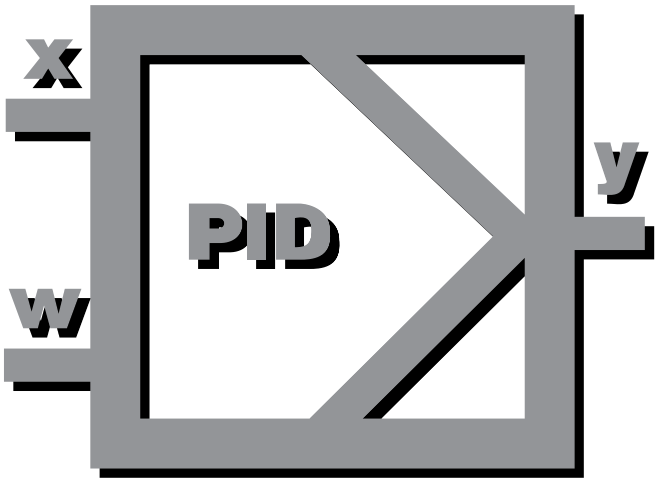
Elsag Bailey
Process Automation

Hartmann & Braun
Instrumentation
Heiligenhaus

Data Sheet
60-0.15 EN

Fundamentals of Control Engineering



1 Basic terminology in control engineering

1.1 General

The terms automation, closed-loop control and open-loop control are frequently used synonymously, although there are considerable differences between them.

Closed-loop control is a subset of **automation.**

Closed-loop tasks are encountered in numerous situations in daily life. The object is to cause the status of a system to approach that of a predefined value. In control technology [5] this task is described as follows:

The **controlled variable (actual value) x** of a **controlled system** is measured continuously and fed as a **feedback variable** r to a **comparing element** where it is compared to a **reference variable (set point) w**. A **controller output variable** Y_R is calculated from the resultant **control deviation** $x_w = x - w$ or the **error signal e = w - x.** This output variable Y_R is then used as a **manipulated variable y** to bring about a reduction in control deviation in the controlled system. This yields a closed **control loop.**

Disturbance variables z act on this control loop to repeatedly elicit a control deviation.

The controlled variable x may be replaced by an **object variable** $\mathbf{x_A}$ if the variable to be controlled cannot be measured directly for technical reasons.

When controlling the composition of a mixture it may prove impossible to measure that composition (the object variable) directly. Instead, a representative property (pH, density, turbidity) may be adopted as the controlled variable.

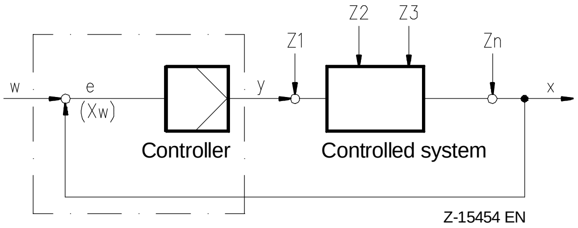


Fig. 1 The control loop

The **control precision or control quality** achievable in the control loop is very dependent on how well the controller is matched to the particular controlled system. The choice of the correct controller and its adaptation to the controlled system are therefore of primary importance.

Open-loop control also acts on a system to change it in the desired manner. The difference between this and closed-loop control is that the success of the intervention cannot be (directly) monitored. For instance, open-loop control opens a valve without checking whether, and if so, how much water flows through the opened valve. In other words, the output signal of the system (water quantity) is **not fed back** to the input of the open-loop control.

1.2 Controlled systems

Controlled systems are characterized by their **time response.**

There are a number of procedures suitable to determine time response. These are based on the controlled system being activated by a suitable test signal. The reaction of the system provides information on its dynamics. A very simple method and therefore commonly adopted approach is to activate the system through an abrupt change in the actuating signal.

The **step response/transfer function** is then evaluated to determine the setting values of the controller.

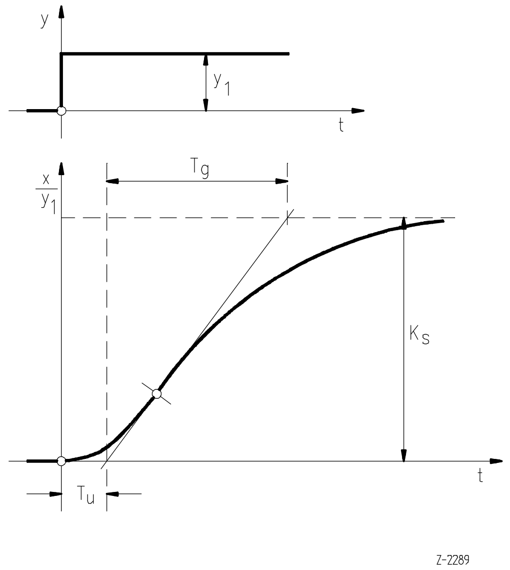


Fig. 2 Self-regulating controlled system, step response/transfer function

Fig. 2 shows a **self-regulating controlled system** in which a new **steady-state condition** results upon an abrupt change in the input variable. This state is reached when the input to the system equals its output.

