SIPART DR Summary

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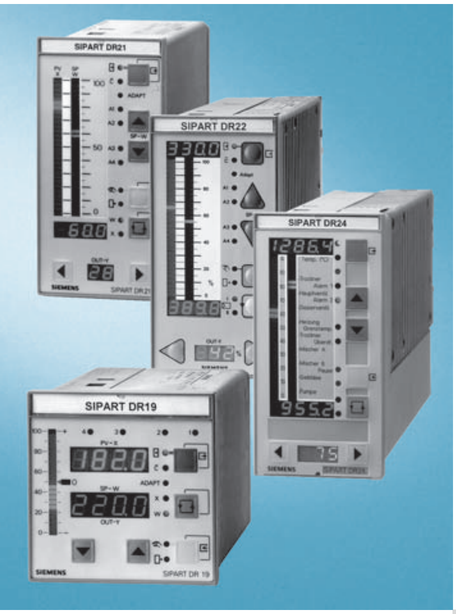


SIPART DR Controllers - Overview


DR19


DR20


DR21


DR22


DR24

	SIPART DR19 industrial controller For all standard tasks	**SIPART DR20 controller** 4) For all standard tasks	**SIPART DR21 controller** For all standard tasks, with comprehensive displays	**SIPART DR22 controller** For complex controls	**SIPART DR24 multi-function unit** Freely-configurable control and computing unit, for complex controls
Input structure					
Fixed setpoint controller	■ (up to 5 setpoints)	■	■ (up to 2 setpoints)	■ (free connection)	■ (free connection)
Slave controller	■	■	■	■	■
(Controlled) ratio controller	■ / ■	■ / –	■ / ■	■ / ■	■ / ■
Cascade controller	–	–	–	■	■
Override controller	–	–	–	■	■
SPC / DDC controller	■ / –	■ / ■	■ / ■	■ / ■	■ / ■
Independent controllers	1	1	1	2	4
Program controller	■	–	–	–	■
Output structure					
Cont. controller (20 mA)	■	■ 2)	■	■	■
Step controller					
Binary signal (24 V)	■	Option	■	■	■
Relay	■	■ 3)	■	–	–
Two-position controller					
Binary signal (24 V)	■	Option	■	–	■
Relay	■	■ 3)	■	–	–
Input and output signals					
20-mA analog inputs	0, max. 3	2, max. 4	2, max. 4	3, max. 11	3, max. 11
Direct sensor connection	1, max. 3	0, max. 2	0, max. 2	0, max. 2	0, max. 2
Analog outputs	1	1 2)	1	3, max. 9	3, max. 9
Binary inputs 1)	2, max. 7	1, max. 2	2, max 7	4, max. 14	4, max. 14
Binary outputs 1)	2, max. 8	1, max. 5	2, max. 8	8, max. 16	8, max. 16
Slot for option modules	4	4	4	5	5
Displays/signalling diodes					
Digital displays (LED)	2 × 4-digit	1 × 4-digit 1 × 2-digit	1 × 4-digit 1 × 2-digit	2 × 4-digit 1 × 3-digit	2 × 4-digit 1 × 3-digit
Analog displays (LED)	1 × 21 segments	1 × 21 segments	2 × 30 segments	2 × 30 segments	2 × 30 segments
Signal diodes / no. of alarms	11 / 4	6 / 2	11 / 4	11 / 4	11 / 4
Further characteristics					
Adaptation procedure	■	–	■	■	■
Arithmetic functions	–	–	–	■	■
RS 232 interface	Option	Option	Option	Option	Option
RS 485 interface	Option	–	Option	–	–
PROFIBUS DP interface	Option	Option	Option	Option	Option
PC configuration software	SIMATIC PDM	SIMATIC PDM	SIMATIC PDM	SIMATIC PDM	SIPROM DR24
Power supply AC/DC	24 V	24 V	24 V	24 V	24 V
AC	230 / 115 V	230 or 115 V	230 / 115 V	230 / 115 V	230 / 115 V
Format	96 mm × 96 mm	72 mm × 144 mm	72 mm × 144 mm	72 mm × 144 mm	72 mm × 144 mm
Mounting depth	199 mm	190 mm	197 mm	278 mm	278 mm

