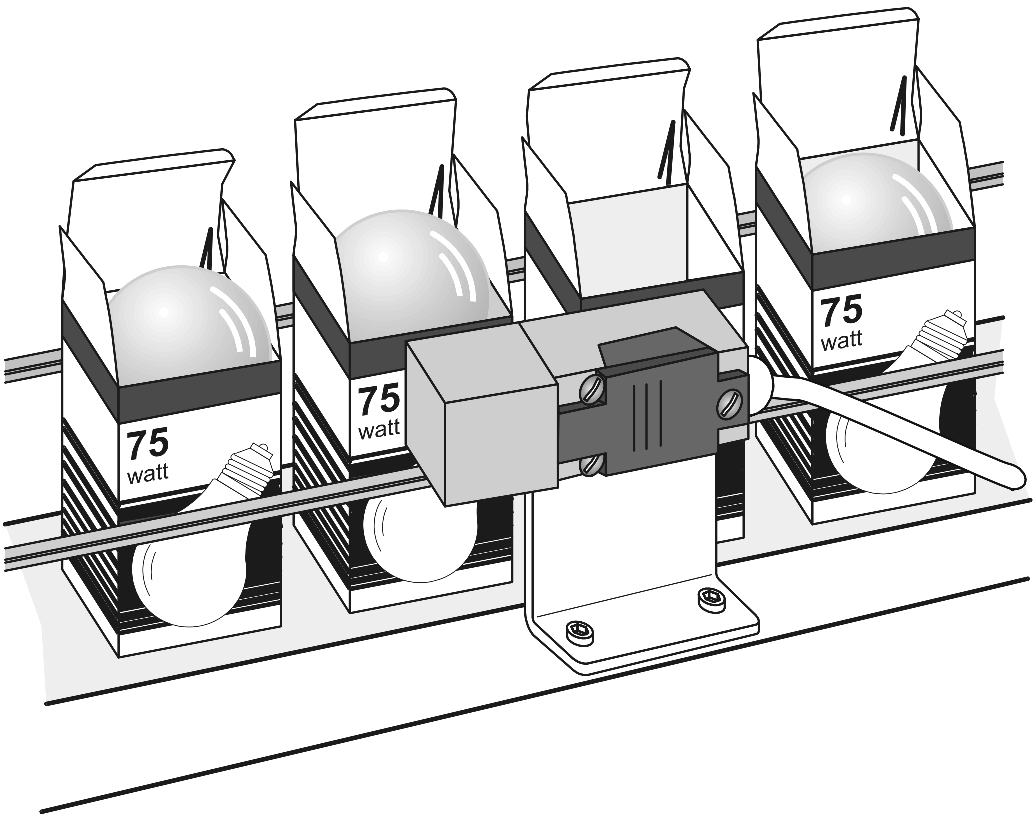
FESTO

Sensors for handling and processing technology

Proximity sensors

Textbook FP 1110



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Contents

Notes on the layout of this book

This textbook forms part of the Function Package FP 1110 "Proximity Sensors" and belongs to the Learning System for Automation and technology by Festo Didactic GmbH & Co. KG.

In this book the trainee becomes familiarised with the subject of proximity sensors. The function package serves both, as a support for vocational and further training programs as well as for self-instruction. The function package consists of an equipment set and training documentation.

Chapter 1 to 10 introduce the area of proximity sensors with notes on application, mode of operation and characteristics. The fundamental basics are taught and with the help of exercises the trainee is guided towards independent problem solving of the various applications of proximity sensors. Solutions to these exercises are contained in chapter 16.

Chapter 11 to 15 deal with the physical and technical fundamentals of individual types of proximity sensors and contains a list of technical terms as well as an overview of the applicable standards. In addition, examples of special variants of proximity sensors are described in detail.

The index at the end of the book makes it possible to look up information with the help of key words.

When conducting practical exercises with the equipment sets of Function Package FP 1110, an additional workbook (Order no. 529 939) with exercises and a collection of component data sheets are available as a supplement.

1. General notes

1.1
The importance of sensor technology

The ever increasing automation of complex production systems necessitates the use of components which are capable of acquiring and transmitting information relating to the production process.

Sensors fulfil these requirements and have therefore in the last few years become increasingly important components in measuring and in open and closed loop control technology. Sensors provide information to a controller in the form of individual process variables.

Process status variables, for instance, are physical variables such as temperature, pressure, force, length, rotation angle, container level, flow etc.

There are sensors for most of these physical variables which react to one of these variables and pass on the relevant signals.

1.2
Terms

1.2.1 Sensor
A sensor is a technical converter, which converts a physical variable (e.g. temperature, distance, pressure) into a different, more easily evaluated variable (usually an electrical signal).

Additional terms for sensors are:
Encoders, effectors, converters, detectors, transducers.

The designation "measuring sensor" should be avoided. In sensing terms, a "displacement encoder" does not cause displacement, but rather records the "displacement" variable.

A sensor does not necessarily have to generate an electrical signal.

Example
– Pneumatic limit valves generate a pneumatic output signal (in the form of a pressure change).

Sensors are devices which can operate both by means of contact, e.g. limit switches, force sensors, or without contact, e.g. light barriers, air barriers, infrared detectors, ultrasonic reflective sensors, magnetic sensors etc.

Even a simple limit switch can be interpreted as a sensor.

Within a controlled process, sensors represent the "perceivers" which monitor a process by signalling faults and logging statuses and transmitting such information to other process components.

To quote a human example:
Eye → brain (visual faculty) → limbs

A sensor becomes useful only with regard to processing or evaluating.
e.g. Eye + visual faculty → outline recognition, colour, 3D-vision, motion sequences

1.2.2 Sensor component

Apart from the word "sensor", the following terms are also used:
By a sensor component we are talking about the part of a sensor or sensor system, which records a measured variable, but does not permit an independent utilization, because additional signal processing and pre-assembling (housing, connections) are required.

1.2.3 Sensor system

A sensor system consists of several measuring and evaluating components, often with a significant proportion of signal processing functions.

The components are often modular and can be interchanged within a product family. Apart from sensors, signal processors, micro computers and data compatible interfaces are also available for signal conditioning.

Example
– Image processing systems with CCD image sensor,
– Laser measuring systems, identification systems.

In the case of signal processing capabilities, one speaks of intelligent sensors or "smart sensors".

1.2.4 Multi-sensor system

Sensor system with several similar or different types of sensors.

Example

- A temperature and humidity sensor or a pressure and temperature sensor, each forming part of the same device.
- A combination of several proximity sensors to distinguish shape and material of workpieces.
- A combination of several chemical sensors for gases, whereby sensors have overlapping response ranges and by means of intelligent evaluation provide more information as a whole than an individual sensor.
- Use of several human sense organs (smell, taste, optical perception, feeling by tongue) during the intake of food.

1.3 Typical output signals of sensors

When using sensors, it is important to know the different types of electrical output signals.

Type A

Sensors with switching signal output (binary signal output).

Examples
- Proximity sensors
- Pressure sensors
- Filling level sensor
- Bimetal sensor

As a rule, these sensors can be connected directly to programmable logical controllers (PLC).

Type B

Sensors with pulse rate output.

Examples
- Incremental length and rotary angle sensors.

Generally, PLC-compatible interfaces are available. PLC requirements: Hardware and software counters with the possibility of greater word length.

Type C

Sensor components with analogue output and without integrated amplifier and conversion electronics, which provide very small analogue output signals not for immediate evaluation (e.g. in the millivolt range) or a signal which is to be evaluated only by using additional circuitry.

Examples
- Piezoresistive or piezoelectric sensor components
- Pt-100- or thermoelectric cells
- Magnetoresistor and Hall sensor components
- pH- and conductivity measuring probes
- Linear potentiometer

These are often applications where, in the case of high production, the user chooses his own electronic solutions.

Type D

Sensors with analogue output and integrated amplifier and conversion electronics providing output signals which can be immediately evaluated.

Typical example of output signals
- 0 to 10 V
- 1 to 5 V
- -5 to +5 V
- 0 to 20 mA
- 4 to 20 mA
- -10 to +10 mA

Type E

Sensors and sensor systems with standardised signal output, e.g. RS-232-C, RS-422-A, RS-485 or with data bus interfaces such as field bus (Profibus, sensor-actuator-bus).

1.4 Binary and analogue sensors

1.4.1 Binary sensors

Binary sensors are sensors which convert a physical quantity into a binary signal, mostly an electrical switching signal with the status "ON" or "OFF".

Examples of binary sensors

- Limit valve
- Examples of binary sensors
- Proximity sensor
- Pressure sensor
- Filling level sensor
- Temperature sensor

1.4.2 Analogue sensors

Analogue sensors are sensors which convert a physical quantity into an analogue signal, mostly an electrical analogue signal such as voltage or current.

Examples of analogue sensors

- Sensors for length, distance, displacement
- Examples of analogue sensors
- Sensors for linear and rotational movement
- Sensors for surface, form, geometry
- Force sensors
- Weight sensors
- Pressure sensors
- Sensors for torque
- Flow sensors (for gases and fluids)
- Throughput sensors (for solid materials)
- Filling level sensors
- Sensors for temperature/other thermal values
- Sensors for optical values
- Sensors for acoustic values
- Sensors for electromagnetic values
- Sensors for physical radiation
- Sensors for chemical substances
- Sensors for physical matter characteristics

1.5 Proximity sensors

In this textbook, sensors dealing with "discrete position" form the main topic, i.e. sensors which detect whether or not an object is located at a certain position. These sensors are known as proximity sensors. Sensors of this type provide a "Yes" or "No" statement depending on whether or not the position, to be defined, has been taken up by the object. These sensors, which only signal two status, are also known as binary sensors or in rare cases as initiators.

With many production systems, mechanical position switches are used to acknowledge movements which have been executed. Additional terms used are microswitches, limit switches or limit valves. Because movements are detected by means of contact sensing, relevant constructive requirements must be fulfilled. Also, these components are subject to wear. In contrast, proximity sensors operate electronically and without contact.

The advantages of contactless proximity sensors are:

- Precise and automatic sensing of geometric positions
- Contactless sensing of objects and processes; no contact between sensor and workpiece is required with electronic proximity sensors
- Fast switching characteristics; because the output signals are generated electronically, the sensors are bounce-free and do not create error pulses.
- Wear-resistant function; electronic sensors do not include moving parts which can wear out
- Unlimited number of switching cycles
- Suitable versions are also available for use in hazardous conditions (e.g. areas with explosion hazard).

Today, proximity sensors are used in many areas of industry for the reasons mentioned above. They are used for sequence control in technical installations and as such for monitoring and safeguarding processes. In this context sensors are used for early, quick and safe detection of faults in the production process. The prevention of damage to man and machine is another important factor to be considered. A reduction in downtime of machinery can also be achieved by means of sensors, because failure is quickly detected and signalled.

1.5.1 Overview of position sensors

Fig. 1.5.1 illustrates the different types of contactless position sensors in separate groups according to physical principles and type, whereby basically each sensor type can be either an analogue or binary sensor. In this instance, we are only concerned with the binary type.

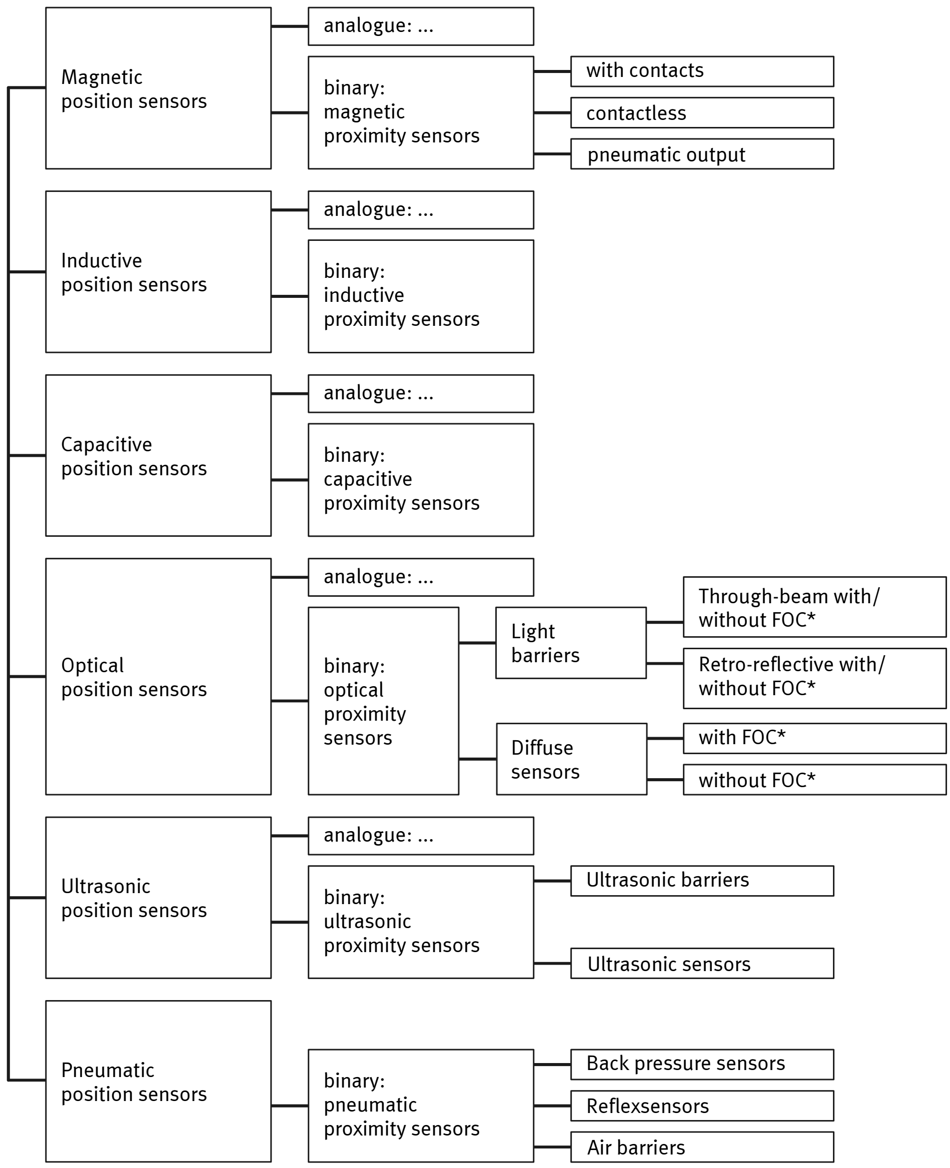


Fig. 1.5.1: Classification of sensors for position detection (FOC = Fibre optic cable)

1.5.2 Operating voltages

In European countries, proximity sensors are primarily operated with nominal 24 V DC, whereby sensors are generally designed for a range between 10 – 30 V or 10 – 55 V.

In South East Asia, North and South America as well as Australia and South Africa an estimated share of 30 % of inductive and optical proximity sensors are operated via AC supply.

Inductive, capacitive and optical proximity sensors are often available not only for DC but also for AC voltage, whereby the AC voltage is usually 24 V, 110 V, 120 V or 220 V. Inductive, capacitive and optical proximity sensors are also available in universal voltage designs, which can be connected to both DC and AC voltage, e.g. within a range of 12 – 240 V DC or 24 – 240 V AC. Other manufacturers, for instance, offer designs for 20 – 250 V DC AC voltage (e.g. 45 – 65 Hz). An alternative term used is universal current design (UC).

1.6 Fields of application for proximity sensors

Typical fields of application for proximity sensors are in the areas of:
- Automotive industry
- Mechanical engineering
- Packaging industry
- Timber industry
- Printing and paper industry
- Drinks and beverages industry
- Ceramics and brick industry

The possibilities of application of proximity sensors in automation technology are so diverse and vast that it is impossible to provide a comprehensive description of these. This book therefore lists a selection of typical examples of possible applications.

Detecting objects

In applications to detect whether an object is available at a specific position; e.g. for the operation of pneumatic cylinders, electrical drives, grippers, protective guards, winding systems and doors.

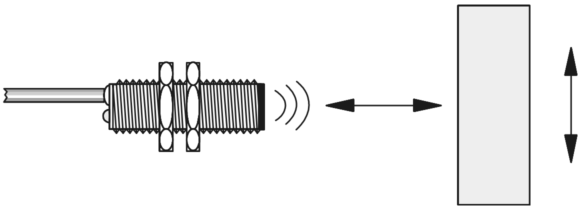


Fig. 1.6.1: Non-contacting actuation

Positioning

In workpiece positioning applications, e.g. in machining centres, workpiece transfer slides and pneumatic cylinders.

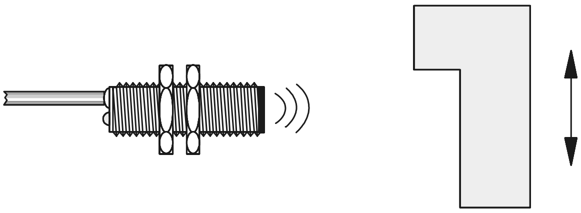


Fig. 1.6.2: Positioning

Counting

Counting application for parts and motion sequences, e.g. conveyor belts, sorting devices.

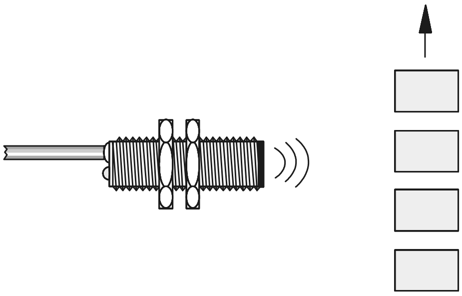


Fig. 1.6.3: Counting items

Measuring rotational speed

Application for measuring the speed of rotation, e.g. of gear wheels or for detecting zero-speed.

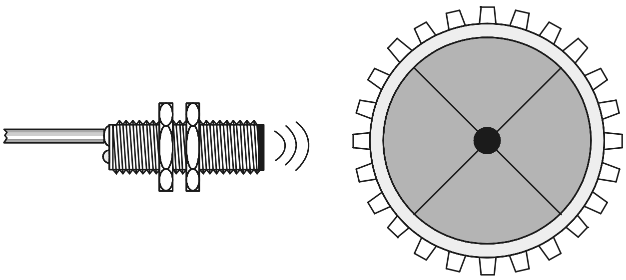


Fig. 1.6.4: Detection of rotational movements

Detecting materials

Application for material detection, e.g. for providing or sorting material (re-cycling).

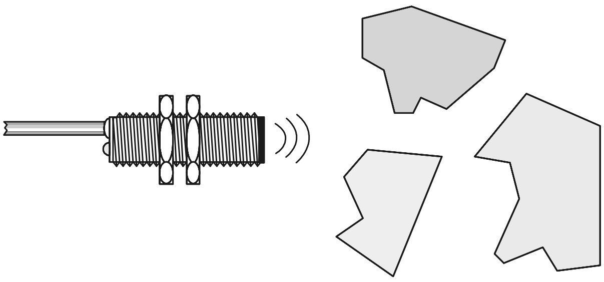


Fig. 1.6.5: Distinguishing materials

Defining direction

Application for defining the direction of linear or rotary movement, e.g. defining direction for parts sorting.

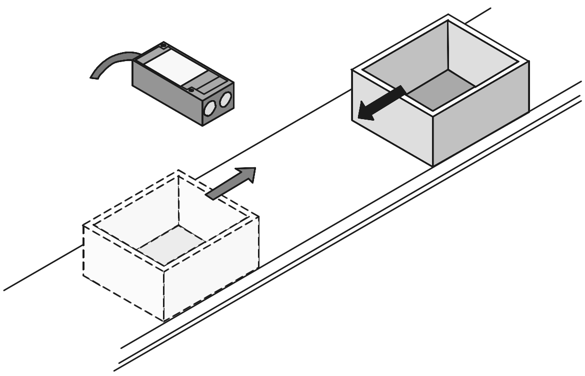


Fig. 1.6.6: Directional sensing

There are inductive sensors, which only detect the movement of an object in one direction, but not the opposite direction ("Idle return function", see chapter 15).

Monitoring tools

Tool monitoring applications.

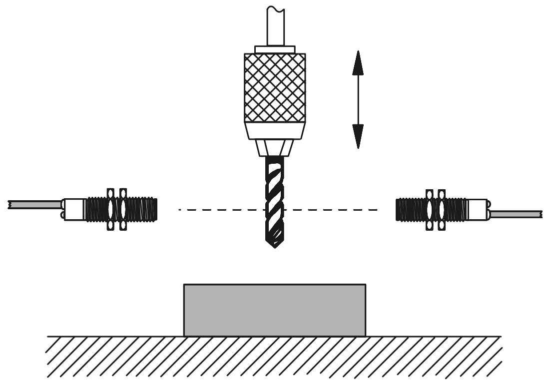


Fig. 1.6.7: Checking for drill breakage

Monitoring filling levels

Application for monitoring filling levels by means of optical, capacitive or ultrasonic proximity sensors.

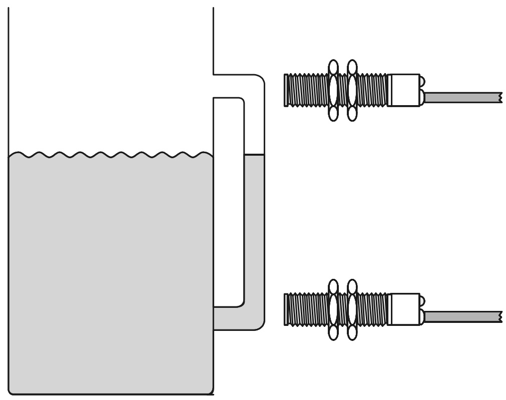


Fig. 1.6.8: Filling level limit switch

Measuring distance

Application for approximate distance measuring (distance x).

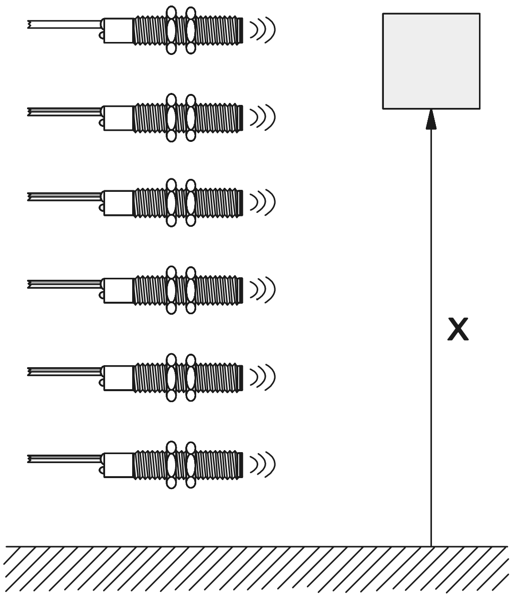


Fig. 1.6.9: Measuring distances

Measuring speed

Application for measuring speed (speed v).

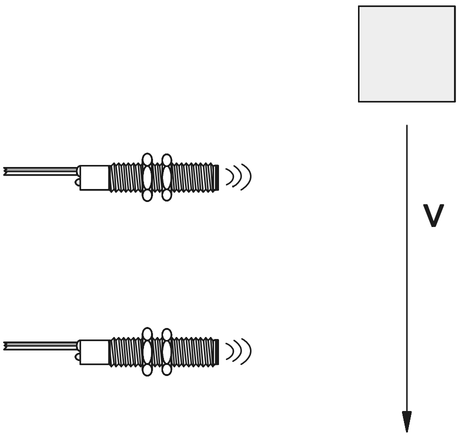


Fig. 1.6.10: Measuring the speed of a moving object

Accident protection

Application for protecting machinery against dangerous contact.

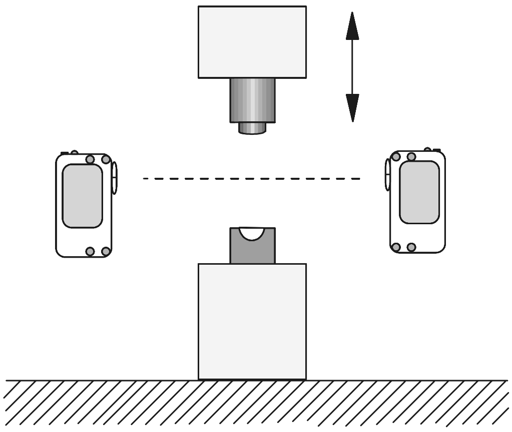


Fig. 1.6.11: Accident prevention, e.g. by means of sensors

Note

Light barriers used for accident prevention often have to satisfy certain conditions, which are laid down in specific regulations as required by the individual countries.

Contour recognition

Applications for the detection of the shape of an object by means of several proximity sensors arranged to sense the contours.

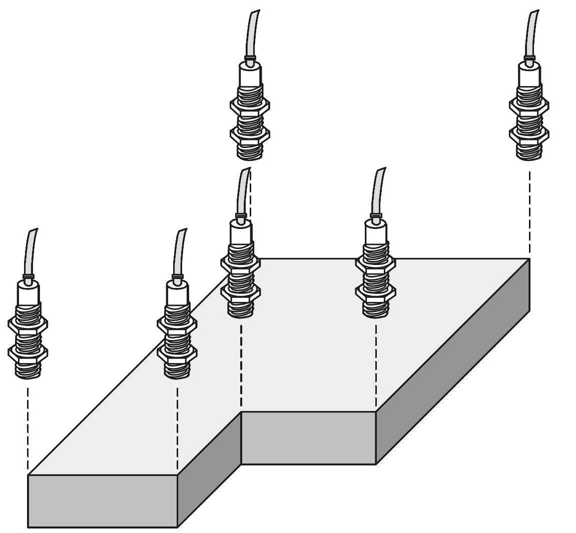


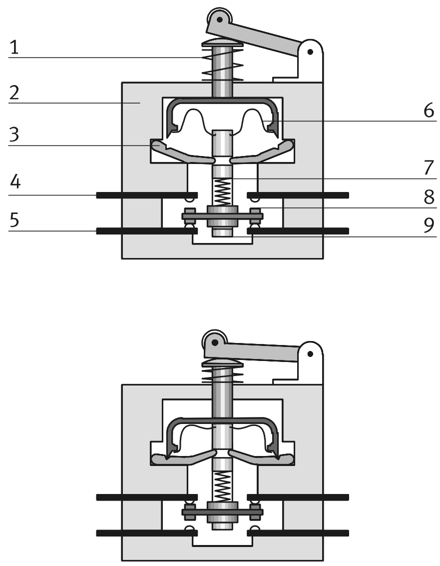
Fig. 1.6.12: Detecting the shape of an object

2. Mechanical position switches

2.1
Electro-mechanical position switches

2.1.1 Function description

With mechanical limit switches an electrical contact is established or interrupted by means of an external force. The contact service life would be a maximum of approximately 10 million switching cycles. Depending on design, relatively high electrical voltages and currents can be transmitted. In the case of a mechanical limit switch, the gap which separates two open contacts of different polarity is described as the contact gap. Switch-over times of mechanical micro limit switches are in the range of 1 – 15 ms. When electromechanical position switches are used for counting operations, contact bounce should be taken into consideration.



Compression spring (1)
Housing (2)
Detent lever (3)
Normally open contacts (4)
Normally closed contacts (5)
Arched spring (6)
Contact pressure spring (7)
Contact blade (8)
Guide bolt (9)

Fig. 2.1.1: Limit switch (unactuated and actuated position)

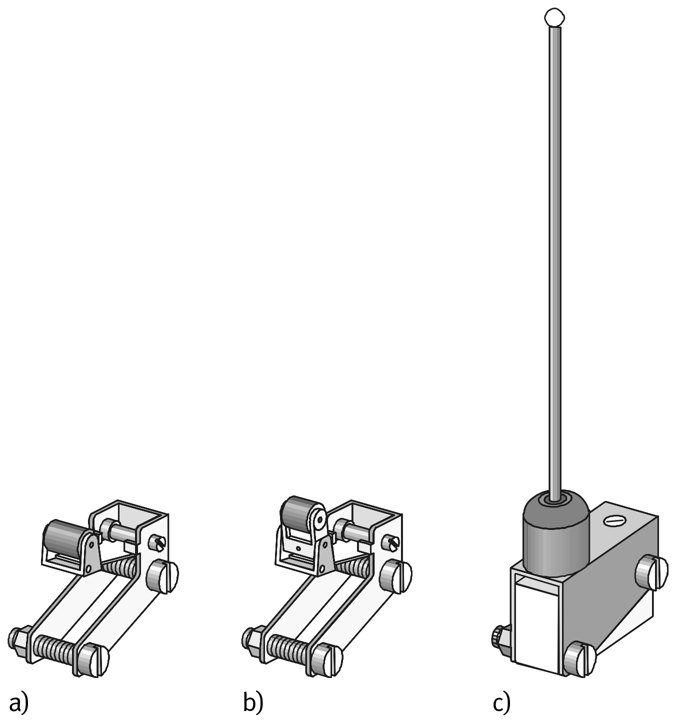
2.1.2 Technical characteristics

The following types of electro-mechanical position switches can be differentiated:
Miniature position switches, miniature and subminiature micro switches

- Control switches, limit switches
- Snap-action or slow make-and-break switches
- Unenclosed position switches
- Plastic-clad position switches
- Metal-clad position switches
- Safety position switches
- Precision position switches

The most important components of a mechanical micro limit switch are the contacts. The most widely used contact materials are: gold-nickel, fine gold, silver, silver-cadmium oxide, silver-palladium and silver-nickel. By making an appropriate choice of contact material, it is possible to achieve favourable operating conditions in any field of operation of limit switches.

By fitting actuators, limit switches can be used for a wide range of application possibilities. Typical types of such actuators are shown in the illustration.



a) Roller lever
b) Roller lever with idle return
c) Whisker actuator

Fig. 2.1.2: Actuators for mechanical limit switches

The table below lists the key technical data relating to micro switches. The figures listed in this table are typical examples and merely provide an overview.

