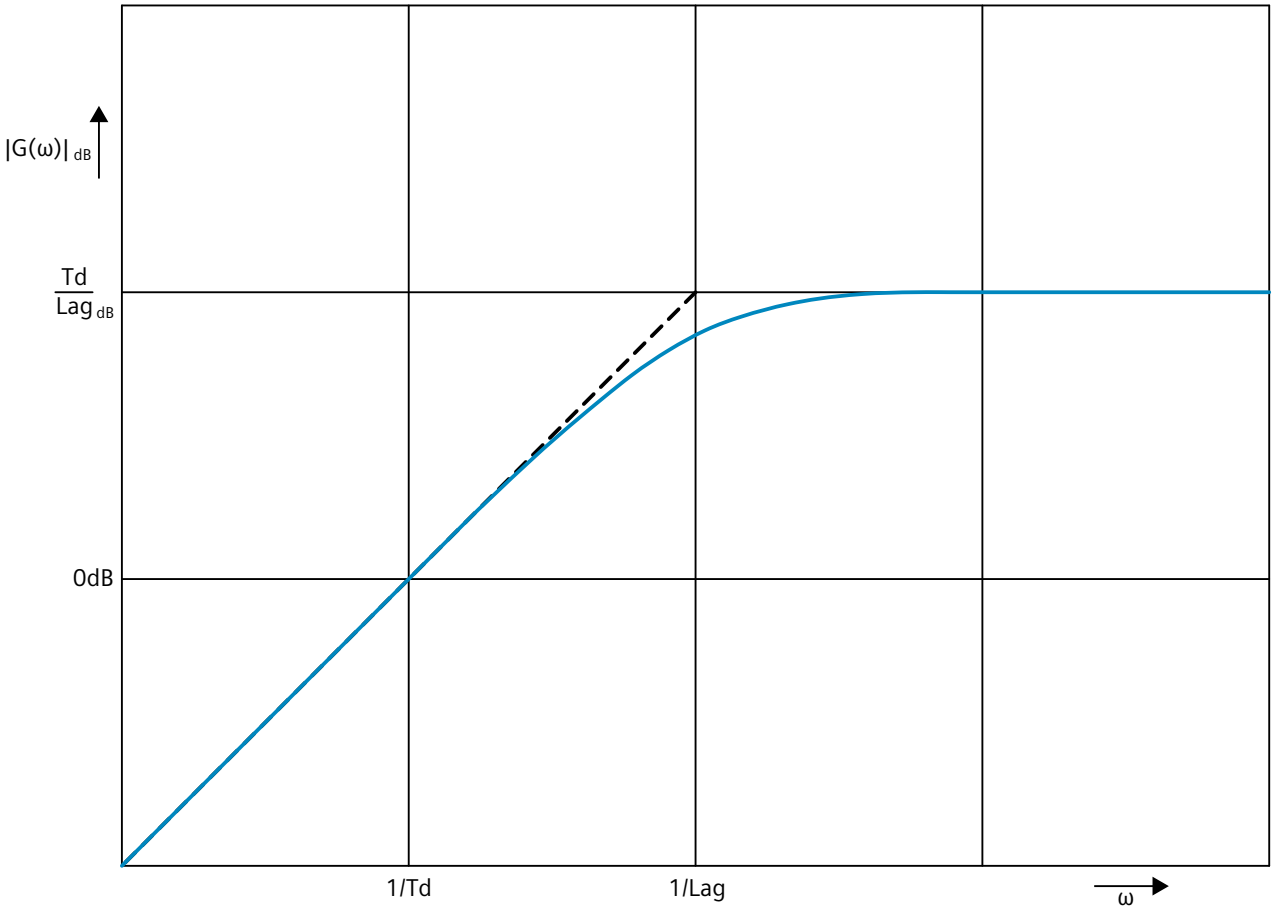
The following equation describes the amplitude response of a DT1 element:

$$|G(\omega)| = \frac{\omega \cdot Td}{\sqrt{1 + (\omega \cdot Lag)^2}}$$

|G(ω)| Signal gain as a function of the angular frequency

ω Angular frequency

The following figure shows the amplitude response of a DT1 element:



The phase response describes the phase offset of a signal through the transfer element depending on the angular frequency of the signal.

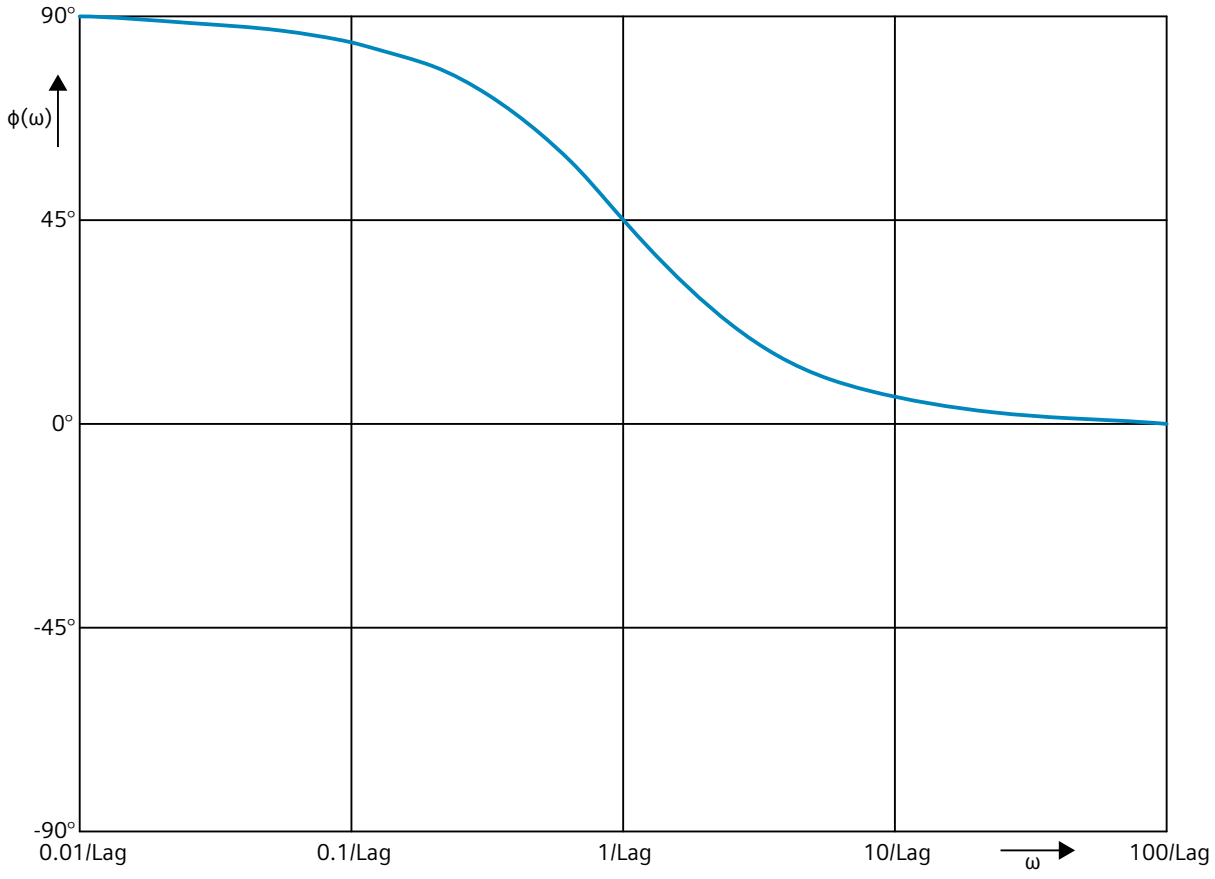
The following equation describes the phase response of a DT1 element:

$$\varphi(\omega) = \tan^{-1}(\omega \cdot Lag)$$

φ(ω) Phase offset as a function of the angular frequency

ω Angular frequency

The following figure shows the phase response of a DT1 element:



Call

In an OB or FC, Filter_DT1 is called as single-instance DB. In an FB, Filter_DT1 can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. No parameter assignment interface or commissioning interface is available. You assign the Filter_DT1 parameters directly using the instance DB and commission Filter_DT1 using a watch table of the user program in the CPU or HMI.

