Basic terminology

cf. DIN 19226-1 to -5 (1994-02)

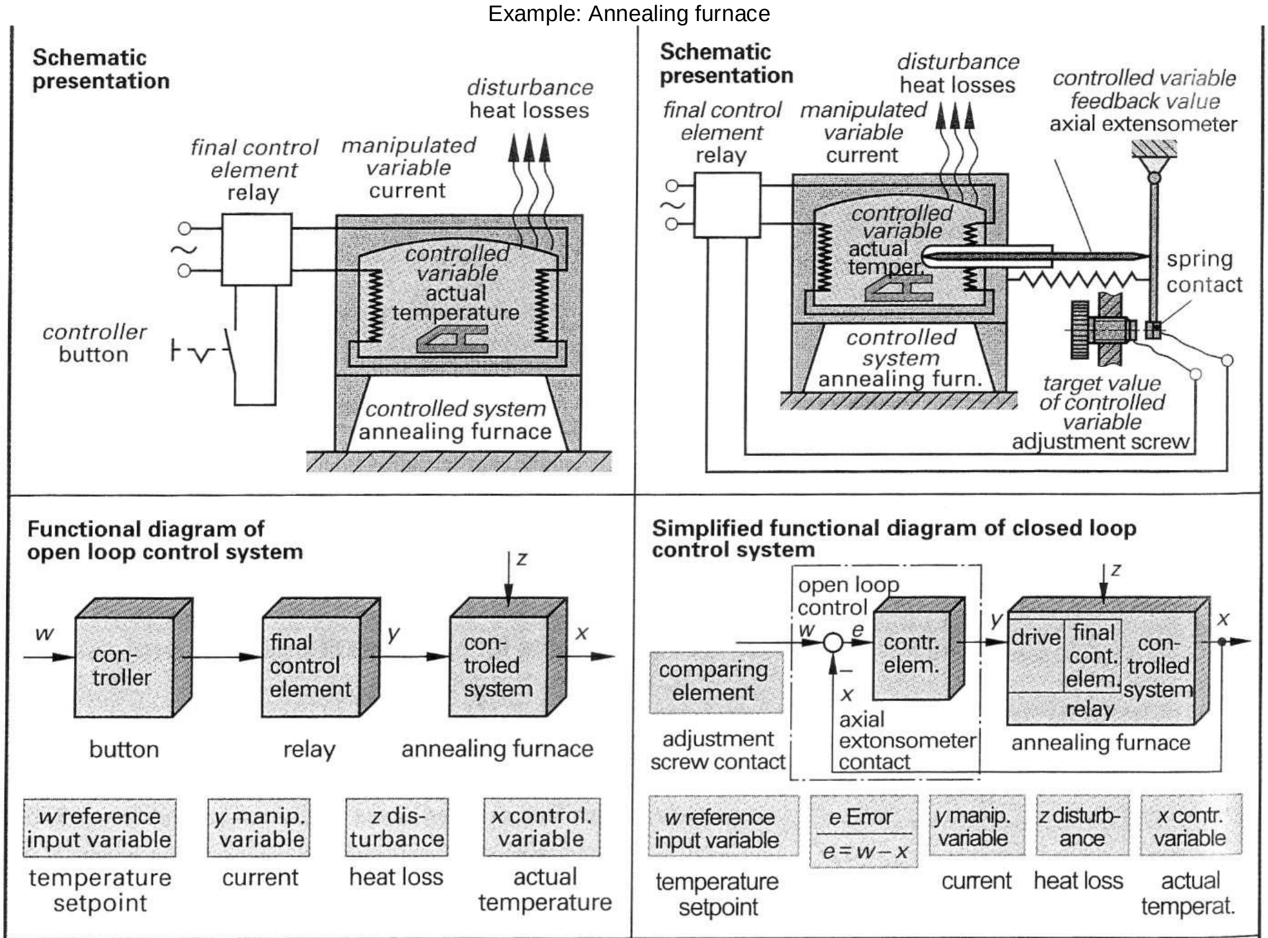
Open loop control

For open loop control the output variable, such as the temperature in a hardening furnace, is influenced by the input variable, such as the current in the heating coil. The output variable does not have an effect on the input variable. Open loop control has an open action flow.

Closed loop control

For closed loop control the controlled variable, such as the actual temp, in an annealing furnace, is continuously monitored and compared to the target temp, (reference variable) and, if there are deviations, adjusted to the reference input variable. Closed loop control has a closed action flow.

Example: Annealing furnace



Application-based code letters

cf. DIN 19227-1 (1993-10)

Designation example: PDIC

First letters

- D density
- E electrical parameters
- F flow, throughput
- G distance, position, length
- H manual input/intervention
- K time
- L status (e.g. level)
- M humidity
- P pressure
- Q quality parameters
- R radiation parameters
- S speed, rotational speed
- T temperature
- W weight, mass

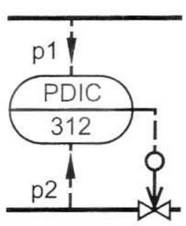
Supplementary letters

- D difference
- F ratio
- J control point query
- Q sum, integral

Succeeding letters

- A error indication
- C automatic closed loop control
- H upper limit value
- I display
- L lower limit value
- R registration

Example: Differential pressure closed loop control



Explanation:
- P pressure
- D difference
- I display
- C automatic closed loop control

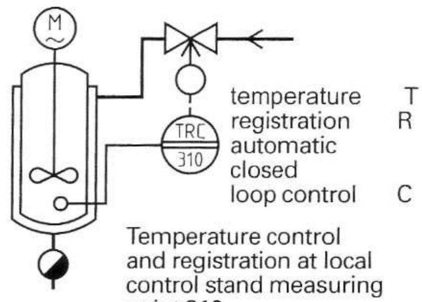
In plain language: Pressure differential closed loop control with display of pressure difference

Location of output & user control	
or	Local, general
	Process control room
	Local control console
	Local, implemented by process control system
	Local, implemented by process computer

Effect on the controlled system	
	Servo motor, general
	Servo motor; the setting for minimal mass flow or flow of energy is set during loss of auxiliary power.
	Servo motor; the setting for maximum mass flow or flow of energy is set during loss of auxiliary power.
	Servo motor; the final control device remains in the most recently acquired setting during loss of auxiliary power.