Parameter	**Value**
Switching capacity (resistive load)	24 V DC, 6 A 250 V AC, 6 A
Switching point accuracy	0.01 – 0.1 mm (Precision switch up to 0.001 mm)
Switching frequency	Approx. 60 – 400 switching operations/min.
Service life	10 Million switching cycles
Protection class (IEC 529, DIN40050)	IP00 – IP67

Table 2.1.1: Technical data of a micro switch

2.1.3 Notes on installation

Because limit switches are components of mechanical precision, the following must be observed with regard to installation:

- Accuracy with regard to assembly, (precise gap between switch actuating component and object)
- Rigidity of switch/mounting support connection
- Careful observation of the activating devices (approach from side or front)

Care must be taken when making the electrical connections. In the case of clamp or screw connections, connections must be insulated. If the cables are soldered on, care should be taken to avoid any heat damage to the switch housing during soldering. A distorted housing can lead to faulty functioning of the switch. The connecting lines to the limit switch are to be kept free of tension.

If the limit switch is to be approached directly, it should be noted that it cannot be used as a mechanical end stop (in normal cases).

There are many applications, where the disadvantages of mechanical limit switches, such as actuation through touch operation, contact bounce or wear, do not matter. In these cases, it is possible to take advantage of these moderately priced components.

Typical areas of application for mechanical limit switches include, for example. instances where there is noisy electrical environment as a result of electro-magnetic fields, such as in the case of welding facilities, where electronic proximity sensors can fail.

There are precision control switches with a very high switching point accuracy of e.g. 0.001 mm, which are suitable for accurate positioning tasks.

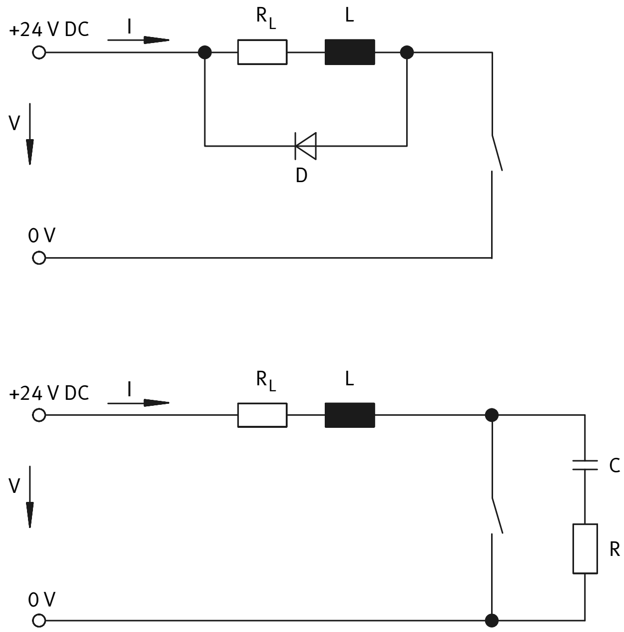
With electro-mechanical position switches, maximum current must be restricted as this can otherwise lead to arc discharge during switching on and off and therefore burning out of the contacts. A series resistor serves as a current limiter thus prolonging the service life of the contacts.

When switching inductive loads, a high voltage spike is created at the moment of cut-off. For this reason, a protective circuit must be provided for the position switch.

The protective circuit can either be a suitable RC element or a corresponding diode or Varistor (see circuit diagram). The electrical values of these components depend on the following power component (e.g. relay, contactor etc.).

If a relay or contactor is activated, it is essential that the technical data of the switch and the relay or contactor be observed.

The pull-in power of a relay or contactor is several times higher (8- to 10-fold) than the holding power. Therefore it is important that the pull-in power is used as a main reference.



Load resistance (R_L)
Inductance of load (L)
Protective resistor (R)
Protective capacitor (C)
Protective diode or varistor (D)

Fig. 2.1.3: Protective circuits for electro-mechanical position sensors

2.1.4 Examples of application

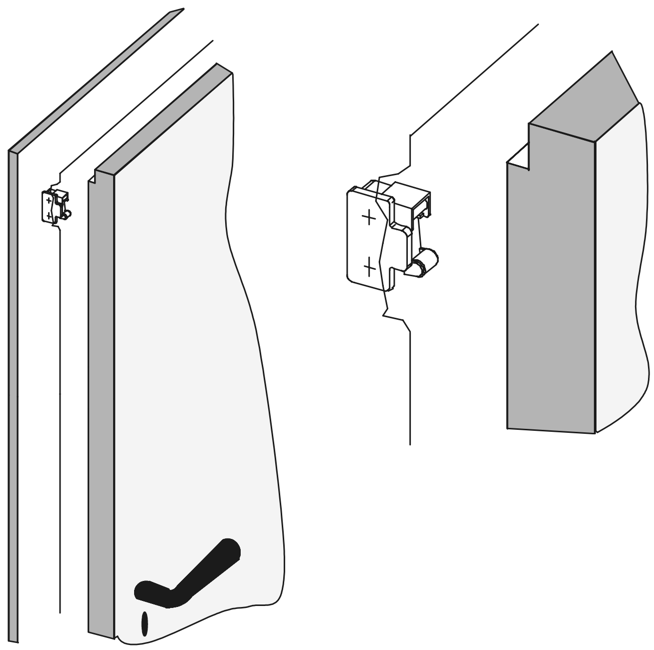


Fig. 2.1.4: Door monitoring

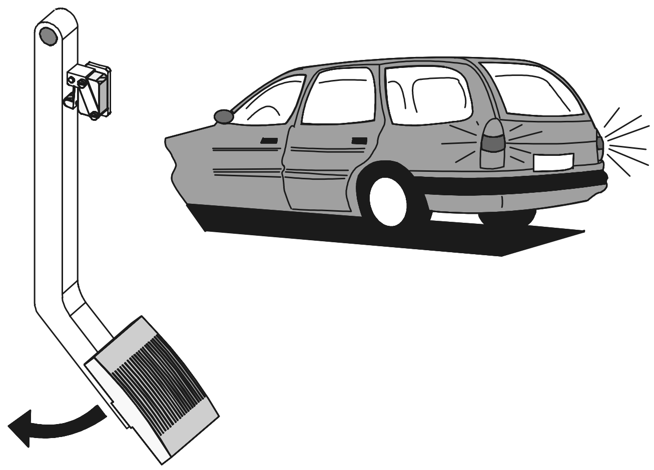


Fig. 2.1.5: Braking light switch

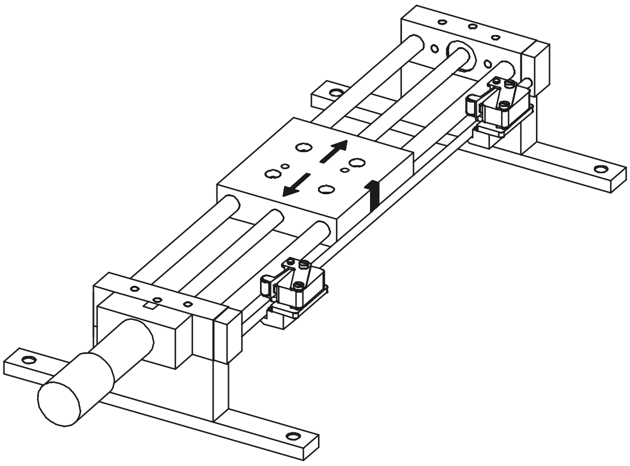
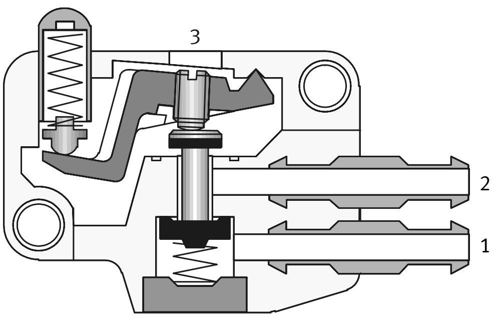


Fig. 2.1.6: End position checking of transfer unit

2.2 Mechanical-pneumatic position switches

2.2.1 Function description

With this type of proximity sensor, a pneumatic circuit is directly effected by means of the mechanical effect of an approaching object. A plunger, for example, actuates a pneumatic valve. As far as the design principles are concerned, this type of valve is similar to the previously described electro-mechanical position switches. However, they have the advantage that in view of the absence of electrical switching contacts, contact burn-out cannot occur.



Supply port (1) Working or output lines (2) Exhaust (3)

Fig. 2.2.1: Pneumatic position sensor (micro-stem valve)

2.2.2 Technical characteristics

The table below lists the key technical data relating to mechanical-pneumatic position sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	Value
Working pressure	-95 – +800 kPa (-0.95 – 8.0 bar)
Temperature range	-10 – +60 °C
Actuating force at 6 bar operating pressure	6 – 10 N
Switching point	pressure-dependent, varies max. 0.8 mm within pressure range of 0 – 800 kPa (0 – 8 bar)

Table 2.2.1: Technical characteristics of a mechanical-pneumatic position sensor

2.2.3 Notes on application

These limit switches are preferably for use in areas of application where pneumatic components are already in use. In this case, the supply of compressed air required for the switches is already available and a conversion of the switch output into an electrical value is not necessary.

2.2.4 Examples of application

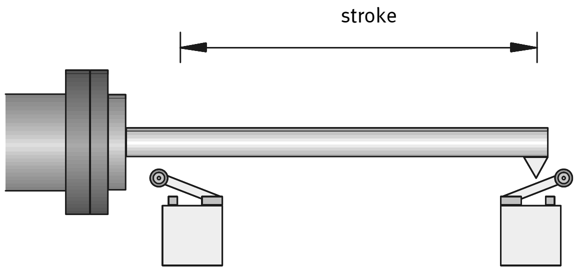


Fig. 2.2.2: Reversing of a double-acting cylinder by means of adjustable position sensors

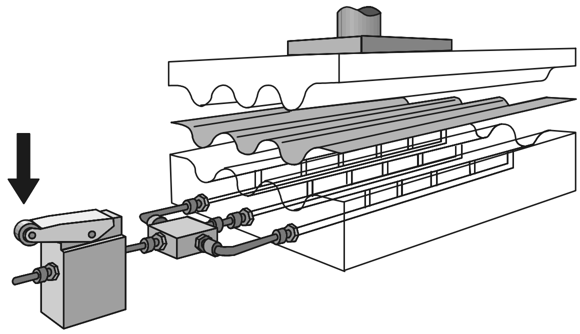


Fig. 2.2.3: Auxiliary function for lifting of thin workpieces

2.3
Exercises

Exercise 2.1

Protective circuits for electro-mechanical limit switches
Describe the different types of load which can occur with the connection of a limit switch. You do not need to take into account mixed types of load. Indicate the different options of protective circuits.

Exercise 2.2

Switching with low electrical power
A limit switch is to be used for switching very low power. The voltage is approx. 5 V DC, the current is less than 1 mA. At this level even the smallest amounts of dirt on the contacts can to lead to faults. Suggest a circuit, which overcomes this problem.

3. Magnetic proximity sensors

3.1
Reed proximity sensors

3.1.1 Function description

Magnetic proximity sensors react to the magnetic fields of permanent magnets and electro magnets.

In the case of a reed sensor, contact blades made of ferromagnetic material (Fe-Ni alloy, Fe = iron, Ni = nickel) are sealed in a small glass tube.

The tube is filled with an inert gas i.e. nitrogen (inert gas meaning a non active, non combustible gas).

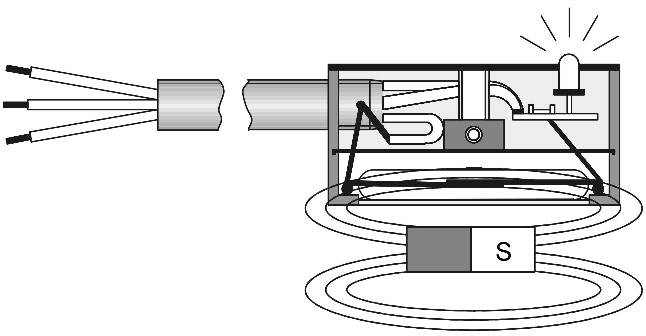


Fig. 3.1.1: Magnetic reed proximity sensors

If a magnetic field approaches the reed proximity sensor, the blades are drawn together by magnetism, and an electrical contact is made.

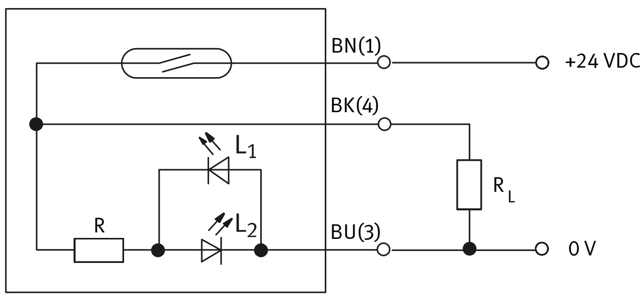
3.1.2 Technical characteristics

The table below lists some of the most important technical data relating to contacting proximity sensors.

Parameter	**Value**
Switching voltage	12 – 27 V DC or AC
Switching accuracy	±0.1 mm
Maximum contact rating	40 W
Maximum magnetic interference induction	0.16 mT
Maximum switching current	2 A
Maximum switching frequency	500 Hz
Switching time	≤2 ms
Conductance	0.1 Ω
Contact service life (with protective circuit)	5 Million switching cycles
Protection class (IEC 529, DIN 40050)	IP66
Ambient operating temperature	-20 – +60 °C

Table 3.1.1: Technical characteristics of reed proximity sensor

Reed proximity sensors often have a built-in light emitting diode to indicate operating status. Fig. 3.1.2 illustrates the internal and external connections. The light emitting diodes in conjunction with the series resistor assume the function of a protective circuit for an inductive load.



Load resistance (R_L) Light emitting diodes (L_1, L_2) Protective resistor (R)

Fig. 3.1.2: Block circuit diagram of a reed proximity sensor with light emitting diode

When a permanent magnet is moved past a reed proximity sensor, several switching ranges are possible (see Fig. 3.1.3). The switching ranges depend on the orientation of the pole axis of the magnet.

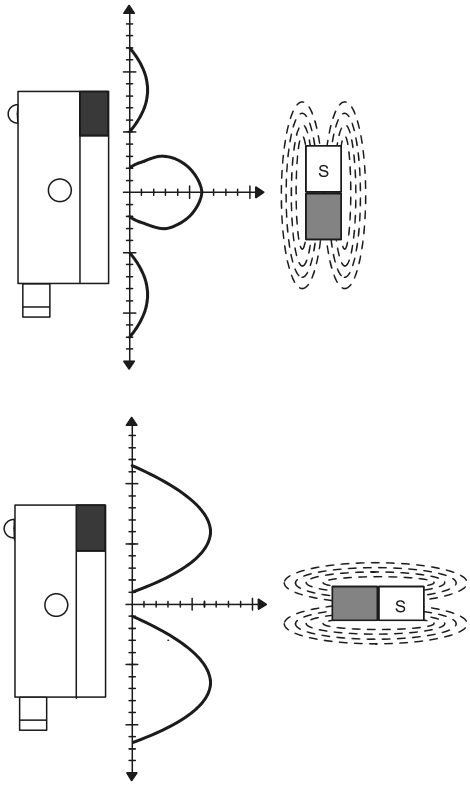


Fig. 3.1.3: Response characteristics of a reed proximity sensor

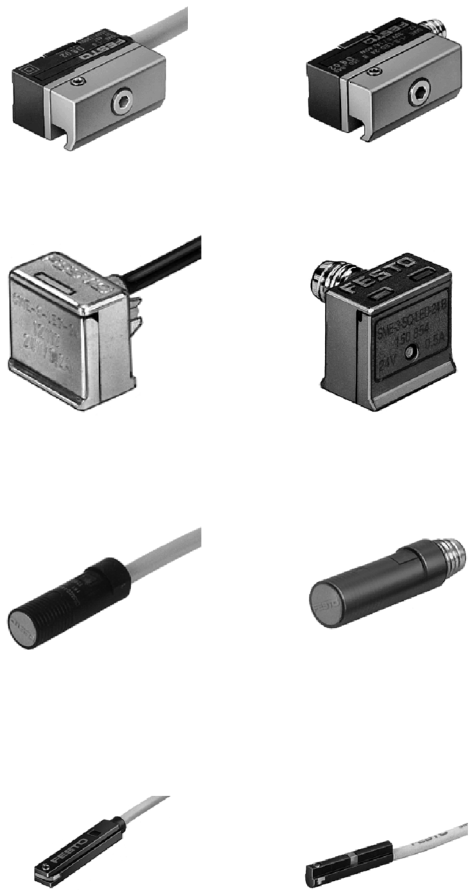


Fig. 3.1.4: Examples of magnetic reed switches for detection of cylinder positions ("cylinder sensors")

3.1.3 Notes on application

When installing reed type proximity sensors, it is important to ensure that there are no interfering magnetic fields near the sensor exceeding a field strength of more than 0.16 mT (T = Tesla). Should this be the case, then the proximity sensor must be shielded accordingly.

If several pneumatic cylinders are fitted with proximity sensors, a minimum distance of 60 mm is required between the proximity sensors and the adjoining external cylinder walls. If these distances are reduced, a shift in switching points will occur.

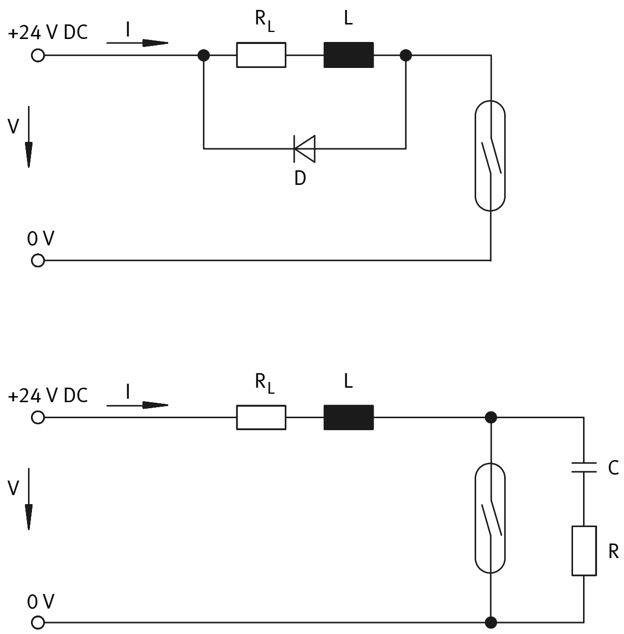
With reed sensors, maximum current flow must be reduced. Otherwise this can lead to arc discharge during switching on or off and therefore burning of the contact blades. A resistor fitted in series serves as a current limiter and leads to extended service life of the contacts.

When switching inductive loads, a high voltage peak is created at the moment of switch-off. For this reason a protective circuit must be provided for the proximity sensor unless one is already built in.

The protective circuit can either be a suitable RC element or a corresponding diode or varistor (see circuit diagram Fig. 3.1.5). The electrical values of these components depend on the following power component (e.g. relay, contactor etc).

If a relay or contactor is to be actuated, the technical data of both the proximity sensor and the relay or contactor must be observed.

The pull-in power of a relay or contactor is considerably higher (8- to 10-fold) than that of the holding power. Therefore, it is important to take the pull-in power as a reference.



Load resistor (R_L)
Inductance of load (L)
Protective resistor (R)
Protective capacitor (C)
Protective diode or Varistor (D)

Fig. 3.1.5: Protective circuits for reed contacts

3.1.4 Examples of application

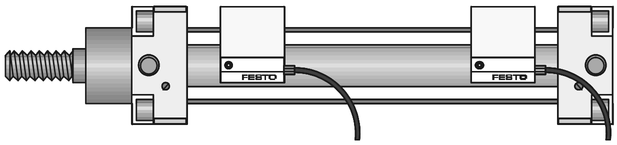
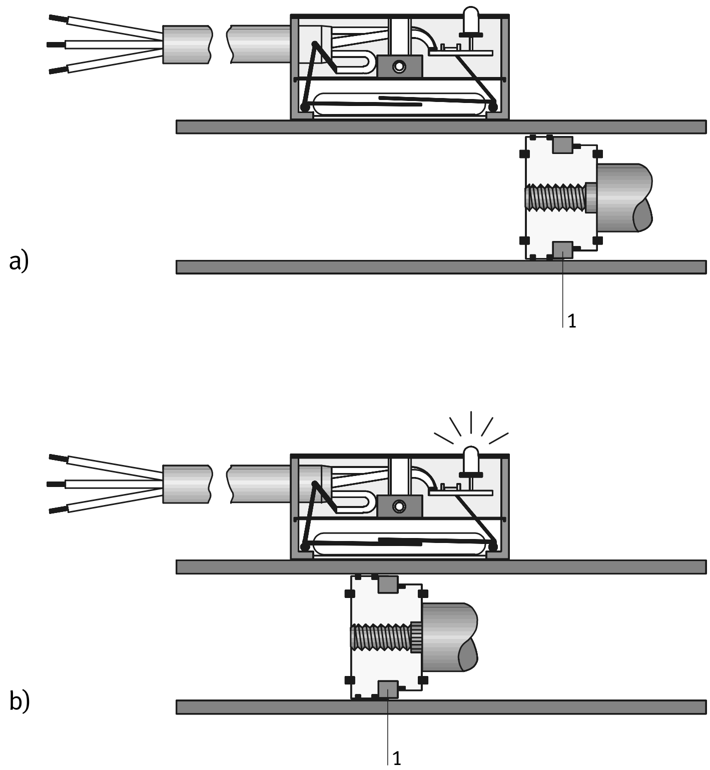


Fig. 3.1.6: Pneumatic cylinder with magnetic proximity sensors

- Most widely known and used application: Cylinder switches
- With the use of magnetic proximity sensors a wide range of other sensor problems can be solved if the object to be detected is fitted with a magnet, e.g.:
  – Measuring the rotational speed of parts made of any material
  – Selective sensing of individual workpieces from a similar series.
  – Incremental displacement encoding systems
  – Counting devices
  – Door switches
  – Material positioning



Permanent magnet on cylinder piston (1)

a) The proximity sensor is unactuated; the switching contacts are open.

b) With the approach of a magnetic field the switching contacts

Fig. 3.1.7: Principle of application of magnetic proximity sensors for the detection of cylinder positions

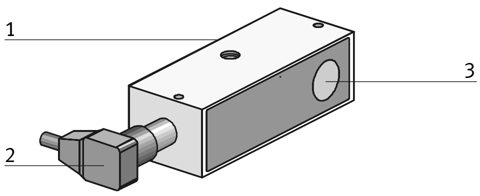
3.2
Contactless magnetic proximity sensor

3.2.1 Function description

Inductive-magnetic proximity sensors

These proximity sensors, similar to inductive proximity sensors, have a built-in oscillator (LC oscillating circuit). In contrast to inductive proximity sensors, however, the oscillating coil is not of a half-shell core design creating a magnetic field directed outwards, but a coil with a closed-shell core design, e.g. a coil with a shielded ferrite core. With the approach of a permanent magnet, the core material of the oscillator coil is saturated, thereby causing a variation in the oscillator current of the proximity sensor. A trigger stage evaluates the change and converts it into a defined output signal. These proximity sensors only react to magnetic fields, but not to any metallic objects.

With these proximity sensors, the direction of the magnetic polar axis in comparison with the proximity sensor axis must be taken into consideration.



LED display on the reverse side (1) Cable or plug-type connection (2) Active surface (3)

Fig. 3.2.1: Inductive-magnetic proximity sensor

Magnetoresistive proximity sensors

Resistor strips (e.g. Wi- or InSb, Wi=Wismut, In=Indium, Sb=Antimon) change their electrical resistance in magnetic fields. This effect, i.e. magnetoresistive, can be used for various sensor types.

Hall proximity sensors

If a semiconductor (e.g. InSb) is exposed to a magnetic field, a voltage is created perpendicular to the direction of the current, i.e. the so-called Hall voltage. Certain physical dimensions apply in this particular case, i.e. the thickness of the plate must be small in comparison with the dimensions of length and width. Voltages of up to 1.5 V can be created.

The underlying physical effect is described as the Hall effect after the American physicist, E. Hall.

Wiegand proximity sensors

The Wiegand sensors consist of a wire which is made from a ferromagnetic alloy of vanadium, cobalt and iron. The direction of magnetisation of this wire changes spontaneously when an approaching magnetic field exceeds a certain value. If a coil is wound around this Wiegand wire, a voltage pulse of up to 3 V is induced.

In principle, Wiegand sensors do not require any external voltage supply.

3.2.2 Technical characteristics

Only the inductive type of magnetic proximity sensor should be considered from hereon.

Parameter	**Value**
Operating voltage	10 – 30 V
Maximum switching current	200 mA
Minimum response induction	2 – 35 mT
Maximum magnetic interference induction	1 mT
Response travel (Dependent on field strength and cylinder)	7 – 17 mm
Hysteresis	0.1 – 1.5 mm
Switching point accuracy	±0.1 mm
Voltage drop (at maximum switching current)	3 V
Maximum current consumption (idling)	6.5 mA
Switching frequency	1000 Hz
Protective circuit for inductive load	integrated
Protection to (IEC 529, DIN 40050)	IP67
Operating temperature	-20 – +70 °C

Table 3.2.1: Technical data of an inductive-magnetic proximity sensor

Inductive-magnetic proximity sensors have the following basic advantages compared with reed proximity sensors:

- No problem with contact bounce
- Wear-free, no moving parts
- Only one single switching area is created, if the magnetic pole axis is suitably aligned, see Fig. 3.2.2.

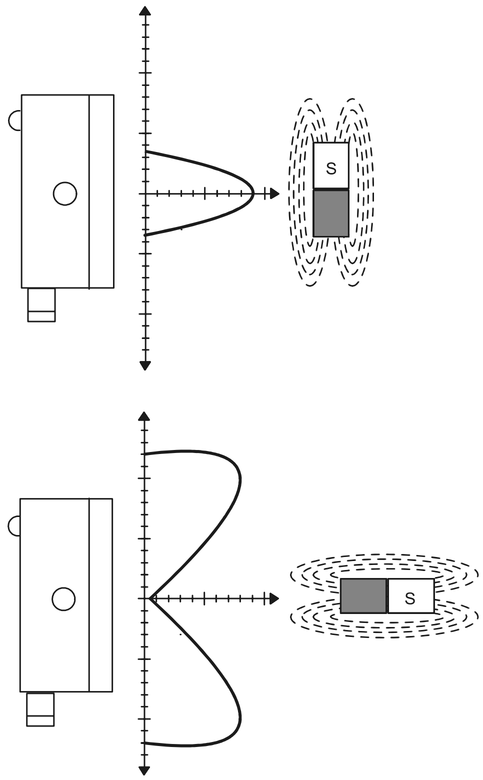


Fig. 3.2.2: Response characteristics of an inductive-magnetic proximity sensor

3.2.3 Notes on application

It should be noted that with the application of inductive-magnetic proximity sensors the proximity sensor may show an asymmetrical switching behaviour. Therefore it should be checked that the sensor switches reliably in the actual circumstances. Ferromagnetic materials near a magnetic proximity sensor may lead to changes in characteristics or to interference, the same as when these sensors are used under strong external magnetic field influence such as in welding plants or aluminium smelting works, for instance.

When several pneumatic cylinders are fitted with magnetic proximity sensors, a minimum distance of 60 mm is required between the proximity sensors and the nearby external wall of the cylinder.

Inductive-magnetic proximity sensors generally have a built-in protective circuit for connecting inductive loads as well as against voltage spikes. An additional protective circuit is therefore superfluous.

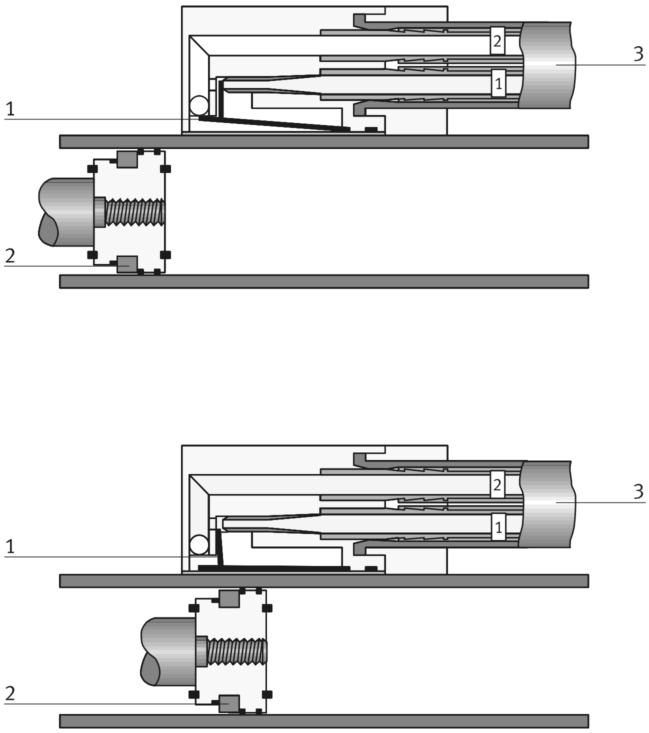
3.2.4 Examples of application

One of the most common fields of application for contactless magnetic proximity sensors is, as in the case of reed proximity sensors, position sensing with pneumatic cylinders. They can however be used for many other applications, similar to reed proximity sensors, refer to 3.1.4.

3.3 Magnetic-pneumatic proximity sensors

3.3.1 Function description

A pneumatic valve is switched by means of a permanent magnet, thereby generating a control signal.



a)

b)

Switching reed (1) Permanent magnet on piston (2) Flexible conduit (3)

a) The proximity sensor is unactuated, a switching reed interrupts the air flow from 1.

b) The switching reed is actuated by a magnetic field, the air flows from 1 to 2.