1) The max. numbers of binary inputs and outputs are not possible simultaneously.
2) Basic unit: K controller
3) Basic unit: S controller
4) Discontinued

Fundamentals of control engineering

Introduction

With the advent of automation, the use of the term control generally suggests properties such as reliable functioning, high accuracy, special quality or increased flexibility. A topical example is the catalytic converter in a modern car.

Although the control principle is used to an increasingly varied extent in all types of processes, it is not a technical invention. It is a natural phenomenon which enables a particular state to be retained automatically despite external interferences. Many biological and environmental processes, but also sociological and economical processes, function according to this control principle.

Development of control engineering

Parallel to practical control engineering, the theory of control problems is also an important aspect.

In the course of time, control engineering has developed into an autonomous science applicable to many fields. The beginning of the technical use of control principles can be found, for example, in the centrifugal governor of the steam engine made by James Watt (1788) and continues with the first mathematical descriptions of control procedures at the start of the 20th century, followed by the introduction of fundamental, systematic methods (e.g. Oldenbourg and Sartorius 1944) and finally the appearance of modern, increasingly computer-based procedures (Kalman 1960).

Open-loop and closed-loop control

An initial impression of the basic problems encountered with control systems and a feeling for their mode of operation can best be explained using a simple example.

Consider a heater whose task is to achieve a specific room temperature (Fig. 2/1). A possibility would be to measure the outside temperature and to vary the flow of heat according to a defined characteristic by means of a motorized valve. The unpracticality of this solution is clearly evident: the room temperature can be influenced, for example, by opening a window. No correction is made to the position of the valve – and thus to the flow of heat – because the actual temperature in the room remains unconsidered.

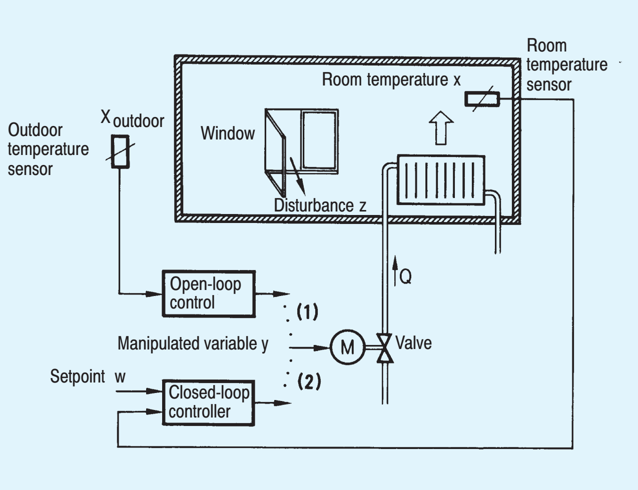


Fig. 2/1 Room heater: open-loop control (1) and closed-loop control (2), function diagram

This is a major characteristic of an open-loop control, i. e. a process is influenced according to a previously defined law, and any type of disturbance can affect the result.

This problem can be solved by a closed-loop control. The principle, in this case, is that the variable of interest (in this case the room temperature) has a feedback on the controlling variable (in this case the heat input).

In the example, the room temperature is measured constantly and compared with the desired temperature. A control device processes the difference such that this is reduced and finally eliminated by appropriately setting the valve position.

The following exactly defined control terms enable a more general description of the relationships.

Fundamental definitions

Closed-loop control is a procedure where a variable *x* (controlled variable, actual value) of a system is constantly measured, compared with a defined variable *w* (command variable, setpoint) and influenced in the sense of adaptation to the defined variable. The actions take place in a closed loop.

This general definition to DIN 19 226 is clarified by Fig. 2/2.