Measuring point, control point	
	Reference line
	Measuring point, sensor
	Final control element, control point

Example



Temperature control and registration at local control stand measuring point 310

Solution based symbols for devices

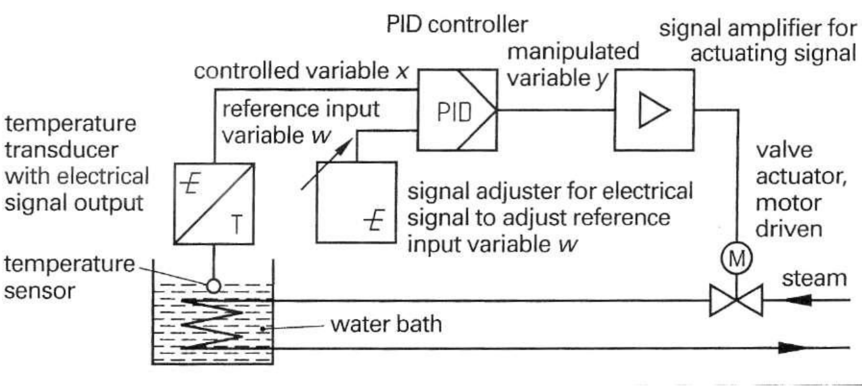
cf. DIN 19227-2 (1991-02)

Symbol	Explanation
Sensors	
T or T	Sensor for temperature, general
P	Sensor for pressure
L	Sensor for level with float
W	Sensor for weight, scales; indicating
Output devices	
	Basic symbol, general display
6	Printer, analog, no. of channels as a numeral
	Monitor

Symbol	Explanation
Controllers	
	Controller, general
PID	Two-point controller with switching output and PID behavior
	Three-point controller with switching output
Adapters	
P	Pressure transducer with pneumatic signal output

Symbol	Explanation
Final controlling & user control elements	
M	Valve actuator with motor drive
	Valve actuator with solenoid drive
	Adjuster for electric signal
Signal designators	
	Signal, electrical
	Signal, pneumatic
∩	Analog signal
#	Digital signal

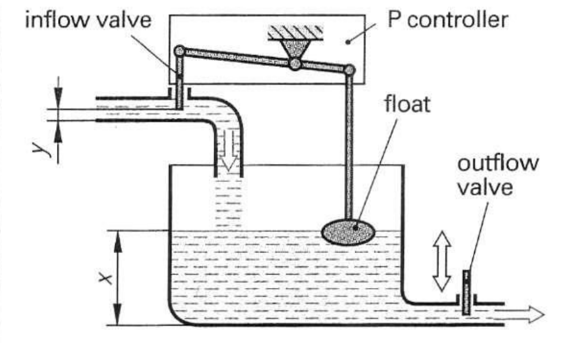
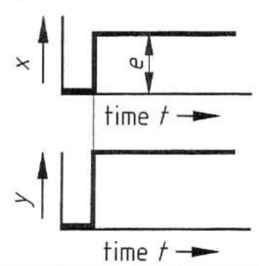
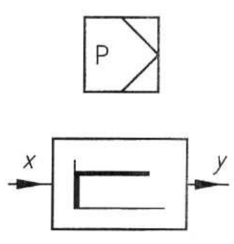
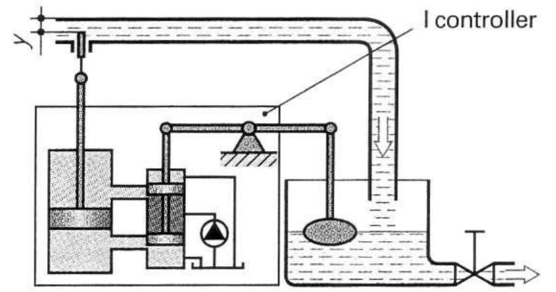
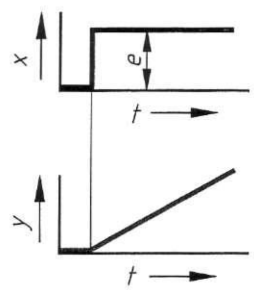
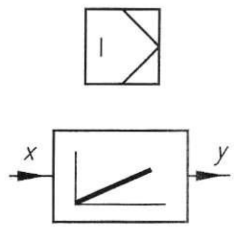
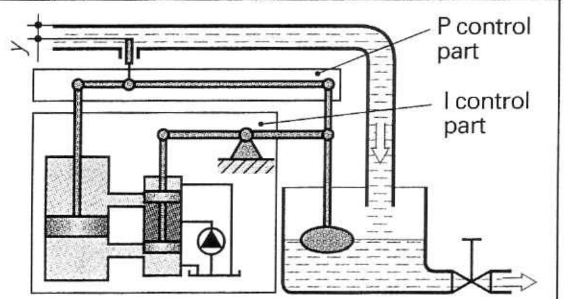
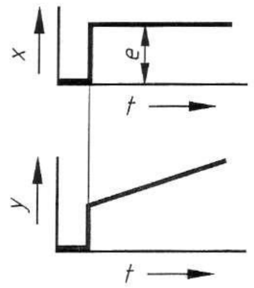
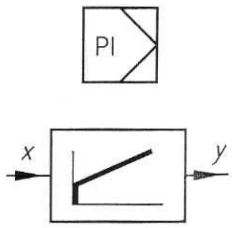
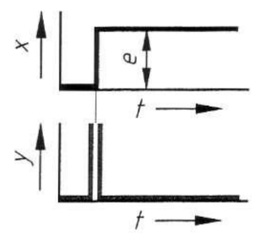
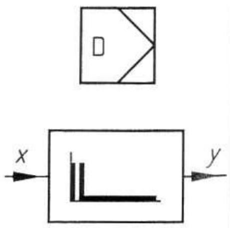
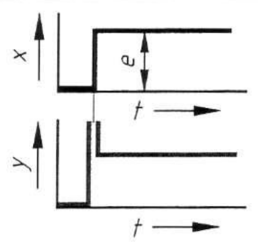
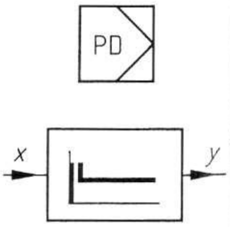
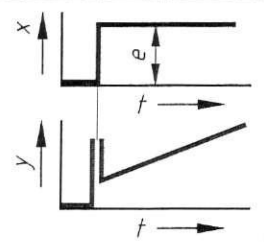
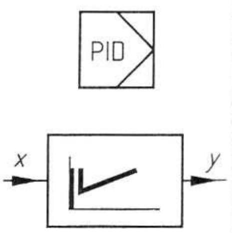
Example: Temperature controller