Fig. 3.3.1: Principle of application of a magnetic-pneumatic proximity sensor for detection of cylinder positions

3.3.2 Technical characteristics

Parameter	Value
Operating pressure range	400 – 600 kPa (4 – 6 bar)
Signal pressure (supply pressure 500 kPa)	8 kPa (80 mbar)
Switching accuracy	±0.2 mm
Maximum magnetic interference induction	0.2 mT
Switching frequency	approx. 50 Hz
Ambient operating temperature	-20 – +60 °C

Table 3.3: Technical characteristics of a magnetic-pneumatic proximity sensor (example)

The proximity sensor corresponds in principle to an air barrier, whereby a switching blade continually interrupts the air flow of an impending signal. As the magnetic field approaches (e.g. permanent magnet on the piston of a cylinder) the switching blade is attracted and releases the air flow, thus creating a signal at the outlet. Some sensor types are operated in combination with a pressure amplifier.

3.3.3 Notes on application

The distance between two magnetic-pneumatic proximity sensors should be at least 50 mm. It should be checked that the available magnetic field is sufficient for the reliable operation of the proximity sensor.

If the low pressure output signal is to be used for further processing, then it is recommended to fit a pressure amplifier in series.

3.3.4 Example of application

Magnetic-pneumatic proximity sensors are primarily used for position sensing of pneumatic cylinders.

They are particularly suitable for purely pneumatic solutions, i.e. if compressed air is the only source of auxiliary energy.

3.4 Exercises

Exercise 3.1

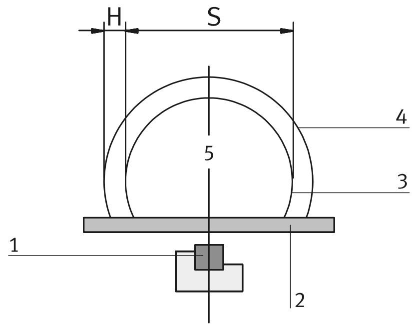
Maximum passing speed
Calculate the maximum passing speed of a cylinder piston, the position of which is to be sensed by means of a reed contact. To do this, assume that the switching time of the proximity sensor used is 2 ms and take the response travel from table 3.4.1.

Calculate the value for a Festo cylinder, type DNNZ with a diameter of 32 mm as an example.

What is the change in maximum speed if, for instance, a valve is to be switched with a switching time of 15 ms?

Piston diameter [mm]	Type	Hysteresis H_{max} [mm]		Response travel S_{min} [mm]	
		SME	SMP	SME	SMP
8	ESN, DSN	2	1.5	7	9
10	ESN, DSN	2	1.5	5	9
12	ESN, DSN	2	2	8	11
16	ESN, DSN	2	2	6	9
20	ESN, DSN	2	2.5	7	9
	DGS				
25	ESN, DSN	1.5	2	6	17
	DGS	2	1.5	7	10
32	ESW, DSW	2	1.5	10	12
	DN, DNZ	2.5	4	7	15
	DNNZ	2.5	4	7	15
40	ESW, DSW	2	2	9.5	12
	DN, DNZ	2.5	4.5	8	15
	DNNZ	2.5	4.5	8	15
50	ESW, DSW	2	2	10.5	12
	DN, DNZ	3	5	8	17
	DNNZ	3	5	8	17

Table 3.4.1: Hysteresis and response travel of various cylinders (example)



Permanent magnet (1)
Cylinder barrel (2)
Sensor on (3)
Sensor off (4)
Centre of sensor (5)
Hysteresis (H)
Response range (S)

Fig. 3.4.1: Schematic representation of hysteresis and response travel of a magnetic proximity sensors

Exercise 3.2

Electrical connection of a reed proximity sensor
Describe the behaviour of a reed sensor as shown in Fig. 3.1.2, with the supply voltage being reversed, i.e. polarity reversal of the proximity sensor.

Can this damage the reed sensor?

Exercise 3.3

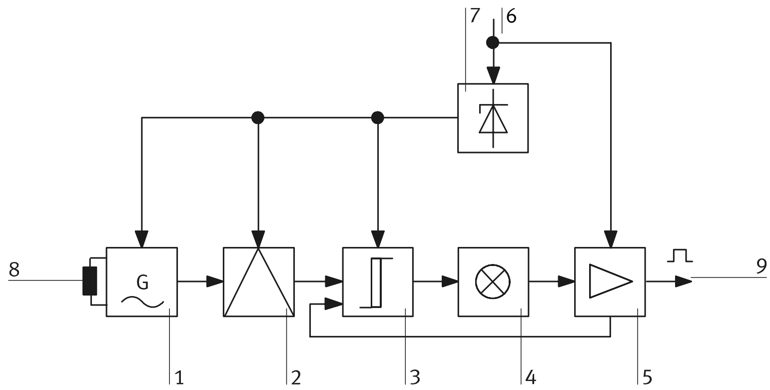
Resolution of a reed proximity sensor
What is the smallest possible cylinder stroke that can be detected by two reed proximity sensors?

Use the technical data in table 3.2.1 and 3.4.1 for your answer.

4. Inductive proximity sensors

4.1
Function description

The most important components of an inductive proximity sensor are an oscillator (LC resonant circuit), a demodulator rectifier, a bistable amplifier and an output stage.

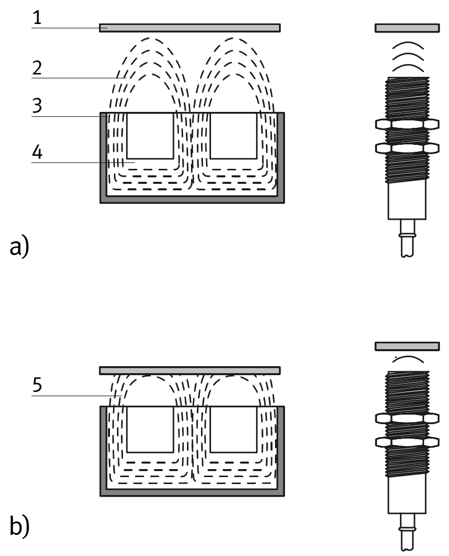


Oscillator (1)	Switching status display (4)	Internal constant voltage supply (7)
Demodulator (2)	Output stage with protective circuit (5)	Active zone (coil) (8)
Triggering stage (3)	External voltage (6)	Sensor output (9)

Fig. 4.1.1: Block circuit diagram of an inductive proximity sensor

The magnetic field which is directed towards the outside, is generated via a half-open ferrite core shell of an oscillator coil and additional screening. This creates a limited area across the active surface of the inductive proximity sensor, which is known as the active switching zone.

When a voltage is applied to the sensor, the oscillator starts and a defined quiescent current flows. If an electrically conductive object is introduced into the active switching zone, eddy currents are created, which draw energy from the oscillator. Oscillation is attenuated and this leads to a change in current consumption of the proximity sensor. The two statuses – oscillation attenuated or oscillation unattenuated – are electronically evaluated.



Actuating element (1)
High-frequency magnetic field (2)
Active surface (3)
Resonant circuit coil (4)
Energy is drawn from the high-frequency magnetic field (5)

a) Proximity sensor unactuated (oscillator unattenuated)
b) Proximity sensor actuated (oscillator attenuated)

Fig. 4.1.2: Method of operation of an inductive proximity sensor

Only electrically conductive materials can be detected by means of inductive proximity sensors.

Depending on switch type (normally open contact or normally closed contact), the final stage is switched through or inhibited if a metallic object is present in the active switching zone. The distance to the active area, where a signal change of the output signal occurs, is described as the switching distance. The important criteria for inductive proximity sensors is therefore the size of the coil incorporated in the switching head. The bigger the coil, the greater the active switching distance. Distances of up to 250 mm can be achieved.

A standardised calibrating plate is used to determine the switching distance of inductive proximity sensors. Only in this way can useful comparisons of switching distances of different inductive proximity sensors be made. The standard measuring plate is made of steel S 235 JR and is 1 mm thick. It is square and the length of a side is equal to

- the diameter of the active surface of the sensor,

or

- three times the nominal switching distance.

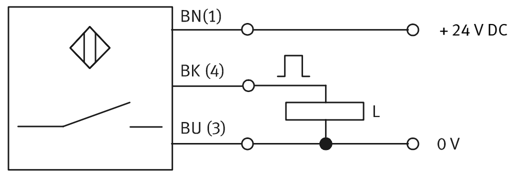
The higher of the two values is to be used as the lateral length of the standard calibrating plate. Using plates with larger areas does not lead to any significant changes in the switching distance measured. However, if smaller plates are used this leads to a reduction of the switching distance derived.

Also, the use of different materials leads to a reduction of the effective switching distance. The reduction factors for different materials are listed in the table below.

Material	**Reduction factor**
Steel S 235 JR (old: St37)	1.0
Chrome nickel	0.70 – 0.90
Brass	0.35 – 0.50
Aluminium	0.35 – 0.50
Copper	0.25 – 0.40

Table 4.1.1: Guide values for the reduction factor

The above table shows that the largest switching distances achieved are for magnetic materials. The switching distances achieved for non-magnetic materials (brass, aluminium, copper) are clearly smaller.



Load (L)

Fig 4.1.3: Connection symbol of an inductive proximity sensor in direct voltage three-wire technology

The connection designations of inductive proximity sensors are standardised, see chapter 10 and 14. For further notes on circuit layout see chapter 10.

4.2 Technical characteristics

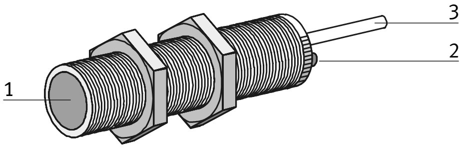
The table below lists the key technical data relating to inductive proximity sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	**Value**
Object material	Metals
Operating voltage	10 – 30 V
Nominal switching distance	0.8 – 10 mm, maximal 250 mm
Maximum switching current	75 – 400 mA
Vibration	10 – 50 Hz, 1 mm amplitude
Sensitivity to dirt	insensitive
Service life	very long
Switching frequency	10 – 5000 Hz, maximal 20 kHz
Design	cylindrical, block-shaped
Size (examples)	M8x1, M12x1, M18x1, M30x1, Ø 4 – 30 mm, 25 mm x 40 mm x 80 mm
Protection class to IEC 529 (DIN 40050)	up to IP67
Ambient operating temperature	-25 – +70 °C

Table 4.2.1: Technical data of DC inductive proximity sensors

Many of the inductive proximity sensors which are available on the market have the following built-in precautions to guarantee simple handling and safe operation:

- Reverse polarity protection (against damage as a result of reversing connections)
- Short circuit protection (against short circuiting of output against earth)
- Protection against voltage peaks (against transient overvoltages)
- Protection against wire breakage (The output is blocked if a supply line is disconnected)

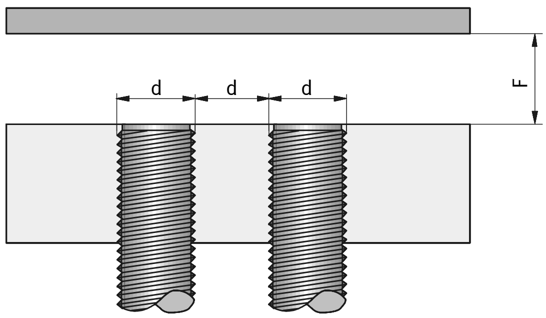


Active surface (1) LED (2) Cable or plug-in connection (3)

Fig. 4.2.1: Inductive proximity sensor in threaded design

4.3 Notes on application

If inductive proximity sensors are fitted in metal fixtures, care should be taken that the characteristics of the proximity sensor are not be altered. Differentiation should be made here between the two different types of proximity sensors, i.e. flush-fitting and non-flush fitting proximity sensors.

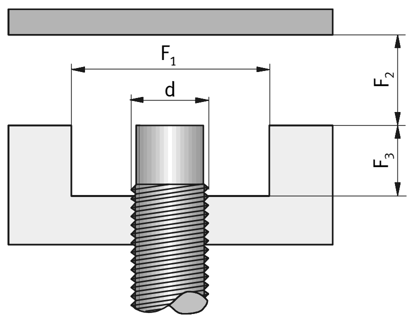


Diameter of proximity sensor (d) Free zone ≥3 x s_n (F) Nominal switching distance (s_n)

Fig. 4.3.1: Flush-fitting inductive proximity sensors

Where proximity sensors are to be flush-fitted in metal, they must be installed in such a way as to ensure that the electromagnetic field is directed from the active zone forwards. In this way, the characteristics of the proximity sensor cannot be influenced by the method of assembly. In the case of series assembly of proximity sensors, a minimum gap corresponding to their respective diameter must be provided. This is essential in order to prevent the proximity sensors from influencing one another. The free zone in front of the proximity sensor should be at least three times the nominal switching distance of the proximity sensor used. The free zone is the area between the proximity sensor and a background object.

The advantage of flush-fitting proximity sensors is that these are very easy to install and space saving. Their disadvantage compared to non-flush-fitting proximity sensors is that although the external diameter of the proximity sensor housing is identical, the switching distance is smaller.



Diameter of proximity sensor (d) Nominal switching distance (s_n)

Free zone 1 = 3 x s_n (F_1) Free zone 2 ≥ 3 x s_n (F_2) Free zone 3 ≥ 2 x s_n (F_3)

Fig 4.3.2: Non-flush fitting inductive proximity sensors

Recessed proximity sensors which are mounted in a material which influences their characteristics (metal) require a free zone which surrounds the entire active area. However, these proximity sensors can be embedded in plastics, wood or other non-metallic materials without the characteristics of the proximity sensor being affected. This type of sensor can often be recognised by the coil head protruding from the housing of the proximity sensor.

4.4 Examples of application

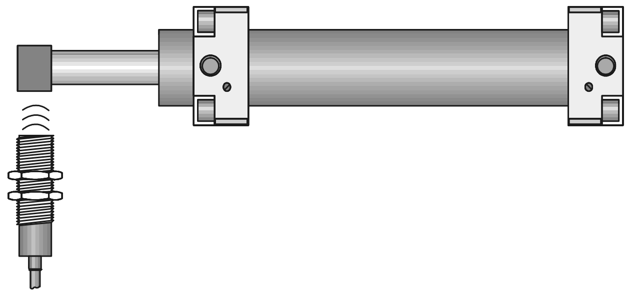
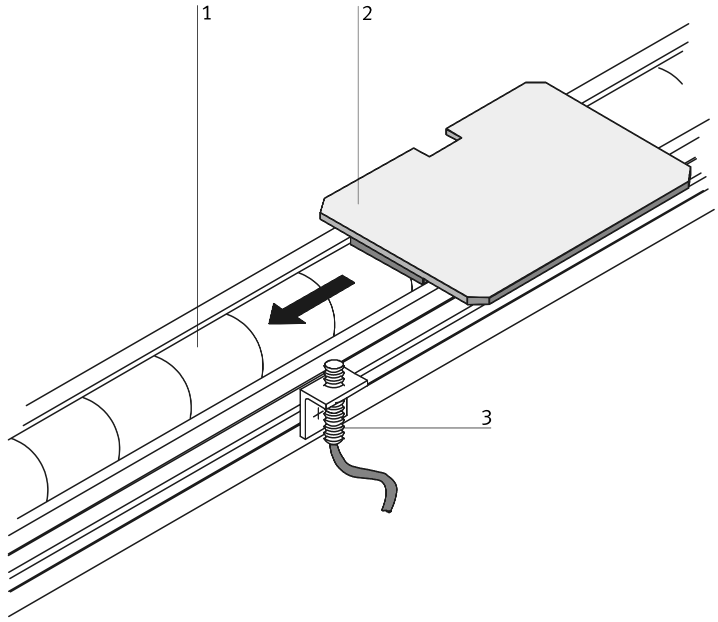


Fig. 4.4.1: Sensing the piston rod on a pneumatic or hydraulic cylinder



Band conveyor (1) Workpiece carrier (2) Proximity sensor inductive (3)

Fig. 4.4.2: Detection of metallic workpiece carriers on a band conveyor

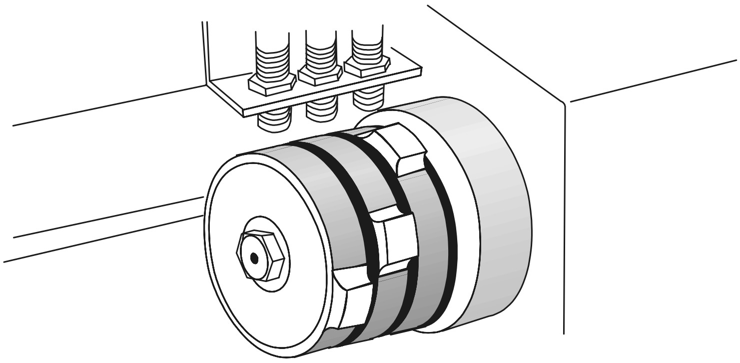


Fig. 4.4.3: Sensing a cam controller by means of inductive proximity sensors (Source: Turck)

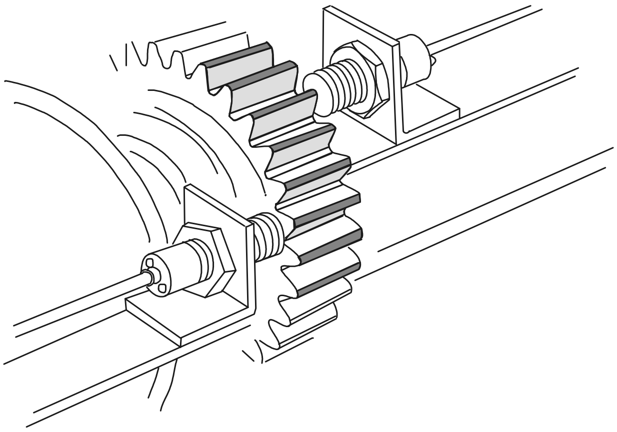
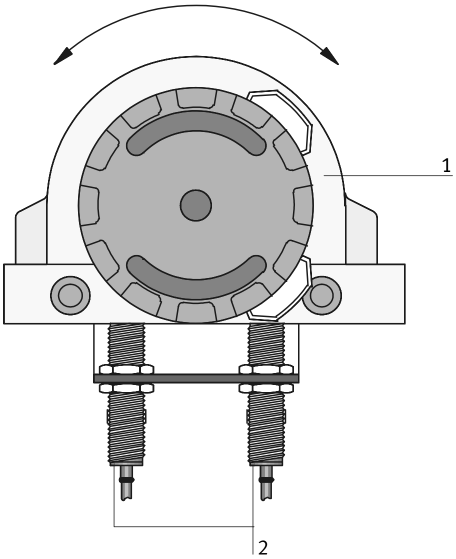
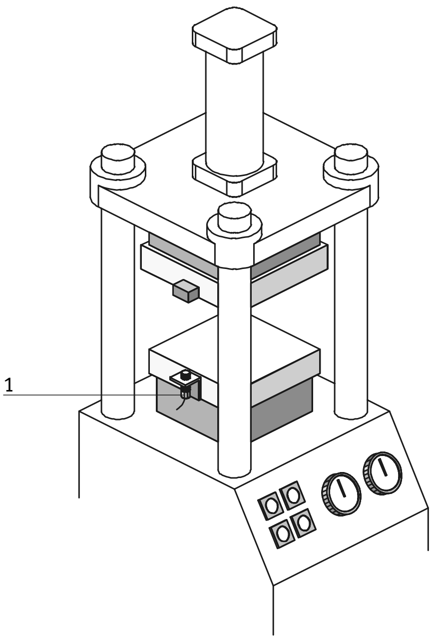


Fig. 4.4.4: Measurement of speed and direction of rotation (Source: Turck)



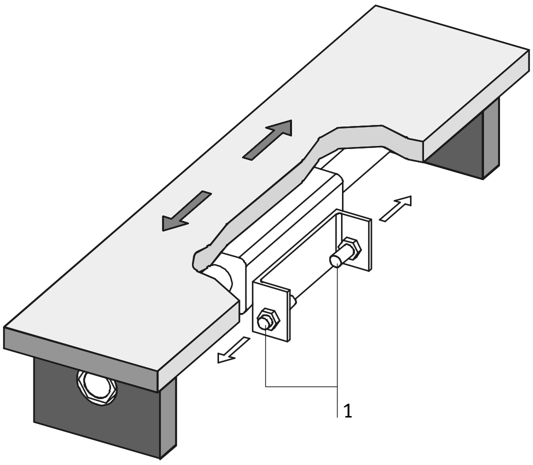
Pneumatic swivel drive (1) Inductive proximity sensor (2)

Fig. 4.4.5: Two inductive proximity sensors check the end positions of a semi-rotary drive



Inductive proximity sensor (1)

Fig. 4.4.6: Detecting end position of a press ram



Inductive proximity sensor (1)

Fig. 4.4.7:
Two inductive proximity sensors check whether the slide of a feeding device is in one of two normal end positions

4.5 Exercises

Exercise 4.1

Application of an inductive proximity sensor
The number, distance and direction of transport of material containers are to be checked on a conveyor belt. For the purpose of marking, the transport containers are provided with an aluminium marking plate. What do you need to consider when selecting an inductive proximity sensor for this task?

How do you achieve the largest possible switching distance for a given sensor diameter?
What do you need to pay particular attention to in this instance?

What is the positive influence of the hysteresis on the switching behaviour of an inductive proximity sensor? Consider what you would need to observe in practice if switch-on and switch-off point were exactly the same distance from the proximity sensor.

Exercise 4.2

Detection of vibrating steel cylinders

Steel cylinders are transported on a conveyor belt, see fig. 4.5.1 and 4.5.2. The steel cylinders are to be counted by means of an inductive proximity sensor, which is to be connected to a programmable logic controller. Due to conveyor vibrations, the steel cylinders also effect a slight vibration movement with amplitude "a".
An inductive proximity sensor is to be used.

What problems can occur with the counting of the steel cylinders?

The proximity sensor has a nominal switching distance of 8 mm. The hysteresis can be 1 % to 5 % of the switching distance. This is on the assumption that these hysteresis values also apply for lateral approach of the proximity sensor, as in this case. What is the maximum vibration amplitude "a" permitted without causing the problems which occur in paragraph 1?

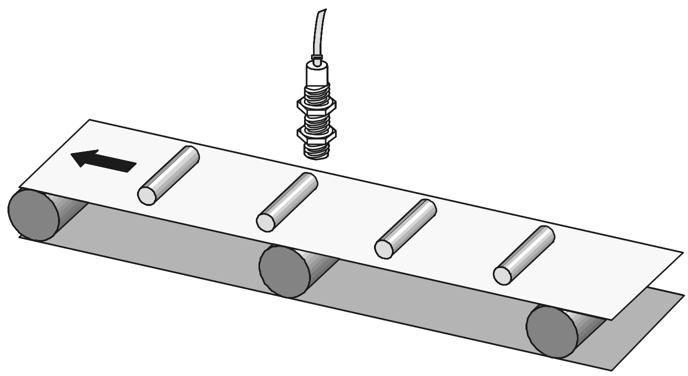
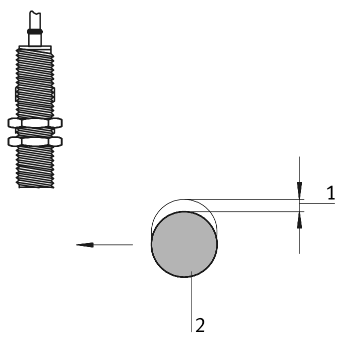


Fig. 4.5.1: Counting of steel cylinders on a conveyor belt by means of an inductive proximity sensor



Vibration amplitude (1) Cylinder (2)

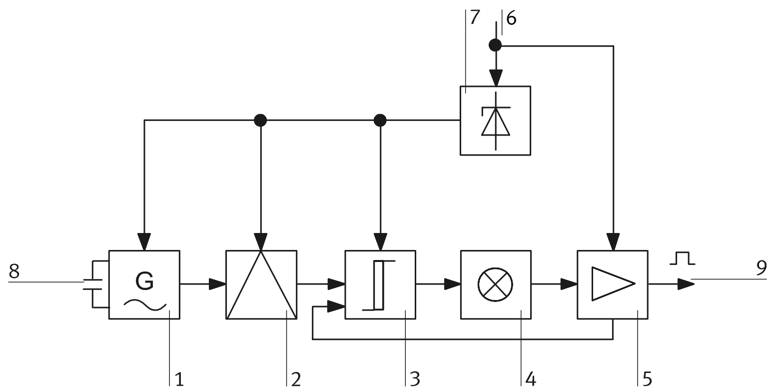
Fig. 4.5.2: Vibratory movement of the steel cylinders

5. Capacitive proximity sensors

5.1
Function description

The operational principle of a capacitive proximity sensor is based on the measurement of the change of electrical capacitance of a capacitator in a RC resonant circuit with the approach of any material.

An electrostatic stray field of a capacitive proximity sensor is created between an "active" electrode and an earth electrode. Usually, a compensating electrode is also present which compensates for any influence of the proximity sensor through humidity.



Oscillator (1)	Switching status display (4)	Internal constant voltage supply (7)
Demodulator (2)	Output stage with protective circuit (5)	Active zone (capacitor) (8)
Triggering stage (3)	External voltage (6)	Switching output (9)

Fig. 5.1.1: Block circuit diagram of a capacitive proximity sensor

If an object or medium (metal, plastic, glass, wood, water) is introduced into the active switching zone, then the capacitance of the resonant circuit is altered.

This change in capacitance essentially depends on the following parameters:
- The distance of the medium from the active surface,
- the dimensions of the medium and
- the dielectric constant of the medium.

The sensitivity (switching distance) of most capacitive proximity sensors can be adjusted by means of a potentiometer. In this way it is possible to suppress the detection of certain media. For instance, it is possible to determine the fluid level of hydrous solutions through the wall of a bottle.

The switching distance of a capacitive proximity sensor is determined by means of an earthed metal plate. The table below lists the variation in switching point distances in respect of different materials. The maximum obtainable switching distance of industrial capacitive sensors is approximately 60 mm.

Material thickness [mm]	**Switching distance [mm]**
1.5	–
3.0	0.2
4.5	1.0
6.0	2.0
7.5	2.3
9.0	2.5
10.5	2.5
12.0	2.5

Table 5.1.1:
Variation of switching distance as a function of the material thickness using a cardboard strip (width = 30 mm)

With capacitive proximity sensors it should be noted that the switching distance is a function resulting from the type, lateral length and thickness of the material used. Most metals produce roughly the same value and a number of different values are listed in respect of other materials.

Material	**Reduction factor**
All metals	1.0
Water	1.0
Glass	0.3 – 0.5
Plastic	0.3 – 0.6
Cardboard	0.5 – 0.5
Wood (dependent on humidity)	0.2 – 0.7
Oil	0.1 – 0.3

Table 5.1.2: Guide values for reduction factor

5.2 Technical characteristics

The table below lists the key technical data relating to capacitive proximity sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	Value
Object material	all materials with dielectric constant 1
Operating voltage	10 – 30 V DC or 20 – 250 V AC
Nominal switching distance	5 – 20 mm, max. 60 mm (usually variable, adjustable via potentiometer)
Maximum switching current	500 mA
Sensitivity to dirt	sensitive
Service life	very long
Switching frequency	up to 300 kHz
Design	cylindrical, block-shaped
Size (examples)	M12x1, M18x1, M30x1, up to Ø 30 mm, 25 mm x 40 mm x 80 mm
Protection (IEC 529, DIN 40050)	up to IP67
Ambient operating temperature	-25 – +70 °C

Table 5.2.1: Technical data of capacitive proximity sensors

5.3 Notes on application

As with inductive position sensors, flush and non-flush fitting capacitive proximity sensors are to be distinguished. Furthermore, it should be noted that these sensors can be easily contaminated. Also, their sensitivity with regard to humidity is very high due to the high dielectric constant of water ($\varepsilon = 81$). On the other hand, they can be used for the detection of objects through a non-metallic wall. The wall thickness in this case should be less than 4 mm and the dielectric constant of the material to be detected should be higher by a factor of 4 than that of the wall.

Due to its ability to react to a wide range of materials, the capacitive proximity sensor can be used more universally as an inductive proximity sensor. On the other hand, capacitive proximity sensors are sensitive to the effects of humidity in the active zone. Many manufacturers, for instance, use an auxiliary electrode to reduce the effects of moisture, dew or ice thus compensating these disturbances.

5.3.1 Considerations for application

- For cost reasons, the use of inductive as opposed to capacitive proximity sensors is generally preferred to detect metallic objects.
- For the detection of non-metallic objects, optical proximity sensors compete as a viable alternative.
- There is a particular field of application where the use of capacitive sensors provides a distinct advantage.

5.4 Examples of application

Capacitive proximity sensors for instance are suitable for monitoring filling levels of storage containers. Other areas of application include the detection of non-metallic materials.

Detection of matt, black objects

These objects can be made of rubber, leather, plastic and other materials, which are not detected by diffuse optical sensors and where ultrasonic proximity sensors are too expensive.