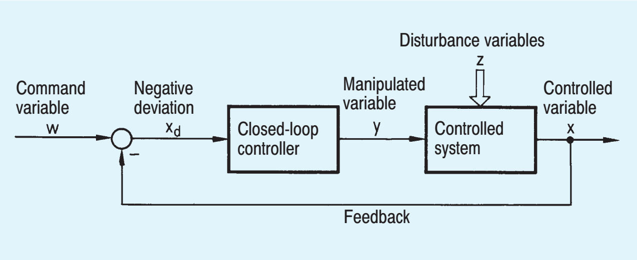


Fig. 2/2 Function diagram of closed-loop control

The closed-loop controller processes the negative deviation x_d calculated from the controlled variable *x* and the command variable *w* into a manipulated variable *y*. This is then the input variable of the process to be controlled, the so-called control loop, and counteracts the deviation of the controlled variable from its setpoint as caused by the disturbance *z*. The controlled variable is eventually returned to the value of one command variable and the disturbance is compensated.

The characteristic feature of a closed loop is thus the feedback of the controlled variable to the controller.

The quality of the control decisively depends on how well the controller response is tuned to the characteristics of the respective control loop. This tuning of the controller in accordance with the requirements is the main problem of control engineering.

The development of theoretical methods is based on various mathematical descriptions in the time or frequency domain. The transfer function representation is commonly used in cases where merely the input-output behaviour is of interest, since the processes are sufficiently linear and time-invariant.

If the response of the control loop to the influence of the command variable is observed, this is referred to as the response to setpoint changes. In a similar manner, the response to disturbance changes describes the influence of a disturbance variable on the relevant process variable.

Fundamentals of control engineering

The operating state at which all changes have stopped and where the manipulated variable and controlled variable have settled at stationary values y_S and x_S is referred to as the working point.

Sensors and transmitters

The controlled variable may be any physical quantity. Variables frequently encountered in process engineering include e. g. pressure, temperature, flow and level. Certain sensors used to detect the actual value, such as resistance thermometers or thermocouples, can be directly connected to the controller. Otherwise, transmitters supplying an electrical output variable must be connected between the sensor and the controller. The controllers are usually designed for transmitters with standard output signals (0 to 20 mA or 4 to 20 mA).

Controllers

In the example shown for controlling the room temperature, it was not considered how the controller converts the negative deviation into the manipulated variable. The most simple solution – and thus that used most frequently – is to simply switch the supply of heat on or off depending on the sign of the negative deviation. A controller which only has the extreme conditions “ON” and “OFF” is referred to as a two-step controller. The disadvantage is the constant oscillation of the controlled variable around the setpoint.

Controllers for higher accuracy applications therefore operate continuously. They vary the manipulated variable continuously in order to obtain a negative deviation decaying to zero.

It is insufficient for a high-quality of control, however, if only the actual difference between the setpoint and actual value is used to generate the manipulated variable. The mean value with respect to time and the rate of change of the deviation should also contribute to determination of the manipulated variable. The result is then a controller with three different active components, a **p**roportional component, an **i**ntegral component and a **d**ifferential component. This is the well-known **PID controller.**