Startup

The tags in the static area of Filter_DT1 are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN. If you change the actual values in online mode and these values are to be retained after the operating state transition of the CPU, back up these values in the start values of the data block.

Specify the initialization value for the Output parameter at the StartMode tag.

During the first call of Filter_DT1 after the

- Operating state transition of the CPU

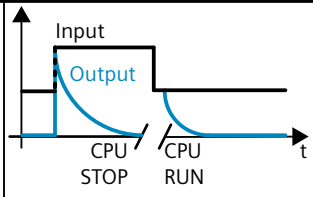
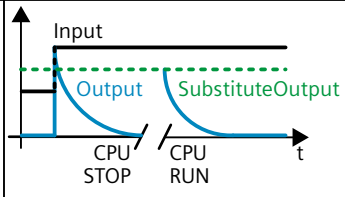
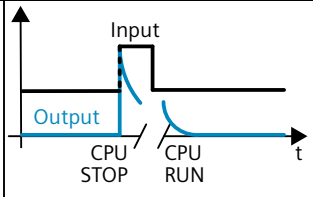
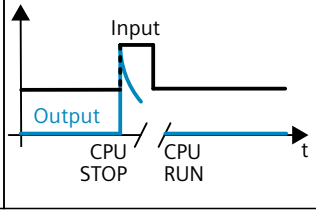
or

- Execution of "Load start values as actual values" (only with "All values" option, not with "Only setpoints" option)

the initialization value is output at the Output parameter.

For subsequent calls, Filter_DT1 calculates the output value, starting from this initialization value, based on the input value and the filter configuration.

The following table shows the dependency between the StartMode tag and the Output parameter. The values in the Output column are output at the Output parameter after the operating state transition of the CPU.

StartMode	Output	Example
0	Value of the Input parameter	
1	Value of the SubstituteOutput parameter	
2	Remains unchanged Output parameter is retentive Default setting Is used when StartMode is not in the range 0...3	
3	0.0	

The following applies in addition for all values of the StartMode tag:

- The initialization value is limited to the value range of the data type REAL. Only then is the initialization value output at the Output parameter.
- If the initialization value is not a valid REAL value, the substitute output value is output at the Output parameter. The substitute output value is configured by the ErrorMode tag. The substitute output value is limited to the value range of the data type REAL before it is output at the Output parameter. If the substitute output value is also not a valid REAL value, 0.0 is output at the Output parameter. For subsequent calls, the instruction calculates the output value starting from this substitute output value.
- The StartMode tag only takes effect when the Reset = FALSE parameter is set at the first call of the instruction and at the same time no error with error message ErrorBits ≥ 16#0002_0000 is pending. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

Response to errors

The Filter_DT1 instruction detects different errors that can occur during the calculation of the output value. The result of this calculation can be output at the output despite a pending error. If an error prevents correct calculation of the output value, a substitute output value is output at the output.

Specify the substitute output value that is output if an error occurs that prevents correct calculation of the output value at the ErrorMode tag.

The following table shows the dependency between the ErrorMode tag and the substitute output value that is output by the Filter_DT1 at the Output parameter:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter
2	The last valid filter output value 0.0 if no valid filter output value is available Default setting Is used when ErrorMode is not in the range 0...3
3	0.0

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

11.11.3 Operating principle Filter_DT1

Reset response

Filter_DT1 behaves as follows depending on the Reset parameter:

- If the Reset =TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter.
- If the Reset = FALSE parameter is set, the value that is output at the Output parameter is calculated by the filter algorithm.
- When the Reset parameter is set from FALSE to TRUE, the value at the Output parameter changes directly to the value of the SubstituteOutput parameter. An output jump can occur during this transition. In addition, the ErrorBits parameter is reset.
- When the Reset parameter is set from TRUE to FALSE, the filtering algorithm is added so that the transition is bumpless.

Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE.

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

Measuring the cycle time automatically

To calculate the output value, Filter_DT1 needs the time that has expired since the last call of Filter_DT1.

By default, the cycle time is measured automatically and output as of the second call at the CycleTime.Value tag. Filter_DT1 measures the cycle time for each call of the instruction and can therefore be used in non-isochronous call cycles, e.g. in OB1.

Note that conditional calls of the instruction, active breakpoints, or the loading of snapshots as actual values during automatic measurement of the cycle time will extend the cycle time value. A cycle time that is too long is identified as error with error message ErrorBits = 16#0008_0000.

If measurement of the cycle time returns no valid result, Filter_DT1 calculates the current output value with the last valid cycle time. In addition, Filter_DT1 outputs an error message at the ErrorBits parameter.

When you disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement tag = FALSE, you must enter the cycle time manually at the CycleTime.Value tag. Filter_DT1 checks the CycleTime.Value tag for validity at each call.

Automatic measurement of the cycle time with breakpoints

When breakpoints are active between two calls of Filter_DT1, automatic measurement of the cycle time results in the actual time that has elapsed between two calls. When one breakpoint is active, the CPU is in HOLD operating state.

NOTE

The active breakpoints extend the time period between two calls of Filter_DT1.

The longer the time period between two calls, the greater the change of the output value at the Output parameter.

Furthermore, it is possible that the longer time intervals violate the conditions Lag ≥ CycleTime.Value/2 or Td ≥ CycleTime.Value. An error is then detected with the error message ErrorBits = 16#0008_0000 .

If you do not need the calculation of the output value based on the actual time with active breakpoints, follow these steps:

- Disable automatic measurement of the cycle time by setting the CycleTime.EnableMeasurement tag = FALSE.
- Enter the cycle time manually at the CycleTime.Value tag.

11.11.4 Input parameter Filter_DT1

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
Substitu-teOutput	REAL	0.0	SubstituteOutput is used as the substitute output value when • Reset = TRUE or • An error with error message ErrorBits ≥ 16#0001_0000 prevents the correct calculation of the output value, and ErrorMode is configured to the value 1.
ErrorAck	BOOL	FALSE	Deletes the error messages • Edge FALSE -> TRUE ErrorBits is reset.
Reset	BOOL	FALSE	Performs a restart of the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output at the output. • As long as Reset is set to FALSE, the calculation of the output value is performed.

11.11.5 Output parameter Filter_DT1

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value The output value is retentive.
ErrorBits	DWORD	DW#16#0	The ErrorBits parameter (Page 574) shows which error messages are pending. ErrorBits is retentive and is reset upon a positive edge at Reset or ErrorAck.
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.