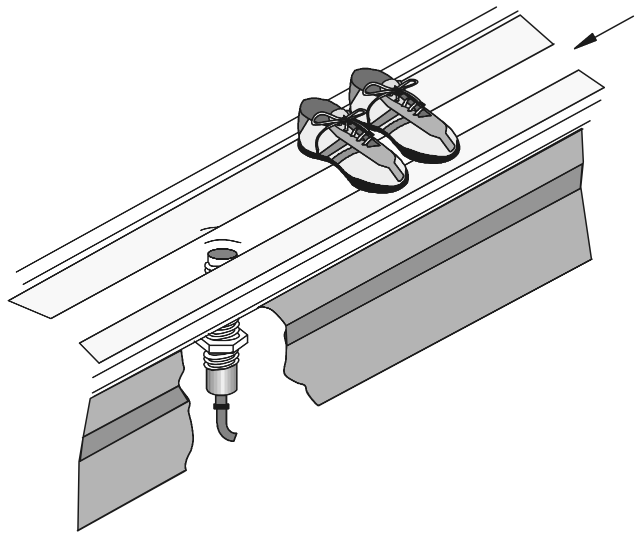


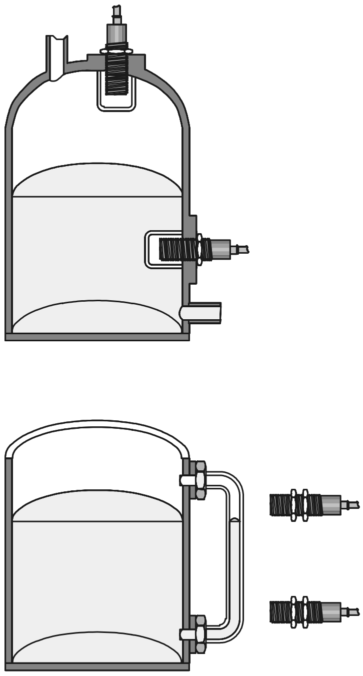
Fig. 5.4.1: Detection of black rubber soles

Detecting filling levels of fluids

In the case of detecting filling levels of fluids through thin walls of plastic containers, inspection glass etc., the wall thickness must be limited such as to enable the capacitive proximity sensor to respond to the contents alone.

a)

b)



a) Capacitive proximity sensor encapsulated in plastic or quartz glass

b) Detection of liquid level through plastic or glass tube

Fig. 5.4.2: Detection of filling level inside a steel container

Detecting filling levels of granular material

Capacitive proximity sensors are suitable for the detection of powder, grain or granular type bulk goods through containers or silos.

For example, it is possible to check the filling volume inside food containers through the sealed packaging by means of capacitive proximity sensors.

The illustration below shows four capacitive proximity sensors at the base of a cardboard box to check that four soft drinks bottles have been inserted.

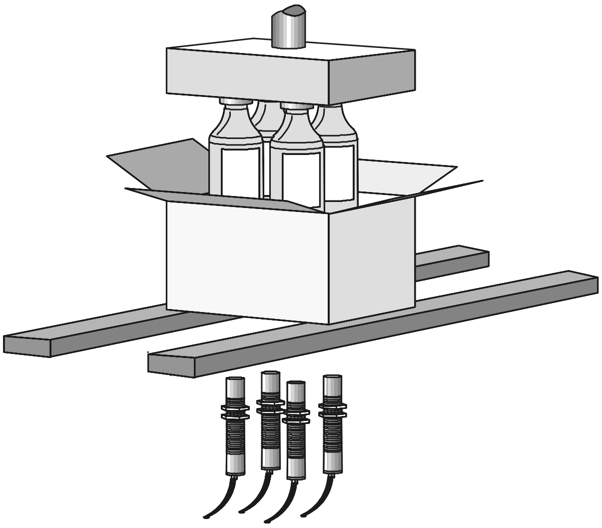


Fig. 5.4.3: Checking of packaging contents through cardboard

Monitoring the winding of electrical wires and cables

Capacitive proximity sensors react to copper containing electrical wires or cables of relatively small diameter, whereas inductive proximity sensors react at a smaller switching distance or not at all. Optical proximity sensors too may fail in this instance.

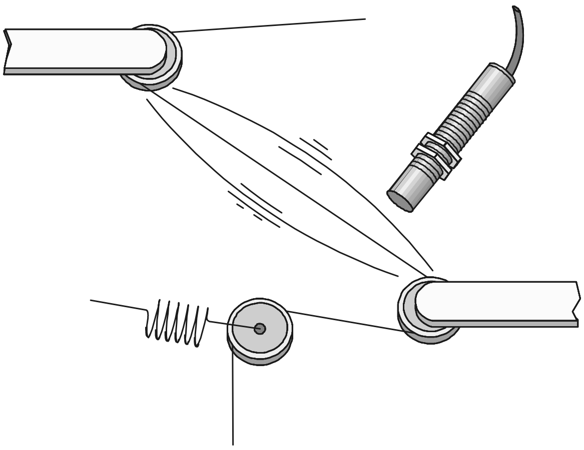


Fig. 5.4.4: Monitoring for cable breakage by means of a capacitive proximity sensor

Checking the presence of bulbs inside assembled cardboard boxes

A capacitive proximity sensor checks whether each box travelling past contains a light bulb.

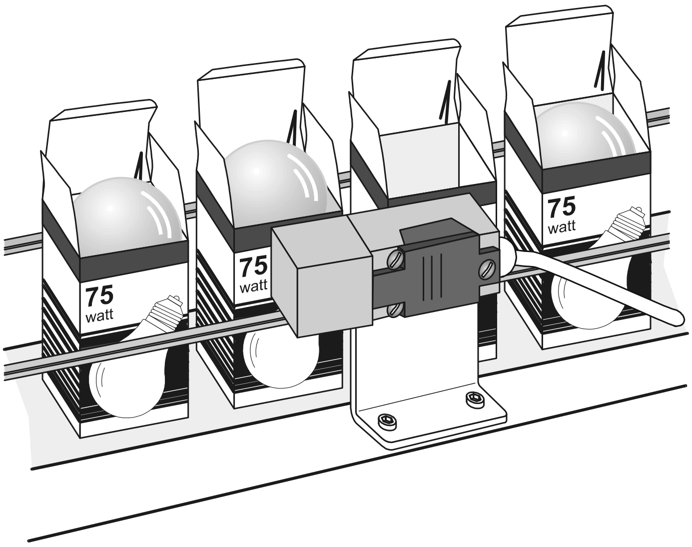


Fig. 5.4.5: Checking the presence of bulbs inside cardboard boxes (Source: Turck)

5.5
Exercises

Exercise 5.1

Measuring the filling level in a grain silo
You intend to use a capacitive proximity sensor to detect the filling level in a grain silo.

What do you have to remember?

Exercise 5.2

Environmental effects on capacitive proximity sensors
You are using a capacitive proximity sensor on an outdoor installation.

What do you need to remember, particularly in the spring and autumn?

Exercise 5.3

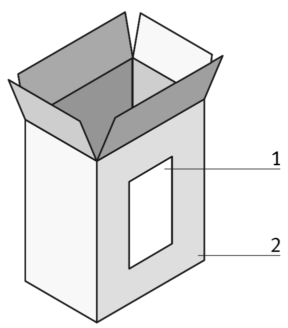
Detection of cardboard boxes
You intend to use a capacitive proximity sensor for the detection of cardboard boxes of varying material thickness.

What do you have to remember?

Exercise 5.4

Detection of a transparent panel
In a factory producing food products, the presence of a panel made of transparent film is to be checked on empty cardboard packaging (see fig. 5.5.1). You are not sure whether to use a capacitive, an optical or an ultrasonic proximity sensor.

What are your arguments for this?



Transparent panels 50 x 30 mm, Cling film 0.1 mm thick (1)   Cardboard packaging (2)

Fig. 5.5.1: Packaging with transparent panel

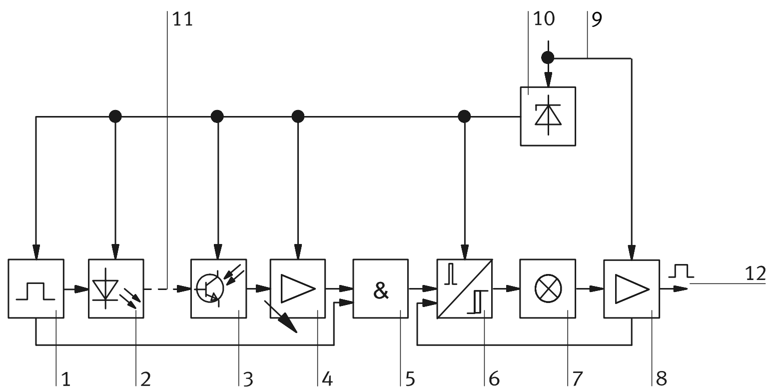
6. Optical proximity sensors

6.1
General characteristics

Optical proximity sensors employ optical and electronic means for the detection of objects. Red or infrared light is used for this purpose. Semiconductor light emitting diodes (LEDs) are a particularly reliable source of red and infrared light. They are small and robust, have a long service life and can be easily modulated. Photodiodes or phototransistors are used as receiver elements. When adjusting optical proximity sensors, red light has the advantage that it is visible in contrast to infrared light. Besides, polymer optic cables can easily be used in the red wavelength range because of their reduced light attenuation.

Infrared (non visible) light is used in instances, where increased light performance is required in order to span greater distances for example. Furthermore, infrared light is less susceptible to interference (ambient light).

With both types of optical proximity sensor, additional suppression of external light influences is achieved by means of modulating the optical signal. The receiver (with the exception of through-beam sensors) is tuned to the pulse of the emitter. With through-beam sensors an electrical band-pass is used in the receiver. Particularly in the case of infrared light, the use of daylight filters further improves insensitivity to ambient light.



Oscillator (1)	Switching status display (7)
Photoelectric emitter (2)	Output stage with protective circuit (8)
Photoelectric receiver (3)	External voltage (9)
Preamplifier (4)	Internal constant voltage supply (10)
Logic operation (5)	Optical switching distance (11)
Pulse/level converter (6)	Switch output (12)

Fig. 6.1.1:
Block circuit diagram of an optical proximity sensor (Emitter and receiver are installed in the same housing)

6.1.1 Emitter and receiver elements in optical proximity sensors

Emitter

For versions without fibre-optic connection:
- GaAlAs – IRED
- Wavelength 880 nm (non visible, infrared)

For versions with fibre-optic connection:
- GaAlAs – IRED
- Wavelength 660 nm (visible, red)

Receiver

Silicon-phototransistor
(Versions with in series connected daylight filters are used for proximity sensors operating at 880 nm.)

Optical proximity sensors usually have already built-in protective measures:
- Reverse polarity protection
- Short-circuit protection of outputs
- Protection against voltage peaks

With through-beam sensors and retro-reflective sensors, switching functions are distinguished as follows:
- Light switching method
  The output is switched through when the light beam is undisturbed by an object (Normally open output, N/O = Normally Open). In the case of a light switching through-beam sensor, the receiver output is switched through if no object is in the light beam.
- Dark switching method
  The output is open (not switching) when the light beam is undisturbed by an object (Normally closed output, N/C = Normally Closed). In the case of a dark switching through-beam sensor, the receiver output is switched through if there is an object in the light beam.

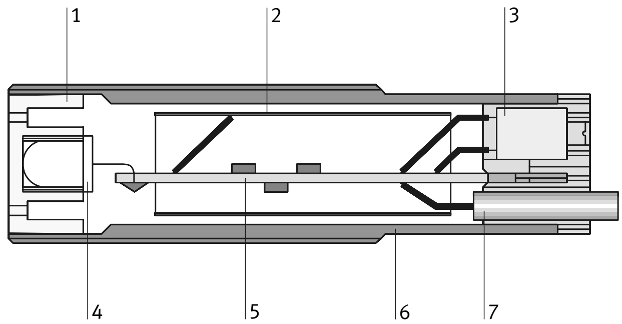
The switching function of optical diffuse sensors is as follows:
- Light switching method
  The output closes, if an object to be detected enters the light beam.
  (Normally open output, N/O = Normally Open)
- Dark switching method
  The output opens, if an object to be detected enters the light beam.
  (Normally closed output, N/C = Normally Closed)

6.1.2 Construction of an optical proximity sensor

Optical proximity sensors basically consist of two main units: the emitter and the receiver. Depending on type and application, reflectors and fibre-optic cables are required in addition.

Emitter and receiver are either installed in a common housing (diffuse sensors and retro-reflective sensors), or housed separately (through-beam sensors).

The emitter houses the source of red or infrared light emission, which according to the laws of optics extends in a straight line and can be diverted, focussed, interrupted, reflected and directed. It is accepted by the receiver, separated from external light and electronically evaluated.



Transparent cover (1)
Shield (2)
Potentiometer (3)
Photoelectric modules (4)
Electronics (SMD-technology) (5)
Brass sleeve (6)
Cable (7)

Fig. 6.1.2: Construction of an optical proximity sensor with cylindrical design

The proximity sensor is fitted with an internal shield, which is insulated from the housing. The electronic components are encapsulated and a potentiometer is fitted at the output end for the adjustment of sensitivity.

Usually, proximity sensors include a light emitting diode (LED), which lights up when the output is switched through. The LED display serves as a means of adjustment and functional testing.

6.1.3 Operating margin for optical proximity sensors

Optical proximity sensors may be exposed to contamination such as dust, splinters or lubricants during operation. Contamination can cause interference with proximity sensors. Both contamination of the lens forming part of the proximity sensor optics as well as contamination of the reflector with retro-reflective sensors and of the object to be detected in the case of diffuse sensors can cause failure.

Heavy contamination in the light beam of through-beam sensors and retro-reflective sensors can cause an interruption of the light beam. This then continually feigns the presence of an object. In the case of diffuse sensors, heavy contamination of the lens system can be evaluated as an object present, if the light emission is reflected back to the receiver as a result of the contamination of the lens. Heavy contamination of the object itself can lead to the evaluation of an object not present, if less light is reflected as a result of contamination.

In order to achieve reliable operation, the following measures should be taken:

1. Operating the optical proximity sensor with sufficient operating margin.
   – Carrying out pre-trials.
   – Selecting a suitable proximity sensor with sufficient operating margin.
2. Using proximity sensors with setting aids, e.g. flashing LED function in marginal areas.
3. Using proximity sensors with an automatic contamination warning signal.

Optical proximity sensors have a certain operating margin (also known as function reserve) β, being the quotient of the actual optical signal power on the receiver input P_R divided by the just detectable optical signal power at the switching threshold P_T:

$$\beta = \frac{P_R}{P_T}$$

If the received optical emission is at the switching threshold level, this means $\beta = 1$, i.e. there is no operating margin. If the factor is for instance $\beta = 1.5$, then an operating margin of 50 % is available.

Factor β on the one hand depends on the distance between the emitter and the receiver in the case of the through-beam sensor, between the emitter and reflector in the case of retro-reflective sensors or between the proximity sensor and object in the case of a diffuse sensor.

On the other hand, the pattern of the operating margin factor is dependent on distance s with regard to the individual proximity sensor. Figs. 6.1.3 to 6.1.5 illustrate a number of schematic operating margin curves.

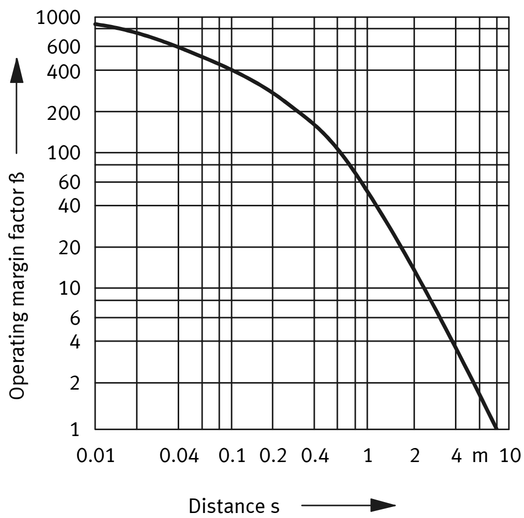


Fig. 6.1.3: Example showing the pattern of the operating reserve factor using a through-beam sensor

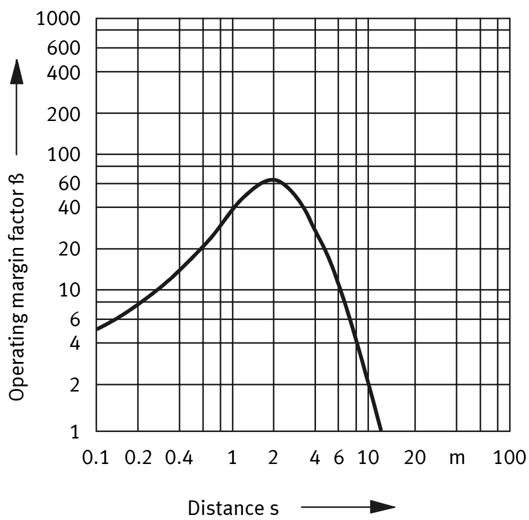


Fig. 6.1.4: Example showing the pattern of the operating reserve factor using a retro-reflective sensor

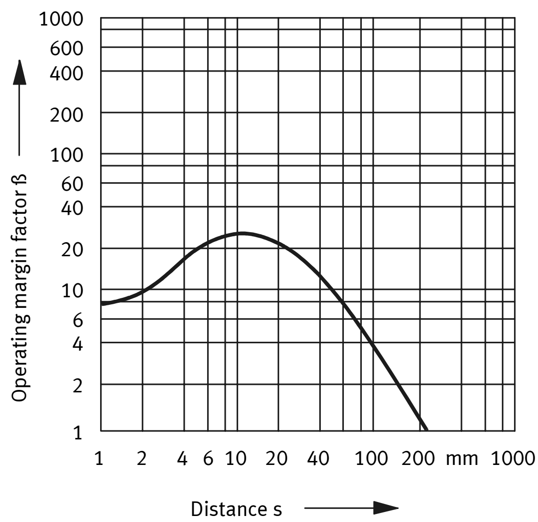


Fig. 6.1.5: Example showing the pattern of the operating reserve factor using a diffuse sensor

The higher the risk of contamination, the higher the required operating margin factor. If the manufacturer specifies operating margin curves, then a specific value can be defined when dimensioning the layout of a proximity sensor application. The anticipated contamination can be estimated considering the transmission factor τ.

If one takes $\tau = 1$ for transmission without contamination then $\tau = 0.1$ means that with contamination, only 1/10 of the optical signal capacity reaches the receiver. In this case, an operating margin factor of $\beta > 10$ is required.

In the absence of manufacturer's specifications, the operating margin can be tested by means of simulating contaminated conditions.

A flashing indicator on the proximity sensor is useful for checking the operating margin. This is actuated if the sensor falls below the minimum operating margin. Designs are available, which start to flash if the operating margin factor of $\beta = 1.5$ is reached, thereby signalling that 50 % operating margin is still available.

A flashing indicator can also be used as a setting aid during the assembly and adjustment of a proximity sensor layout and at the same time serve as an indicator of contamination during the subsequent operational process if the operating margin gradually reduces.

A different type of contamination indicator operates dynamically by checking with each actuation of the proximity sensor whether, on reaching the switching threshold, the optical signal capacity has increased to a level which still leaves sufficient operating margin. For this mode of operation, switching operations are presumed to take place. An LED flashes, if there is insufficient operating margin or an electrical warning signal is provided at an additional output.

Other reasons, apart from contamination, can be the cause for falling below the operating margin, e.g.:
– Exceeding of safe sensing range
– Changes in the material surface of objects detected
– Incorrect assembly (maladjustment)
– Ageing of emitter diode
– Fracture in fibre-optic cable

6.1.4 Variants of optical proximity sensors

Schematically, the variants can be divided as follows:

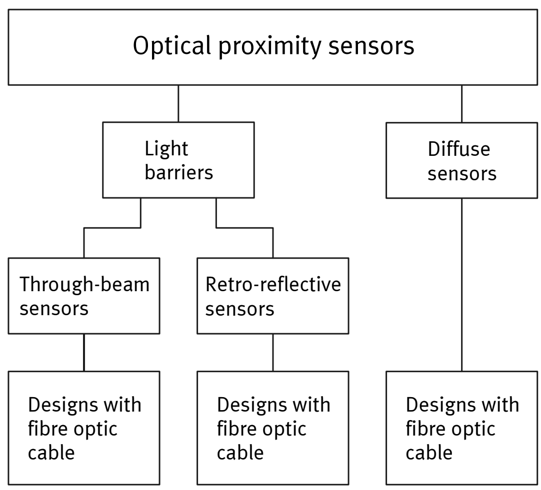


Fig. 6.1.6: Variants of optical proximity sensors

6.2 Through-beam sensors

6.2.1 Function description

Through-beam sensors consist of separately assembled emitter and receiver components whereby wide sensing ranges can be achieved. For the interruption of the light beam to be evaluated, the cross-section of the active beam must be covered. The object should permit only minimum penetration of light, but may reflect any amount of light.
Failure of the emitter is evaluated as "object present".

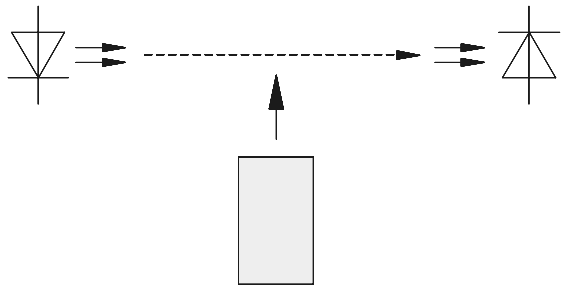


Fig. 6.2.1: The principle of the through-beam sensor

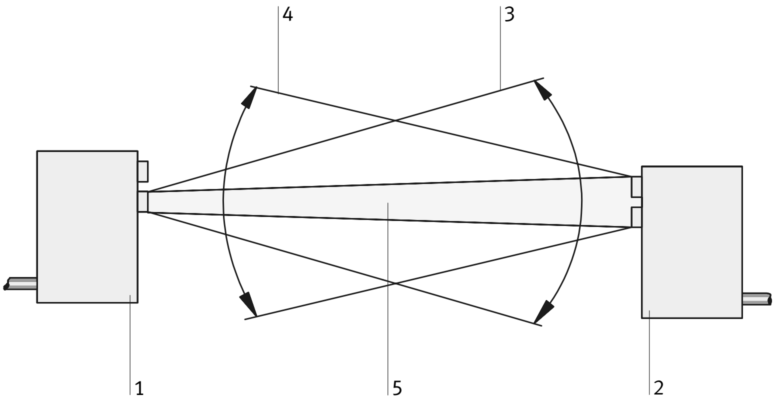
6.2.2 Technical characteristics

The table below lists the key technical data relating to through-beam sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	Value
Object material	any, problems with highly transparent objects
Operating voltage	10 – 30 V DC or 20 – 250 V AC
Range	1 – 100 m (usually adjustable)
Switching current (transistor output)	100 – 500 mA
Sensitivity to dirt	sensitive
Service life	long (approx. 100 000 h)
Switching frequency	20 – 10 000 Hz
Designs	generally block-shaped but also cylindrical designs
Protection (IEC 529, DIN 40050)	up to IP67
Ambient operating temperature	0 – 60 °C or -25 – +80 °C

Table 6.2.1: Technical data of through-beam sensors

Receivers have PNP or NPN transistor outputs and partly additional relay outputs.



Emitter (1)
Receiver (2)
Emission range (3)
Reception range (4)
Response range (5)

Fig. 6.2.2: Response range of through-beam sensors

The response range is precisely defined by the size of the optical aperture of the emitter and the receiver. In this way, precise lateral position sensing is given.

6.2.3 Notes on application

Advantages of a through-beam sensor

- Enhanced reliability because of permanent light during non-operation.
- Wide range.
- Small objects can be detected even at large distances.
- Suitable for aggressive environment.
- Objects can be diffuse reflecting, mirroring or low transluscent.
- Good positioning accuracy.

Disadvantages of a through-beam sensor

- Two separate proximity sensor modules (emitter and receiver) and separate electrical connections are required.
- Cannot be used for completely transparent objects.

Notes

- In the case of transparent objects, it is possible to reduce the emitter power by means of the built-in potentiometer to the extent where the receiver is deactivated if the object enters the light beam.
- Failure of the emitter is evaluated as "object present" (important with accident prevention applications).

6.2.4 Examples of application

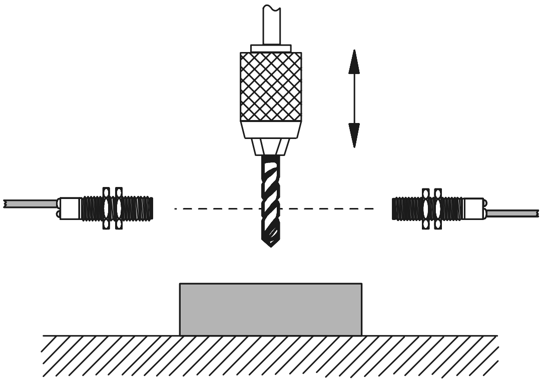
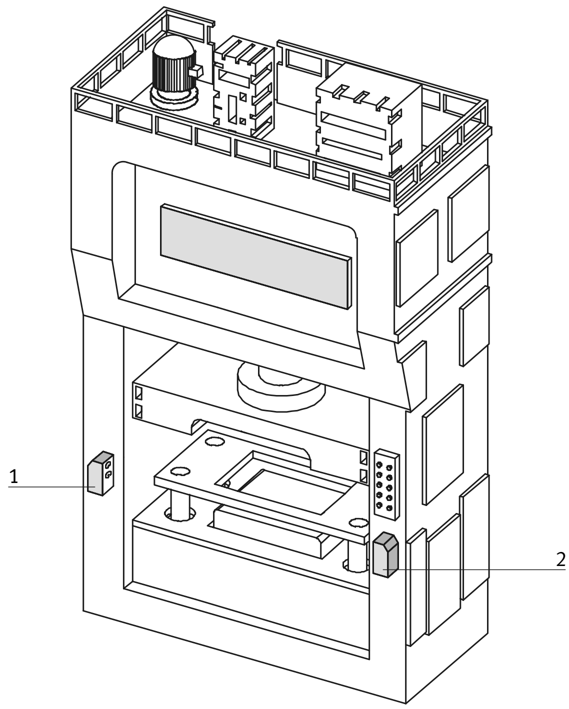


Fig. 6.2.3: Checking for broken drills by means of a through-beam sensor



Through-beam sensor, Emitter (1) Through-beam sensor, Receiver (2)

Fig. 6.2.4: Accident prevention on a press by means of a through-beam sensor

Safety barriers must comply with the accident prevention regulations of the employer's liability insurance associations. Equipment must be constantly self-monitoring and tested by the technical control boards and passed in relation to the design. Access to presses and cutting machines in particular must be monitored because of their high accident risk rate.

6.3 Retro-reflective sensors

6.3.1 Function description

Light emitter and light receiver are installed in one single housing. An additional reflector is required. Interruption of the light beam is evaluated.

Interruption of the light beam must not be compensated by direct or diffuse reflection of an object. Transparent, bright or shiny objects may in some cases remain undetected.

Mirroring objects must be positioned in such a manner that the reflecting beam does not impinge on the receiver.

Compared to a diffuse sensor, the retro-reflective sensor has a greater range.

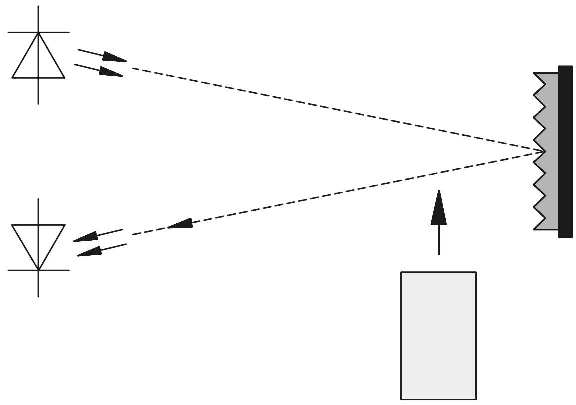


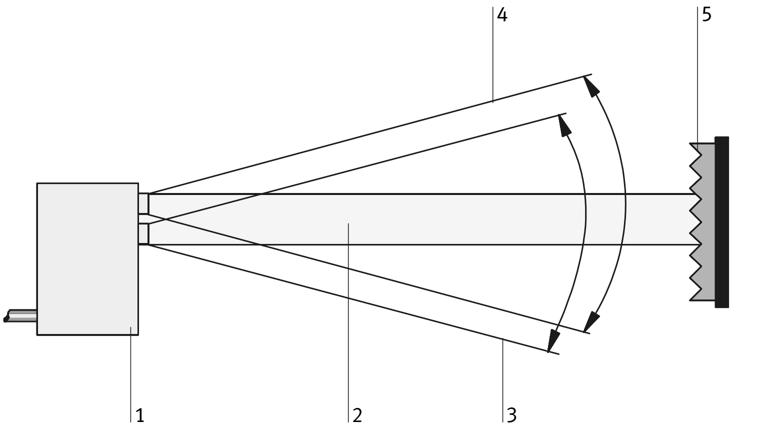
Fig. 6.3.1: The principle of the retro-reflective sensor

6.3.2 Technical characteristics

The table below lists the key technical data relating to retro-reflective sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	Value
Object material	any, problems with reflecting objects
Operating voltage	10 – 30 V DC or 20 – 250 V AC
Range	up to 10 m (usually adjustable)
Switching current (transistor output)	100 – 500 mA
Sensitivity to dirt	sensitive
Service life	long (approx. 100 000 h)
Switching frequency	20 – 1000 Hz
Design	cylindrical, block-shaped
Protection (IEC 529, DIN 40050)	up to IP67
Ambient operating temperature	0 – 60 °C or -25 – +80 °C

Table 6.3.1: Technical data of retro-reflective sensors



Emitter/receiver (1)
Response range (2)
Reception range (3)
Emission range (4)
Retro-reflector (5)

Fig. 6.3.2: Response range of retro-reflective sensors

The response range is within the lines which form the limit of the aperture edge of the emitter/receiver optics and the edge of the reflector. As a rule, the response range near the reflector is smaller than the reflector cross section, depending on the distance of the proximity sensor and the potentiometer setting.

6.3.3 Notes on application

Advantages of a retro-reflective sensor

- Enhanced reliability because of permanent light during non-operation.
- Simple installation and adjustment.
- Object can be diffuse reflecting, mirroring or transparent as long as a sufficiently high percentage of the light is definitely absorbed.
- In most cases, a greater range in comparison with diffuse sensors.

Disadvantages of retro-reflective sensors

- Transparent, very bright or shiny objects may remain undetected.

Notes

- In the case of transparent objects, the light beam passes the object twice and as a result is attenuated. It is possible to detect objects of this type by means of an appropriate potentiometer setting.
- Reflecting objects must be arranged in such a manner to ensure that the reflection does not hit the receiver.
- With particularly small objects, an orifice in the light beam can improve the effectiveness.
- Failure of the emitter is evaluated as "object present".
- Reflectors can deteriorate with age and dirt; At temperatures of over 80 °C plastic can be affected permanently, unsuitable reflectors can limit the range and effectiveness considerably.