The PID operation

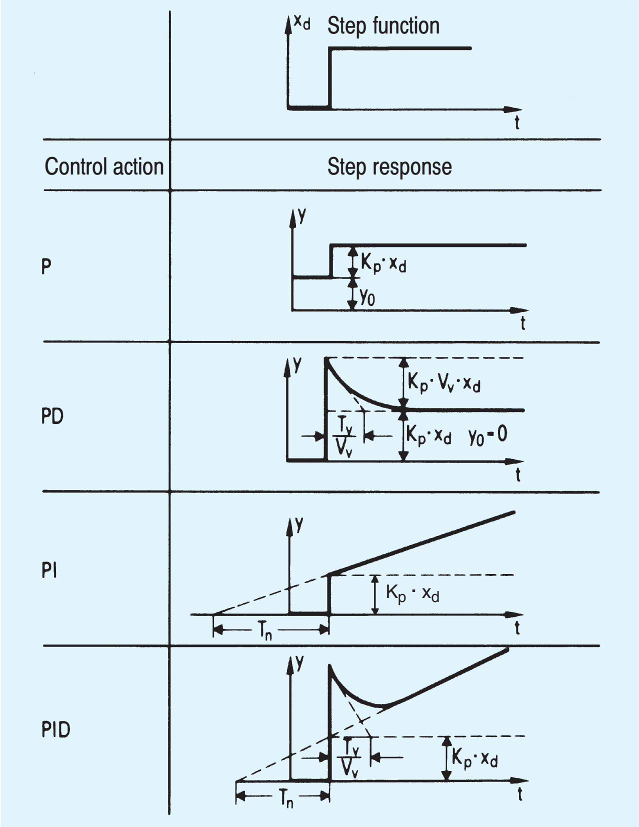
$$y(t) = K_P\{x_d(t) + \frac{1}{T_n}\int_0^t x_d(\tau)d\tau + T_v\dot{x}_d(t)\}$$

is, with small modifications, the core of most industrial controllers. The proportional gain K_P, the reset time T_n and the derivative action time T_v are the controller parameters which determine the function. A P, PD, PI or PID response can be achieved depending on the values set for these parameters.

Instead of the proportional gain K_P, the proportional band X_p (in %) is another way of expressing the parameter of the **P controller.** The following relationship then exists:

$$K_P = \frac{100}{X_P}.$$

A steady-state deviation offset is prevented in the **PI controller** independent of the working point, value of the setpoint and changes to the disturbance variables by means of the integrating component which can be defined using the reset time T_n.



K_p	Proportional gain	V_v	Derivative action gain
T_n	Reset time	x_d	Negative deviation
T_v	Derivative action time	y	Manipulated variable
t	Time	y_0	Working point

Fig. 2/3 Step responses with different values for the parameters

The **PID controller** achieves an improvement in the dynamic control performance by the addition of a D component. The characteristic parameter is the derivative action time T_v.

The effect of the controller’s parameters can be seen in Fig. 2/3 from the response of the controlled variable following a step change in the negative deviation.

Final control elements and actuators

In most process engineering applications, the manipulated variable *y* acts on the controlled system via a valve, a damper or another mechanical positioning device. Three types of device are common for actuating such final control elements:

- Electric actuators, consisting of an electric motor and gear box (robust, low maintenance requirements, economical)
- Pneumatic actuators with compressed air as the supply and with electropneumatic converter (fast, explosion-proof)
- Hydraulic actuators with electrically driven oil pump and with electrohydraulic positioner (for large positioning forces).

In temperature control circuits with electric heating elements, relays, contactors or semiconductor switches are used as final control elements.

Fundamentals of control engineering

Classification of controllers

The example of room temperature control already shows that controllers can be divided according to their mode of operation into

- continuous controllers and
- step controllers.

Another important difference is the type of controller characteristic implemented, e. g. the PID operation. Whereas electronic controllers were previously designed using analog technology, digital technology based on microprocessors and computers is now used. There is therefore a difference between

- analog controllers and
- digital controllers.

A characteristic of digital controllers is the implementation of the control function as an algorithm in the form of a program.

Compared to the continuously operating analog controller which acts almost without any delay, a digital controller can only process the current actual value and generate a new manipulated variable at discrete points in time. Analog-to-digital and digital-to-analog converters are also required to allow connection to the process.

Whereas the first digital controllers were implemented in process computers, they can be found today not only in complex process control and automation systems but primarily in the design of a compact controller.

Digital PID controller (Fig. 2/4)

Since the PID structure has been proven in practical applications and because a number of practical design procedures are available it has become a standard. Therefore, many attempts have been made to retain the advantages of the PID characteristics when converting from analog to digital control. This means that the digital controller operating at discrete points in time must approximate the dynamic response of the analog controller as well as possible.