Controlled systems which are **not self-regulating** are also of importance. These are generally containers in which the filling level is to be controlled.

The following data, of importance to the evaluation of the controlled system, can be derived from the step response:

Controlled system gain:	$K_S = x/y1$
Delay time:	T_u
Recovery time:	T_g

In process engineering and similar industrial processes, the value of T_g will vary from a few seconds to several hours.

In addition to the absolute value of these variables, the ratio T_u/T_g is also very important.

Systems in which $T_u/T_g \ll 0.1$ are easily controlled. Those in which $T_u/T_g \leq 0.3$ can still be controlled. If this value is exceeded then the results obtained with a controller will deteriorate in inverse proportion to the increase. In such cases the possibility of interrupting the control loop should be investigated so that cascade control can be tested.

1.3 Actuating signals and final controlling elements

Actuating signals constitute the input signals of controlled systems. They allow changes in power supply, flow cross-sections and the like.

Relays, contactors, semiconductor switches or continuously-variable thyristor actuators can all be used to vary the power supply to electrically-heated systems. Relays and contactors are inexpensive and their performance can be easily checked. A disadvantage, however, is that their mechanical life is limited, possibly resulting in down-time of plant. By contrast, semiconductor switches and thyristor sets are more expensive, but free of wear.

Electrically-driven or pneumatically-driven valves and flaps are usually used for the temperature control of gas or oil-heated plant and for the control of flow rates, pressure and the like.

The H&B product range includes electrical actuators (Catalogue 68), electropneumatic and intelligent positioners and electropneumatic signal converters **TEIP** (Catalog 18).

2 Selecting the controller

2.1 Controller or automation system

Very different types of controller are used in industrial process control.

Compact controllers are preferred for the control of individual control loops. These are characterised by having all the necessary functions contained in a single case.

In this sense, controllers constitute the least expensive stage of process automation. They are provided with direct inputs and outputs for process variables as well as a front panel for operation and monitoring of the process. In addition, controllers fulfil the requirements for use under adverse environmental conditions.

Digital controllers with serial interfaces are used for **centralized operating** and **monitoring** of a few control loops in small and medium size process plants. These, together with computer aided **process visualization units** such as the **WIZCON,** offer the least expensive way of entering process automation. Although operation and monitoring are grouped together centrally, the controllers are still independent in function. This ensures a high degree of safety and availability for the process.

Even if **freely programmable control systems** with integrated PID controllers are used, in many cases there is still the need to underlay digital controllers. This is especially the case if the safety and availability of control loops is the primary consideration or if the controlled systems are fast-acting.

Automation systems, such as the **Contronic P,** are generally used for the automation of large industrial process plants. These assume control and other tasks.

2.2 Selection according to actuating signal

Controllers fall into different categories, depending on the type of final controlling element:

- **On/off controllers** for the control of relays, contactors and solenoid valves. There are only two positions "on (1)" and "off (0)".

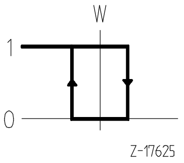


Fig. 3 On/off control

Modern digital on/off controllers function internally as continuous controllers. However, the continuous actuating signal y is converted into a proportional pulse/pause ratio. The value of $T_{in}/(T_{in} + T_{out})$ is referred to as the **control action** and corresponds to y.

On/off controllers can be used with all slow controlled systems if the switching frequency does not have to be too high. If a mechanical life of 107 operating cycles is assumed with 6 switching operations per minute, then a contactor will have a life of approx. 3 years.

If semiconductor switches or thyristor switches are used then the maximal switching frequency will be limited by the processing speed of the controller. The cycle time for digital compact controllers ranges from 30 to 50 ms. The controller outputs are thus reset approx. 20 times a second. Therefore, for control purposes the switching frequency of the circuit-breaker should not exceed 10 Hz.

- **Three-position controllers or dual on/off controllers**

These controllers have three positions, eg.,
"strong" – "weak" – "off" or
"heating on" – "off" – "cooling on"

"Strong" – "weak" – "off"

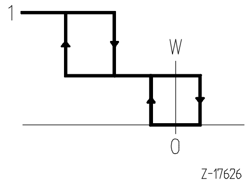


Fig. 4a Three-position control

"Heating on" – "off" – "cooling on"

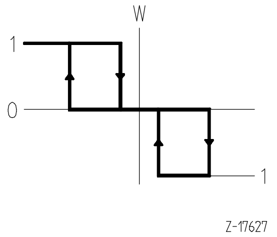


Fig. 4b Three-position control

The "strong-weak-off" controller is more properly referred to as a on/off controller with a limit signal contact since switching between "strong" and "weak" is achieved through a limit contact which has no time response. This limit contact is always derived from the control deviation so that irrespective of the set point value which has been set, the switching operation will occur, for instance, 10 °C before the set point is reached.