6.3.4 Examples of application

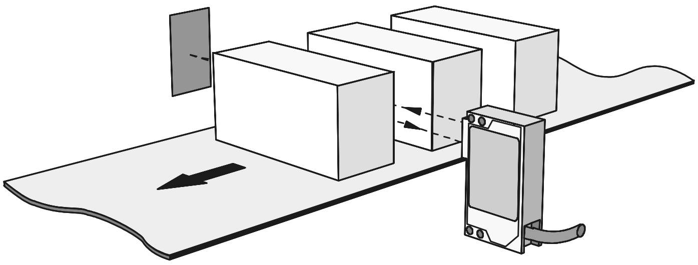


Fig. 6.3.3: Monitoring build-up and counting of objects by means of retro-reflective sensors

Advantage

Only the passive reflector is required on one side of the conveyor without the need for electrical cabling for the receiver of a through-beam sensor.

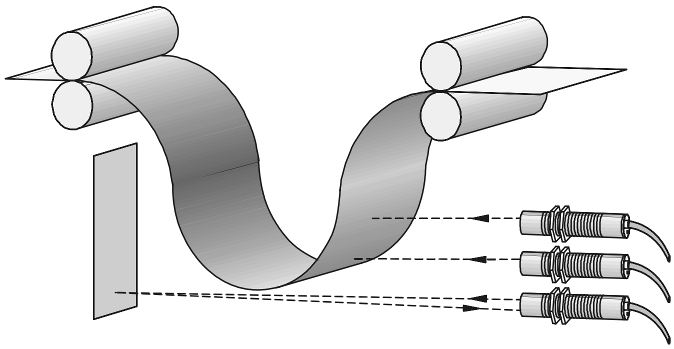


Fig. 6.3.4: Slack control by means of retro-reflective sensors

Reflector

Reflective foil or individual triple reflectors

The solution shown in Fig. 6.3.4 is not applicable in the case of transparent material.

6.4 Diffuse sensors

6.4.1 Function description

The emitter and receiver are fitted in the same housing. The object diffusely reflects a percentage of the emitted light thereby activating the receiver. Depending on the design of the receiver, the output is then switched through (normally open function) or switched off (normally closed function). The switching distance largely depends on the reflectivity of the object. The size, surface, shape, density and colour of the object as well as the angle of impact determine the intensity of the diffused light so that as a rule only small distances within a range of a few decimeters can be scanned. The background must absorb or deflect the light emission, i.e. when an object is not present, the reflected light beam must be clearly below the response threshold of the receiving circuit.

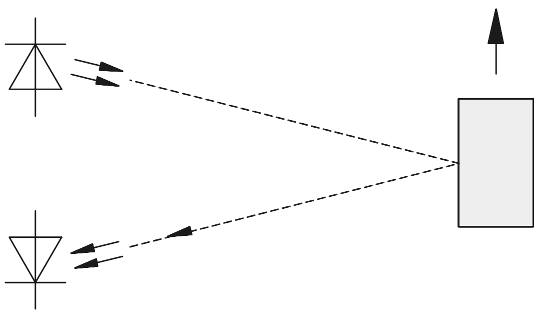


Fig. 6.4.1: The principle of diffuse sensors

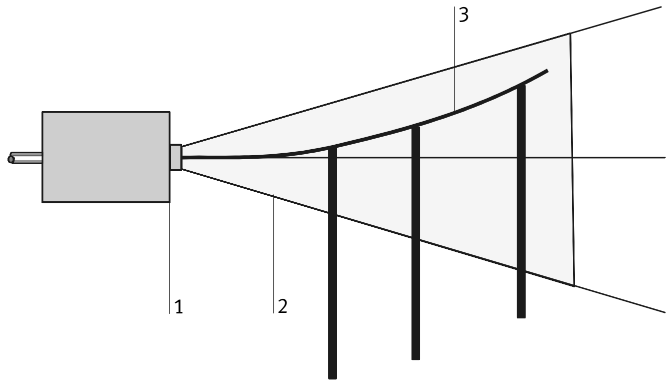
6.4.2 Technical characteristics

The table below lists the key technical data relating to diffuse sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	**Value**
Object material	any
Operating voltage	10 – 30 V DC or 20 – 250 V AC
Sensing range	50 mm – 2 m (usually adjustable)
Switching current (transistor output)	100 – 500 mA
Sensitivity to dirt	sensitive
Life cycle	long (approx. 100 000 h)
Switching frequency	20 – 2000 Hz
Design	cylindrical, block-shaped
Protection (IEC 529, DIN 40050)	up to IP67
Ambient operating temperature	0 – 60 °C or -25 – +80 °C

Table 6.4.1: Technical data of diffuse sensors

As a rule, the sensing width specified in data sheets refers to white cardboard, whereby the white reverse side of a Kodak grey card CAT 152 7795 is generally used. The white side of this test card has a constant reflection of 90 % within a spectral range of approximately 450 – 700 nm. The grey side reflects 18 %.



Emitter/Receiver (1) Emitting range (2) Response curve (3)

For small distances: Small diffuse reflecting surface required.
For large distances: Large back-reflection surface required.

Fig. 6.4.2: Response curves of diffuse sensors

6.4.3 Notes on application

Advantages of the diffuse sensor

- Because the reflection on the object activates the receiver, an additional reflector is not required.
- The object can be diffuse reflecting, mirroring or transparent to translucent as long as a sufficiently high percentage of the light beam is definitely reflected.
- Whereas with through-beam sensors objects can only be detected laterally to the light beam, diffuse sensors allow frontal detection, i.e. in the direction of the light beam.
- Depending on the setting of the diffuse sensor, objects can be detected selectively in front of a background.

Disadvantages of a diffuse sensor

- The response curves according to Fig. 6.4.2 are not completely straight. Therefore, diffuse sensors are not as suitable as through-beam sensors, if accurate lateral response is crucial.

Notes

- The size, surface, shape, density and colour of the object determine the intensity of the diffused light emission and hence the actual sensing range. The nominal sensing range given in data sheets is measured using the white side of the standard Kodak test card. The background must absorb or deflect the light emission, i.e. in the absence of an object, the reflected light emission must be clearly below the response threshold of the receiving circuit.

- Failure of the emitter is evaluated as "no object present".

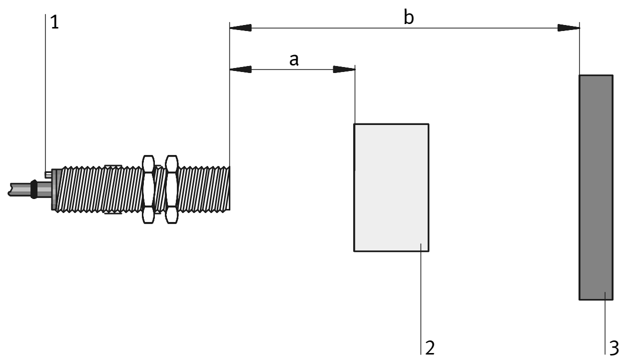
Correction factors to take into account different object surfaces
The switching distance must be multiplied by the correction factor.

Material	Factor
Cardboard, white [1)]	1.0
Expanded polystyrene, white	1.0 – 1.2
Metal, shiny	1.2 – 2.0
Wood, coarse	0.4 – 0.8
Cotton material, white	0.5 – 0.8
Cardboard, black matt	0.1
Cardboard, black shiny	0.3
PVC, grey	0.4 – 0.8

1) Matt white reverse side of Kodak grey card CAT 152 7795

Table 6.4.2: Correction factors for the switching distance of retro-reflective sensors

Background masking with diffuse sensors



Setting potentiometer (1) Object (2) Background (3)

Distance between proximity switch and object (a),
Distance between proximity switch and background (b)

Fig. 6.4.3: Background fade-out with diffuse sensor

Adjustable sensitivity

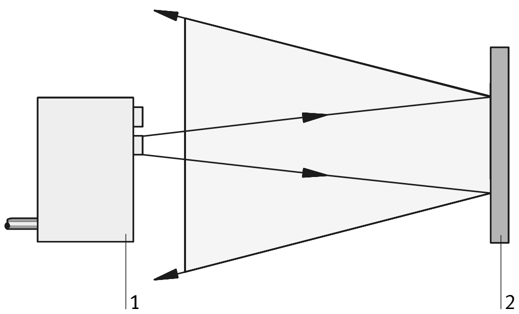
The effect of the diffuse sensor depends on the difference in reflection of the object and the background. With only a slight contrast, the response threshold can, if necessary, be selected via the sensitivity setting on the proximity sensor (1-turn potentiometer or multiturn potentiometer) in a way that the object is reliably detected even under these difficult conditions.

However, a tolerance range must be taken into consideration in respect of ageing, voltage and temperature fluctuations and dirt. For this reason, the setting range must not be taken up completely when making the adjustment.

When carefully setting the diffuse sensor with the potentiometer, a certain margin must be made to take into account changes in the condition of the object such as contamination of the proximity sensor, dust in the atmosphere etc. Close, barely functional adjustments can lead to problems.

Some diffuse sensor haves a built-in flashing LED display to facilitate reliable setting, which flashes if the sensing object is not clearly detected. The adjustment of a proximity sensor with normally open output should be made in such a way that the light emitting diode is on in the active status without flashing.

Behaviour of a diffuse sensor with a mirroring object



Emitter/Receiver (1) Reflecting surface (2)

Fig. 6.4.4: Object is detected

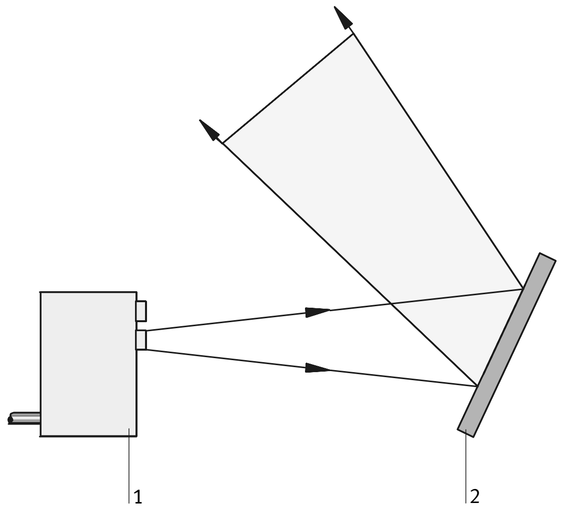


Fig. 6.4.5: Object is not detected

Transparent objects

- Light glass
- Light plexiglass
- Transparent cling film

These materials usually have smooth, reflecting surfaces and a diffuse sensor can therefore be used.
Condition: The surface of the object must be vertically aligned to the direction of the light beam.

Objects with reduced reflection

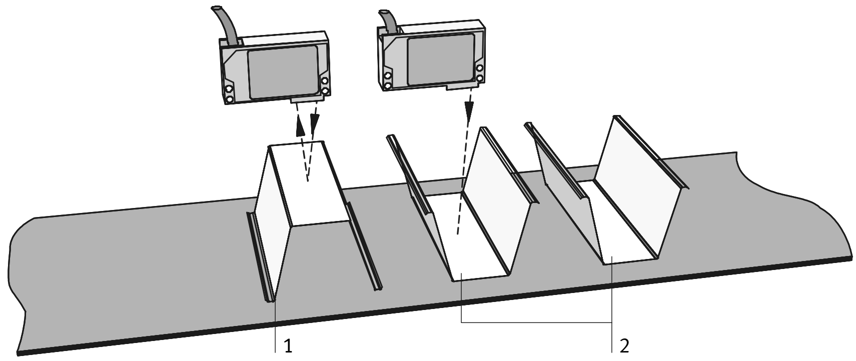
- Matt black plastic
- Black rubber
- Dark materials with a rough surface
- Dark textiles
- Burnished steel

Diffuse sensors do not react to this type of material or only at a very small distance.

Alternative solutions

- Through-beam sensors or retro-reflective sensors for lateral approach
- Capacitive proximity sensor or ultrasonic proximity sensor for frontal approach.

6.4.4 Examples of application



correct (1) wrong (2)

Fig. 6.4.6: Monitoring the position of a workpiece by means of a diffuse sensor

Careful adjustment of sensitivity on the potentiometer is required, whereby tolerances with regard to differences in material, dirt, etc. must be taken into account.

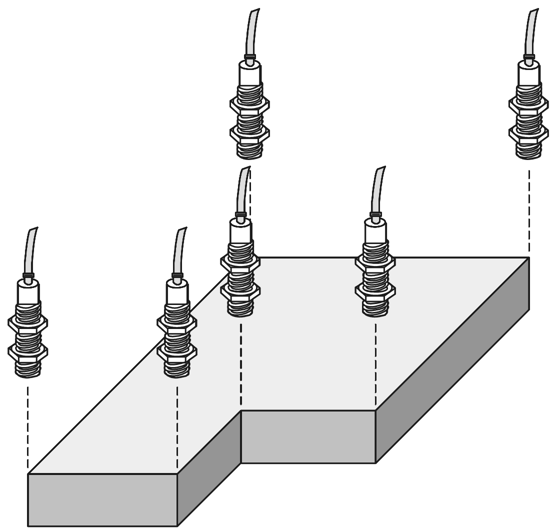


Fig. 6.4.7: Shape and position checking using diffuse sensors

A connected controller checks whether all sensors respond (the proximity sensor outputs are connected according to AND-logic). For high accuracy and small distances, diffuse sensors with fibre-optic cables should be considered.

6.5 Optical proximity sensors with fibre-optic cables

6.5.1 Function description

Optical proximity sensors with fibre-optic cable adaptors are used if conventional devices take up too much room. Another application, where the use of fibre-optic cable adaptors is of advantage, is in areas with explosion hazard. With the use of fibre-optic cables the position of small objects can be detected with high accuracy.

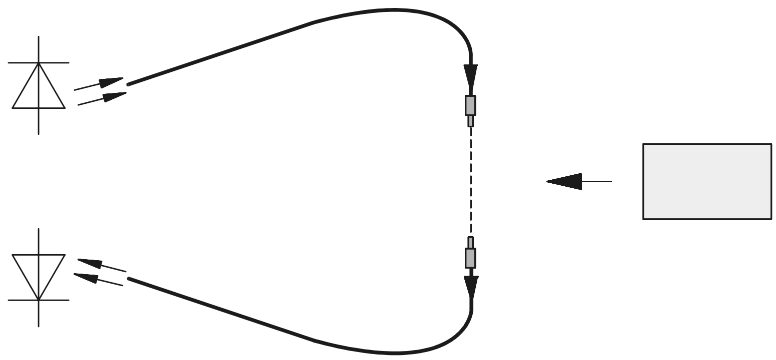


Fig. 6.5.1: Through-beam sensor with fibre-optic cables (principle)

By using two separate fibre-optic cables it is possible to construct a through-beam sensor. Because of their handling flexibility, these can be used universally.

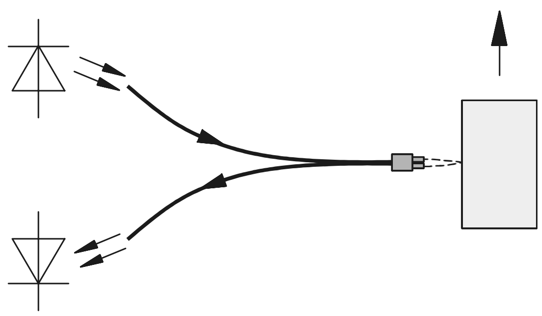
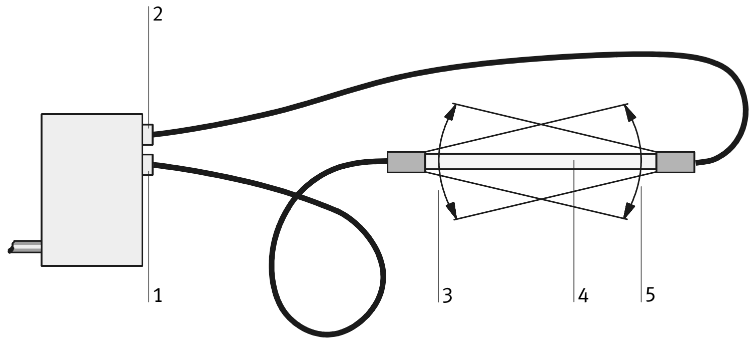


Fig. 6.5.2: Diffuse sensor with fibre-optic cables (principle)

Emitter and receiver fibre-optic cables are incorporated in sensor head.

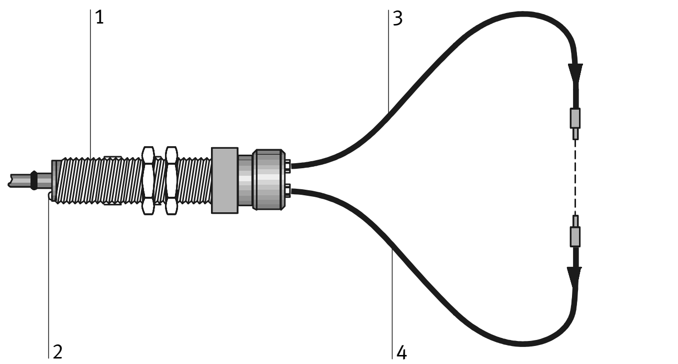
6.5.2 Technical characteristics



Emitter (1) Reception range (3) Emission range (5)
Receiver (2) Response range (4)

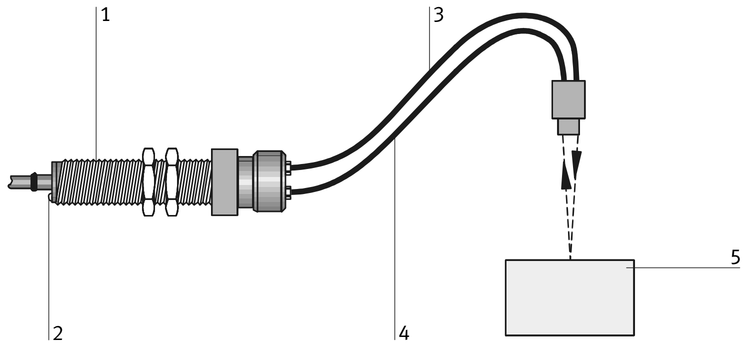
Fig. 6.5.3: Response range of through-beam sensors with fibre-optic cables

The response range is accurately determined by the aperture of the fibre-optic cable ends. This makes possible an accurate lateral approach, even with small objects.



Optoelectronic proximity sensor (1) Emitter fibre-optic cable (3)
LED display and adjusting screw (2) Receiver fibre-optic cable (4)

Fig. 6.5.4: Through-beam sensor with fibre-optic cables (design example)



Optoelectronic proximity sensor (1) Emitter fibre-optic cable (3) Object (5)
LED display and adjusting screw (2) Receiver fibre-optic cable (4)

Fig. 6.5.5: Diffuse sensor with fibre-optic cables (design example)

6.5.3 Notes on application

Advantages of optical proximity sensors adapted for use with fibre-optic cables

- Detection of objects in areas of restricted access, e.g. through holes.
- Possibility of remote installation of proximity sensor housing (e.g. hazardous environment: heat, water, radiation, explosion risk).
- Accurate detection of small objects.
- Sensing elements can be moved.

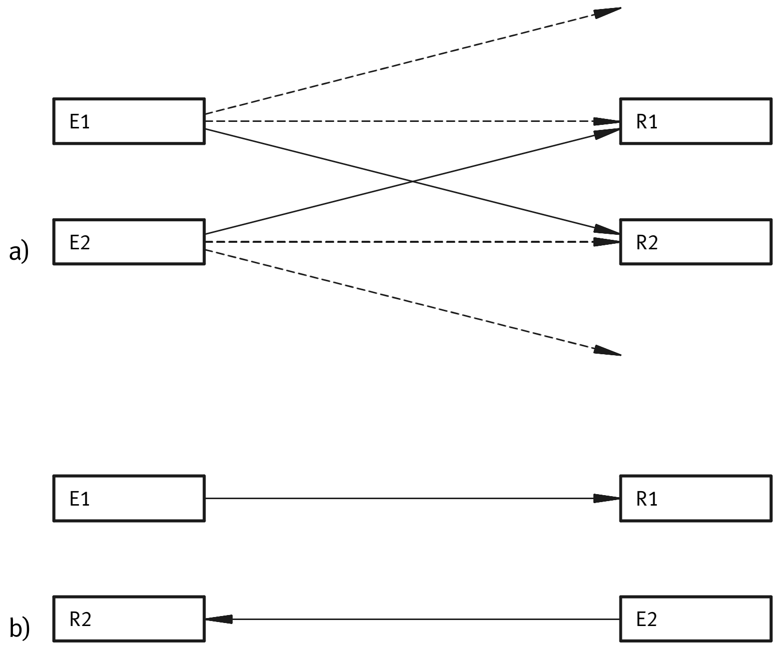
Advantages of polymer fibre-optic cables

- Mechanically stronger than fibre-glass.
- Length can be reduced easily by cutting the ends on the proximity sensor with a sharp knife.
- Cost saving.

Advantages of glass fibre-optic cables

- Suitable for higher temperatures.
- Reduced optical attenuation with large distances as well as at close infrared range.
- Longer lasting.

If emitter/receiver units with separate housing (as with through-beam sensors) are used, it should be noted that if several sensors are similarly orientated, mutual interference can occur.

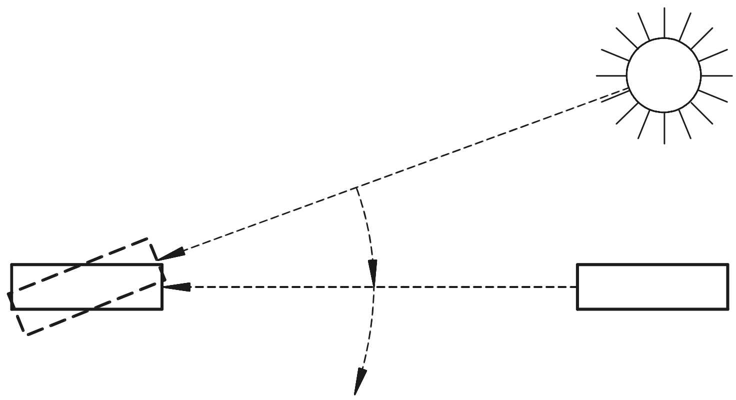


a) Problem: Mutual interference of emitter and receiver

b) Solution: Alternate arrangement of emitter and receiver

Fig. 6.5.6: Avoiding mutual interference

Although optical proximity sensors are to a certain extent protected against external light influences, excessive external light (e.g. filming lights, flash lights, strong sunlight) can cause interference.



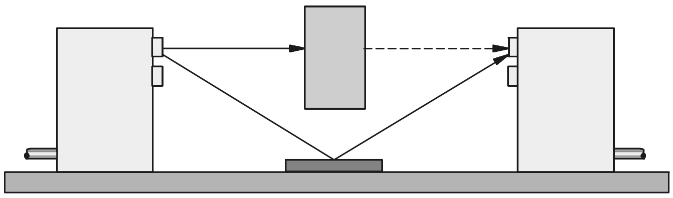
Problem: Interference from extraneous light

Solution: Turn away optical axis from the external source or install an orifice in the light beam

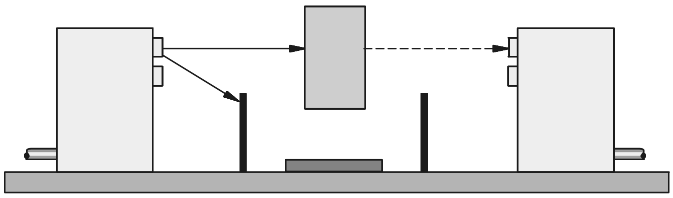
Fig. 6.5.7: Avoiding interfering light

A reflecting surface in the vicinity of some types of optical proximity sensors can lead to interference, if stray light from the emitter reaches the receiver via a reflecting surface, see Fig. 6.5.8. If diffuse sensors are used, then a reflecting background (e.g. light anodised aluminium parts) can create problems.

a)



b)



a) Problem: Reflecting surfaces in surrounding area.

b) Solution: Cover reflecting surfaces or reflection by means of orifices.
Further possibilities are:
– To set the optical axis at an angle in order to "deflect away" the interfering reflection.
– To reduce the sensitivity of the receiver.

Fig. 6.5.8: Avoidance of reflective interference

The lenses of optical proximity sensors must be screened against dirt or regularly cleaned (e.g. with jets of compressed air). If dirt could cause interference, basic consideration should be given to whether alternative proximity sensors less affected by dirt should be used.

6.5.4 Examples of application

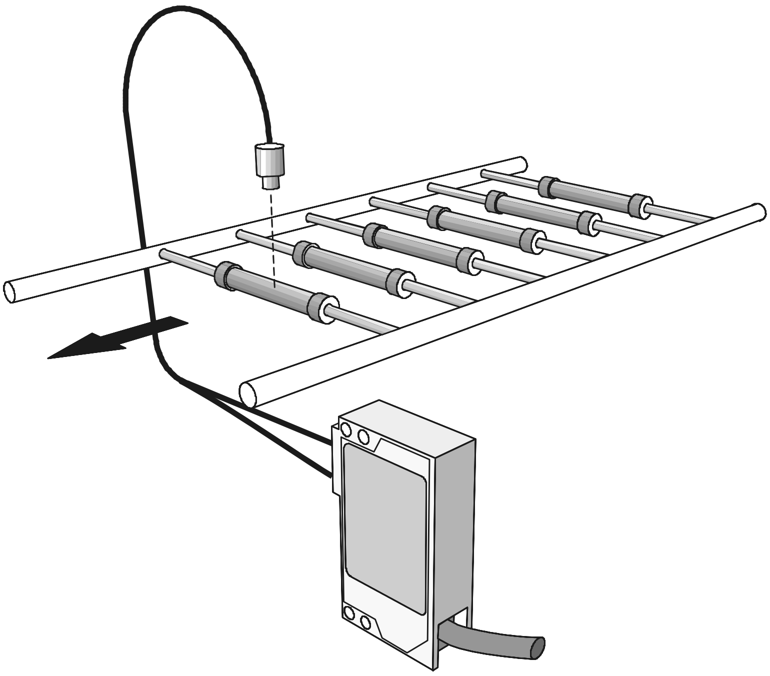


Fig. 6.5.9: Detecting small objects by means of a diffuse sensor with fibre-optic cables

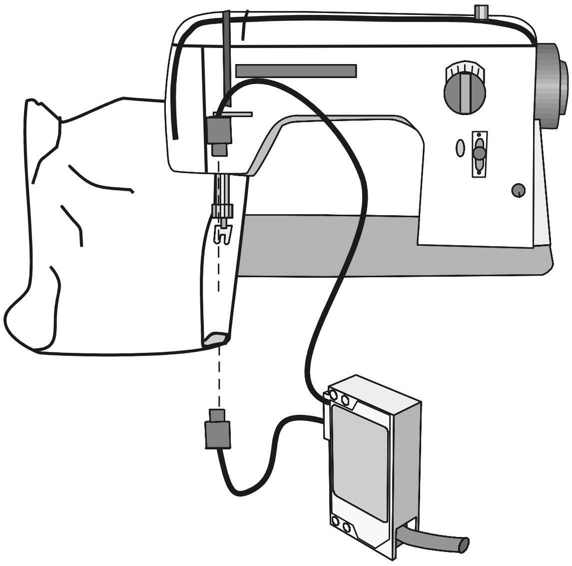


Fig. 6.5.10:
Distinguishing between one or two layers of fabrics by means of a through-beam sensor with fibre-optic cable

One layer of fabric lets through more light than two, which leads to switching with an appropriate proximity sensor setting.

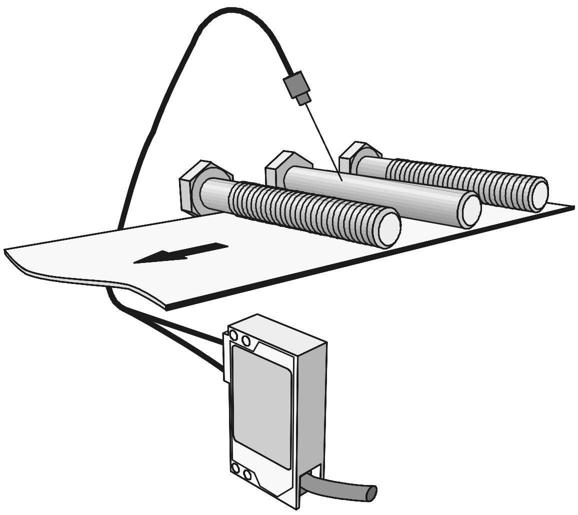


Fig. 6.5.11: Checking of threads

Threaded screws reflect sufficient diffused light to make the receiver switch. If the surface is smooth, the emitted light beam is deflected away from the sensor.

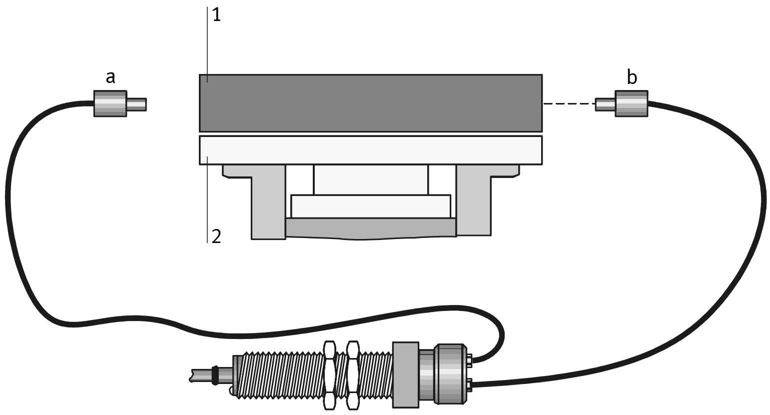


Fig. 6.5.12: Detection of workpieces on a workpiece carrier

6.6
Exercises

Exercise 6.1

Environmental effects on optical proximity sensors
What do you need to consider when using an optical proximity sensor in a dusty environment?
Suggest options for solving this problem.