How can this be envisaged?

- The controlled variable is measured ("sampled") and digitized in the processing cycle of the controller program, i. e. at discrete points in time

  $t_k = k\,T_A, \quad k = 0, 1, 2, \ldots$

- The PID operation is simulated by a PID algorithm contained in the controller firmware. A differential equation is then calculated at each sampling point using stored values of the process signals. The P, I and D components can be set independently of one another in the case of an algorithm implemented as a parallel interaction-free structure.

  A controller therefore, which generates a corresponding sequence of manipulated variables

  $y\,(t_k), \quad k = 0, 1, 2, \ldots$

  from a sequence of input values

  $x_d\,(t_k), \quad k = 0, 1, 2, \ldots$

  is also referred to as a sampling or discrete controller. The time between two updating operations is referred to as the sampling time or the sampling period T_A.

- The calculated manipulated variable is connected to the controlled system following digital-to-analog conversion and retained until the next value is applied. The manipulated variable therefore has a staircase response.

The demand for a quasi-continuous mode of operation for the digital PID controller can clearly be satisfied by sufficiently frequent sampling, i. e. by suitable selection of the sampling time.

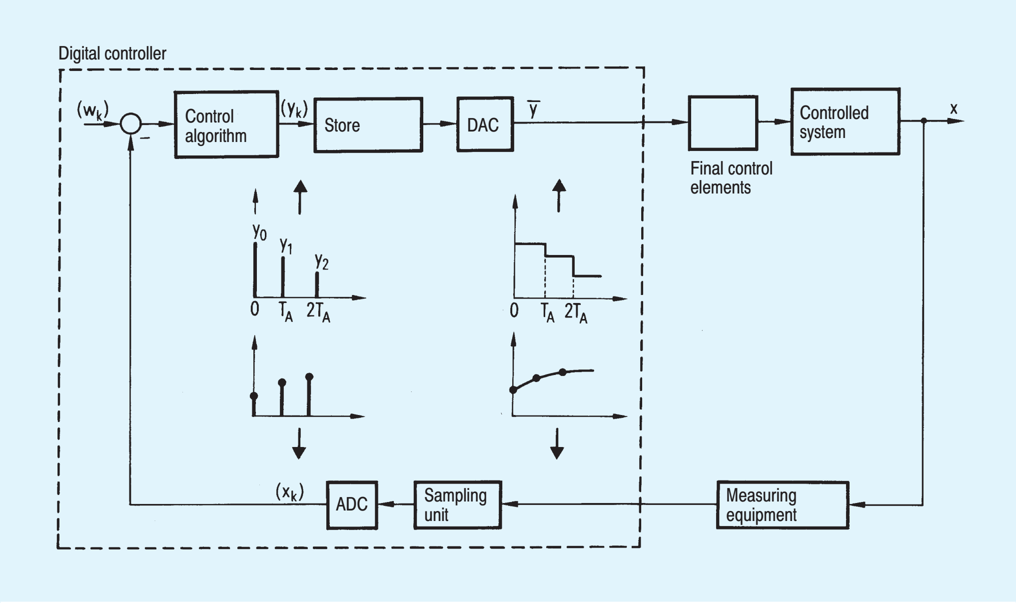


Fig. 2/4 Structure of digital closed-loop control

Fundamentals of control engineering

Advantages of digital controllers

The basic mode of operation of digital controllers is largely identical to that of analog controllers, but the former have a number of significant advantages:

- **Flexibility:** The control functions are implemented using software. They can be used flexibly by the user for many different applications.
- **Variety of functions:** Functions of any complexity can be implemented very easily using the software, e. g.
  - Bumpless manual/automatic switchover
  - Prevention of integral saturation (anti-reset-wind-up) on attainment of manipulated variable limits
  - Adjustable limiting of setpoint and manipulated variable
  - Parameterizable setpoint ramp
  - Filtering of process variables containing noise.
- **Accuracy:** Digital parameters are drift-free. They can also be set exactly as required. Mathematical operations present no problems.