In three-position controllers for "heating-out-cooling", both control switching points have a time response which has to be parameterized separately. The limiting of switching frequency must be borne in mind with three-position controllers too.

- **Step controllers.** A step controller is a three-position controller for the control of electrical positioning motors with the switching positions "clockwise rotation" – "stop" – "counter-clockwise rotation" (open-stop-close).

Step controller "Open" – "Stop" – "Close"

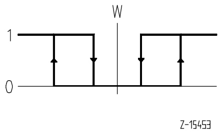


Fig. 5 Step controller

The limits of application of a step controller are governed by two criteria:

Similarly to an on/off controller, the switching frequency value must not be too high because of the mechanical life of the contactor.

The actuating time of the positioning motor for the positioning distance effectively used should be of the order of 60 s and should not drop below approx. 30 s, otherwise control will no longer be stabile. Assuming this operating period for 100 % of the positioning distance, the motor has to run for 150 ms for a positioning distance of 0.5%. ON-delays and OFF-delays for relays and contactors become apparent here.

The position feedback signal y is not normally required for loop control. Position feedback signalling is only necessary if output limits which have been set in the controller have to be adhered to. Otherwise in manual operation it provides those responsible for supervising process plant with information.

- **Continuous controllers**

Continuous controllers change their output signal continuously (0 ...20 mA or 4 ... 20 mA). They are used for the control of rapid-action electro-pneumatic drives, thyristor controllers and frequency converters.

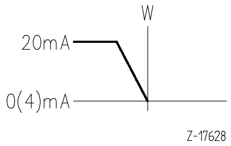


Fig. 6 Output signal "continuous controller"

2.3 Selection according to time response

The simplest type of controller is an alarm signalling unit which, for instance, switches off the heating of a furnace upon a predefined value being reached. The control performance which can be achieved with this is in most cases inadequate for industrial plant since a control oscillation remains of amplitude b and cycle time T, upon which the values T_u, T_g and K_s depend.

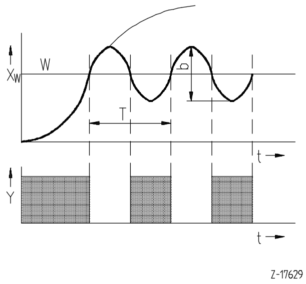


Fig. 7 Control result of an alarm signalling unit without time response

It can easily be seen that the control oscillation diminishes as the switching frequency is increased. This is achieved by expanding the alarm signalling unit to an on/off controller.

To improve control performance, it is provided with a structure which takes into account not just the instantaneous control deviation but the previous mean time value and the current rate of change when calculating the actuating signal.

This leads to the **PID controller.** Its transfer function can be described by the following equation:

$$F_{(S)} = \frac{1}{X_p} \cdot (1 + \frac{1}{T_n \cdot s} \cdot \frac{T_d \cdot s}{1 + T_1 \cdot s})$$

where X_p is the proportional band, T_n is the integral-action component, T_d is the derivative-action component and T_1 is the time-delay constant of the D-component which is always present. This equation also describes the on/off controller sufficiently accurately if the cycle duration derived from the switching frequency has a small value relative to the time constants of the controlled system, so that the control oscillation is no longer manifest in the control performance.

If $T_n = \infty$ or $T_d = 0$, then the corresponding part of the transfer function is rendered inoperative and P-, PI- and PD action is obtained.

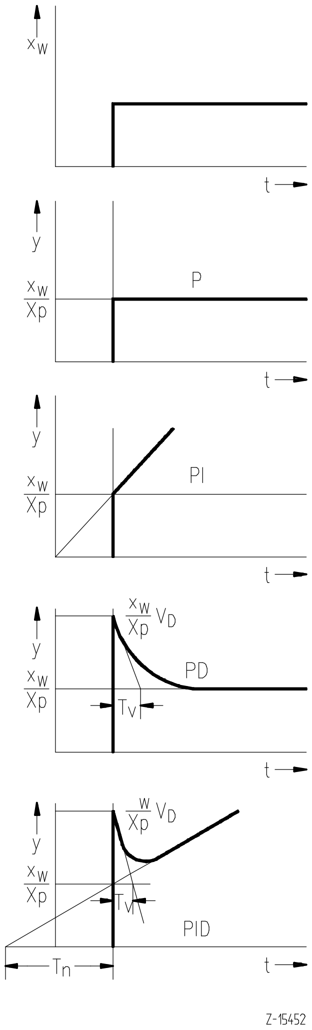


Fig. 8 Transfer functions

Fig. 8 shows the typical transfer functions of the controller for this equation if there is an abrupt change in the input signal.

Depending on the application, P-, PD-, PI- and PID-controllers may be used. Their main properties are described below.

P-controllers and PD-controllers lead without special measures to a rapid and in most cases overshoot-free course of the controlled variable. However, a **steady-state deviation** will always exist outside a defined operating point.