11.11.6 Static tags Filter_DT1

Tag	Data type	Default	Description
Td	REAL	25.0	Derivative action time in seconds Permissible value range: Td ≥ CycleTime.Value
Lag	REAL	5.0	Lag time constant in seconds Permissible value range: Lag ≥ CycleTime.Value/2
ErrorMode	INT	2	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid filter output value • 3 = 0.0 Permissible value range: 0 to 3
StartMode	INT	2	Selecting the output value for the first call of the instruction • 0 = Input • 1 = SubstituteOutput • 2 = Last output value • 3 = 0.0 Permissible value range: 0 to 3
CycleTime	AuxFct_CycleTime	-	Cycle time data
CycleTime.Value	REAL	0.1	Cycle time in seconds (time interval between two calls) Permissible value range: CycleTime.Value > 0.0
CycleTime.Enable Measurement	BOOL	TRUE	Automatic measurement of the cycle time • FALSE = Deactivated • TRUE = Activated

11.11.7 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

For Filter_DT1, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
- Errors with error messages ErrorBits ≥ 16#0001_0000

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 are pending, Filter_DT1 reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:** If the value determined by the filter function is output at the output (Reset = FALSE and ErrorBits < 16#0001_0000), check the following tags used in the filter calculation: • Input • Td • Lag • CycleTime.Value When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the tag ErrorMode: • Input • SubstituteOutput When Reset = TRUE, check the SubstituteOutput parameter.
0000_0002	**Cause of error:** The measurement of the cycle time yields in an invalid value while the output value is being calculated (Reset = FALSE). **Response to error:** If a valid value of the cycle time has already been measured, Filter_DT1 calculates the output value based on the last value of the CycleTime.Value tag. If no valid value of the cycle time was previously measured, Filter_DT1 still outputs the output value configured with the StartMode tag at the Output parameter.

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 are pending, Filter_DT1 reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, Filter_DT1 reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th>Description</th></tr>
<tr><td>0001_0000</td><td>Cause of error:
The SubstituteOutput parameter or a different tag that is being used as output value has no valid REAL value.
Response to error:
The output is set to 0.0.
Solution:
Make sure that the tag used as output value is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF). The tag that is used as output value depends on Reset and ErrorMode:
<table>
<tr><th>Reset</th><th>ErrorMode</th><th>Output value</th></tr>
<tr><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td>TRUE</td><td>-</td><td>SubstituteOutput</td></tr>
</table></td></tr>
<tr><td>0002_0000</td><td>Cause of error:
The Input parameter has no valid REAL value while the calculation of the output value is being performed (Reset = FALSE).
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. When ErrorMode = 0, 0.0 is used as output value.
Solution:
Make sure that the parameter Input is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF).</td></tr>
<tr><td>0004_0000</td><td>Cause of error:
The calculation of the output value yields an invalid REAL value for the Output parameter.
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter.
Solution:
Check all tags involved in the calculation of the output value:
• Input
• Td
• Lag
• CycleTime.Value
These tags have valid values. The calculation of the output value fails in this combination of tags.</td></tr>
</table>

ErrorBits (DW#16#...)	Description
0008_0000	**Cause of error:** The Lag or Td tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions for the values of the Td and Lag tags are met: • CycleTime.Value ≤ Td ≤ 3.402823e+38 • CycleTime.Value/2 ≤ Lag ≤ 3.402823e+38 • The values are valid REAL values (≠ NaN, for example 16#7FFF_FFFF) Additional information: Note that the conditions CycleTime.Value/2 ≤ Lag and CycleTime.Value ≤ Td may be violated in the following scenarios: • The time interval between two calls of Filter_DT1 is longer than 2 * Lag or Td, for example, due to conditional calls in the program sequence or active breakpoints. • A snapshot of the Filter_DT1 instance DB is loaded into the CPU as actual values, and the snapshot was created more than 2 * Lag or Td ago. In these scenarios, an error message ErrorBits = 16#0008_0000 is detected during automatic measurement of the cycle time.
0020_0000	**Cause of error:** The tag (configured with StartMode) for the initialization of the Output parameter at the first call of the instruction does not have a valid REAL value. **Response to error:** The substitute output value is output with the first call of the instruction at the Output parameter that is configured at the ErrorMode tag. For subsequent calls, Filter_DT1 calculates the output value starting from this substitute output value. **Solution:** Make sure that the tag for initializing the parameter Output is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). When Reset = FALSE is set, the initialization takes effect with the first call of the instruction after the operating state transition of the CPU from STOP to RUN. The tag that is used for the initialization of the Output parameter depends on StartMode: • StartMode = 1: SubstituteOutput • StartMode = 2: Output
0040_0000	**Cause of error:** The CycleTime.Value tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions are met: • 0.0 < CycleTime.Value ≤ 3.402823e+38 • CycleTime.Value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF) **Additional information:** To automatically calculate the value of the CycleTime.Value tag, set the CycleTime.EnableMeasurement tag to TRUE.

11.12 Filter_Universal

11.12.1 Compatibility with CPU and FW

The following table shows which version of Filter_Universal can be used on which CPU:

CPU	FW	Filter_Universal
S7-1200 G2	V1.0 or higher	V1.0
S7-1500-based CPUs	as of V2.0	V1.0

11.12.2 Description Filter_Universal

Description

The Filter_Universal instruction is a configurable filter of the order 1 to 10.

It is used to manipulate a signal in such a way that specific frequency components of this signal are either allowed through or attenuated.

Filter_Universal can be used for the following purposes:

- High-pass filter
- Low-pass filter
- Bandpass filter
- Bandstop filter

The following filter parameters can be specified based on the corresponding tags in order to achieve the desired filter behavior:

- Type (Type tag)
- Frequency (Frequency tag)
- Bandwidth (Bandwidth tag)
- Order (Order tag)
- Characteristic (Characteristic tag)

An extended description of the filter parameters and corresponding tags can be found in section Filter parameters (Page 579).

Call

Filter_Universal requires a constant cycle time and therefore needs to be called in a cyclic interrupt OB.

In an OB or FC, Filter_Universal is called as a single-instance DB. In a function block, Filter_Universal can be called as a single-instance DB, as a multi-instance DB, and as a parameter instance DB.

When the instruction is called, no technology object is created. In the Inspector window of the programming editor, a parameterization interface is available for individual instances. This represents the amplitude response resulting from the configured filter parameters.

Startup

The tags in the static area of Filter_Universal are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN. If you change the actual values in online mode and these values are to be retained after the operating state transition of the CPU from STOP to RUN, back up these values in the start values of the data block.

With the tag StartMode (Page 584), you can define the start behavior of the Filter_Universal instruction at the first call after the operating state transition of the CPU from STOP to RUN.

Response to errors

If the output value cannot be correctly calculated, the Filter_Universal instruction instead outputs a substitute output value and an error with an error message ErrorBits >= 16#0002_0000. You can use the tag ErrorMode (Page 591) to define the substitute output value as follows:

ErrorMode	Output
0	Value of the Input parameter
1	Value of the SubstituteOutput parameter
2	Last valid filter output value 0.0 if no valid filter output value is available
3	0.0

The following applies in addition for all values of the ErrorMode tag:

- If the substitute output value is not a valid REAL value, 0.0 is output as output value.
- The substitute output value is limited to the value range -3.402823e+38 .. +3.402823e+38 of the data type REAL. Only then is the substitute output value output at the Output parameter.
- The ErrorMode tag only takes effect when the Reset = FALSE parameter is set. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter or 0.0 is output at the Output parameter.