Analog (continuous) controllers

cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

In analog controllers the manipulated variable *y* may assume any desired value within the control range.

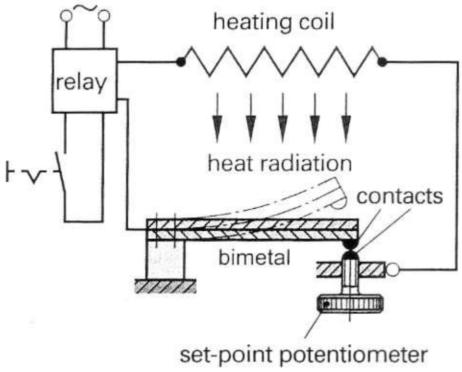
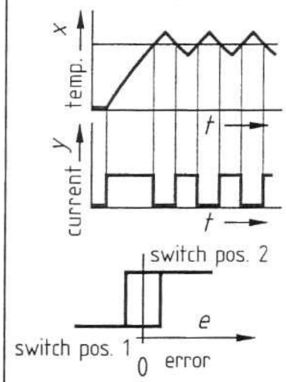
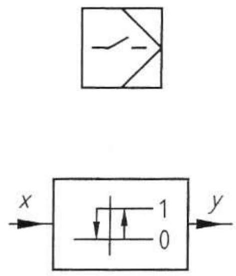
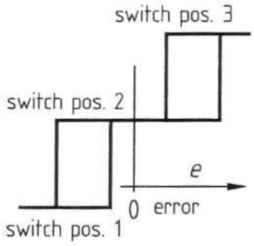
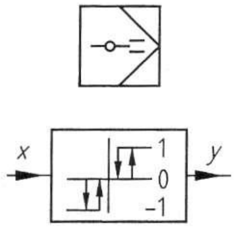
Controller design	Level control example, description	Transition function	Symbol[1] Block representation[2]
		x controlled variable *y* manipulated variable *e* error	—— step function[3] —— step response[4]
P-controllers Proportional controllers Output variable is proportional to input variable. P-controllers have steady-state errors.			
I-controllers Integral controllers I-controllers are slower than P-controllers, but they eliminate all errors.			
PI-controllers Proportional integral controllers In PI-controllers a P-controller and a I-controller are connected in parallel.			
D-controllers Derivative controllers	D-controller systems only occur with P- or PI-controller systems, since pure D-controller behavior with constant error does not provide any manipulated variable and therefore no closed loop control.		
PD-controllers Proportional derivative controllers	PD-controllers are created when a P controller and a D element are connected in parallel. The D part changes the output variable at a rate proportional to the rate of change of the input variable. The P part changes the output variable so that it is proportional to the input variable itself. PD-controllers act quickly.		
PID-controllers Proportional integral derivative controllers	PID-controllers are created by connecting P, I and D-controllers in parallel. Initially the D part reacts with a large change to the control signal, afterwards this change is reduced to approximately the magnitude of the P element, and finally the effect of the I element causes the response to rise linearly.		

1) Symbol as per DIN 19227-2
2) Block representation as per DIN 19226-2
3) Signal curve at controlled system input
4) Signal curve at controlled system output

Switching (discontinuous) controllers

cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

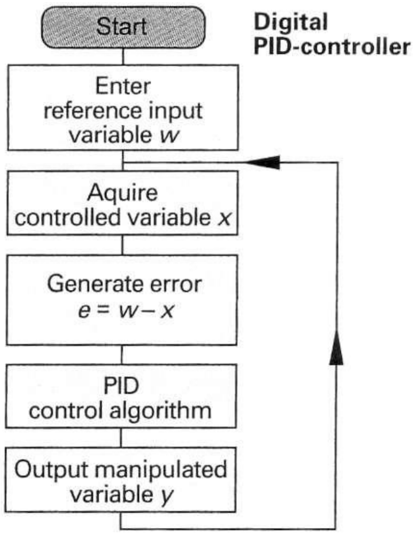
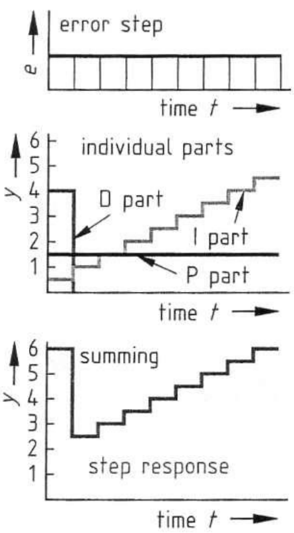
Switching controllers change the manipulated variable *y* discontinuously by switching in several steps.