Exercise 6.2

Selection of optical proximity sensors
Objects are to be detected on processing equipment in a highly inaccessible place where ambient temperature may increase up to 100 °C. The use of optical proximity sensors is intended.

Which solution is particularly suitable in this case?
What is to be considered when selecting the means of detection?

Exercise 6.3

Operational reliability of optical proximity sensors
What effect does the modulation of light emission have on the operational reliability of optical proximity sensors?

Exercise 6.4

Detection of burnished steel

A diffuse sensor is installed in a production plant. When installed, it responds without being actuated by the object, i.e. its switching output switches through and the light emitting diode responds. In the presence of an object, it switches off. The object in question is a burnished steel part.

How can this behaviour be explained?

Exercise 6.5

Electrical connection of proximity sensors

In a factory, a number of optical proximity sensors have failed for unknown reasons when installed. The engineer has no experience in dealing with proximity sensors, therefore wrong connection cannot be ruled out. On the other hand, short-circuit proof and reverse polarity protected proximity sensors have been used. The engineer confirms that the proximity sensors have been connected to a power supply of 24 V DC. The power supply unit which has been fitted has a filter circuit (inductance and filter capacitor), but without electronic control.

What, in your opinion, are the reasons causing the failure?

Exercise 6.6

Measurement of filling level by means of optical proximity sensors

This illustration shows an application where an optical proximity sensor is used for liquid level measurement.

1. Which types of optical proximity sensor are to be considered for this application?
2. Does this solution permit accurate liquid level monitoring? Why?
3. Under which conditions could this solution fail?
4. Is this solution suitable for measuring the liquid level in a container of melted candle wax?
5. What other solutions do you know for liquid level measurement?

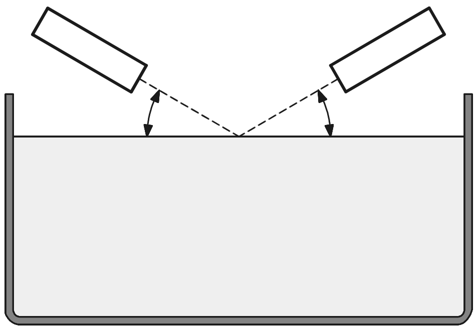


Fig. 6.6.1: Liquid level measurement by means of a through-beam sensor

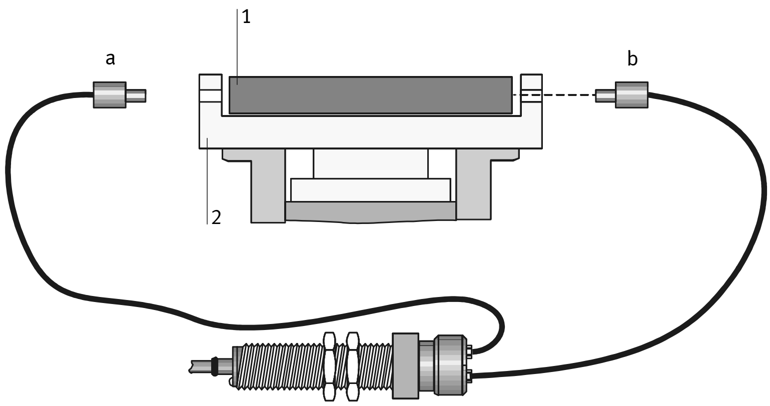
On reaching a defined liquid level, the light emitted by the emitter will be reflected on the surface and will reach the receiver.

Exercise 6.7

Detection of workpieces

Figure 6.6.2 shows a workpiece on a conveying slide. The workpiece is po- sitioned in a recess of the workpiece carrier. The edge of the workpiece is to be detected through holes.

1. Is it possible to solve this problem by using a through-beam sensor? Or is too much light lost when the light passes through the hole?
2. With other conveying slides, sufficient space is available on one side only or above the slide for a proximity sensor or fibre-optic cable to be mounted.
   The workpiece is made of plastic and has a matt lateral sawn edge as well as a smooth reflecting surface. The slide is made of matt aluminium.
   Which solution can you recommend?



Workpiece (1) Workpiece carrier (2) Through-beam sensor with fibre-optic cable (a – b)

Fig. 6.6.2: Interrogation by means of a through-beam sensor with fibre-optic

Exercise 6.8

Use of optical proximity sensors in car washes
A decision is to be made as to whether optical proximity sensors can be used for car washes to control movement of the drying nozzle as shown in the illustration below. After the car has been washed, a gantry bearing the drying nozzle which extends across the width of the car, traces the contours of the car. The task of the proximity sensors is to ensure that the drying nozzle constantly follows the contour of the car at a certain distance. The proximity sensors may be splashed by water during the preceding wash cycle.

Which type of proximity sensor would you recommend?
How many proximity sensors would you suggest for each car wash unit and in which order?

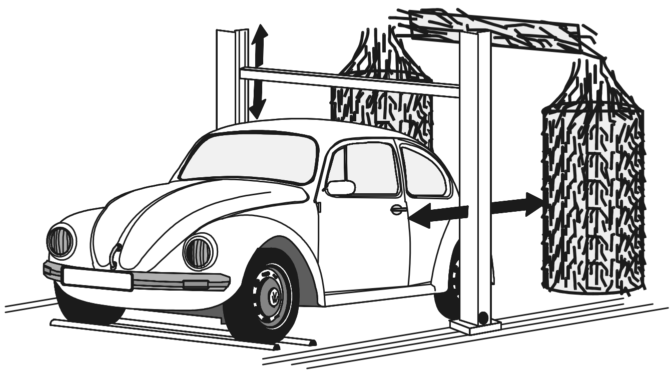


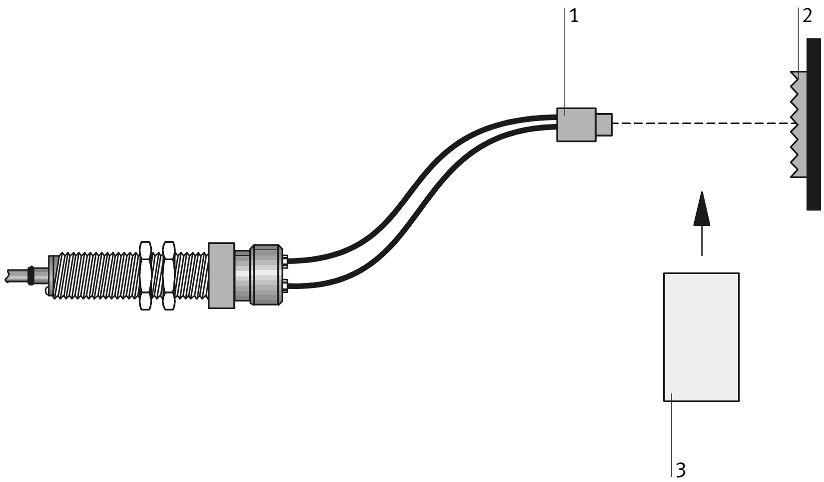
Fig. 6.6.3: Drying in a car wash

Exercise 6.9

Use of optical proximity sensors equipped with fibre-optic cables

An enterprising designer would like to use an optical diffuse sensor equipped with fibre-optic cables as a retro-reflective sensor and thereby employing a reflector as shown in the illustration. With this solution, he hopes to achieve a greater range of detection for dark, matt workpieces, which can only be approached via restricted access.

Does this solution work?
What, in your opinion, are the characteristics of this solution?



Fibre-optic diffuse sensor (1) Triple mirror reflector (2) Object (3)

Fig. 6.6.4: Application of a diffuse sensor with fibre-optic cable as a retro-reflective sensor

Exercise 6.10

Checking of bottles

A drinks manufacturer would like to use a proximity sensor to detect automatically which empty bottles returns are fitted with light metal screw caps. The bottles are to pass below a proximity sensor on a conveyor belt (see illustration). Because of the variation in bottle height and the different screw caps fitted a maximum tolerance in height H of 8 mm should be calculated.

1. Which solution of optical proximity sensors is to be recommended?
2. Is it also possible to use inductive proximity sensors (e.g. proximity sensors with a nominal switching distance of 8 mm)?

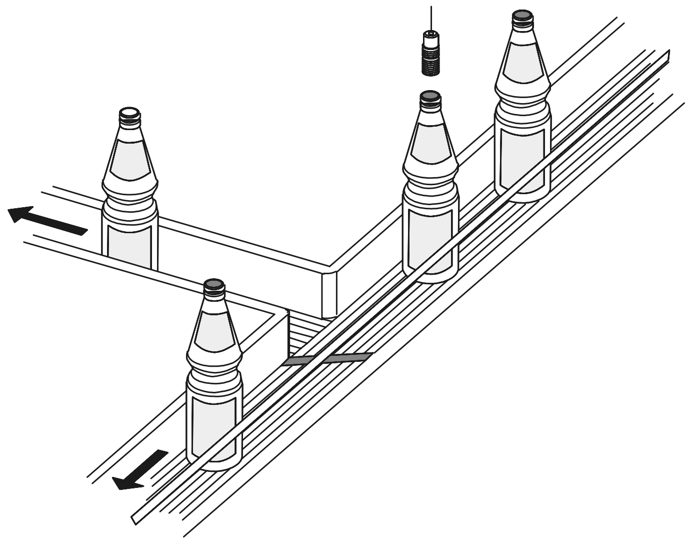
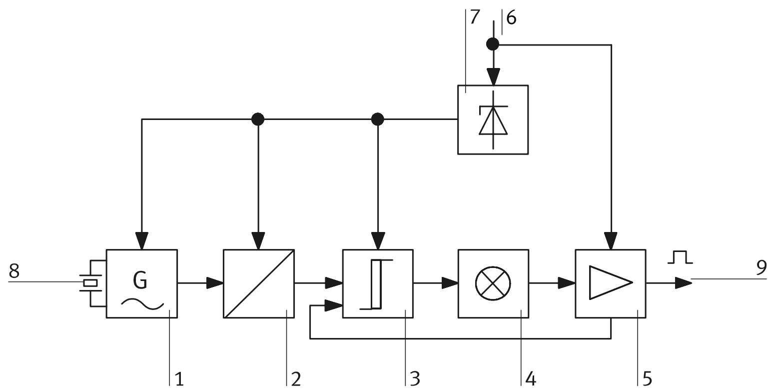


Fig. 6.6.5: Separating bottles with or without sealing caps

7. Ultrasonic proximity sensors

7.1
Function description

The operational principle of an ultrasonic proximity sensor is based on the emission and reflection of acoustic waves between an object and a receiver. Normally, the carrier of these sound waves is air. The travelling time of the sound is measured and evaluated.

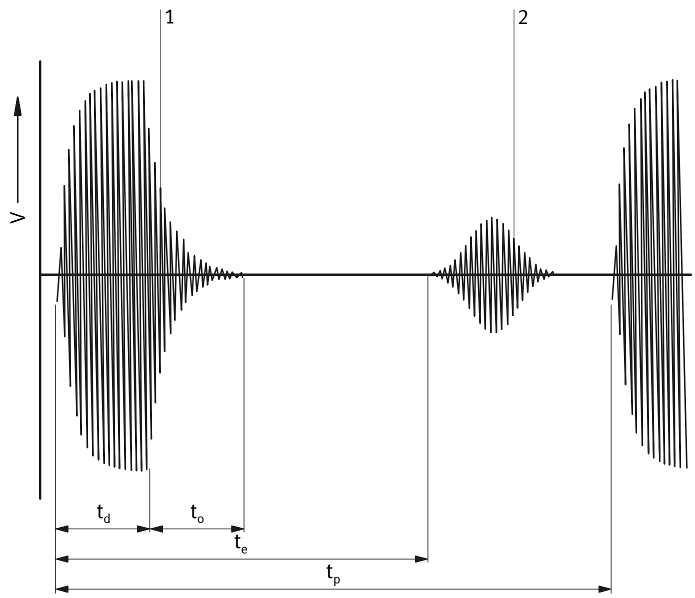


Oscillator (1)
Evaluation unit (2)
Triggering stage (3)
Switching status display (4)
Output stage with protective circuit (5)
External voltage (6)
Internal constant voltage supply (7)
Active zone (ultrasonic transducer) (8)
Switch output (9)

Fig. 7.1.1: Block circuit diagram of an ultrasonic proximity sensor

The proximity sensor can be divided into three main modules, the ultrasonic transducer, the evaluation unit and the output stage. A short pulse briefly triggers the ultrasonic transmitter. This is usually a piezo-electric module, e.g. on the basis of piezo-oxides.

The ultrasonic transmitter emits sound waves in the non-audible range at any frequency usually between 30 – 300 kHz. In most cases, the ultrasonic transmitter changes from emission to reception, i.e. now operating in the sense of a microphone. Filters inside the ultrasonic proximity sensor check whether the sound received is actually the echo of the emitted ultrasonic waves.



Emission pulse (1)	Pulse duration (t_d)	Echo transmission time (t_e)
Echo (2)	Oscillation decay time (t_o)	Pulse interval (t_p)

Fig. 7.1.2: Principle of distance measurement by evaluating the transmission time of ultrasonic pulses

The speed of operation of ultrasonic proximity sensors is limited by the maximum pulse repetition frequency which, depending on design, can range between 1 Hz and 100 Hz.

A major advantage of ultrasonic proximity sensors lies in the fact that these can detect a wide range of different materials. Detection is independent of shape, colour and material, whereby the material can be solid, fluid or in powder form. Testing is not affected by dusty, steamy or smoky atmospheres.

Ultrasonic proximity sensors are generally available in the form of diffuse sensors, where the emitter and received are in one housing. In addition, ultrasonic barriers are available, which have separate emitters and receivers.

Preferred areas of application for ultrasonic proximity sensors are:

- Storage facilities
- Transport systems
- Food industry
- Metal, glass and plastics processing
- Monitoring of bulk material

Ultrasonic proximity sensors have the following advantages:

- Relatively large range (up to several meters)
- Object detection irrespective of colour and material
- Safe detection of transparent objects (e.g. glass bottles)
- Relatively dust and dirt insensitive
- Fading out of background possible
- Outdoor application possible
- Feasibility of contactless sensors with accurate variable switching points. The area of detection can be flexibly divided into zones. Programmable versions are available.

Ultrasonic proximity sensors have the following disadvantages:

- If ultrasonic proximity sensors are used for slanting object surfaces, the sound is deflected. It is therefore important that the object surface to be reflected is at a right angle to the axis of the sound propagation or to use ultrasonic barriers instead.
- Ultrasonic proximity sensors react relatively slowly. Maximum switching frequency is between 1 Hz and 125 Hz.
- Ultrasonic proximity sensors are generally more expensive than optical proximity sensors (e.g. factor 2).

7.2 Technical characteristics

The table below lists the key technical data relating to ultrasonic sensors. The figures listed in this table are typical examples and merely provide an overview.

Parameter	**Value**
Object material	any, with the exception of sound-absorbing materials
Operating voltage	typ.24 V DC
Nominal switching distance	100 mm – 1 m, max. up to 10 m, usually adjustable
Switching current (transistor output)	100 – 400 mA
Sensitivity to dirt	moderate
Service life	long
Ultrasonic frequency	40 – 220 kHz
Switching frequency	1 – 125 Hz
Design	cylindrical, block-shaped
Protection (IEC 529, DIN 40050)	typ. IP65, max. up to IP67
Ambient operating temperature	0 – +70 °C, partly as low as -10 °C

Table 7.2.1: Technical data of ultrasonic sensors

Ultrasonic proximity sensors as a rule are equipped with a light emitting diode for status indication and very often with a potentiometer for setting of the operating range. There are also designs with two potentiometers for setting a switching window as well as special programmable designs, with which different operating ranges can be selected via an electronic interface.

Some ultrasonic proximity sensors are equipped with synchronised inputs, whereby trouble free and alternating operation is possible if several adjacent proximity sensors are used.

7.3 Notes on application

7.3.1 Minimum distances

With the installation of ultrasonic proximity sensors, as with that of inductive and capacitive sensors, different minimum distances must be observed between adjacent proximity sensors.

When assembling ultrasonic proximity sensors without the option for synchronisation, make sure that mutual influence of the proximity sensors does not occur. Observe the following listed minimum distances in relation to the detection range of the proximity sensors used. These values apply if the object to be tested is moved in front and vertically to the proximity sensor. The values indicated merely provide examples. Deviations may occur depending on type and manufacturer's instructions.

Detection range [cm]	Typical minimum distance [cm]
6 – 30	>15
20 – 100	>60
80 – 600	>250

Table 7.3.1: Lateral minimum distance between two parallel ultrasonic proximity sensors

Under other operating conditions, the minimum distances are established experimentally for the respective assembly.
If two ultrasonic proximity sensors are opposite one another, then the values given in the table below are to be observed.

Detection range [cm]	Typical minimum distance [cm]
6 – 30	>120
20 – 100	>400
80 – 600	>2500

Table 7.3.2: Minimum distances between opposing ultrasonic proximity sensors

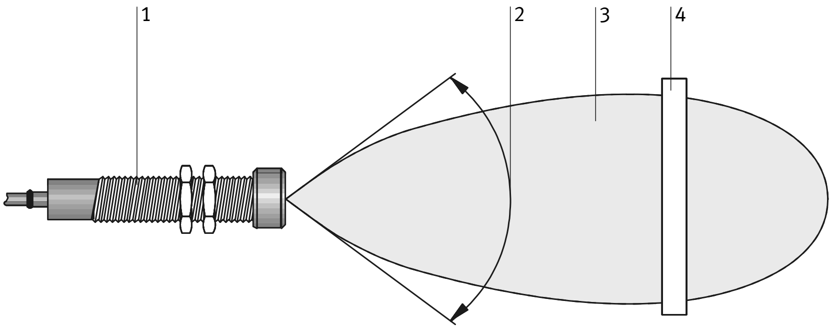
In cases where a wall or other reflecting objects are adjacent to an ultrasonic sensor, the following values apply:

Detection range [cm]	Typical minimum distance [cm]
6 – 30	>3
20 – 100	>15
80 – 600	>40

Table 7.3.3: Minimum distances between ultrasonic proximity sensors and a lateral, reflecting wall

7.3.2 Required minimum size of the object

The required object size depends on the acceptance angle of the ultrasonic beam. If the ultrasonic sound waves travel past an object which is too small, then any objects which may be alongside or in the background may interfere. As there is often insufficient data provided by the manufacturer, a preliminary test is recommended by moving the test plate from the side towards the object to be detected whilst observing the switching distance.



Ultrasonic sensor (1)
Acceptance angle of sound cone (2)
Sound cone (3)
Object (4)

Fig. 7.3.1: Detection area of an ultrasonic sensor

7.3.3 Type of object

Suitable are solid, fluid, pulverised or granulated materials. Unsuitable for ultrasonic sensors are ultrasound absorbing materials such as coarse clothing material, cotton wool, terry cloth, foam rubber, rock wool. On the other hand, it is possible to detect these materials by means of ultrasonic barriers.

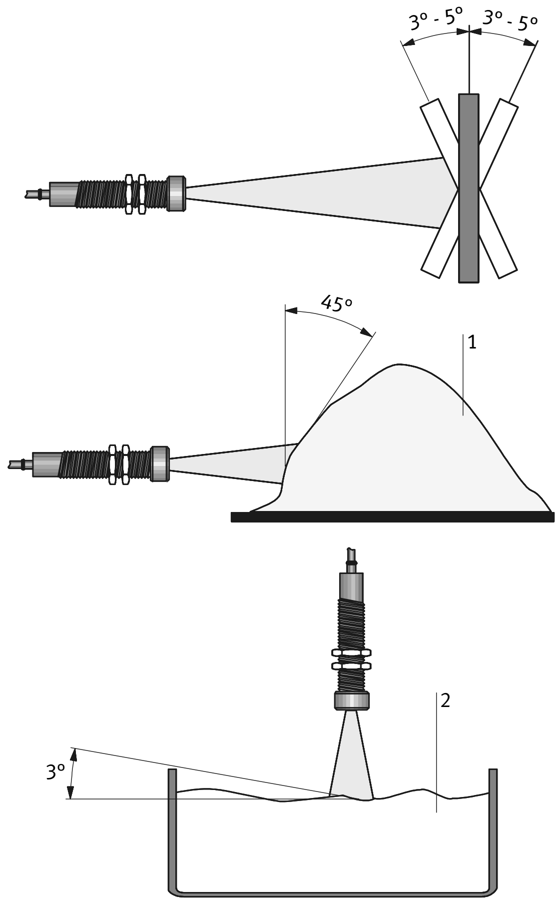
Similarly it is possible to detect transparent, reflecting or jet black objects, where optical proximity sensors may fail. Even very thin transparent film of a thickness of approx. 0.01 mm can be detected head-on by means of ultrasonic proximity sensors.

7.3.4 Minimum possible distance of object

As a proximity sensor requires a minimum processing time to detect the ultrasonic echo, it cannot operate within a certain blind area. In the case of short distances, "secondary lobes" of the ultrasonic sound cone can lead to error pulses. With designs consisting of a single ultrasonic transducer, completion of oscillation must be achieved after emission (see Fig. 7.1.2), before the echo pulse can be registered.

7.3.5 Position of object

Similarly as with light, ultrasound is deflected on flat surfaces. In this case, an ultrasonic sensor does not receive an echo signal. Objects with smooth, even surfaces, can no longer be detected if the deviation is for instance more than ±3° – ±5° of the vertical alignment to the proximity sensor. With objects of a rough or irregular surface a wider angle is possible, whereby the ultrasonic wave length, the surface finish and distance are also relevant.



Sand (1) Liquid (2)

Fig. 7.3.2: Effect of the object surface when using ultrasonic sensors

7.3.6 Effect of ambient temperature, humidity, air pressure

Ultrasonic speed depends on air temperature by approximately 1,8 ‰ per °C. Because ultrasonic proximity sensors are invariably not temperature compensated, a slight change in switching point may occur as a result of ambient temperature. The humidity content of air at a temperature range below 40 °C effects a maximum change in the speed of sound by 1.4 % between a relative air humidity of 0 % and 100 %. Natural changes in atmospheric air pressure do not cause any significant changes in the speed of sound. Only at high altitudes does the speed of sound decrease slightly.

7.3.7 Diverting the ultrasonic beam

The ultrasonic sound wave beam can be diverted by means of even or slightly concave reflectors, whereby objects can be detected "around the corner".

7.3.8 Effect of temperature of the object

Very hot objects, such as melting baths or red hot metal leads to strong air striation and can interfere with ultrasonic propagation. Preliminary experiments are therefore recommended.

7.3.9 Effect of ambient noise

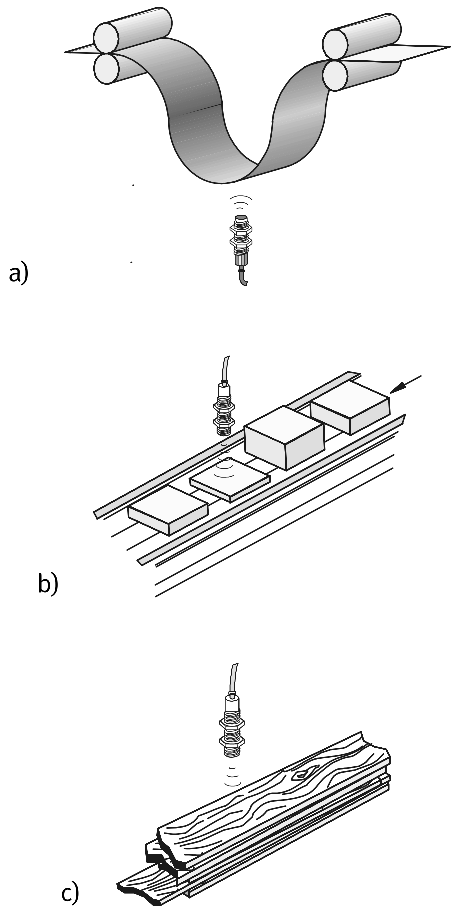
As the transmission frequencies are in the range of 30 – 250 kHz and due to the limited receiver bandwidth, ultrasonic proximity sensors are generally little affected by external noise. In exceptional cases they may react to intensive, selective interference.

7.4 Examples of application

Ultrasonic proximity sensors are used for monitoring filling levels in silos.

Ultrasonic proximity sensors have also proved reliable for the control of automatic trolleys in warehouses.

The following illustrations show a few additional examples:



a) Monitoring slack between web feed rollers

b) Sorting according to different height

c) Monitoring of batch thickness

Fig. 7.4.1: Examples of application for ultrasonic proximity sensors

7.5 Exercises

Exercise 7.1

Smallest measurable distance
When distance measuring with ultrasonic proximity sensors, the smallest measurable distance has to be taken into account.

Why?

Exercise 7.2

Deflection of ultra-sonic sound waves
Is it possible to deflect sound waves similar to light with a mirror, by 90° for instance?

What do you need to observe?

Exercise 7.3

Detection of boxes on a conveyor belt
A conveyor belt for metal boxes is to be interrogated as to whether boxes are available, filled or empty. The proximity sensors to be used must not only detect whether boxes are present, but also "look inside" the box from above and check whether they have been filled. The use of optical proximity sensors was questioned due to the different colours of containers and the contents as well as the risk of contamination.

Explain the advantages and disadvantages of ultrasonic proximity sensors as opposed to diffuse optical sensors for an application of this type.

8. Pneumatic proximity sensors

8.1
General characteristics

With pneumatic proximity sensors the presence or absence of an object is detected by means of contactless sensing with air jets. When an object is present a signal pressure change occurs, which can be further processed.

The advantages of these proximity sensors are:

- Operational safety in dusty environments
- Operational safety with high ambient temperatures
- Can be used in areas of explosion hazard
- Insensitive to magnetic influences and sound waves
- Reliable even in extreme ambient brightness and for sensing of light transparent objects, where optical proximity sensors may not be suitable.

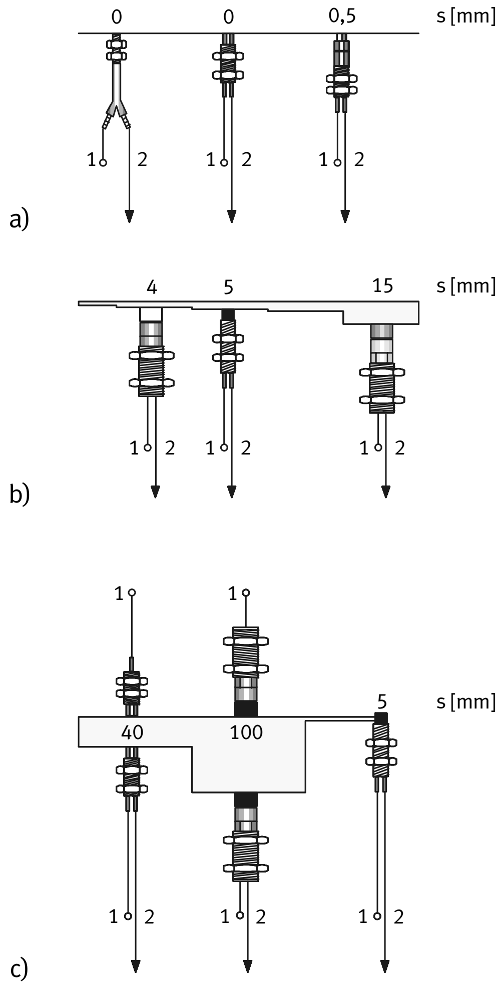
Pneumatic proximity sensors can be differentiated between back pressure sensors, reflex sensors and air barriers. Detectable distances range from 0 to 100 mm, see Fig. 8.1.1

A common requirement for the application of pneumatic sensors is to reduce the system air pressure to a low pressure range by means of pressure regulators. A supply of filtered, oil-free air is essential.

As the pneumatic signal is generally too weak for further evaluation, a pressure amplifier needs to be connected downstream. A pneumatic proximity sensor with binary electrical output signals is created with the help of pneumatic-electric converters (pressure switches).

When obstructing the exhaust nozzles, it is important to ensure that the amplifier is designed for any necessary increased pressure.

When replacing pneumatic sensors, it is generally necessary to adjust the amplifier or threshold setting, due to discrepancies as a result of production tolerances.



Supply pressure (1) Output pressure (signal pressure) (2) Sensing distance (s)

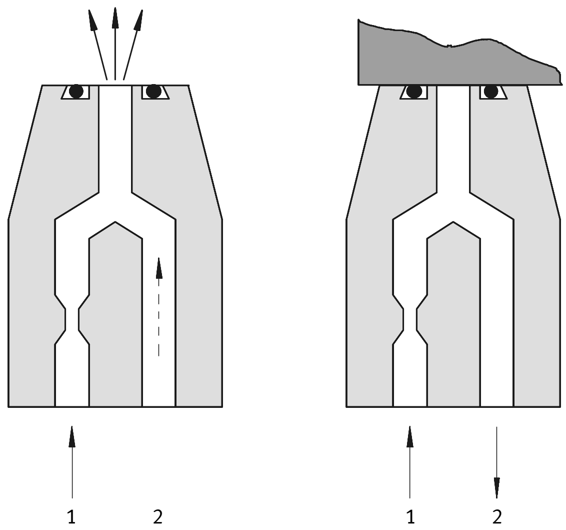
a) Back pressure sensors
b) Reflex sensors
c) Air barriers

Fig. 8.1.1: Typical sensing distances of various pneumatic proximity sensors

Supply pressure can vary, but is generally in the region of 0 – 800 kPa (0 – 8 bar). The signal pressure generated depends on the supply pressure and the distance between the nozzle and the object.