Types of manipulated variable output signal

The controller output signals must be suitable for different types of actuators. Two types of controller are common for most types of actuator:

- Continuous controllers (K controllers) for pneumatic and hydraulic actuators
- Step controllers (S controllers) for electric actuators.

These types of controllers are known as continuous controllers, because the valve can take all positions between “fully open” and “fully closed”.

- Continuous controllers

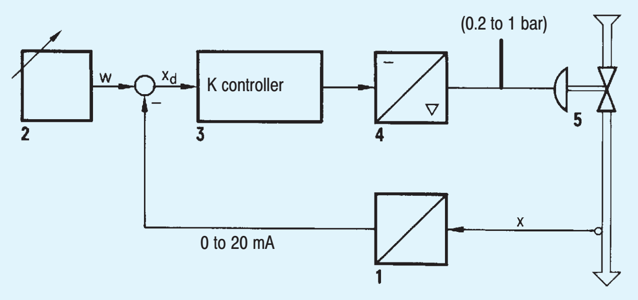
With the quasi-continuous mode of operation of the digital PID controller the controller output signal acts practically continuously on the final control element via a signal converter (Fig. 2/5).

- Step controller

The step controller is a switching controller with a three-position response which can only act on the controlled system together with a motor-driven, integral final control element. It switches the electric motor of the actuator by means of relays or semiconductor switches for activating a valve or damper for clockwise or counterclockwise rotation. The required position is set according to a cyclically calculated pulse length.

In the case of analog technology, the step controller is designed using a three-position element with hysteresis and a delayed feedback. The digital step controller (Figs. 2/6 and 2/7) again uses the PID algorithm. It delivers the positioning increment associated with the current negative deviation, and is usually parameterized with $T_V = 0$. The positioning increment is converted in a pulse shaper stage into a proportional positioning pulse length. The smallest possible positive value is defined in the form of a parameterized minimum pulse length taking into account the operating time of the final control element.

As shown in Fig. 2/8, the transient function generated on the final control element by the pulses of the step controller corresponds to that of a continuous PI controller. The parameters K_P and T_n can again be determined from the first point of intersection between the staircase function and its mean straight line.



x	Controlled variable	3	Continuous controller
x_d	Negative deviation	4	Electropneumatic signal converter
w	Command variable	5	Pneumatic final control element
1	Transmitter		
2	Setpoint adjuster		

Fig. 2/5 Structure of digital closed-loop control

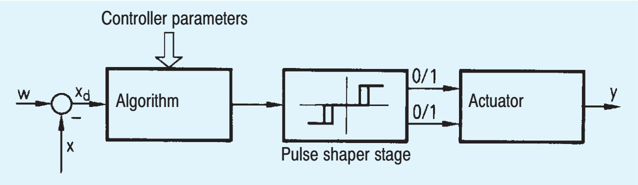
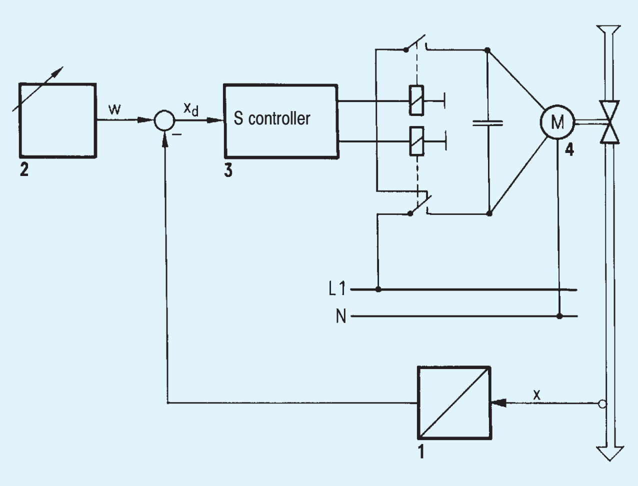
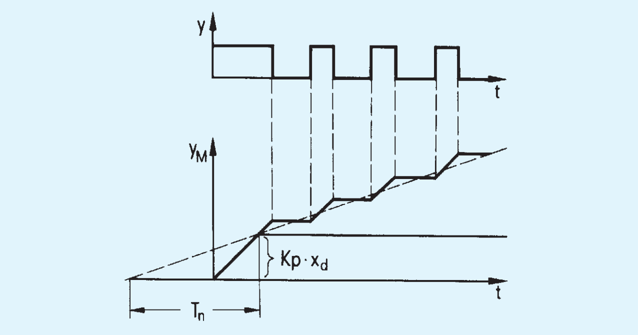