Controller design	Example, description	Transition function, switching behavior	Symbol Block representation
Two-point controller			
Three-point controller	**Air conditioning system** In an air conditioning system three temperature ranges are assigned three switch positions: – heating ON – heating/cooling OFF – cooling ON		

Digital controllers (software controllers)

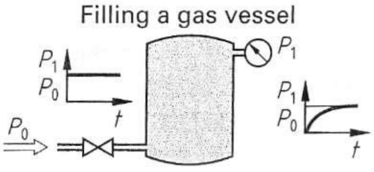
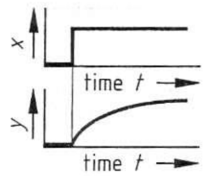
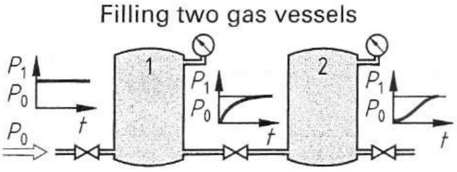
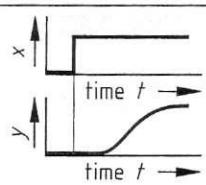
cf. DIN 19225 (1981-12) and DIN 19226-2 (1994-02)

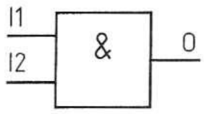
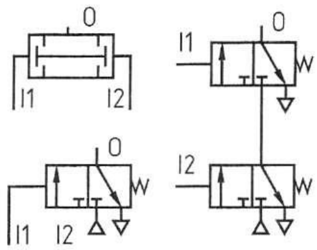
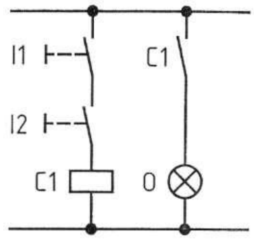
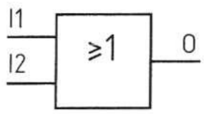
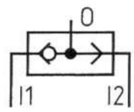
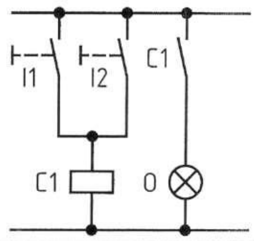
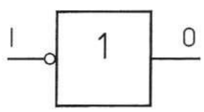
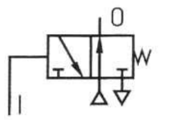
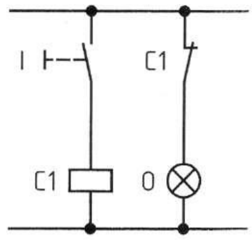
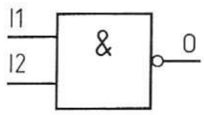
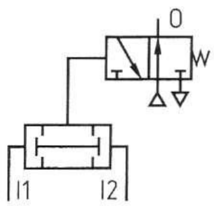
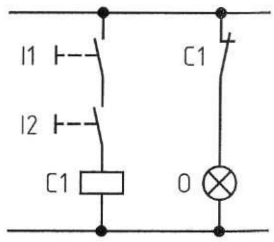
The operating mode of the digital controller is implemented as a computer program.

Controller design	Example (simplified)	Transient function	Explanation
Computers **Programmable Logic Controllers (PLC)** **Microcontrollers** **Microprocessors**			The computer program has the following tasks: – generate error *e* – calculate the manipulated variable *y* based on programmed control algorithms At the step response all P, D and I-parts are summed. Sampling of analog signals and their conversion to digital values and internal program flow causes a time delay of the controlled variable *x* (similar to a T-controlled system).

P-controlled systems with time delay (T part)

cf. DIN 19226-2 (1994-02)

Controller design	Example	Transient function	Explanation
P-controlled system with delay 1st order (P-T_1 controlled system)	Filling a gas vessel 		If the pressure vessel is filled by a flow of gas, pressure p_1 in the vessel gradually reaches the pressure of the gas flow.
P-controlled system with delay 2nd order (P-T_2 controlled system)	Filling two gas vessels 		If two vessels are connected in series, pressure p_2 increases in the second vessel slower than pressure p_1 in the first vessel.