There is no steady-state deviation with **PI and PID controllers,** but the danger of overshoots is greater.

The D-component yields an appreciable improvement in the control performance of controlled systems with a high T_u/T_g ratio, but a poorer performance with irregular controlled variables such as those often encountered in pressure and flow measurements.

Table 1 provides guidance as to the time response of a controller which appears sensible for a given transfer function of a controlled system to enable usable results to be achieved upon parameterization. A distinction is made between the **response to set point changes** and a **good response to disturbances.**

Table 2 shows the controller types which are preferentially used and typical setting ranges for the most important control parameters for control applications most frequently encountered in industrial processes.

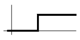
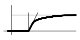
System	Controller	P	I	PI	PD	PID
	Pure dead time	Unusable	Somewhat poorer than PI	Control + Disturbance	Unusable	Unusable
	Dead time + delay 1st order	Unusable	Poorer than PI	Somewhat poorer than PID	Unusable	Control + Disturbance
	Dead time + delay 2nd order	Not suitable	Poor	Poorer than PID	Poor	Control + Disturbance
	1st order + v. sh. dead time (Delay time)	Control	Not suitable	Disturbance	Control upon delay time	Disturbance upon delay time
	Higher order	Not suitable	Poorer than PID	Somewhat poorer than PID	Not suitable	Control + Disturbance
	Without self-regulation with delay	Control (without delay)	Unusable structure unstable	Disturbance (without delay)	Control	Disturbance

Table 1 Time response and transfer functions

	Type of system	Controller type	X_p	T_n	T_d
T	Temperature	PID	5... 50 %	1...30 min	0,2...10 min
P	Pressure	PI	10... 30 %	10...60 s	–
F	Flow	PI	100...200 %	10...30 s	–
A	Analysis	PID	200...500 %	10...20 min	2...5 min
L	Level	P PI	100 % 50 %	– 10 min	–

Table 2 Types of controller

2.4 Selection according to input signal connection

Most controllers in use in process engineering are **fixed-value controllers.** A controlled variable (temperature, pressure, flow) is compared to a set point value stored in the controller and its value controlled to this set point .

Multi-component controllers are used in those situations where it is necessary to improve control performance through the additive injection of one or more auxiliary controlled variables. The best known of these applications is level control with steam boilers. Here, the level control is supported by injecting the feed water quantity and the steam quantity evaporated to the control deviation as disturbance variables.

Ratio control allows a mixing ratio to be controlled. Such controllers are often used with gas-heated furnaces in which a special furnace atmosphere is attained by controlling the air/gas mixture. This allows the combustion process to be optimized or a reduction in the emission levels of pollutants.

In **cascade control**, a **master controller** delivers the set point for a **slave controller**. The slave controller records disturbances in the subordinate control loop and controls these before they can exert an effect on the main controlled variable. The master controller is in most cases a fixed-value controller. The set point of the slave controller can usually be switched between an internal (local) set point and an external set point (from the master controller). With digital controllers, both types are often combined in a single unit.

In **selection control (override control)** two fixed-value controllers act on one final controlling element. Under normal operation only the main controller is engaged. The limiting controller is only activated if a value exceeds or falls below the maximum or minimum set point defined in it.

A time-program controller is a combination of a **program set station** as a set point source and a normal controller in a single unit.

2.5 Analogue or digital control

Digital technology, based on microprocessors and microcomputers, is now commonly used in modern controllers in all price classes. Contrary to the provisions of DIN 19 225, this type of controller is commonly referred to as a **digital controller**, even though it is defined in that standard as a **digitally-functioning analogue controller.**

Although control structures other than PID-action can be realized in digitally-functioning controllers, the proven PID-characteristic is generally retained because it can be deployed more universally than other algorithms. Although internal processing of the digital controller is very rapid compared to the time constants of the processes to be controlled, this serial digital processing is not reflected in the control performance.

The digital controller has become established because of the advantages listed below:

● **Accuracy and reproducibility:** Actual values, set points, alarm values and control parameters can all be read off with very high accuracy and adjusted if necessary. Parameters which have been found to be appropriate can be repeated without a loss in accuracy and transferred to other (replacement) units.

● **Flexibility:** Various technical control functions can be incorporated in a single unit without having to substantially change modules. The unit is adapted to the particular application by activation of software modules stored in the unit – either by the manufacturer and user.

● **Greater range of functions:** Additional computing and control functions can be configured over and above the usual control functions.

● **Ease of adaptation:** The digital technology allows further algorithms to be integrated to adapt the control parameters to the requirements of the controlled system. (See Section 3.2).

● **Self-test and diagnostic functions:** The self-test facility allows the controllers to recognise malfunctions and trigger an alarm before the malfunction affects the system. The diagnostic functions help locate the cause of the fault.

● **Serial interfaces:** These couple the digitally-functioning controller to higher-level systems (computers, automation or process-visualization systems etc), especially for centralized control and operation. Additional front panel interfaces simplify computer-aided feedback documentation, parameterization and configuration of the controller.