Fig. 2/6 Structure of digital closed-loop control



x	Controlled variable	1	Transmitter
x_d	Negative deviation	2	Setpoint adjuster
w	Command variable	3	Step controller
		4	Actuator

Fig. 2/7 Structure of digital closed-loop control



K_P	Proportional gain	x_d	Negative deviation
T_n	Reset time	y	Manipulated variable
t	Time	y_M	Manipulated variable (motor)

Fig. 2/8 Structure of digital closed-loop control

- Two-step and three-step controllers (stepped controllers)

The two-step controller (or three-step for heating/cooling) is used to operate relays, contactors, or thyristor switches in heating and cooling applications.

In the case of SIPART DR two- and three-step controllers, the switching operation is determined by the period, the control deviation and the parameters. The period is programmed in the controller as a constant. The control deviation, in conjunction with the parameters $K_P/T_n/T_V$, determines the cycle time within the period. This means that the switching operation is not just determined by changes in the process variable; if parameterized accordingly, the process variable x can remain more or less constant.

Whereas the positioning pulses of a step controller disappear when the negative deviation has decayed, positioning pulses are still output in the steady-state condition of a two or three-step controller according to the stationary value of the calculated manipulated variable.

Extended control structures

In practice the standard PID controller has a large number of functions and possible structures. Examples include:

- Cascade control

A cascade control is suitable for very fast compensation of disturbances. In this case a master controller does not act directly on the final control element but provides the setpoint for a subordinate slave controller. This reacts to disturbances before they affect the controlled variable.

- Disturbance variable feedforward

If a measurable disturbance variable acts on the input of a controlled system, it can be compensated for at an early point in time by adding it, weighted by a factor to the controller input or output signal.

- Ratio control

A command process variable x_2 is weighted in this case by a ratio w_V and is the setpoint for the controlled process variable x_1.

- Override control

A controller operating in normal mode is overriden by another controller as soon as the latter registers that a limit has been violated.

Adaptation

The most important degrees of freedom of a PID controller are its parameters K_P, T_n, T_V. These basically determine the quality of control, irrespective of the specific configurations made by the user.

Adjustment of the controller parameters according to the requirements is a fascinating theoretical problem but rather a burdensome one in practice.

The conventional procedure in the case of industrial process control

- is usually based on experience,
- often uses trial-and-error procedures,
- occasionally uses simple guidelines,
- only uses systematic, mathematical methods in exceptional cases.

These disadvantages always place the quality of the parameters in doubt. The actual controller adjustment always remains the responsibility of a person. This is totally different with an adaptive controller. This type of controller determines the optimum values of the parameters itself. This decisive innovation has only been made possible by digital technology.

The following methods are of most interest in cases where adaption, the automatic adjustment of the controller to differing process conditions, is being used:

- commissioning adaptation, which is normally initiated in manual mode (e. g. the adaptation procedure on the SIPART DR19 or SIPART DR21/22/24).

- Requested adaptation which is triggered by an event – for example a change in setpoint – and updates the controller parameters during operation.