<table>
<tr><th rowspan="2">Function</th><th rowspan="2">Circuit symbols
Logical equation</th><th rowspan="2">Function table</th><th colspan="2">Technical implementation</th></tr>
<tr><th>pneumatic</th><th>electric</th></tr>
<tr><td>AND</td><td>
$O = I1 \wedge I2$</td><td><table><tr><th>I1</th><th>I2</th><th>O</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td><td></td><td></td></tr>
<tr><td>OR</td><td>
$O = I1 \vee I2$</td><td><table><tr><th>I1</th><th>I2</th><th>O</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>1</td></tr></table></td><td></td><td></td></tr>
<tr><td>NOT</td><td>
$O = \overline{I}$</td><td><table><tr><th>I1</th><th>O</th></tr><tr><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td></tr></table></td><td></td><td></td></tr>
<tr><td>NOT
AND
(NAND)</td><td>
$O = \overline{I1 \wedge I2}$</td><td><table><tr><th>I1</th><th>I2</th><th>O</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td><td></td><td></td></tr>
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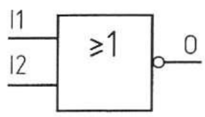
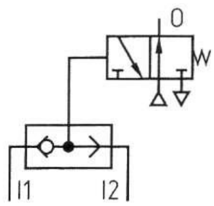
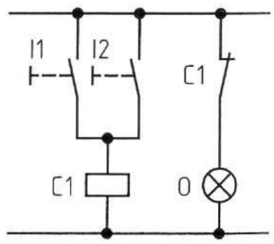
(NOR)</td><td>
$O = \overline{I1 \vee I2}$</td><td><table><tr><th>I1</th><th>I2</th><th>O</th></tr><tr><td>0</td><td>0</td><td>1</td></tr><tr><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>0</td><td>0</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td><td></td><td></td></tr>
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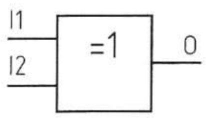
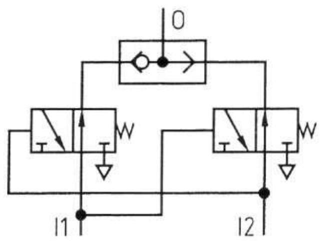
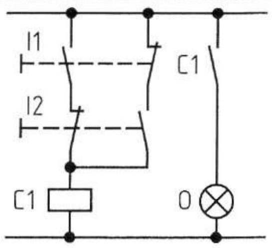
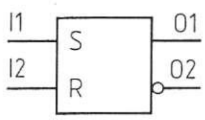
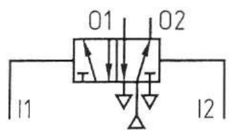
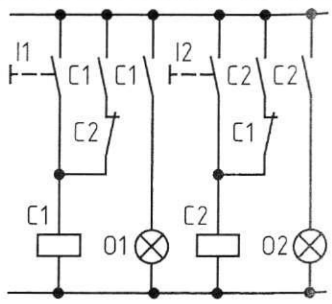
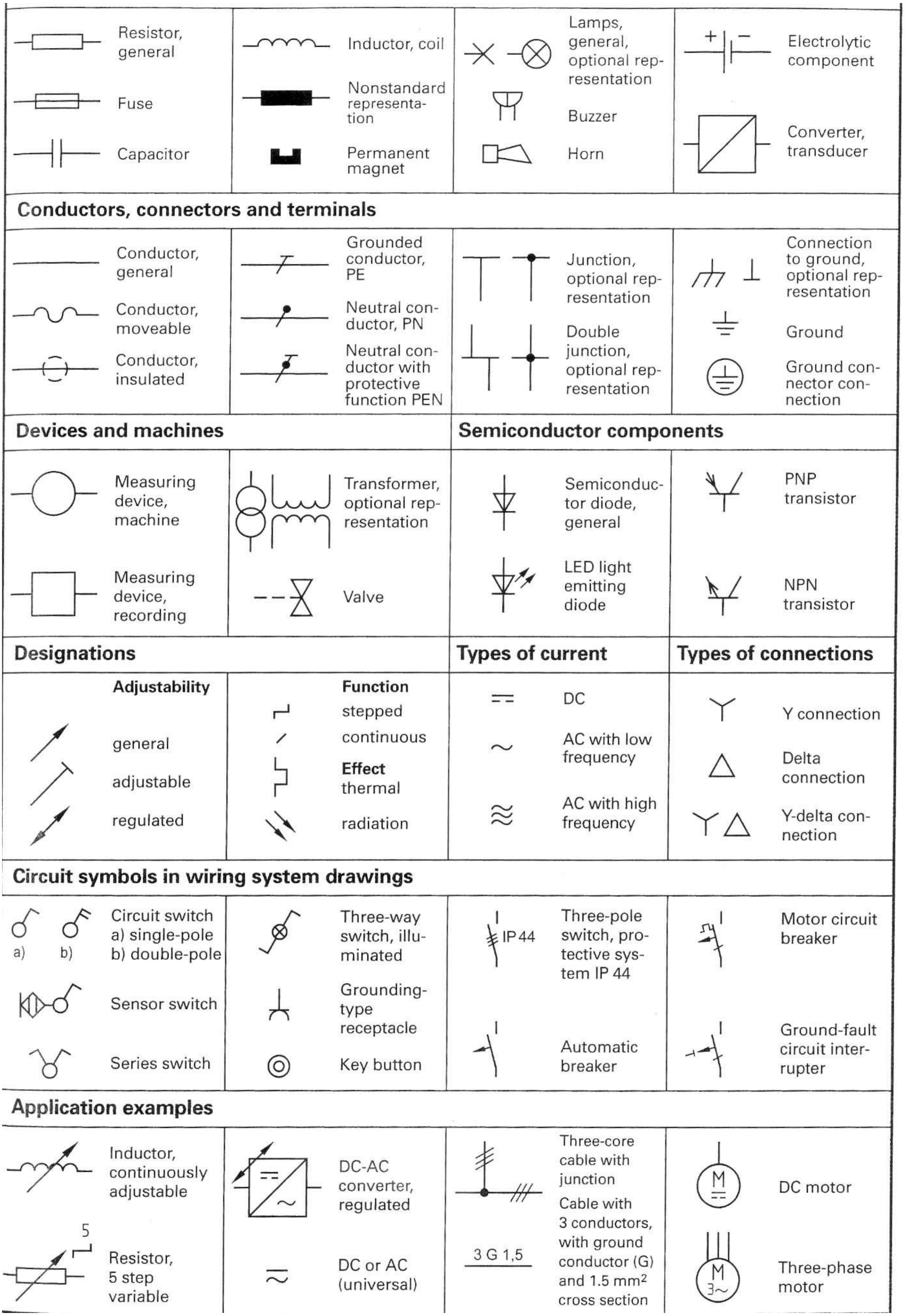
OR
(XOR)</td><td>
$O = (I1 \wedge \overline{I2}) \vee (\overline{I1} \wedge I2)$</td><td><table><tr><th>I1</th><th>I2</th><th>O</th></tr><tr><td>0</td><td>0</td><td>0</td></tr><tr><td>0</td><td>1</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>1</td><td>0</td></tr></table></td><td></td><td></td></tr>
<tr><td>Memory
(RS flip-flop)</td><td>
S set
R reset</td><td><table><tr><th>I1</th><th>I2</th><th>O1</th><th>O2</th></tr><tr><td>0</td><td>0</td><td>•</td><td>•</td></tr><tr><td>0</td><td>1</td><td>0</td><td>1</td></tr><tr><td>1</td><td>0</td><td>1</td><td>0</td></tr><tr><td>1</td><td>1</td><td>□</td><td>□</td></tr></table>• state unchanged condition
□ indeterminate state</td><td></td><td></td></tr>
</table>