2.6 Additional functions

In addition to the actual control function, digital controllers offer a number of other functions.

2.6.1 Remote control and logical operations

The operating modes can be controlled remotely and important parameters set via binary inputs. The interventions are reported back via additional analogue and binary outputs. A number of binary and analogue computing modules permit special logical operations to be generated to solve particular problems.

The applications which can be tackled will depend primarily on the inputs and outputs which are available.

2.6.2 Computing functions

In numerous applications the variable to be controlled cannot be directly measured for technical reasons. However, it can often be calculated from one or more measured variables. Examples of this include:

- Calculating the volume of a container from its the liquid level
- Pressure and temperature of gases, vapours and fluids.

Moreover, a range of linearization, mean value derivation, square root extraction and similar functions are often necessary. Such functions can be integrated into controllers at Hartmann & Braun facilities or by the user without a knowledge of programming (possibly even upon commissioning).

2.7 Selection according to constructive characteristics

The main construction characteristics are the front panel format, the front panel protection against dust and spraywater, the electrical connections and the installed depth. For the sake of uniformity, various industrial sectors have decided on certain specific formats.

The controllers made by Hartmann & Braun are so designed that they can be easily replaced in case of breakdown or failure. The advantage for users is that the systems or equipment units can resume operation in no time, thus avoiding expensive production losses.

Uniform for all the various types of construction is the housing, which is inserted into the panel from the front and fixed firmly at the back, using clamps.

2.8 Selection according to safety engineering requirements

Certain industrial processes or applications necessitate controllers which satisfy **safety engineering requirements.**

For instance, heat generating plant which is heated with fluid, gaseous or solid fuels requires controllers which meet the requirements of **DIN 3440** [6]. This also holds for controllers used in heat-generating or heat-transfer plant which, irrespective of the type of heating energy, heat a thermal transfer medium such as water, steam, oil or air.

Land-type boiler systems must use **water-level controllers** which meet the specifications of VdTÜV Data Sheet No. 100/1 [7] and thereby satisfy the requirements of the "Technical Guidelines for Steam Boilers" (TRD). Controllers with corresponding approval are also required for boiler plant with only limited or periodic monitoring.

Controllers used on sea-going or inland waterway vessels, or in offshore facilities, have to satisfy the requirements of Germanischer Lloyds.

Hartmann & Braun controllers satisfy these requirements.

Controller	Germanischer Lloyd	DIN 3440	TRD, VdTÜV Publication Water-level 100/1
Bitric P	H&B Publication 48/61-13 GL	H&B Publication 48/61-11 DIN	H&B Publication 48/61-12 TÜV
Digitric P (96 mm × 96 mm)	H&B Publication 48/61-10 TÜV	–	–
Digitric P 144 (72 mm × 144 mm)	H&B Publication 48/61-10 GL	–	–
Protronic PE	H&B Publication 48/62-01 GL	H&B Publication 48/62-05 DIN	H&B Publication 48/62-04 TÜV
Protronic PS	H&B Publication 48/62-01 GL	H&B Publication 48/62-05 DIN	H&B Publication 48/62-04 TÜV
Protronic 500/550	–	H&B Publication 48/62-01 DIN	H&B Publication 48/62-06 TÜV

Table 3 Approval certificates

3 Matching the controller to the controlled system

Matching the control parameters X_p, T_n and T_d to the control application and the controlled system is often referred to as **optimization.** However, optimization is a decision process which precedes **parameterization.** In the optimization phase a decision is made as to whether the controller should

- adjust for a set point deviation as rapidly as possible, accepting that an overshoot may result
- adjust for a set point deviation without any overshoot
- compensate for disturbances in an optimal manner
- reach the set point with the lowest power consumption
- u. a. m.

Once the target has been established, the control parameters can be determined and set on the controller.

3.1 Manual determination and setting of control parameters

The parameters X_p, T_n and T_d are established for controllers by

- trial and error
- experience
- evaluation, for instance of transfer functions using a rule of thumb

or

- the use of mathematical methods. PC programmes are used here.

These approaches are in general very time consuming and often too imprecise to achieve optimal results at the first attempt. Consequently, there has long been a need for controllers which find their own parameters and adapt themselves.

3.2 Adaptive controllers

The term "adaptive controller" is inadequate to describe the function of such a controller. VDE/VDI Guideline 3685 gives more details on the classification of the various options:

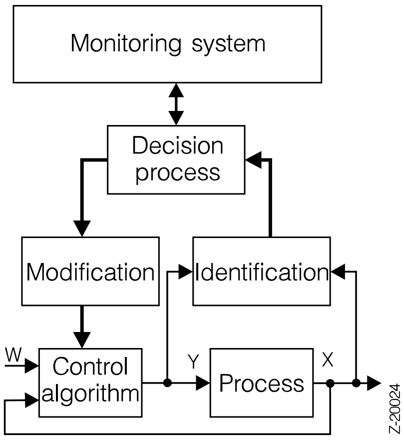


Fig. 12: An adaptive system

"An adaptive control system is one in which characteristics which can be influenced are automatically set to variable or unknown process characteristics so as to elicit an improvement. The terms self-setting, self-adapting and self-optimizing in the sense of this definition are all synonyms for the term "adaptive" [8].