8.2
Back pressure sensors (Back pressure nozzles)

The obstructing of an air jet drilling by means of an object to be detected leads to a signal pressure build-up in the control port to the level of the supply pressure. Alternative designation: Back pressure nozzle



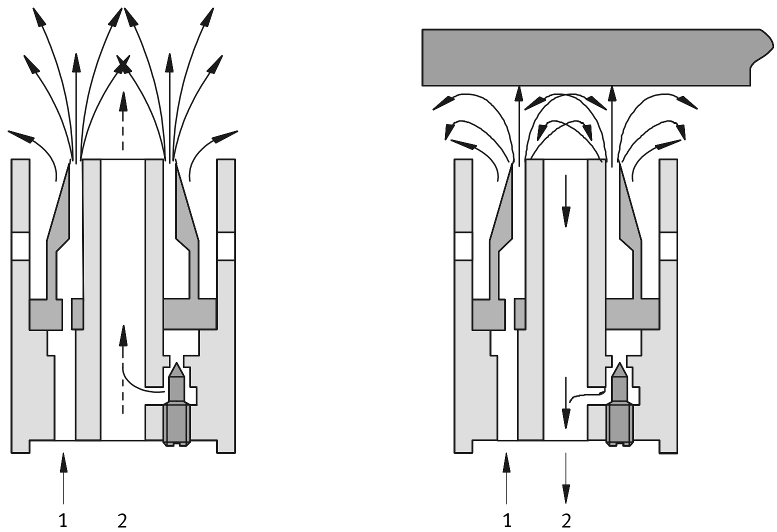
Supply pressure (1) Output pressure (signal pressure) (2)

Fig. 8.2.1: Method of operation of back pressure nozzle

8.3
Reflex sensors

The reflex type of sensor consists of an annular ring jet nozzle and a central receiver nozzle.

If an object is moved towards the air escaping from the ring jet nozzle (sender), an excess pressure builds up in the central nozzle (receiver nozzle) when the object is at a certain distance from the ring jet. Fig. 8.3.1 provides a schematic representation of the air flow.



Supply pressure (1) Output pressure (signal pressure) (2)

Fig. 8.3.1: Method of operation of a reflex sensor

The reflection of the air jet on an object to be detected creates a signal pressure build-up in the control port relative to the sensing distance and supply pressure.

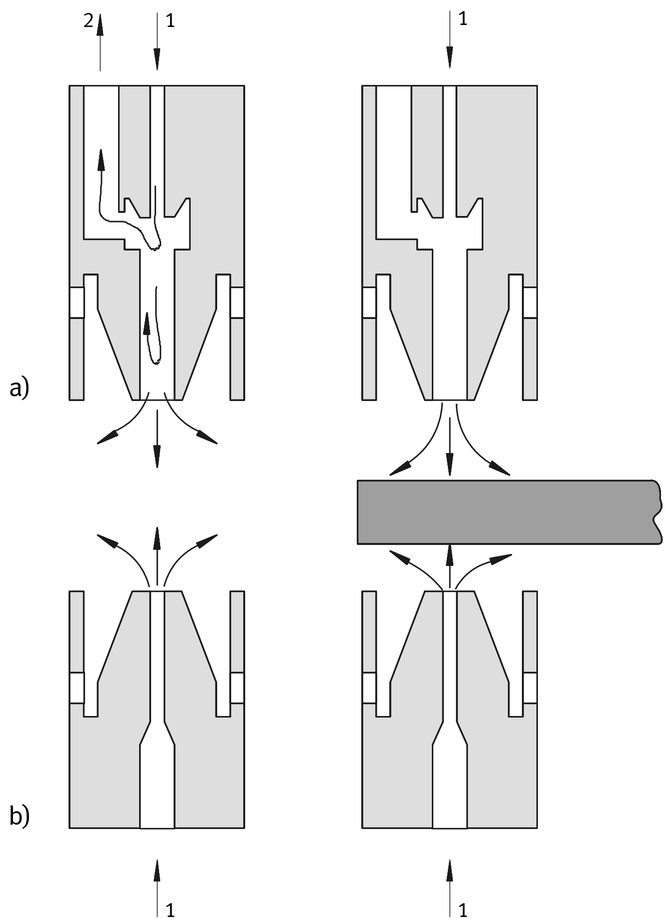
The reflex sensor is typical of this design. A reflex sensor generally consists of a sender and receiver nozzle arranged concentrically. A constant air jet is emitted by the sender.

The approach of an object towards the reflex sensor influences this air jet and a back pressure (reflex) builds up in the receiver nozzle, which can be evaluated as a signal (output 2).
Alternative designation: Reflex nozzle

8.4
Air barriers

By placing a ring jet nozzle directly opposite a receiver nozzle, it is possible to construct an air barrier (analogous to a through-beam sensor) which is interrupted by an object. With this type, it is also possible for an air jet to be interrupted by an opposite air jet instead of an object. This is known as an interference jet barrier. Distances of up to 100 mm can be spanned by air barriers.

Simple air barriers, where the air escapes from the sender only, are subject to dirt collecting in the receiver nozzle, because the flow of air collects dirt particles from the surrounding area. This can lead to a malfunction or a total breakdown due to blockage.



Supply pressure (1)   Output pressure (signal pressure) (2)

a) Receiver nozzle
b) Emitter nozzle

Fig. 8.4.1: Method of operation of an air barrier

Most air barriers on the market operate on the principle of the deflecting jet, whereby air escapes on both sides of the barrier. The function of the receiver side mode of operation can be compared to that of a reflex sensor. In this way, it is possible to greatly reduce susceptibility to contamination.

8.5 Notes on application

Since the price of a complete pneumatic proximity sensor (nozzle and pressure amplifier/pressure switch) is generally higher than that of a standard inductive, capacitive or even optical proximity sensor, pneumatic proximity sensors are used preferably for special applications in new developments, where other proximity sensors are unsuitable.

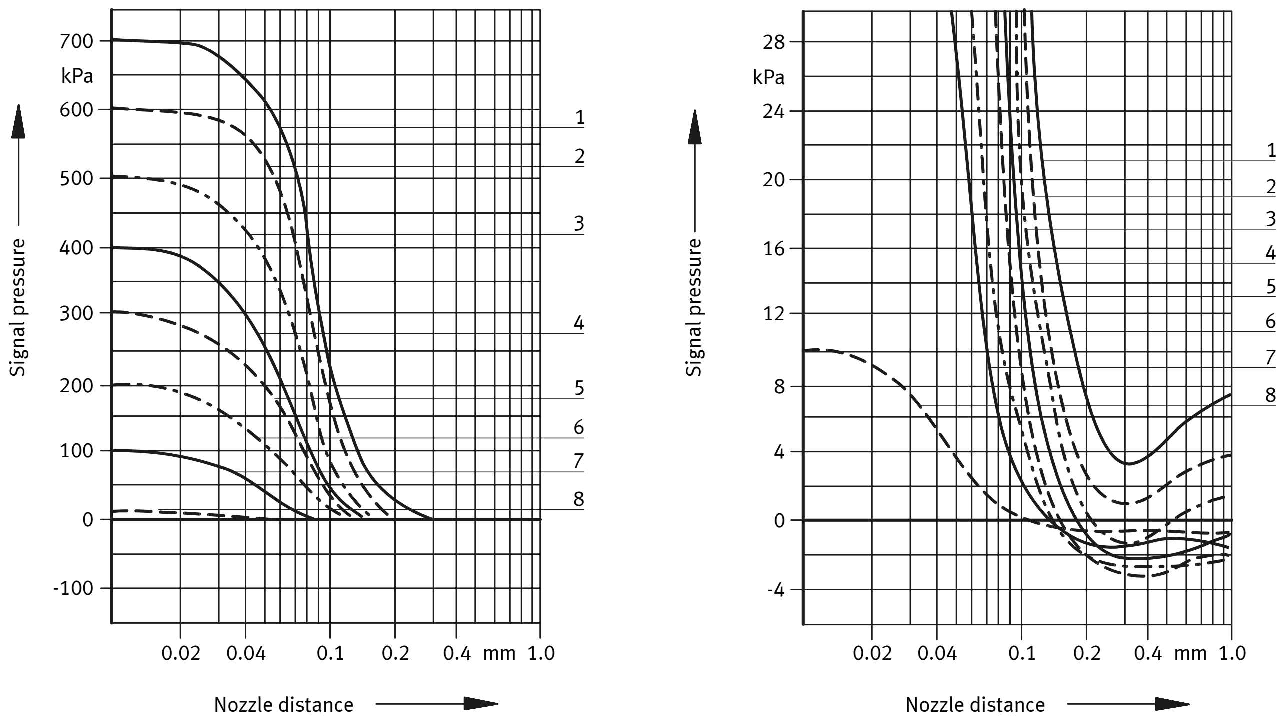
Advantageous applications for pneumatic proximity sensors:

- Use in areas with explosion hazard.
- Use in welding installations, where AC and DC fields are generated.
- Use in damp and dirt and dust laden environment.
- Use in high ambient temperatures.
- Used in measuring filling levels of foaming liquids.

8.6
Characteristic curves of pneumatic proximity sensors

The following illustrations show the characteristic curves relating to the performance of pneumatic proximity sensors, using Festo products as an example. The data indicated is in respect of back pressure sensors, reflex sensors and air barriers.

8.6.1 Characteristic curves of back pressure sensors



Supply pressure: 700 kPa (1), 600 kPa (2), 500 kPa (3), 400 kPa (4), 300 kPa (5), 200 kPa (6), 100 kPa (7), 10 kPa (8)

Fig. 8.6.1:
Signal pressure as a function of nozzle distance and supply pressure with a Festo SD-3 back pressure sensor

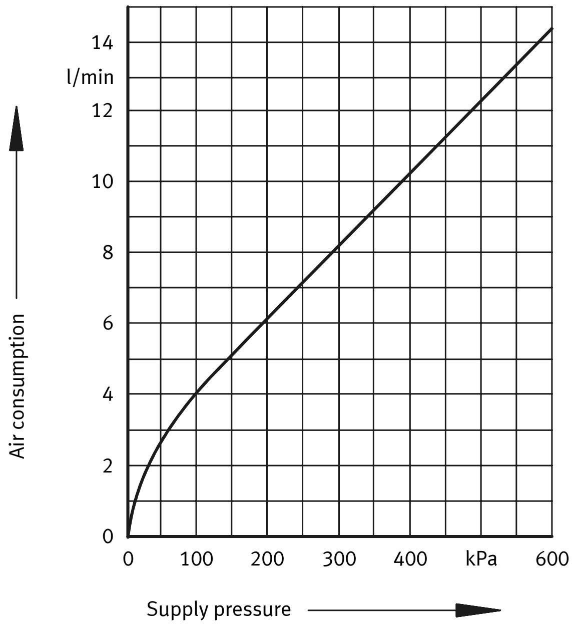
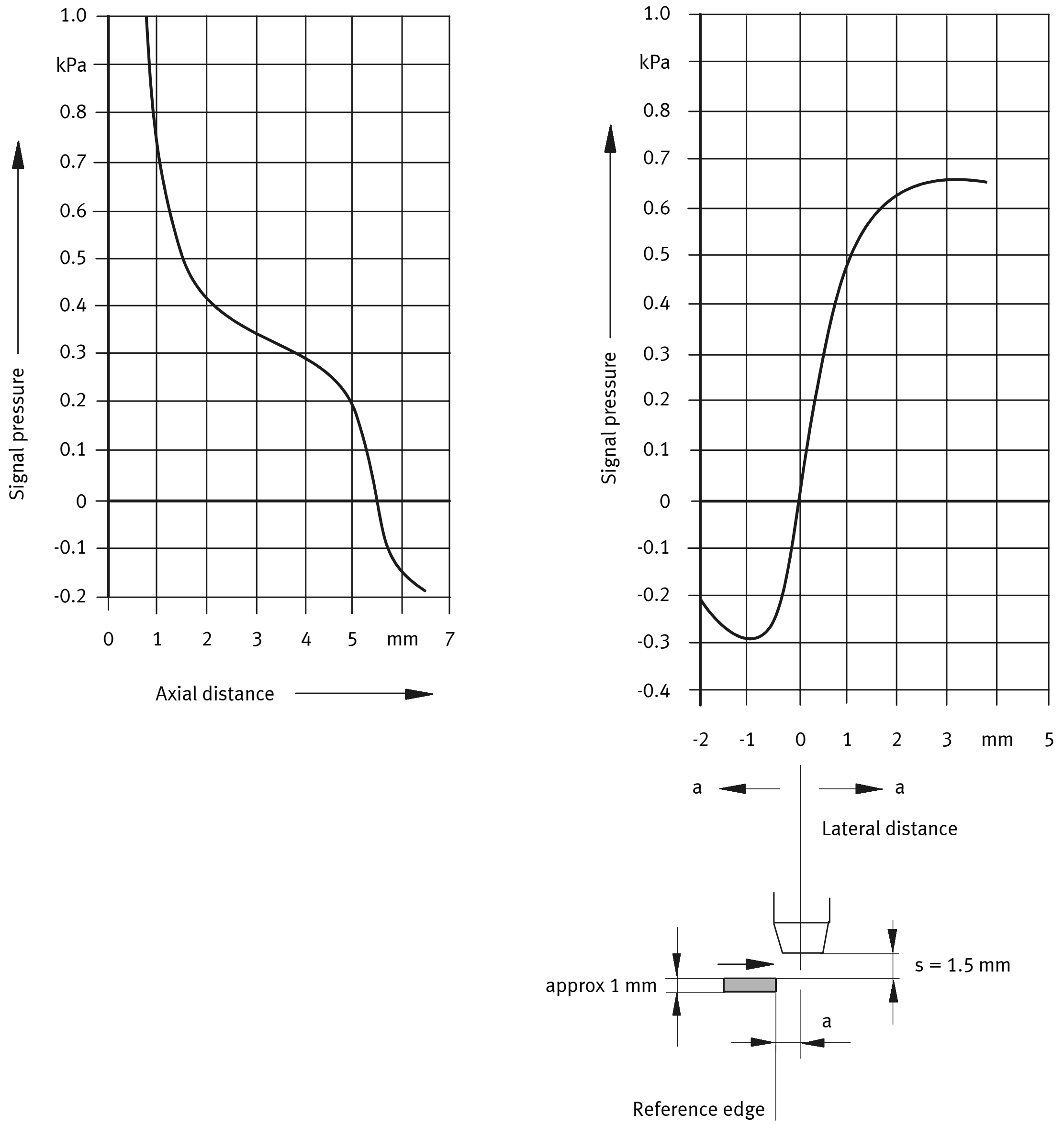


Fig. 8.6.2: Air consumption as a function of supply pressure with a Festo SD-3 back pressure sensor

8.6.2 Characteristic curves of reflex sensors



Supply pressure = 15 kPa (0.15 bar)

Fig. 8.6.3: Signal pressure as a function of nozzle distance and supply pressure with a Festo RML-5 reflex sensor

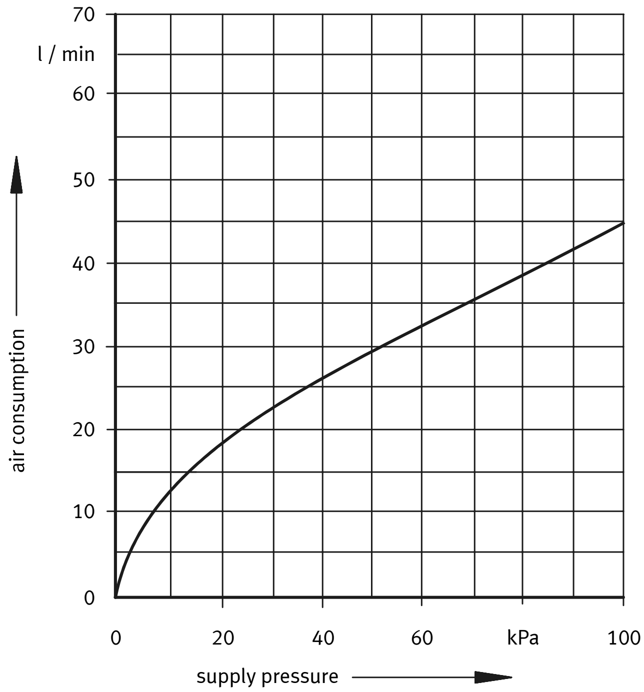
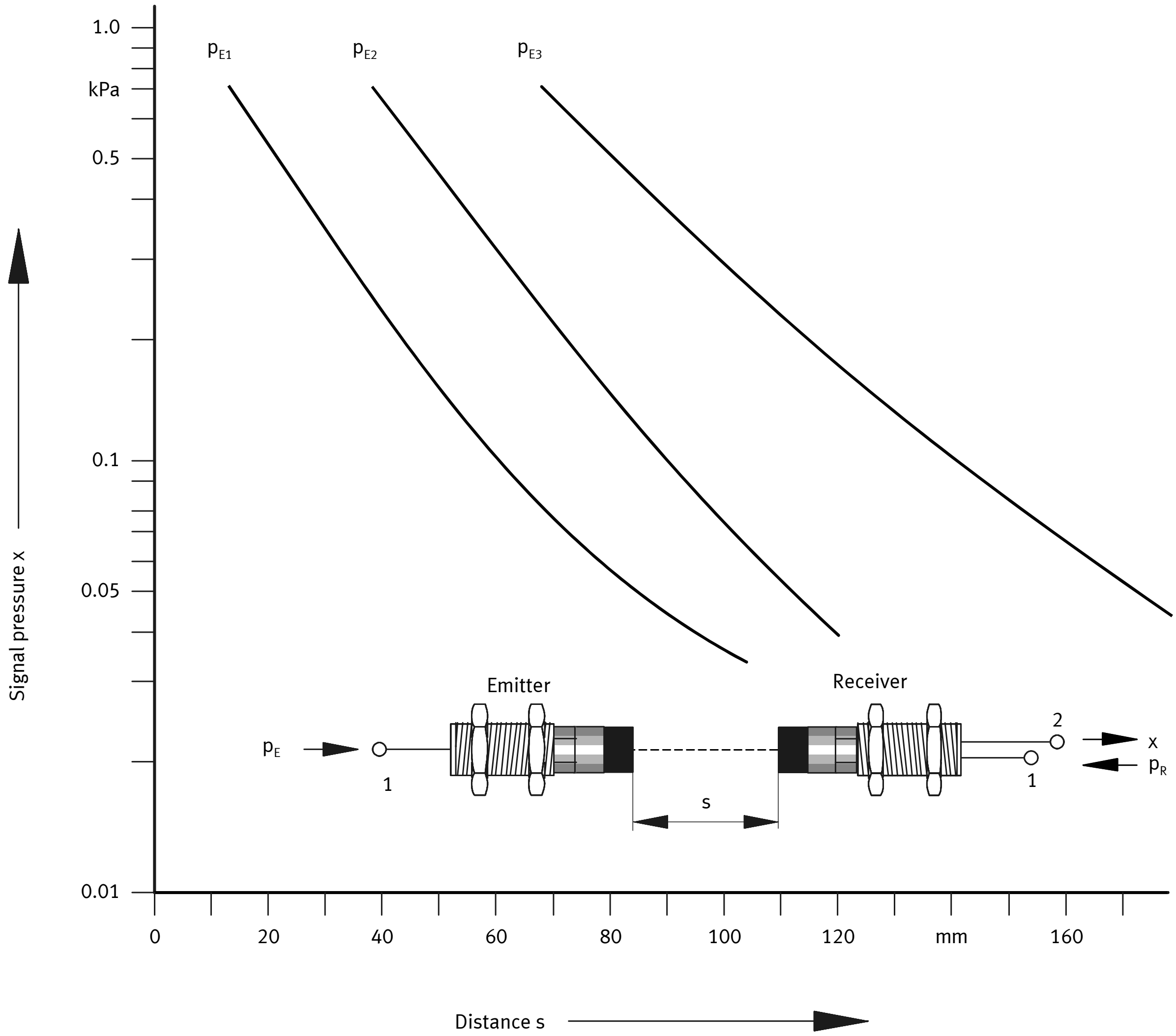


Fig. 8.6.4:
Air consumption as a function of supply pressure with uninhibited air outlet on a Festo RML-5 reflex sensor

8.6.3 Characteristic curves of air barriers



p_R = 10 kPa = const. p_{E1} = 10 kPa p_{E2} = 20 kPa p_{E3} = 50 kPa

Fig. 8.6.5: Signal pressure as a function of supply pressure and distance of the Festo SFL-100 air barrier

8.7 Examples of application

- Measuring the speed of transport of screens (plastic screens) for silk screen printing. These screens are easily contaminated and optical proximity sensors are therefore unsuitable. A possible solution is to provide holes at specified intervals along the edge of the screens and to use pneumatic sensor nozzles for sensing.
- Monitoring of tools (e.g. checking for broken drill) in environments where for instance optical proximity sensors are unsuitable because of contamination due to oil or cooling agents.
- Checking holes after drilling operation.
- Testing ceramic plates for smoothness after burning.

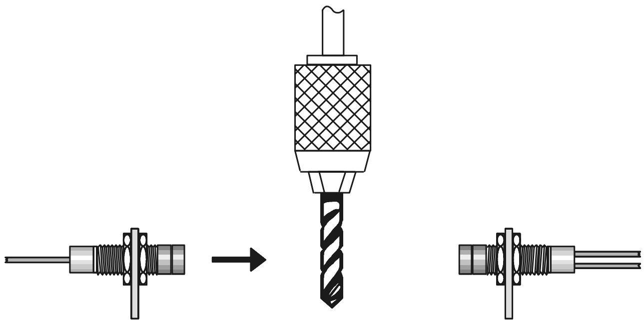


Fig. 8.7.1: Checking for broken drills by means of an air barrier

By using an air barrier, it is possible to check that a drill is in position immediately before drilling the workpiece.

If the drill is broken, the air jet from the sender nozzle hits the receiver thus creating a signal. With an air barrier a signal is created only if an object is not present.

A major advantage of this solution (as opposed to an optical proximity sensor for instance) is in that contamination such as drilling fluid does not interfere with operation.

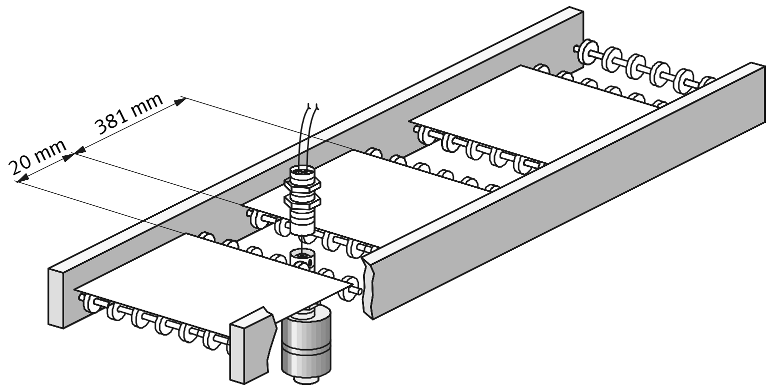


Fig. 8.7.2: Use of an air barrier for counting plastic sheets

Clear plastic sheets pass on a transport device in gaps of 20 mm.

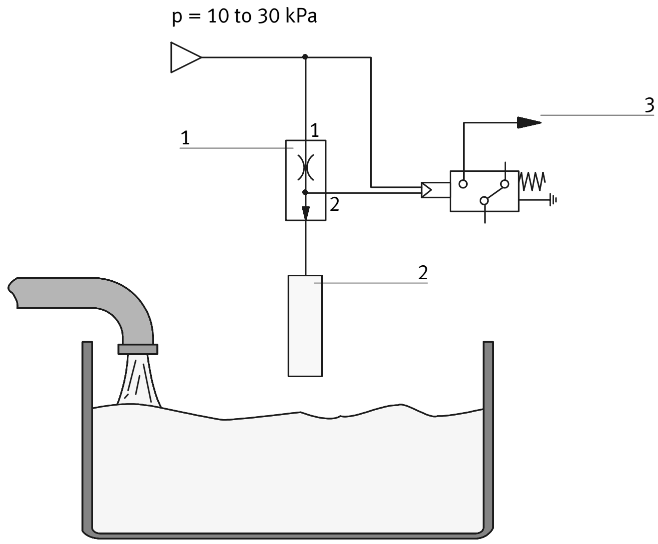
The gaps between the sheets are used for the purpose of counting.

A pressure amplifier is fitted downstream of the air barrier receiver.

Key data

- Supply pressure of sender 25 kPa (0.25 bar)
- Response time 16 ms
- Maximum speed of transport device 37 m/min.

The use of optical or capacitive proximity sensors would present problems in this instance; ultrasonic proximity sensors would be a possible alternative.



Back pressure nozzle (1) Immersion tube (2) to the pump (3)

Fig. 8.7.3: Filling level monitoring by means of a back pressure nozzle

The threaded end of the back pressure nozzle enables the attachment of an immersion tube. Once the level of fluid in the immersion tube has reached a certain height, the back pressure nozzle and the pressure amplifier fitted downstream respond.

The pressure of the output signal is proportional to the height of the fluid level. The maximum pressure of output signal 2 corresponds with the supply pressure.

This solution is primarily suitable for foaming liquids, as pneumatic proximity sensors only react to the fluid, but not to the foam.

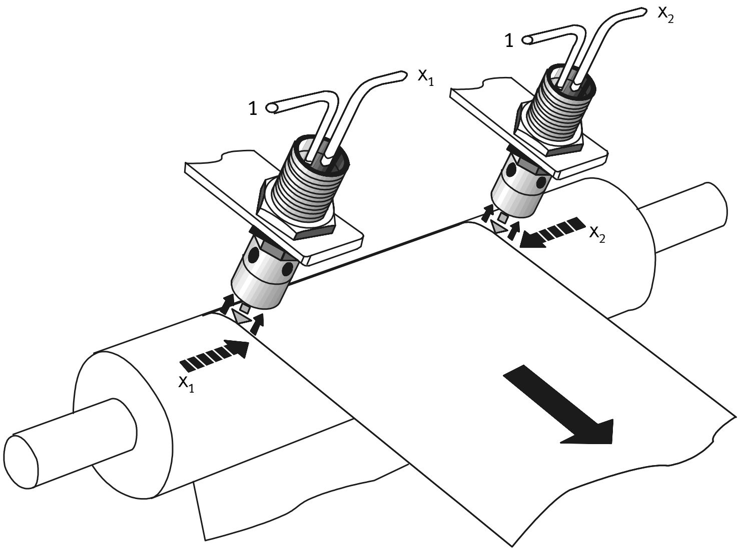


Fig. 8.7.4: Band edge control

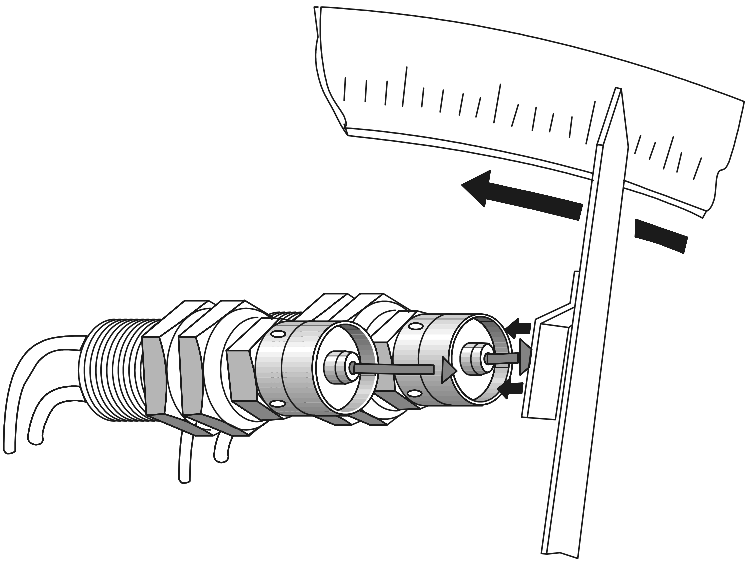


Fig. 8.7.5: Sensing of instrument pointers

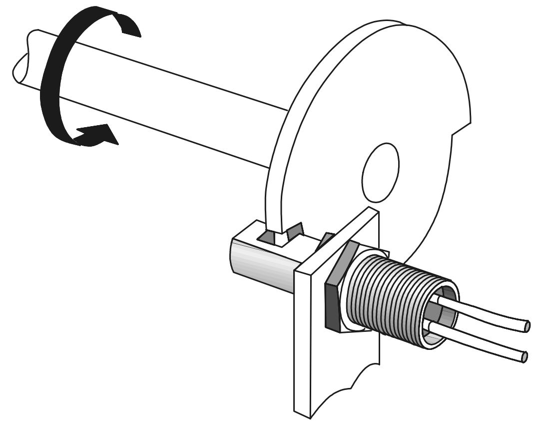


Fig. 8.7.6: Camshaft control using air barrier sensor

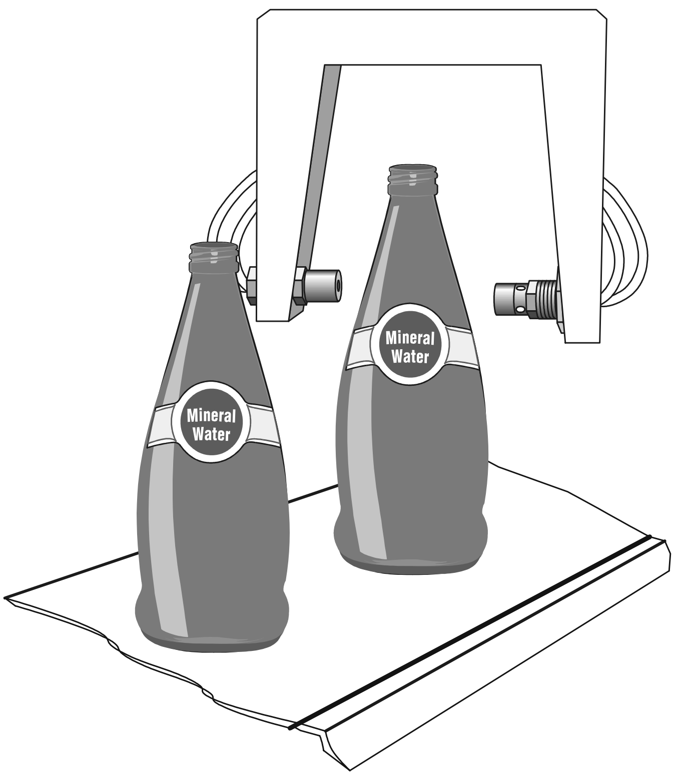


Fig. 8.7.7: Counting of glass bottles

8.8 Exercises

Exercise 8.1

Range of air barrier sensors
Parts of a width of 90 mm are to be detected in an area subject to explosion hazard. Check whether on the basis of the characteristics of air barrier sensors of type Festo SFL listed in chapter 8.6, these can be used in this instance. Specify the value of the output signal in kPa (mbar).