I = inputs O = outputs, e.g. lamps C = relays, contacts

[redacted]

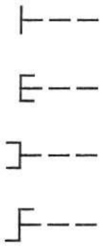
General circuit symbols



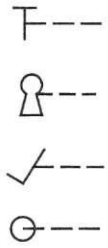
Relay contacts

- NO contact, normally open
- NC contact, normally closed
- Single pole double throw

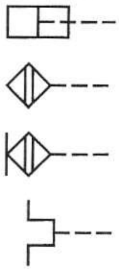
Actuation types



- Manual, general
- By pressing
- By pulling
- By turning

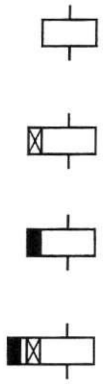


- By tilting
- By key
- By pedal
- By coil



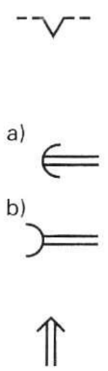
- By pressure energy
- By proximity
- By touching
- By bimetal (thermal)

Electromech. relays



- Relay coil, general
- Timer on delay
- Timer off delay
- Timer on off delay

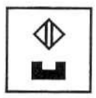
Switch behavior



- Lock, prevents automatic return
- Delayed action (parachute effect) for movement a) to the right b) to the left
- Symbol for "actuated state"

Sensors (Block representation)

Capacitive sensor, reacts to proximity of all substances

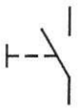


Magnetic sensor, reacts to close proximity of a magnet (reed switch)

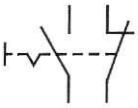
Inductive sensor, reacts to proximity of metals

Optical sensor, reacts to reflection of infrared beam

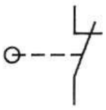
Examples of switch applications



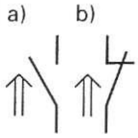
NO contact manually



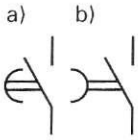
Double pole single throw



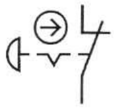
NC contact with roller actuation



a) NC contact b) NO contact Representation in actuated condition



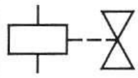
NO contact a) closes b) delayed opening when actuated



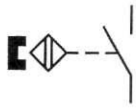
Emergency palm button

Limit switch, NO contact

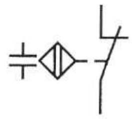
Limit switch, NC contact



Valve with electro-magnetic actuation



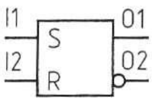
Magnetic proximity switch with NO contact, reacts to proximity of magnetic material.



Capacitive proximity switch with NC contact, reacts to proximity of all materials.

Flip-flop elements

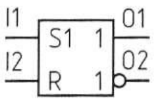
RS[1] flip-flop



Function table[2]

I1	I2	O1	O2
0	0	●	●
0	1	0	1
1	0	1	0
1	1	□	□

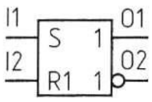
RS flip-flop set dominant



Function table

I1	I2	O1	O2
0	0	●	●
0	1	0	1
1	0	1	0
1	1	1	0

RS flip-flop reset dominant



Function table

I1	I2	O1	O2
0	0	●	●
0	1	0	1
1	0	1	0
1	1	0	1

Flip-flops are integrated circuits which store signal conditions.

1) R = reset
S = set

2) ● unchanged state
□ indeterminate state

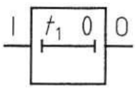
The numeral 1 after an R or S input indicates that the logical state of this input is dominant.

If a signal simultaneously lies at inputs I1 and I2 (I1 = 1 and I2 = 1) the following applies:

Input without the numeral 1 (R for set dominant, S for reset dominant RS flip-flop) is always set to logical state 0.

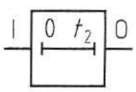
Delay elements

With rise-delay time



When a signal is applied to input I, output O assumes value 1 after time t_1 elapses.

With turn-off delay



With loss of a signal at input I, output O takes the value 0 after completion of time t_2.

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Designation of devices in circuit diagrams

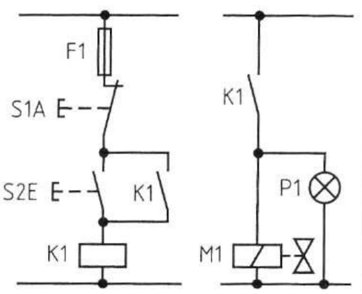
Example: S 2 E

Type of device	Sequential number	Device function

Code letters for type (selection)	
B	Sensor, proximity switch
F	Fuse
K	Switch relay, timed relay
Q	Circuit breaker, contactor
M	Solenoid valve, solenoid
P	Indicator light, horn
R	Resistor
S	Control switch, push-button switch

Code letters for function (not standardized)	
A	Function OFF
B	Direction of movement
E	Function ON
G	Test
K	Jog operation
S	Save, set
R	Clear, reset

Example of circuit diagram



Designation of wires and connections

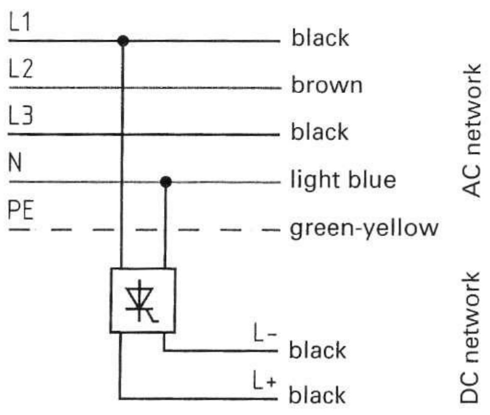
cf. DIN EN 60446 (1999-10) and DIN EN 60445 (2000-08)