The Error parameter indicates if an error is pending. When the error is no longer pending, Error is set to FALSE. The ErrorBits parameter shows which errors have occurred. ErrorBits is retentive and is reset only by a positive edge at the Reset or ErrorAck parameter.

Filter_Universal returns to output value calculation through the filter algorithm as soon as there are no more pending errors with error messages ErrorBits ≥ 16 0002_0000. Switchover depends on the filter type:

- For high-pass and bandpass filters (Type = 1 or 2), the filter algorithm is set up as if it were in a steady state with Output = 0.0. If the Input parameter remains constant, the output value will jump to Output = 0.0. If the Input parameter changes, the output value jumps to an appropriate value.
- For low-pass and bandstop filters (Type = 0 or 3), the filter algorithm is set up as if it were in a steady state with Output = SubstituteOutput. Switchover is bumpless.

11.12.3 Operating principle Filter_Universal

11.12.3.1 Filter parameters

The filter parameters Type, Frequency, Bandwidth, Characteristic and Order can be specified based on the corresponding tags in order to achieve the desired filter behavior.

Filter type

The filter type determines the general transfer behavior for the different frequency components of the input signal. It is defined by the Type tag.

The following table shows the different filter types:

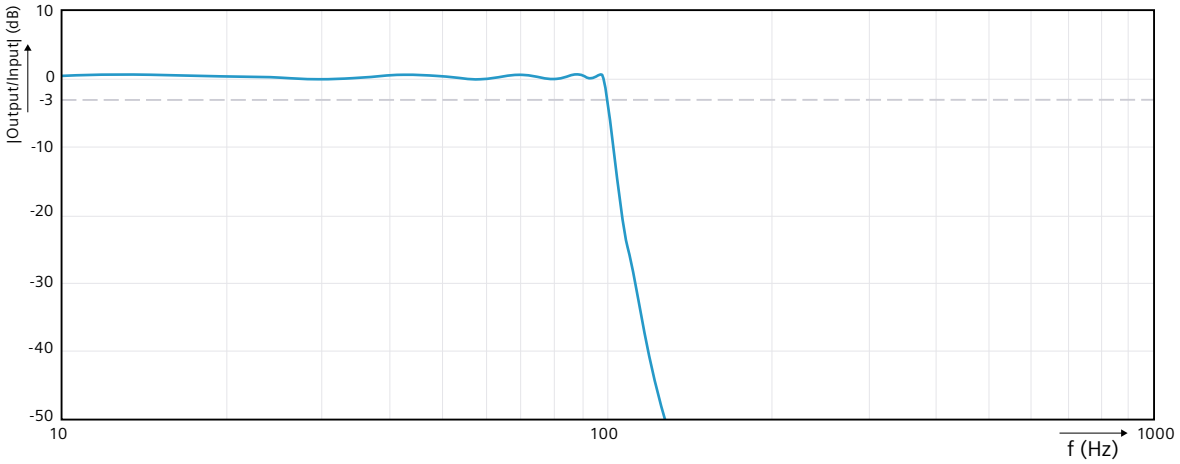
Type	Description	Application example
0	Low-pass filter: The filter allows frequency components below the cutoff frequency through, and attenuates frequency components above the cutoff frequency.	Noise reduction at a measured input value to obtain smoother signal characteristics
1	High-pass filter: The filter allows frequency components above the cutoff frequency through, and attenuates frequency components below the cutoff frequency.	Suppression of DC or low frequency components, e.g. DC component in signal
2	Bandpass filter: The filter allows frequency components within a specific range around the center frequency through, and attenuates frequency components outside of this range.	Determination of the wanted signal with a specific frequency range from a signal that contains additional frequency components
3	Bandstop filter: The filter attenuates frequency components within a specific range around the center frequency, and allows frequency components outside of this range through.	Attenuation of interferences in a specific frequency range, e.g. interruptions due to the line frequency

Frequency and bandwidth

For low-pass and high-pass filters, the cutoff frequency is determined by the Frequency tag. The cutoff frequency is the frequency at which the gain is reduced to $1/\sqrt{2} \approx 0.707 \approx -3$dB. A sinusoidal input signal with amplitude 1.0 and a frequency equal to the cutoff frequency will result in a sinusoidal output signal with amplitude 0.707.

The ratio of output value to input value (gain) depending on the frequency can be shown in the amplitude response. The value 0 dB corresponds to a gain = 1.0.

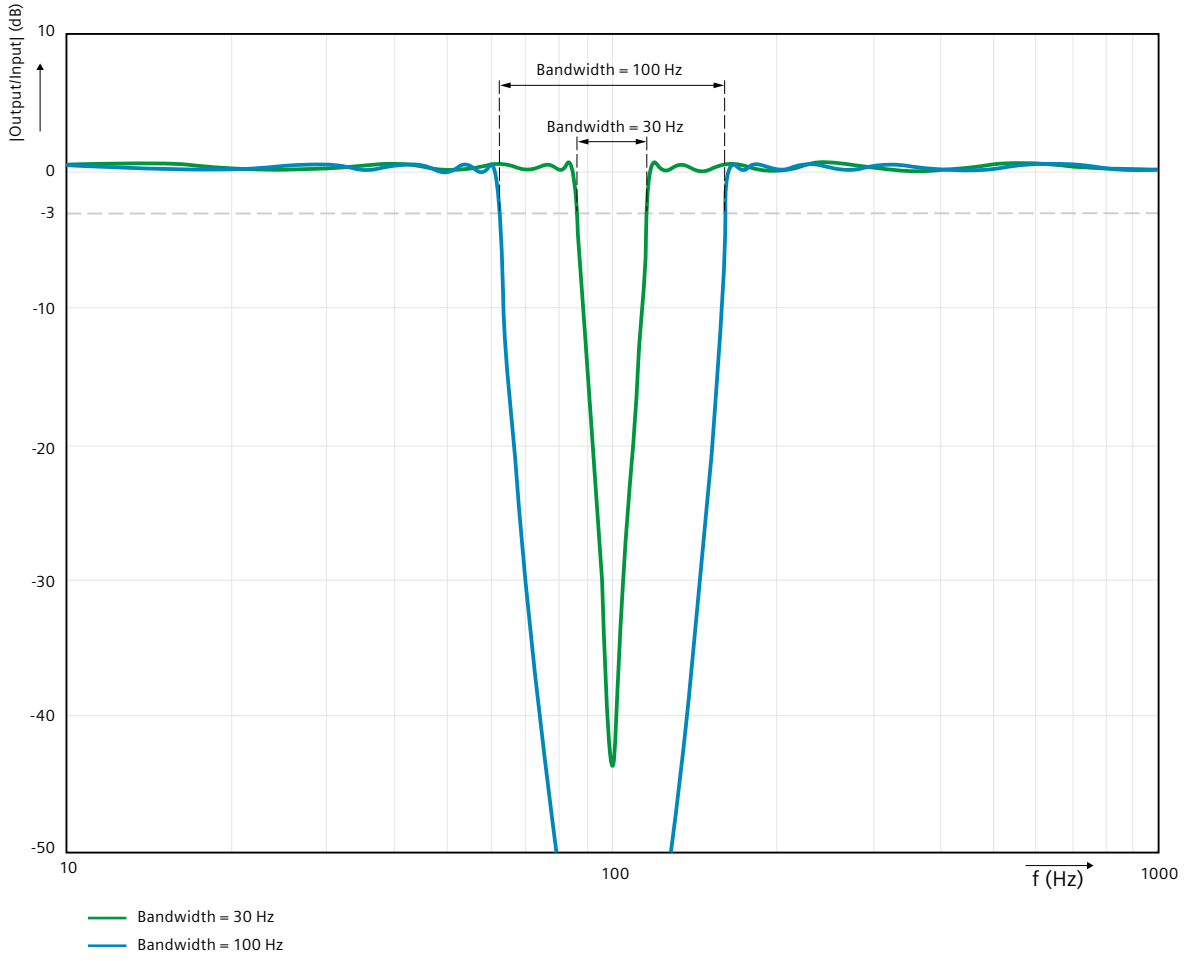
The following figure shows the amplitude response of a low-pass filter with Frequency = 100 Hz (Order = 10, Characteristic = 2):