Such an adaptive system is described by reference to Fig. 12:

"**Identification** in an adaptive control system serves to establish the characteristics of a system or part system."

"In the **decision process**, that information received about the identification is compared to the desired characteristics and a decision made as to how the controller is to be adapted."

"**Modification** is the realization of the result of the decision process. (Calculation and adoption of the parameter)."

"A superordinate **monitoring system** can be implemented which ensures the proper functioning of the part system and/or the entire system so that errors are recognised and corresponding measures initiated."

Further important criteria for the description of an adaptive system are the frequency and type of adaptation.

A distinction is drawn between:

- **Start-up adaptation.** Here, the operator starts the identification in an open control loop (manual operation) at the time of start-up. The controller establishes the appropriate parameters and offers them to the operator for acceptance.
- **Occasional adaptation** is started, for instance, with large jumps in the set point value.
- **Continuous adaptation.** The set parameters here are continuously checked to see if they can be improved.
- **Open-loop adaptation.** The success of the adaptation is not fed back to the decision process.
- **Closed-loop adaptation.** The effects of adaptation are continuously fed back in a closed loop.

Start-up adaptation is sufficient for most continuous industrial processes since the parameters of the controlled system change little with time.

However, major changes in the system parameters may be derived as a function of the loading of a system (charging of a furnace, set temperature etc). Such effects are in most cases reproducible and can be measured. If so, then the best results are obtained, particularly with batch processes, if the most important control parameters are controlled directly by the variables which influence them.

An example of parameter control by the controlled variable is pH control. The controlled system gain changes from very low values at pH 0 to very high values at pH 7 and again to very low values at pH14. The controlled variable pH thus has to control the controller gain or proportional band such that the loop gain is constant over the entire measuring range.

3.3 Realization in H & B controllers

Start-up adaptation is realized in H&B controllers under the designation **self-parameterization.** This simplifies and speeds up the start-up process and leads to better control performance than the usual methods in which exact measurements are often omitted to save time and the parameters are only approximated.

Control of the parameters through the set point, the controlled variable or other measured signals is a simple matter with Hartmann & Braun controllers. Since no general approach is possible for such tasks, a special configuration has to be drawn up for such applications by either Hartmann & Braun or the operator. Self-parameterization can be a valuable aid to establishing various parameters for different loading conditions.

4 Serial Interfaces

Two interfaces, of equal functional value, are available for different applications. A configuration interface which can be accessed from the front allows the functions parameterization, configuration and feedback documentation to be carried out. The controller itself is generally off line whilst they are being carried out. The computers used for this are mostly portable so that they can be used at different sites. They are connected to the controller via an adapter cable.

The rear interface allows the control of one or more units via a bus. Although this interface can also be used for configuration and parameterization, the bus is best used for operational (on-line) functions.

For these tasks the computers are generally stationary, with a fixed connection to the controller.