Insulated wires

Type of wire		Designation: Code letters	Designation: Wire color	Designation: Symbols
DC network	positive	L+	black[1]	+
	negative	L–	black[1]	–
	neutral wire	M	light blue	
AC network	Phase conductor 1	L1	black[1]	
	Phase conductor 2	L2	black[1]	
	Phase conductor 3	L3	black[1]	
	neutral wire	N	light blue	
Ground wire		PE	green-yellow	
PEN wire (neutral wire with ground function, PE + N)		PEN	green-yellow[2]	
Ground		E	black[1]	

Example

Rectifier circuit

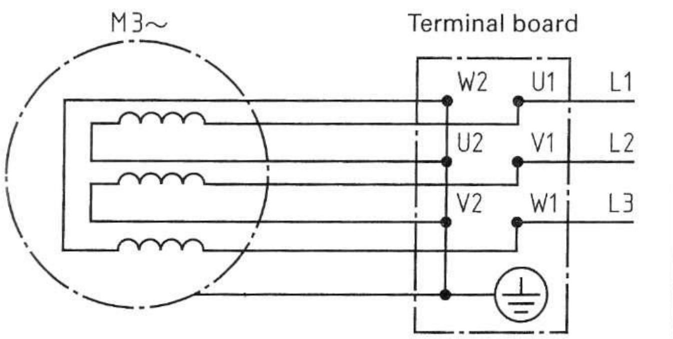


Device connections

Connections for	Designation
Phase conductor 1	U
Phase conductor 2	V
Phase conductor 3	W

Example

Star-connected (squirrel) cage motor



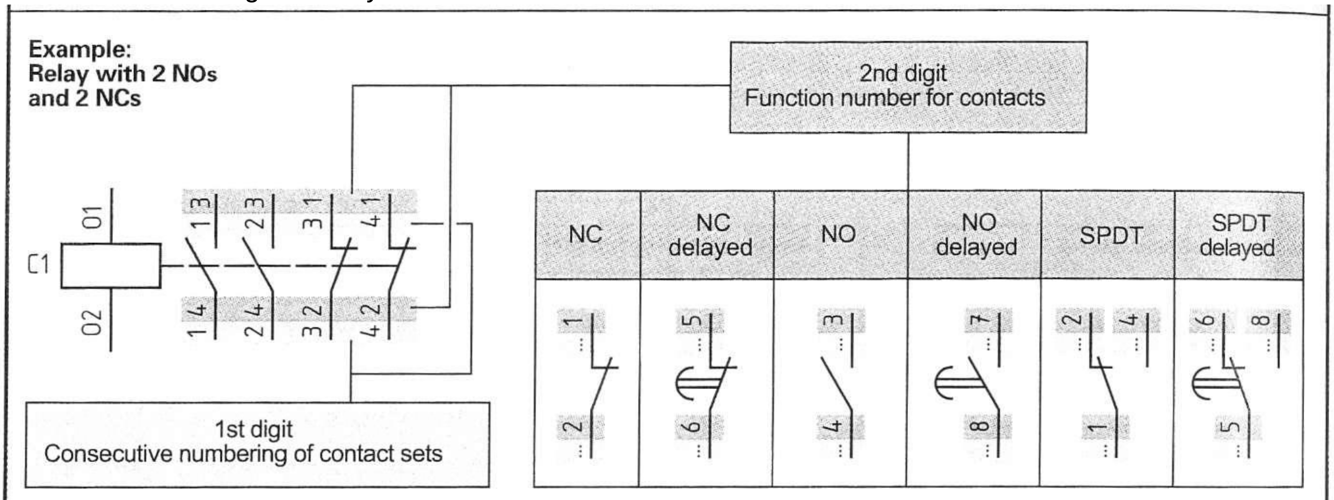
[1] Color is unspecified. Black is recommended, brown to differentiate. Green-yellow may not be used.

[2] PEN-wires have a continuous green-yellow conductor color. To avoid confusion with PE wires, PEN wires are additionally marked with light blue on the ends of the wires, e.g. with a wire clip or adhesive tape.

*) According to European Standards

[redacted]