Bandpass and bandstop filters have a low and a high cutoff frequency whose position is defined by the center frequency and bandwidth. The following table shows the corresponding tags that are configured for such filters:

Tag	Description
Frequency	Determines the center frequency that is the geometrical mean of the low and high cutoff frequency. In logarithmic frequency scaling, the center frequency is midway between the low and high cutoff frequency.
Bandwidth	The bandwidth determines the difference between the low and high cutoff frequency. It defines the width of the frequency range that is attenuated or allowed through.

The following figure shows the amplitude response of a bandpass filter with Frequency = 100 Hz and different values for the tag Bandwidth (Order = 10, Characteristic = 2):



The maximum cutoff or center frequency that can be used depends on the cycle time. The permitted range of values is Frequency < 0.5 / CycleTime.Value.

The maximum bandwidth that can be used depends on the cycle time and the center frequency. The permitted range of values is Bandwidth < 0.5 / CycleTime.Value - Frequency.

NOTE

To avoid aliasing, the sampling rate for the Filter_Universal (= 1 / cycle time) must be at least double the maximum frequency of the processed signals or signal components. The recommendation is to set a cycle time that is lower than this limit.

Example: A signal with frequency components up to 100 Hz requires a sampling rate greater than 200 Hz. This corresponds to a maximum cycle time of 5 ms, but the recommendation is to set a lower value.

Order

The filter order determines how quickly attenuation increases beyond the cutoff frequency. This corresponds to the slope of the amplitude response beyond the cutoff frequency. The filter order is defined by the Order tag.

With a higher-order filter:

- The same frequency is attenuated more strongly beyond the cutoff frequency. The amplitude response shows a higher slope.
- Increases the execution time of Filter_Universal.
- The overshoot of the step response increases after an input jump for Butterworth and Chebyshev filter characteristic (Characteristic tag = 1 or 2).

For bandpass and bandstop filters, the recommendation is to use only higher order filters; otherwise, the desired filter effect in the frequency range around the center frequency may not be reached.

Values from 0 to 10 can be configured at the Order tag for the filter order.

With the setting Order = 0, the filter has no effect and Output = Input.

Characteristic

The filter characteristic is defined by the Characteristic tag.

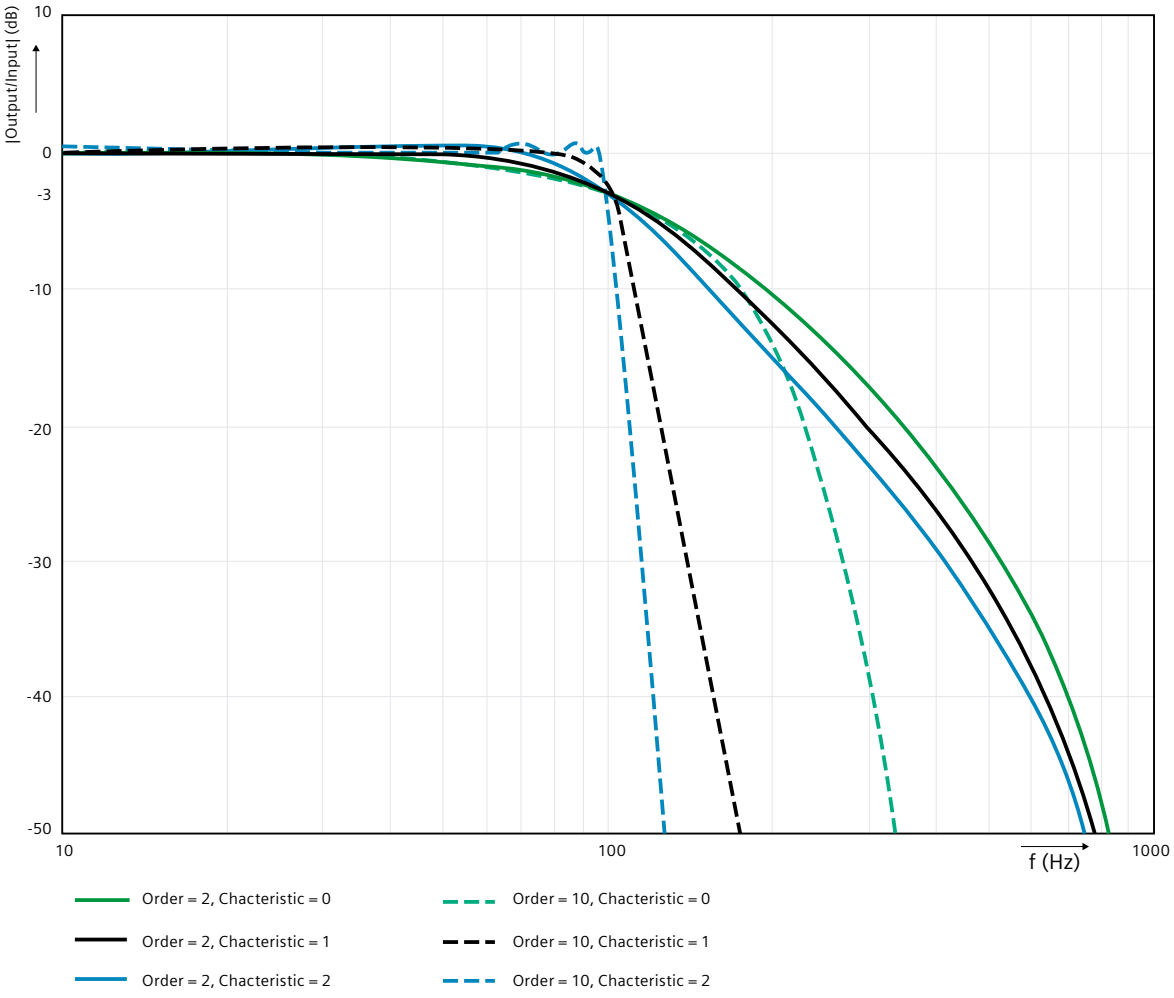
This affects:

- The ripple of the amplitude response in the passband
- The slope of the amplitude response beyond the cutoff frequency (how fast attenuation increases)
- The overshoot in the step response after an input jump

Three characteristics can be configured for Filter_Universal based on the Characteristic tag:

Characteristic	Description
0	Bessel: This filter has a flat amplitude response in the passband. The slope of the amplitude response beyond the cutoff frequency is smaller as compared to the Butterworth filter and Chebyshev filter. The step response only shows a small overshoot.
1	Butterworth: This filter has a flat amplitude response in the passband. The slope of the amplitude response beyond the cutoff frequency is greater as compared to the Bessel filter and smaller as compared to the Chebyshev filter. The overshoot of the step response is greater as compared to the Bessel filter and smaller as compared to the Chebyshev filter.
2	Chebyshev Type I: This filter has a 0.5 dB ripple of the amplitude response in the passband. The slope of the amplitude response beyond the cutoff frequency is greater as compared to the Bessel filter and to the Butterworth filter. The step response shows a greater overshoot as compared to the Bessel filter and the Butterworth filter.