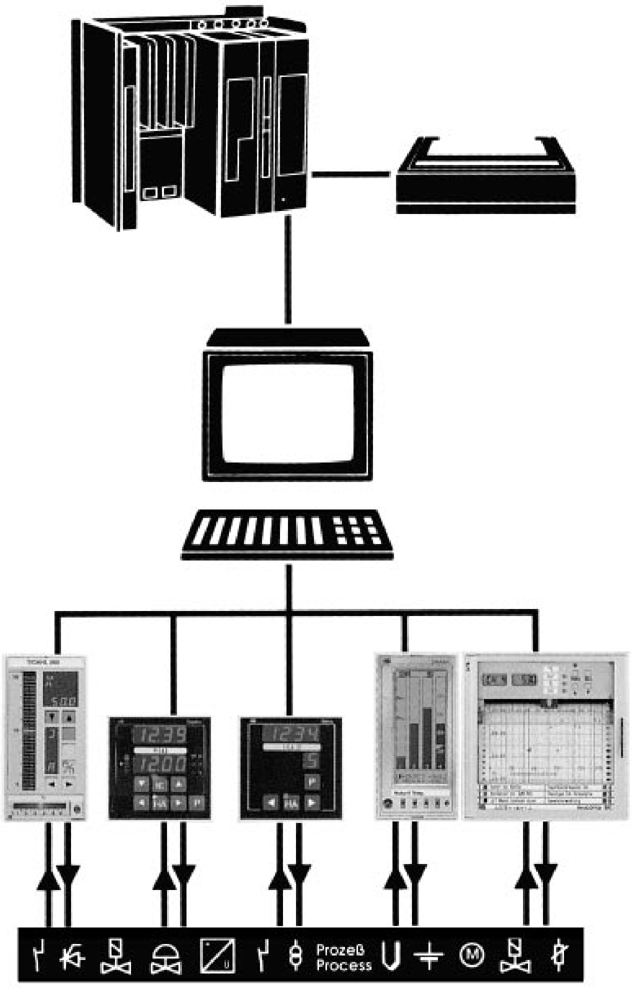


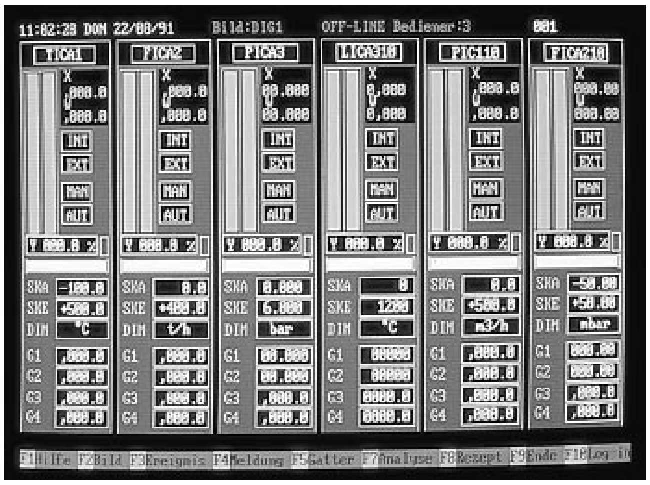
Fig. 13 H & B units connected to a PC for operation and monitoring

5 Computer applications

Hartmann & Braun offers complete, powerful software programmes for the functions operation and monitoring as well as **process visualization, parameterization, configuration and feedback documentation.** The applications **set point control** and **direct digital control** are in most cases so closely bound to the controlled system that no generally-valid programmes can be written for them. The interfaces, however, are documented such that coupling programmes can be written for the computer at any time by the customer.

The serial interfaces of the controller can be used for very different purposes. A distinction is drawn between:

- **Configuration** via a PC which enables various controller functions to be drafted, documented and archived.
- **Parameterization** via a PC or other computer which enables parameters to be set and archived in a given configuration.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	TICA1	FICA2	PICA3	LICA310	PIC110	FICA210
X	,000.0	,000.0	00.000	0,000	,000.0	000.00
U	,000.0	,000.0	00.000	0,000	,000.0	000.00
Y	000.0 %	000.0 %	000.0 %	000.0 %	000.0 %	000.0 %
SKA	-100.0	0.0	0.000	0	0.0	-50.00
SKE	+500.0	+400.0	6.000	1200	+500.0	+50.00
DIM	°C	t/h	bar	°C	m3/h	mbar
G1	,000.0	,000.0	00.000	00000	,000.0	000.00
G2	,000.0	,000.0	00.000	00000	,000.0	000.00
G3	,000.0	,000.0	,000.0	0000.0	,000.0	,000.0
G4	,000.0	,000.0	,000.0	0000.0	,000.0	,000.0

Fig. 14 Visualization of discrete controllers on a PC:

- **Set point control** through a computer of any design. With such an arrangement, the computer adjusts the set point according to superordinate criteria. These may include the order book situation at any given time, the breakdown of the orders, the power consumption at a given time or any of numerous other criteria. The aim is in most cases to **optimize** production.

- **Direct Digital Control.** In normal cases control is a task of a superordinate computer. Compact controllers are subordinate to this computer and assume the control function in a bumpless manner if there is a computer fault.

  The following operating modes are conceivable:
  Retention of the last computer correction value in
  manual operation
  Automatic operation with safety set point
  Automatic operation with the last value of the controlled
  variable adopted as the current controller set point (x-tracking)
  Cascade control.

- **Operation and monitoring of the system.** Important information for operation of the system is displayed in a suitable manner on one or more screens to enable processes to be monitored and changes made if necessary.

- **Feedback documentation** of the parameters set in the controller and any change made to their configuration.

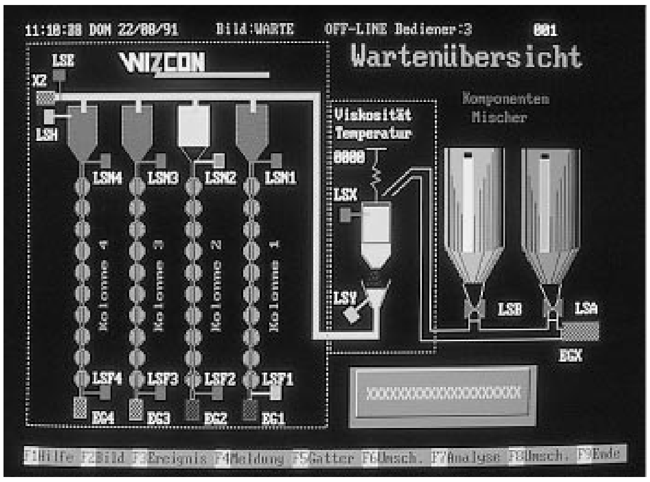

Fig. 15 Visualization of process plant on a PC

- **Process visualization:** A powerful software programme, in conjunction with a master computer or PC, makes it simple for a user to centrally operate, monitor, control and automate a process.