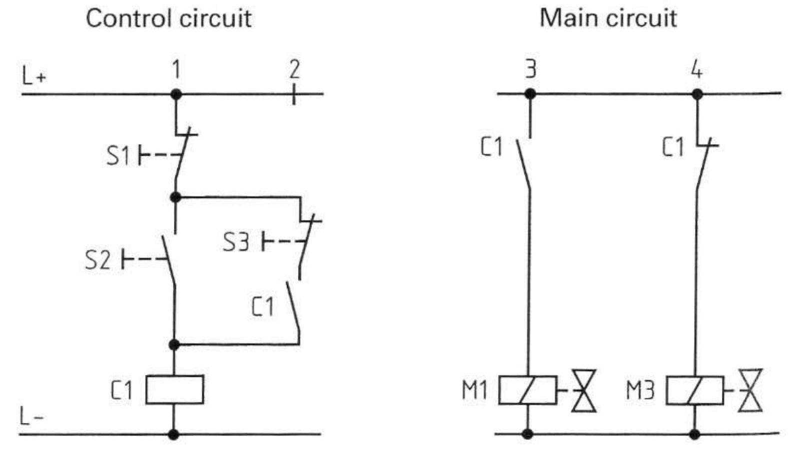
Connector markings on relays



Designing circuit diagrams

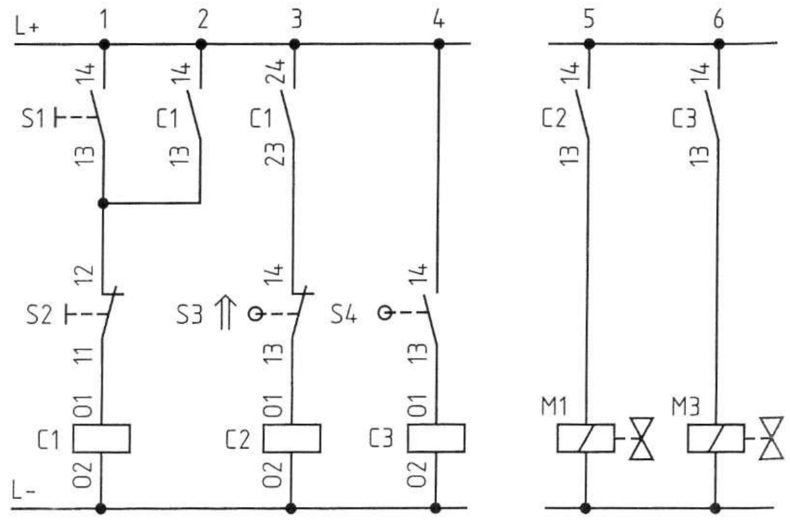
Current sections and distribution of electric circuits

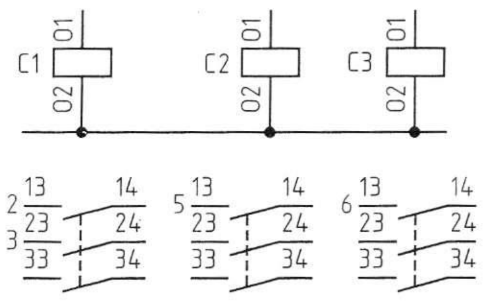
- Every electrical device is shown with a vertical current section regardless of the actual spatial arrangement of the elements.
- Current sections are numbered sequentially from left to right.
- The **control circuit** contains devices for signal input and signal processing.
- The **main circuit** contains the necessary final control elements for the working elements.
- The spatially shared devices, e.g. relay coil and relay contact, are not represented.



Designation of devices

- Contacts and the associated relay coils are marked with the same code numeral.
  Example: Current sections 1, 2 and 3
- 2 NO contacts belong to relay coil C1, both marked as C1. They are used to latch the relay coil.
- All contacts of a relay are entered as a complete contact set or as a table under the current path of the relay. Both representations indicate the current section on which a contact is located.





Representation as contact set

Contacts C1	Section
13 – 14 23 – 24	2 3

Contacts C2	Section
13 – 14	5

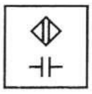
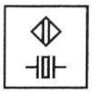
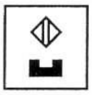
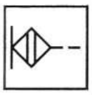
Contacts C3	Section
13 – 14	6

Representation as table

Sensors (selection)

- **Sensors**
  - Sensors that are sensitive to proximity
    - Inductive sensors
    - Capacitive sensors
    - Photoelectric sensors
    - Ultrasound sensors
    - Magnetic sensors
  - Tactile sensors
    - Limit switches

Characteristics of sensors

Sensor type	Symbol	Principle	Advantages	Disadvantages	Object distance
Inductive		Triggers if an object interferes with the alternating magnetic leakage field of the sensor	High degree of protection (IP67), very high switch point precision, dirt tolerant	Only objects with high electrical conductivity, unsuitable where there is greater accumulation of metal chips	1 mm to 150 mm
Capacitive		Triggers if an object interferes with the alternating electric leakage field of the sensor	High degree of protection (IP67), detects all materials; dirt tolerant	Small object distances, larger design than comparable inductive sensors	20 mm to 40 mm
Photoelectric		Triggers if an object returns the infrared field of the sensor	Detects all materials, large distances	Sensitive to dirt, smoke and secondary light, auxiliary power necessary	approx. 2 m
Ultrasound		Evaluates transit times of reflected ultrasonic pulses to determine the distance to an object	Tolerant to dust, dirt and light; detects very small objects at large distances	Slow, use only with standard pressure, not in areas subject to explosion hazards and no high-frequency noise	60 mm to 6 m
Magnetic		A permanent magnet actuates a proximity switch (reed contact) using two contact springs	Suitable in rough environment, high service life, suitable for switches in high frequency circuits	Risk of contact welding; suppresses the current peaks of RC modules	–
Mechanical		Triggered by manual actuation or lever system	Low price, robust, small, unaffected by interference fields, no auxiliary power necessary	Contact chatter, not allowed in food and chemical industries	–

Designation of proximity sensors

cf. DIN EN 60947-5-2 (2004-11)

Example: **U 1 A30 A F 2 N**

Type of detection	Mechanical mounting conditions	Design and size	Circuit element function	Type of output	Type of connection	NAMUR function
I inductive C capacitive U ultrasound D photoelectric diffuse reflected luminous beam M magnetic R photoelectric reflected luminous beam T photoelectric direct luminous beam	1 flush mounting possible 2 flush mounting not possible 3 unspecified	FORM A cylindrical threaded sleeve B smooth cylindrical sleeve C rectangular with square cross-section D square, with rectangular cross-section SIZE (2 digits) for diameter or side length	A NO contact B NC contact C single pole double throw P programmable by user S other	P PNP output, 3 or 4 DC connections N NPN output, 3 or 4 DC connections D 2 DC connections[1] F 2 AC connections[2] U 2 AC or DC connections S other	1 integrated connection line 2 plug connection 3 screw connection 4 : 8 unused 9 other type of connection	N NAMUR[3] function Note: NAMUR sensors are 2 wire sensors that are connected to an external switching amplifier

[1] DC = Direct Current
[2] AC = Alternating Current
[3] NAMUR = **N**ormen**a**rbeitsgemeinschaft für **M**ess- **u**nd **R**egelungstechnik (Standardization Association for Measurement and Control)