The following figure shows the effect of different order and characteristic values on the amplitude response of the low-pass filter:



Changing filter parameters

Before the filter algorithm calculates the output value, Filter_Universal needs to determine the filter coefficients once based on the filter parameters. This is triggered in the following situations:

- On the first execution after the change of operating state of the CPU from STOP to RUN
- Every time the filter parameters are changed
- When "Load start values as actual values" is executed

The following conditions for the filter parameters are checked in this process:

- 0.0 < Frequency < 0.5 / CycleTime.Value
- 0.0 ≤ Bandwidth < 0.5 / CycleTime.Value - Frequency
- 0 ≤ Type ≤ 3
- 0 ≤ Characteristic ≤ 2
- 0 ≤ Order ≤ 10

If one of these conditions is not met and Reset = FALSE at the same time, correct calculation of the output value by the filter algorithm is not possible. In this case, an error message is output and a substitute output value is output at the Output parameter until all filter parameters have a valid value.

When all values are valid, the filter coefficients are determined once and saved internally for the filter algorithm calculation.

The reaction of the output value to valid changes to the filter parameters depends on the filter type:

- For high-pass and bandpass filters (Type = 1 or 2), the filter algorithm is set up as if it were in a steady state with Output = 0.0. If the Input parameter remains constant, the output value will jump to Output = 0.0. If the Input parameter changes, the output value jumps to an appropriate value.
- For low-pass and bandstop filters (Type = 0 or 3), the filter algorithm is set up as if it were in a steady state with Output = SubstituteOutput. Switchover is bumpless.

For time-critical applications, it should be taken into account that determining the filter coefficient requires a multiple of the execution time for calculating the filter algorithm.

11.12.3.2 Initializing output values

The Output parameter is initialized after the following actions for the first execution:

- Operating state change of the CPU from STOP to RUN
- Execution of "Load start values as actual values" with the option "All values"

The first value of the Output parameter depends on the filter type:

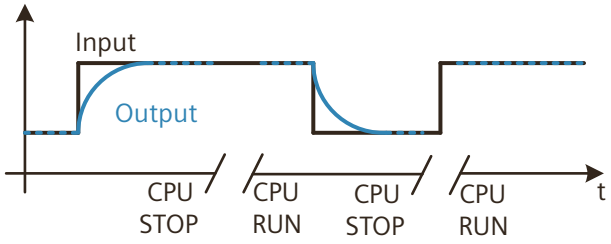
- For high-pass and bandpass filters (Type = 1 or 2), the first value of the parameter Output = 0.0.
- For low-pass and bandstop filters (Type = 0 or 3), the first value of the Output parameter can be configured via the StartMode tag.

For subsequent calls, Filter_Universal calculates the output value, starting from this initialization value, with consideration of the input value and the filter parameters.

The following settings of the StartMode tag are possible for low-pass and bandstop filters:

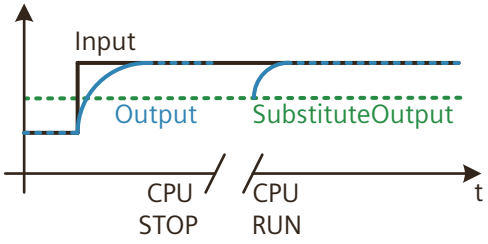
- StartMode = 0

  The Output parameter assumes the value of the Input parameter.



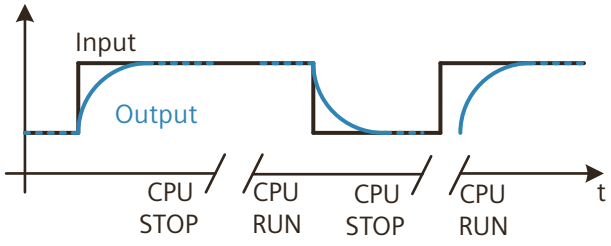
- StartMode = 1

  The Output parameter assumes the value of the SubstituteOutput parameter.



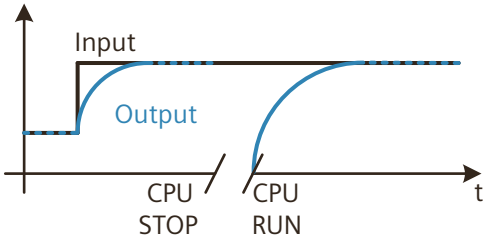
- StartMode = 2

  The Output parameter remains unchanged.



- StartMode = 3

  The Output parameter adopts the value 0.0.



The following applies in addition for all values of the StartMode tag:

- The StartMode tag and the filter parameters are not retentive. These tags are initialized with the start values after each operating state transition of the CPU from STOP to RUN. Make sure that at the first call of the Filter_Universal instruction, after the operating state transition of the CPU from STOP to RUN, these tags have suitable values to achieve the desired behavior.
- The value selected through StartMode is limited to the value range of the REAL data type. Only then is it output at the Output parameter.
- If the value selected through StartMode is not a valid REAL value, the substitute output value is output at the Output parameter. The substitute output value is configured by means of the ErrorMode tag and is limited to the value range of the REAL data type. If the substitute output value is also not a valid REAL value, 0.0 is output at the Output parameter. For subsequent calls, the instruction calculates the output value starting from this substitute output value.
- Only if the parameter Reset = FALSE has been set and, at the same time, there is no error pending with an error message ErrorBits ≥ 16#0002_0000, does the StartMode tag act on the Output parameter. If the Reset = TRUE parameter is set, the value of the SubstituteOutput parameter is output at the Output parameter. If an error with error message ErrorBits ≥ 16#0002_0000 is pending, the substitute output value that is configured at the ErrorMode tag is output at the Output parameter.

11.12.3.3 Final value in steady state

If the input value is constant, the output value of the Filter_Universal should also reach a constant final value after some time:

- Output = 0.0 for high-pass and bandpass filters (Type = 1 or 2)
- Output = Input for low-pass and bandstop filters (Type = 0 or 3)

The limited accuracy of the floating point arithmetic can have the result that this final value is not reached exactly.

This is more common with odd ordered filters (tag Order = 1, 3, 5, 7, or 9) than with even ordered filters.

In addition to choosing a even filter order, setting the tag FinalValueMode = 1 can help to achieve the final value. If the absolute value of the output value does not change for several cycles, this setting converts the output value to the final value. This option is only effective with a constant input value.

Using the FinalValueMode = 1 option can almost double the calculation time of the filter algorithm. The effect on the execution time depends on the filter parameters, input value and cycle time. For time-critical applications, you can check whether use of the FinalValueMode = 1 tag is necessary or whether the behavior with FinalValueMode = 0 is adequate.

Depending on the filter parameters, input value and cycle time, it is possible that the final value is already reached exactly with the FinalValueMode = 0 option and the FinalValueMode = 1 option is not necessary.