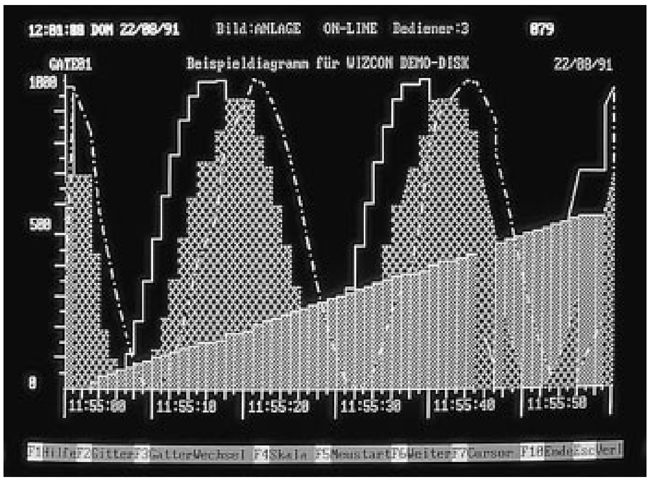

Fig. 16 Trend display

6 Definitions

These definitions are extracts in an abbreviated form from DIN 19 226. Where doubt exists, the original definitions are definitive.

Analogue signal	A signal with a continuous value range.
Limiting control	A combination of at least one main controller and an additional controller which ensures that the variable to be limited does not exceed predefined alarm values.
Binary signal	A digital signal with only two values.
Digital signal	A signal which can assume any one of a finite range of values.
Set value control	The reference variable is set to a fixed value (which can be changed).
Follow-up control	The value of the controlled variable follows the changing value of the reference variable.
Response to set point changes	The response of a controlled system to changes in the reference variable.
Limit signal	The binary signal of a limit monitor.
Limiting value	The value of the input variable of a limit monitor at which its binary output signal changes.
Manual control	Human control of at least one element of a control loop.
Cascade control	The output variable of the (master) controller forms the reference variable for one or more slave controllers.
Configuration	The elaboration of a control concept from pre-constructed programme modules.
Control station	Operating mode switches, adjusters for reference and output variables and the necessary display functions are brought together in the control station.
Optimization	Establishing a quality criterium.
Parameterization	The assignment of values for the characteristics of the modules of a system
Programming	Developing, coding and testing of a computer programme.
Switching point	The value of the input variable of a limit monitor at which its binary output signal changes.
Differential gap	The difference between the switching points (hysteresis) for which the binary output signal of a limit monitor changes with rising and falling input variables.
Actuating time	The time taken for the output variable to run through the entire correcting range at maximum speed.
Disturbance variable	Any variable acting on a system which disturbs the intended effect.
Feedforward control	Integration of the measurement of disturbance variables in the control algorithm.
Disturbance response	The response of a controlled system to disturbances.
Structuring	
a) Analysis	Breakdown of a system so that its relationships become visible.
b) Synthesis	The assembly of a system from functional units so that the requirements are met.
Time-programme control	The reference variable is changed according to a time-schedule.
Cycle time	Time interval between two sequential, identical, cyclical recurring processes.

7 Symbols

The symbols below are taken from DIN 19 226. The symbols used in the controllers may differ in some respects for technical reasons. If so, then please refer to the relevant Operating Manual.

e	Control deviation $e = w - x$ (see also x_w or x_d)
K_D	Derivative-action coefficient ($K_D = T_v \cdot K_p$)
K_I	Integral-action coefficient ($K_I = K_p / T_n$)
K_p	Proportional-action coefficient (see also X_p)
K_s	Controlled system gain (transfer coefficient)
r	Feedback variable (derived from x)
S	Controlled system
t	Time (operating)
T_g	Recovery time
T_h	Half-life
T_n	Integral-action time ($T_n = K_p / K_I$)
T_t	Dead time
T_u	Delay time
T_v	Derivative-action time ($T_v = K_D / K_p$)
U_t	Dead zone
U_{Sd}	Differential gap
w	Reference variable (set point)
W_h	Range of reference variables
x	Controlled variable (actual value)
x_A	Object variable
X_{Ah}	Object range
x_d	Error signal (replaced by e)
X_h	Control range
X_p	Proportional band ($X_p = 1 / K_p$)
X_{Sd}	Differential gap (hysteresis)
x_w	Control deviation ($x_w = x - w$) replaced by e, corresponds to deviation from set point
y	Output variable
Y_h	Correcting range
y_R	Controller output variable
z	Disturbance variable
Z_h	Range of disturbance variables

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