To a certain extent, parameter control utilised in some conventional control devices can also be included amongst the adaptation procedures. In this case, defined sets of parameters for the controller are switched over depending on the working point.

The general structure of adaptive control is shown in Fig. 2/9. The two function blocks “Identification” and “Controller draft” are important. They represent the actions of a methodical control engineer and the fundamental sequence of processes in the software in digital controllers.

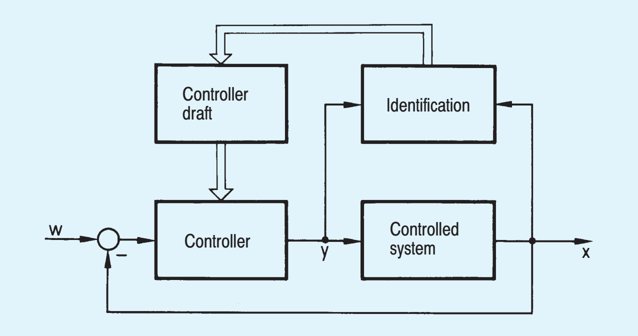


Fig. 2/9 General structure of adaptive control

Fundamentals of control engineering

The SIPART DR controllers use adaptation procedures that have a specific effect on the process.

The adaptation procedure on the SIPART DR19 controller works on the basis of an oscillation of between 0 and 100 % as the result of changes in the manipulated variable. The process variable displays a control oscillation, which is evaluated according to the period and its amplitude, below the required setpoint value. The parameters K_P, T_n and T_V are derived from this oscillation data. Adaptation can be terminated in either manual or automatic mode.

The patented SIEPID procedure is used in the SIPART DR21, SIPART DR22 and SIPART DR24 controllers. This procedure was developed for processes involving compensation and damped response and is based on a concept that has been well proven in practice:

- The adaptation phase is started by triggering in the form of a change in manipulated variable in manual mode.
- The time response of the manipulated variable and controlled variable resulting at the input and output of the controlled system as a reaction to the above changes are determined and recorded.
- A criterion insensitive to interference determines the attainment of the new stationary final value and automatically initiates evaluation of the series of measurements.
- This task, referred to as identification, is handled by a particularly robust procedure for optimum model adaptation. During this procedure the parameters of a process model, mathematically matched to the problem are optimized by simulating the actual process response as exactly as possible.
- Based on the determined process model, the controller parameters are finally calculated according to the proven analytical rules for optimization of the amount.
- The resultant recommended values to be used for commissioning can however be altered by the user.

The convenient implementation of adaptation using the facilities of digital technology is an answer to the practical demands for saving time and costs, simple handling, reproducible control quality and improved product quality.

Compact controllers – universal components for process engineering

The compact controller is a design already encountered during the period of analog technology and which is of great practical significance for modern digital process technology because of its large number of attractive features.

The compact controller combines in a small housing all hardware and software components required to solve common control tasks in vastly different areas of process automation. Apart from the signal converters required in the case of non-electrical process variables, the power supply unit, A/D and D/A converters and the controls and displays are all built into the device.

The compact design means that this type of controller is particularly suitable for mounting in desks and switchboards, or even directly in machines and equipment.

The electronic compact controller is a device suitable for many applications. Its large range of functions means that it can do increasingly more than only control, is increasingly being offered in an adaptive version and is impressively simple to use despite its flexibility.

Configuring, i. e. the activation of specific partial functions according to the individual task, parameterization, i. e. definition of the characteristic data of the device within predefined ranges, and operation in process mode, e. g. changes to setpoints or manual/automatic switchover, all take place using pushbuttons on the front panel with the assistance of digital or bar analog displays.

Compact controllers, originally designed as stand-alone devices for process automation, increasingly offer more than just the reliability of an individual controller in that they can now be connected via serial interfaces to higher-level devices and systems such as personal computers and SIMATIC S5/S7 programmable controllers.

The extremely favorable price/performance ratio is the decisive factor for the success of digital compact controllers.