Example:

The following table shows the effect of the FinalValueMode tag on the output value of a low-pass filter with Frequency = 120.0, Order = 1, Characteristic = 2 and CycleTime.Value = 0.001, on an input jump from 1.0 to 0.0:

Time in seconds	Input	Output with FinalValueMode = 0	Output with FinalValueMode = 1
-0.001	1.0	1.0000000	1.0000000
0.000	0.0	0.7163693	0.7163693
0.001	0.0	0.3100007	0.3100007
...	0.0	...	...
0.075	0.0	-4.597156E-17	-4.597156E-17
0.076	0.0	4.597156E-17	4.597156E-17
0.077	0.0	-4.597156E-17	-4.597156E-17
0.078	0.0	4.597156E-17	0.0000000
0.079	0.0	-4.597156E-17	0.0000000
...	0.0	+/-4.597156E-17	0.0000000

11.12.3.4 Use in time-critical applications

The execution time of Filter_Universal depends to a significant effect on its configuration. With a standard configuration (CycleTime.EnableDetection = TRUE, FinalValueMode = 1), it is not possible for all CPU types to execute a higher order filter in the fastest possible cycle time. When Filter_Universal is used for high signal frequencies, such fast cycle times can be necessary. For example, signal frequencies of up to 2 kHz require a cycle time of at most 250 µsec.

The following adjustments to the configuration can help to reduce the execution time of Filter_Universal in a time-critical application:

- Reduction of the filter order (Order tag) if the desired filter behavior can still be achieved in this way.
- Setting of FinalValueMode to 0 if this does not cause a relevant difference in the filter behavior for constant input values as compared to FinalValueMode = 1.
- Setting of CycleTime.EnableDetection to FALSE and manual specification of the CycleTime.Value tag. This only has an effect on the execution time of the first call, or after the filter parameters have been changed.

The current operating state of Filter_Universal has an effect on the execution time. Determining the filter coefficients during the first execution or after a change to the filter parameters requires a multiple of the execution time required to calculate the filter algorithm with constant parameters.

11.12.3.5 Call environment and automatic detection of the cycle time

To calculate the output value, Filter_Universal requires a constant cycle time and therefore needs to be called in a cyclic interrupt OB. With the default configuration, Filter_Universal detects the cycle time of the OB automatically and saves it in the CycleTime.Value tag. This happens in the following situations:

- On the first execution after the change of operating state of the CPU from STOP to RUN
- Every time the filter parameters are changed
- When "Load start values as actual values" is executed

If the automatic detection of the cycle time does not return a valid result or Filter_Universal is not called in a cyclic interrupt OB, correct calculation of the Output parameter is not possible. In this case, an error message is output and a substitute output value is output at the parameter until until a valid cycle time of a cyclic interrupt OB is detected.

Please note that changes to the call rate due to conditional calls of Filter_Universal lead to deviations between the detected and actual cycle time, which influences the filter behavior. Therefore, avoid conditional calls of Filter_Universal.

Active breakpoints or the loading of snapshots as actual values have no effect on the automatic detection of the cycle time.

When you disable automatic detection of the cycle time by setting the CycleTime.EnableDetection = FALSE tag, you must enter the cycle time manually at the CycleTime.Value tag. Filter_Universal checks the Variable CycleTime.Value tag for validity at each call.

Deactivating the automatic detection of the cycle time reduces the execution time of the Filter_Universal, which can be helpful for time-critical applications.

If automatic detection of the cycle time is disabled, Filter_Universal does not output an error message for calls outside of a cyclic interrupt OB alarm. The output value is calculated by the filter algorithm. Calls outside of a cyclic interrupt OB can have a negative effect on the filter behavior, because the actual cycle time is not constant in this case.

11.12.3.6 Reset response

The Filter_Universal instruction behaves as follows depending on the Reset parameter:

- If the parameter Reset = TRUE is set, the value of the SubstituteOutput parameter is output at the Output parameter.
- If the parameter Reset = FALSE, the value that is output at the Output parameter is calculated by the filter algorithm.
- When the Reset parameter is set from FALSE to TRUE, the value at the Output parameter changes directly to the value of the SubstituteOutput parameter. An output jump can occur during this transition. In addition, the ErrorBits parameter is reset.
- If the Reset parameter is set from TRUE to FALSE, the behavior depends on the filter type:
  - For high-pass and bandpass filters (Type = 1 or 2), the filter algorithm is set up as if it were in a steady state with Output = 0.0. If the Input parameter remains constant, the output value will jump to Output = 0.0. If the Input parameter changes, the output value jumps to an appropriate value.
  - For low-pass and bandstop filters (Type = 0 or 3), the filter algorithm is set up as if it were in a steady state with Output = SubstituteOutput. Switchover is bumpless.

11.12.3.7 Enable behavior EN/ENO

If one of the following conditions is met, enable output ENO is set to FALSE:

- Enable input EN is set to TRUE and the Output parameter is specified by a substitute output value in case of error messages ErrorBits ≥ 16#0001_0000.
- Enable input EN is set to FALSE.

Otherwise, the enable output ENO is set to TRUE.

11.12.4 Input parameter Filter_Universal

Parameter	Data type	Default	Description
Input	REAL	0.0	Input value
Substitu-teOutput	REAL	0.0	SubstituteOutput is used as a substitute output value when Reset = TRUE or one of the following modes is currently in effect: • ErrorMode = 1 • StartMode = 1
ErrorAck	BOOL	FALSE	Deletes the error messages. • Edge FALSE -> TRUE ErrorBits is reset.
Reset	BOOL	FALSE	Resets the instruction • Edge FALSE -> TRUE ErrorBits is reset. • As long as Reset is set to TRUE, the substitute output value SubstituteOutput is output. • As long as Reset is set to FALSE, the calculation of the output value is performed. • Edge TRUE -> FALSE – For high-pass and bandpass filters (Type 1 or 2), the filter algorithm is set up as if it were in a steady state with Output = 0.0. – For low-pass and bandstop filters (Type 0 or 3), the filter algorithm is set up as if it were in a steady state with Output = SubstituteOutput.

11.12.5 Output parameter Filter_Universal

Parameter	Data type	Default	Description
Output	REAL	0.0	Output value The output value is retentive.
ErrorBits	DWORD	16#0	The ErrorBits parameter (Page 591) shows which error messages are pending. ErrorBits is retentive and is reset upon a rising edge at Reset or ErrorAck.
Error	BOOL	FALSE	When Error is set to TRUE, at least one error is currently pending.

11.12.6 Static tags Filter_Universal

Tag	Data type	Default	Description
Frequency	REAL	50.0	Cutoff frequency of low-pass and high-pass or center frequency of bandpass and bandstop in Hz Permissible value range: 0.5/CycleTime.Value > Frequency > 0.0
Bandwidth	REAL	0.0	Bandwidth of bandpass and bandstop in Hz Permissible value range: 0.5/CycleTime.Value - Frequency > Bandwidth ≥ 0.0
Type	INT	0	Filter type • 0 = Low-pass filter • 1 = High-pass filter • 2 = Bandpass filter • 3 = Bandstop filter Permissible value range: 0 to 3
Characteristic	INT	0	Filter characteristic • 0 = Bessel • 1 = Butterworth • 2 = Chebyshev with 0.5 dB ripple in the passband Permissible value range: 0 to 2
Order	INT	2	Filter order (at Order = 0, Output = Input) Permissible value range: 0 to 10
ErrorMode	INT	2	Selection of the substitute output value following an error • 0 = Input • 1 = SubstituteOutput • 2 = Last valid filter output value • 3 = 0.0 Permissible value range: 0 to 3 If the value of ErrorMode does not correspond to the permissible range of values, then ErrorMode = 2.
StartMode	INT	2	Selection of the first output value for low-pass and bandstop filter • 0 = Input • 1 = SubstituteOutput • 2 = Last output value • 3 = 0.0 Permissible value range: 0 to 3 If the value of StartMode does not correspond to the permissible range of values, then StartMode = 2.
FinalValueMode	INT	1	Selection of the behavior in steady state • 0 = Deviations between output value and final value possible • 1 = Output value reaches final value exactly Permissible value range: 0 to 1 If the value of FinalValueMode does not correspond to the permissible range of values, then FinalValueMode = 1.
CycleTime	AuxFct_CycleTimeDetection	-	Cycle time data
CycleTime.Value	REAL	0.001	Cycle time in seconds (interval between two calls) Permissible value range: CycleTime.Value > 0.0
CycleTime.EnableDetection	BOOL	TRUE	Automatic detection of the cycle time • FALSE = Deactivated • TRUE = Activated

11.12.7 ErrorBits parameter

If several errors are pending simultaneously, the values of the ErrorBits are displayed with binary addition. The display of ErrorBits = 16#0000_0003, for example, indicates that the errors 16#0000_0001 and 16#0000_0002 are pending simultaneously.

With Filter_Universal, the errors output at the ErrorBits parameter are divided into two categories:

- Errors with error messages ErrorBits < 16#0001_0000
  The output value can be calculated despite the error.
- Errors with error messages ErrorBits ≥ 16#0001_0000
  The error prevents calculation of the output value. A substitute output value is output.

Errors with error messages ErrorBits < 16#0001_0000

If one or more errors with error messages ErrorBits < 16#0001_0000 is/are pending, Filter_Universal reacts as follows:

- The output value is determined as follows despite this error:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The output parameter Error is set.
- The enable output ENO is not changed.

The output parameter Error is deleted as soon as there are no longer any errors.

ErrorBits (DW#16#...)	Description
0000_0000	No error is pending.
0000_0001	**Cause of error and response to error:** The Output parameter was limited to -3.402823e+38 or +3.402823e+38. **Solution:** If the value determined by the filter function is output at the output (Reset = FALSE and ErrorBits < 16#0001_0000), check the Input parameter. When ErrorBits ≥ 16#0001_0000 and Reset = FALSE, the substitute output value is limited on its output. In this case, check the following parameters depending on the set value at the tag ErrorMode: • Input • SubstituteOutput When Reset = TRUE, check the SubstituteOutput parameter.

Errors with error messages ErrorBits ≥ 16#0001_0000

If one or more errors with error messages ErrorBits ≥ 16#0001_0000 is/are pending, Filter_Universal reacts as follows:

- The output value cannot be determined as expected. The substitute output value is output instead.
- The output parameter Error is set.
- The enable output ENO is set to FALSE.

As soon as there are no longer errors with error messages ErrorBits ≥ 16#0001_0000, Filter_Universal reacts as follows:

- The output value is determined as follows:
  - When Reset = FALSE, output value calculation by the filter algorithm
  - When Reset = TRUE, output of SubstituteOutput
- The enable output ENO is set to TRUE.

The output parameter Error is deleted as soon as there are no longer any errors.

<table>
<tr><th>ErrorBits (DW#16#...)</th><th>Description</th></tr>
<tr><td>0001_0000</td><td>Cause of error:
The SubstituteOutput parameter or a different tag that is being used as output value has no valid REAL value.
Response to error:
The output is set to 0.0.
Solution:
Make sure that the tag used as output value is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF). The tag that is used as output value depends on Reset and ErrorMode:
<table>
<tr><th>Reset</th><th>ErrorMode</th><th>Output value</th></tr>
<tr><td>FALSE</td><td>0</td><td>Input</td></tr>
<tr><td>FALSE</td><td>1</td><td>SubstituteOutput</td></tr>
<tr><td>TRUE</td><td>-</td><td>SubstituteOutput</td></tr>
</table></td></tr>
<tr><td>0002_0000</td><td>Cause of error:
The Input parameter has no valid REAL value while the calculation of the output value is being performed (Reset = FALSE).
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. When ErrorMode = 0, 0.0 is used as output value.
Solution:
Make sure that the parameter Input is a valid REAL value (≠NaN e.g. 16#7FFF_FFFF).</td></tr>
<tr><td>0004_0000</td><td>Cause of error:
The calculation of the output value yields an invalid REAL value for the Output parameter.
Response to error:
The substitute output value that is configured at the ErrorMode tag is output at the Output parameter.
Solution:</td></tr>
</table>

ErrorBits (DW#16#...)	Description
	Check all tags involved in the calculation of the output value: • Input • Frequency • Bandwidth • Type • Characteristic • Order • CycleTime.Value These tags have valid values. The calculation of the output value fails in this combination of tags.
0008_0000	**Cause of error:** One or more filter parameters have an invalid value while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Ensure that the following conditions for the values of the filter parameters are met: • 0.0 < Frequency < 0.5 / CycleTime.Value • 0.0 ≤ Bandwidth < 0.5 / CycleTime.Value - Frequency • 0 ≤ Type ≤ 3 • 0 ≤ Characteristic ≤ 2 • 0 ≤ Order ≤ 10
0010_0000	**Cause of error:** Automatic detection of the cycle time failed because Filter_Universal is not called in a cyclic interrupt OB. **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Make sure that Filter_Universal is called in a cyclic interrupt OB. **Additional information:** Automatic detection of the cycle time can be disabled by setting the tag CycleTime.EnableDetection = FALSE. You then need to specify the cycle time manually at the Variable CycleTime.Value. Calling of Filter_Universal outside of a cyclic interrupt OB can have a negative effect on the filter behavior, because the actual cycle time fluctuates in this case.
0020_0000	**Cause of error:** The tag (configured with StartMode) for the initialization of the Output parameter at the first call of the instruction does not have a valid REAL value. **Response to error:** The substitute output value is output with the first call of the instruction at the Output parameter that is configured at the ErrorMode tag. For subsequent calls, Filter_Universal calculates the output value starting from this substitute output value. **Solution:** Make sure that the tag for initializing the parameter Output is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF). When Reset = FALSE is set, the initialization takes effect with the first call of the instruction after the operating state transition of the CPU from STOP to RUN. The tag that is used for the initialization of the Output parameter depends on StartMode: • StartMode = 1: SubstituteOutput • StartMode = 2: Output
0040_0000	**Cause of error:** The CycleTime.Value tag has an invalid value, while the calculation of the output value is being performed (Reset = FALSE). **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:**

ErrorBits (DW#16#...)	Description
	Ensure that the following conditions are met: • 0.0 < CycleTime.Value ≤ 3.402823e+38 • CycleTime.Value is a valid REAL value (≠ NaN e.g. 16#7FFF_FFFF) **Additional information:** To automatically calculate the value of the CycleTime.Value tag, set the CycleTime.EnableDetection tag to TRUE.
0080_0000	**Cause of error:** An internal error occurred during automatic detection of the cycle time. **Response to error:** The substitute output value that is configured at the ErrorMode tag is output at the Output parameter. **Solution:** Make sure that Filter_Universal is called in a cyclic interrupt OB. If the error continues to occur, contact SIMATIC Customer Support. **Additional information:** Automatic detection of the cycle time can be disabled by setting the tag CycleTime.EnableDetection = FALSE. You then need to specify the cycle time manually at the CycleTime.Value tag.

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