Exercise 8.2

Checking lids by means of a reflex sensor
A reflex sensor is to be used to check that lids have been fitted. Specify a practicable value for the distance between the sensor and the lid. The respective characteristic curves can be found in chapter 8.6.

Also determine the air consumption for this configuration in accordance with the characteristic curves in chapter 8.6.

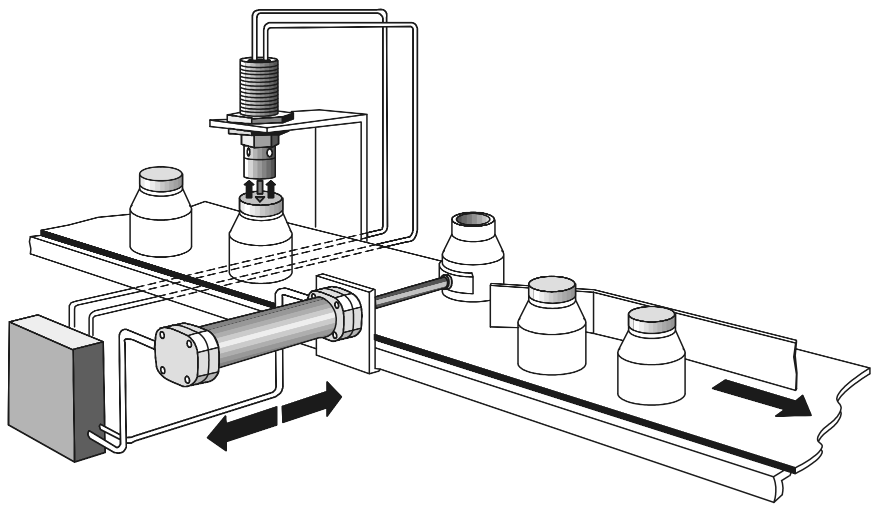


Fig. 8.8.1: Lid monitoring by means of a reflex sensor

9. Selection criteria for proximity sensors

In the first instance, proximity sensors can be selected according to the material which they are to detect. Metals of any kind can be detected easily and economically with inductive proximity sensors if short switching distances only are required (e.g. 0.4 – 10 mm). For greater distances, optical proximity sensors of varying designs are available. The greatest distances can be spanned by means of through-beam sensors.

Capacitive proximity sensors are suitable for the detection of a wide range of materials, but again only for relatively small distances, similar to inductive proximity sensors. Objects to be detected by a capacitive proximity sensor must be of a certain minimum volume. Ultrasonic and optical diffuse reflective proximity sensors are able to detect a wide range of different materials over greater distances. However, the detection of reflecting objects with tilted surfaces may create problems.

Further criteria for the selection of proximity sensors are the conditions under which the object is to be detected, what the installation requirements for the proximity sensor are and the environmental factors to be taken into account. Once all these requirements have been established, a suitable proximity sensor can be selected from the various alternative products on offer.

A systematic listing of the above mentioned criteria is set out overleaf.

9.1 Object material

Electrically conductive material
- Steel
- Stainless steel
- Brass
- Copper
- Aluminium
- Nickel
- Chromium
- Metal-coated, electrically non-conductive materials, depending on specific coating thickness
- Graphite

Electrically non-conductive material
- Plastics
- Cardboard, paper
- Wood
- Textiles
- Glass

Nature of non-conductive materials
- Optically transparent or non-transparent
- Optical reflex ability of surface (absorbent to reflecting)
- Homogenous, non-homogenous (e.g. composite material)
- Porous, fibrous
- Solid, liquid, loose material
- Dielectric constant

Size and shape
- Dimension of structure to be detected and possibly classification to standard shapes, e.g. block, cylinder, sphere, cone inter alia.

9.2
Conditions for the detection of objects

- Contacting or non-contacting
- Required distance between proximity sensor and object, possibly taking into account any tolerances which may occur in respect of distance, e.g. in the case of moving objects.
- Speed of a moving object or time during which the object is present or down time.
- Constant or changing sensing requirements, e.g. different position of object.
- Distance to adjacent objects, required resolution of interrogation.
- Type of background or area below

9.3
Installation conditions

- Free space available (distance/volume) around sensing area. The need to use miniature designs or remotely positioned proximity sensors when using fibre optic attachments or pneumatic sensor heads. The necessity for detecting "around the corner", in crevisses or through holes.
- Necessity of flush mounted installation.
- Required minimum distance between several adjacent proximity sensors.

9.4
Environmental considerations

- Ambient temperature
- Effect of dust, dirt, particles, humidity, splashing water, water jets inter alia, see IP protection classes.
- Influence of magnetic or electric fields, e.g. in a welding environment.
- Influence of external light emissions (peculiarities of ambient lighting).
- Area with explosion hazard
- Clean room environment
- Requirements for hygiene or sterilisation for use with food packaging or in a medical environment.
- Application in high pressure or vacuum conditions.

9.5
Safety applications

- Application in areas with explosion hazard
- Application for the purpose of accident prevention
- Application where increased safety measures are required against breakdown

9.6 Options/features of proximity sensors

- Design/type with specification of dimensions
- Voltage supply (direct current, alternative current)
- Type of switch output and type of protective circuits:
  – Positive switching (PNP output)
  – Negative switching (NPN output)
  – Short circuit protection
  – Reverse polarity protection
- Connection: Cable or plug
- Protection class to IEC 529, DIN 40050
- Permissible ambient temperature during operation
- Available special designs e.g. to DIN 19234 (NAMUR) or intrinsically safe design ("explosion protection"), or accident protection design
- Extent of switching distance or range, fixed value or adjustable value
- Nominal switching distance or nominal range
- Switching hysteresis
- Reproducibility
- Maximum operating frequency (switching frequency)
- Maximum load current
- Flush mounted or non-flush mounted option
- Minimum required distance between adjacent proximity sensors of the same type
- Operating reserve factor for optical proximity sensors
- Fibre optic design available for optical proximity sensors. The following technical data apply in respect of fibre optic designs, e.g.:
  – Range
  – Dimensions of fibre optic head
  – Fibre optic cable length
  – Detection angle, response ranges
  – Permissible ambient temperature
- Available accessories for retro-reflective sensors (reflectors, dimensions)
- Prices or price categories of proximity sensors

10. Connection and circuit technology

10.1
Types of connection

10.1.1 Two-wire DC and AC technology

Proximity sensors in two-wire technology have only two connecting wires. They are connected in series to the load to be switched and thus receive their supply voltage via the load. This has the effect of a certain amount of residual current flowing via the load even if the output is closed, and that of a voltage drop over the proximity sensor in the switched through status.

Proximity sensors are designed with either "normally closed" contacts (N/C) or "normally open" (N/O) contacts, but designs are also available which incorporate the two functions.

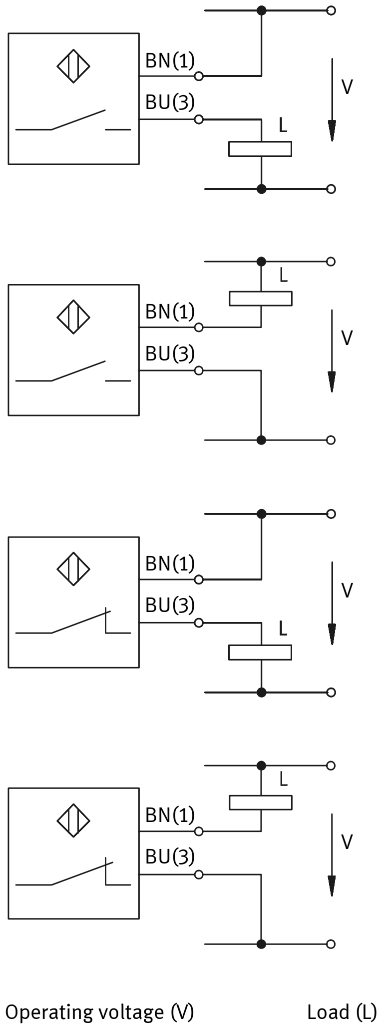


Fig. 10.1.1: Connection diagrams for two-wire technology (DC, AC and DC/AC (universal current) – designs)

A potential protective grounding terminal is identified by green-yellow.

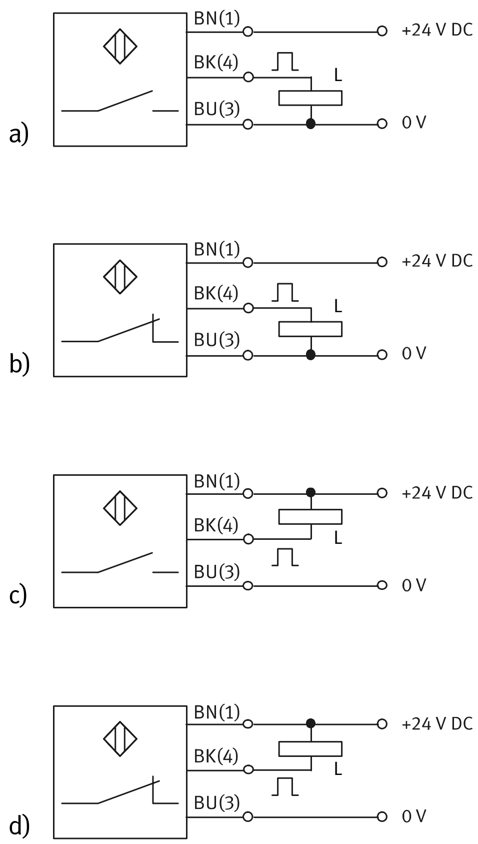
In the case of designs for AC or AC/DC (universal current), the connection cables may be identified in any colour other than green-yellow. Generally, however brown or blue is selected, as for direct current designs.

Voltage supply e.g.: 15 – 250 V DC
20 – 250 V AC

In the case of two-wire sensors it should be noted that in the unactuated status, a residual current must flow to provide a current supply for the proximity sensor. The residual current also flows via the load. In the acknowledged status, a minimum load current must flow to guarantee the reliable operation of the proximity sensor.

10.1.2 Three-wire DC technology

Proximity sensors in three-wire technology have three connecting wires. As a rule, the colours of the connecting wires comply with European standard EN 50 044. Two wires are for the purpose of voltage supply (brown +, blue -). The third wire (black) represents the signal output of the proximity sensor.



Load (L)

a) PNP normally open contact

b) PNP normally closed contact

c) NPN normally open contact

d) NPN normally closed contact

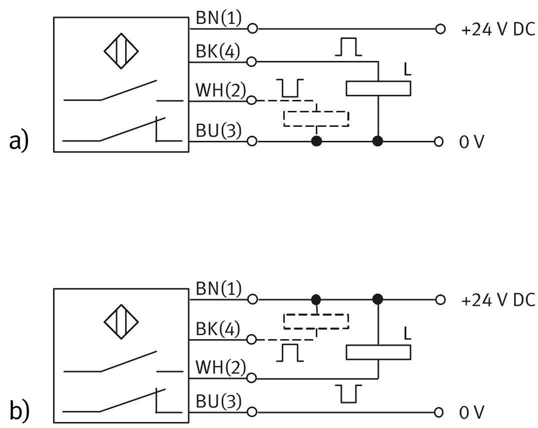
Fig. 10.1.2: Connection diagrams for three-wire technology (DC)

10.1.3 Four- and five-wire DC technology

Proximity sensors designed in four- or five-wire technology are further divided into proximity sensors with PNP outputs (positive switching) and NPN outputs (negative switching).

Unlike proximity sensors in three-wire technology, proximity sensors in four-wire technology are equipped with antivalent switching function, i.e. they possess both a normally open as well as a normally closed output.

Devices in five-wire technology feature electrical isolation between the control voltage circuit and the supply voltage (relay output).



Load (L)

a) PNP normally open/normally closed contacts

b) NPN normally open/normally closed contacts

Fig. 10.1.3: Connection diagram of four-wire technology (DC)

10.1.4 Terminal designation

Function	Colour	Designation
Positive supply voltage (+)	brown	BN
Negative supply voltage (-)	blue	BU
Switch output	black	BK
Antivalent switch output	white	WH

Table 10.1.1: Terminal designation of proximity sensors

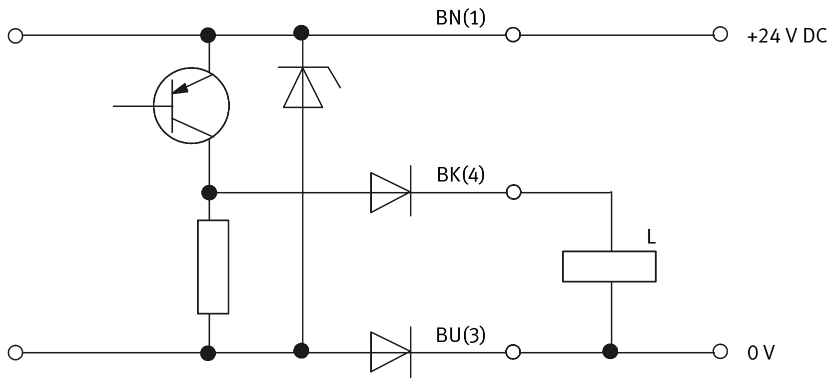
Terminal designation is in accordance with European standard EN 50 044. The colour short code is laid down in the international standard IEC 757.

10.2 Positive and negative switching outputs

Generally, two proximity sensor designs are distinguished, PNP (positive switching) and NPN (negative switching). Other designations are P-switching or positive switching as well as N-switching or negative switching. Positive switching proximity sensors usually have a PNP transistor output. However, positive switching proximity sensors with an NPN transistor output are also possible. The designations PNP and NPN output are nevertheless widely used.

10.2.1 PNP-output

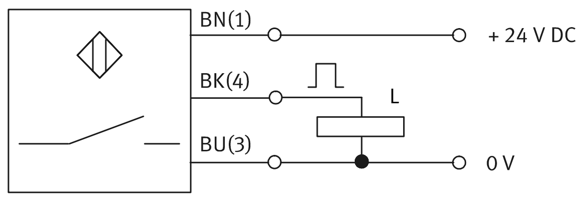
In the case of direct current proximity sensors with PNP output, the output is connected to positive potential in the switched state. This means that if a load is connected (display, relay, ...), one connection must be connected to the proximity sensor output and the other connection to 0 V. PNP proximity sensors are positive switching.



Load (L)

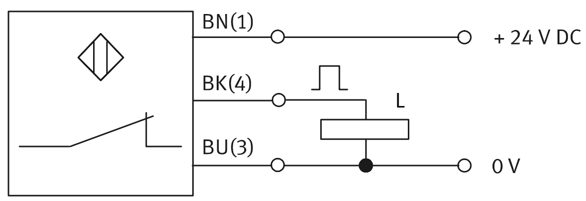
Fig. 10.2.1: PNP output (The purpose of the diodes is to provide a protective circuit)

PNP-proximity sensors can be differentiated as being "normally closed" or "normally open".



Load (L)

Fig. 10.2.2: PNP normally open contact

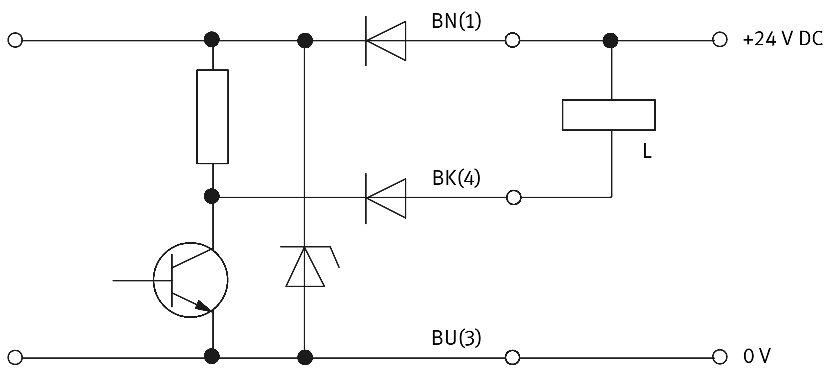


Load (L)

Fig. 10.2.3: PNP normally closed contact

10.2.2 NPN-output

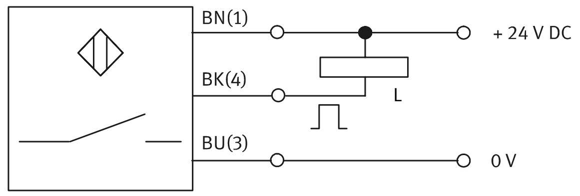
In the case of proximity sensors with NPN-output, the output is connected to the negative potential in the switched state. This means that if a load is connected (display, relay, ...), one connection is connected to the proximity sensor output and the other connection to the positive potential.



Load (L)

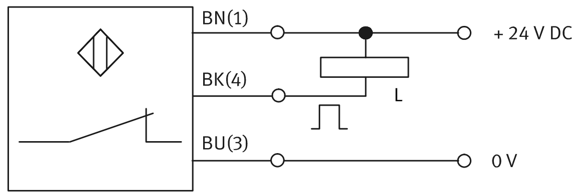
Fig. 10.2.4: NPN output (The purpose of the diodes is to provide a protective circuit)

In the same way, one differentiates between "normally closed" and "normally open" with NPN proximity sensors.



Load (L)

Fig. 10.2.5: NPN normally open contact



Load (L)

Fig. 10.2.6: NPN normally closed contact

10.3 Circuit technology

Usually, logic operations of the proximity sensor are carried out by the controller. By means of series or parallel connections it is possible to achieve the logic operation of several sensors.

10.3.1 Parallel and series connection of proximity sensors

With parallel connection, it is possible to effect a logic (Boolean) OR-connection and with series connection, a logic AND-connection.

The advantages of this type of connections are:

- Logic operations can be achieved without using an electrical controller.
- With the use of electrical controllers, logic operations can be carried out immediately on the spot so that only the logic operation result is signalled to the controller using a minimum amount of cabling.

The disadvantages are:

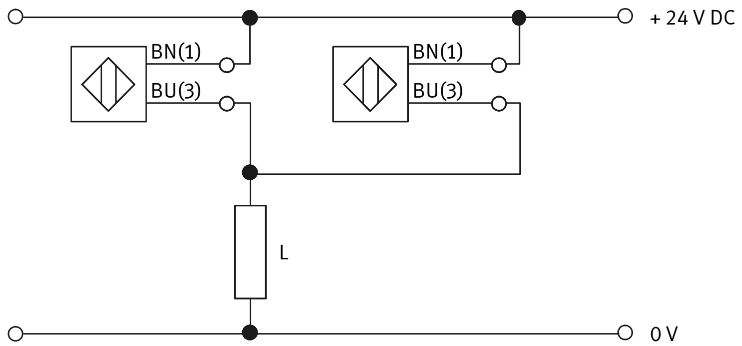
- The design and construction of logic operations requires experience, as the mutual influences of proximity sensors, increases response and drop-off times and a limit in the number of proximity sensors connected must be taken into account.
- Maintenance becomes more difficult.

If however an electrical controller is used for signal processing, then it is more straightforward to carry out all logic operations in the controller.

10.3.2 Parallel connection of proximity sensors using two-wire technology

With parallel connection of proximity sensors in two-wire technology, the following points must be observed:

- Because the sum of all possible quiescent currents of parallel connected proximity sensors flows via the load in the unswitched status, steps must be taken to ensure that this does not lead to a malfunction of controllers connected downstream.
- If a proximity sensor has switched through, then it "withdraws" the supply voltage from the other parallel connected proximity sensors. This has the effect, that the remaining proximity sensors can no longer indicate their actual switching status. If the first proximity sensor now returns to its unswitched status, then a second already activated proximity sensor can only indicate its switching status correctly after the ready delay time of the actual proximity sensor. This can lead to incorrect signals.
- Parallel connection is not possible with NAMUR-technology.



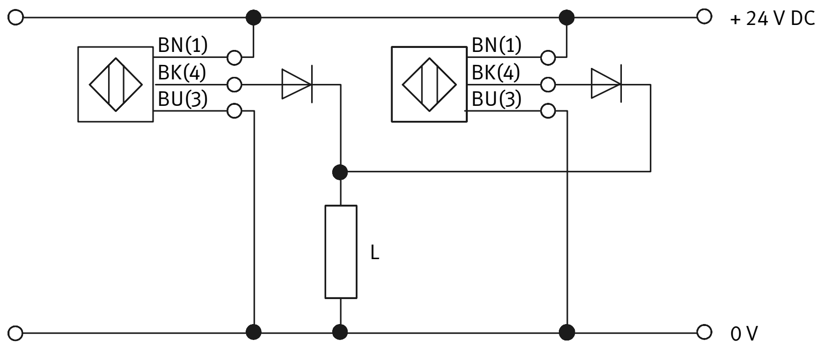
Load (L)

Fig. 10.3.1: Parallel connection in two-wire technology

10.3.3 Parallel connection of proximity sensors using three-wire technology

Parallel connection of proximity sensors in three-wire technology can be achieved without any problems. The following points must be observed:

- In the unswitched status, the low residual currents of the parallel connected proximity sensors accumulate (simultaneous use of mechanical contacts and proximity sensors is possible).
- If proximity sensors with an output stage in the form of an open-collector circuit are used, then there is no mutual effect. In the case of proximity sensors with different switch outputs, decoupling diodes are necessary (see Fig. 10.3.2). The diodes are usually integrated in the sensor for the purpose of reverse polarity protection.



Load (L)

Fig. 10.3.2: Parallel connection in three-wire technology (DC)

Direct current three-wire proximity sensors can be parallel connected without major limitations, if the residual currents of the signal outputs are sufficiently small in the non switched status. This is the case with most proximity sensors so that for instance up to 20 or 30 proximity sensors can be parallel connected. Also, a combination of proximity sensors and mechanical switches is possible.

The decoupling diodes illustrated in the sketch are provided in order to prevent the activated sensor from being loaded with the output operating resistances of other parallel connected sensors. Moreover, this avoids all LEDs illuminating in the case of sensors with LED displays. If the diodes are an integral part of the sensor protection circuitry, no additional external diodes are necessary.

Parallel connection of AC sensors is not recommended, as malfunction can occur during oscillator start-up.

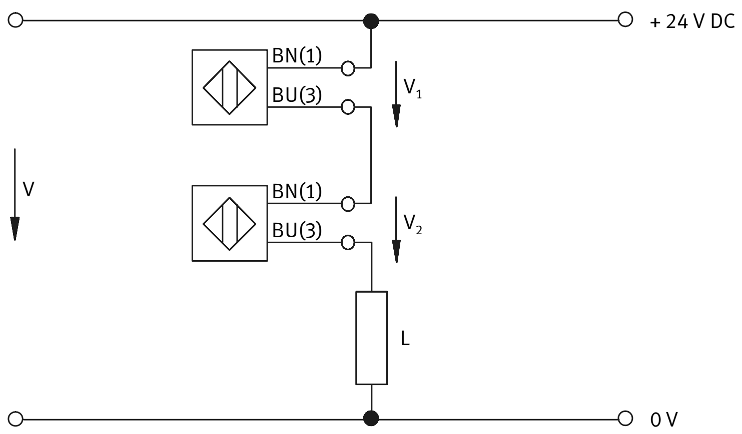
10.3.4 Series connection of proximity sensors using two-wire technology

As a rule, series connection of proximity sensors using two-wire technology is to be avoided. If it is unavoidable, the following points must be observed.

- The supply voltage is distributed to each series connected sensor. If identical proximity sensors are used, the following applies in respect of the voltage for each proximity sensor (in activated status):

$$V_{\text{Proximity sensor}} = \frac{V_{\text{Supply voltage}}}{n} \qquad \text{(n = Number of proximity sensors)}$$

- In the switched through status, a voltage drop occurs through each proximity sensor (approximately 0.7 – 2.5 V per sensor). When calculating the load, it should also be taken into account that the voltage through the load is full supply voltage reduced by the individual voltage drops through the in series connected proximity sensors.



Load (L)

Fig. 10.3.3: Series connection in two-wire technology

10.3.5 Series connection of proximity sensors using three-wire technology

Series connection of proximity sensors using three-wire technology is possible, as shown in Fig. 10.3.4, whereby the following points must be observed:

- The outputs of the individual series connected proximity sensors are loaded additionally: Added to the current consumed by the load is the current consumption of each individual proximity sensor connected in series.
- In the switched through status, a voltage drop occurs with each proximity sensor (approximately 0.7 – 2.5 V per sensor). As a result of this, the supply voltage available for the load is reduced by the sum total of the individual voltage drops.
- As in the case of series connected three-wire sensors, it is always the supply voltage of the proximity sensor connected downstream which is switched, the actual time delay before availability must be taken into account. If a "detection process" falls within the period of the time delay before availability, this can lead to malfunction. In the case of proximity sensors with operating status display (LED,...), correct indication of the operating status cannot be guaranteed.

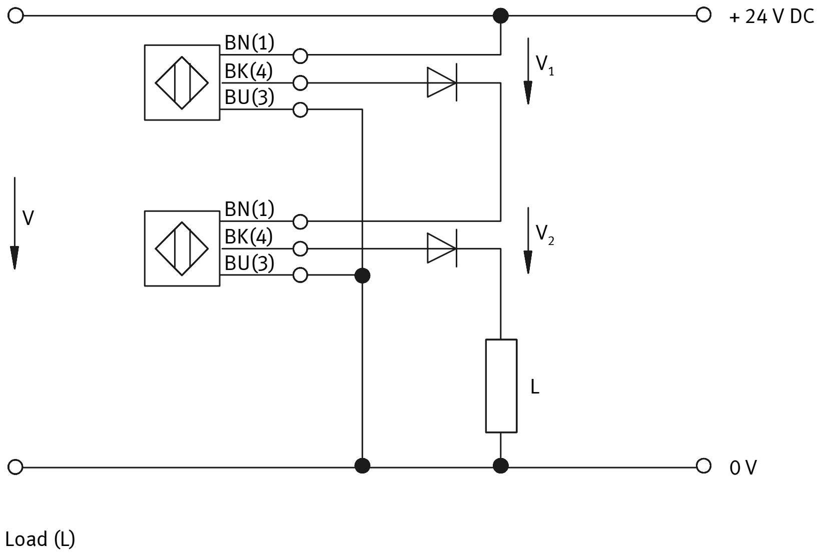


Fig. 10.3.4: Series connection in three-wire technology

10.4 Connection technology under conditions of strong electro-magnetic influence

As far as connection is concerned, it should be ensured that proximity sensor cables are installed separately from supply lines to motors, switching valves etc.

If proximity sensor connection cables run over long distances in cable ducting or cable trays parallel to other cables which conduct alternating currents or strong current pulses, this can lead to interference with the proximity sensor via the connection cable.

If the proximity sensors are used in areas of high interference (welding equipment, motors, magnetic couplings, ...), the following steps are to be taken:

- Keep the connection cables of proximity sensors short
- Screen the sensor connection cables
- If possible, error signal to be limited at source
- Install interference voltage filter into the voltage supply

10.5 Connection of controllers, relay and display elements

If the output of a proximity sensor is loaded as a result of a downstream connected device, the following must be observed:

- Current consumption of the connected load should not exceed the permissible load current of the proximity sensor. Typical values for proximity sensor load currents range between 50 – 500 mA.
- In order to guarantee reliable operation of the proximity sensor in the switched state, the resistance of the connected load should not be too high such as to impair the flow of the minimum load current.
- Proximity sensors can emit irregular switching signals if the supply voltage is switched on or off, depending on whether the proximity sensor is attenuated or unattenuated. These stray pulses can lead to malfunctions in controllers downstream and must therefore be suppressed by using additional hardware or taken into account in the software programming of the controller.
- If lamps are used by way of display elements it should be noted that the switch-on current of lamps with a cold spiral-wound filament is considerably higher than the nominal current. It is therefore possible for the switch-on current to be reduced as a result of preheating the spiral-wound filament by means of a by-pass resistor which is connected in parallel to the proximity sensor.
- If a relay (a valve or an other high-inductance device) is to be actuated by proximity sensors, they should be checked for built-in protection against voltage peaks. If not, additional protection diode circuitry is to be provided.

10.6
Required current supply

When switching on and off power supply units, care should be taken to ensure that there are no voltage peaks which may jeopardise the function of the connected proximity sensors. Power supply units with insufficient electronic control can create voltage spikes during switch-on, which can be above the permissible voltage supply of the proximity sensor and which, depending on the time constant, fade away relatively slowly. In the case of unfamiliar power supply units, it is recommended to check the voltage switch-on behaviour by means of a storage oscilloscope.

Depending on the specification given in the data sheets for proximity sensors, the supply voltage ripple must not exceed a certain limit value.

11. Physical fundamentals

11.1 Fundamentals of inductive and capacitive proximity sensors

Inductive and capacitive proximity sensors are based on the use of oscillators, their oscillating amplitude being affected by an approaching object.

In order to generate sinusoidal oscillation, LC-oscillators (consisting of a coil and an capacitor), quartz oscillators and RC-oscillators (consisting of a resistance, a condenser and an amplifier, e.g. Wien bridge oscillators) are used.

The following denote:

L = Inductance	Unit: Henry (H)	1 H	= 1 Vs/A
C = Capacitance	Unit: Farad (F)	1 F	= 1 As/V
R = Resistance	Unit: Ohm Ω	1 Ω	= 1 V/A.

11.1.1 Inductive proximity sensors

Let us now consider the LC resonant circuit as applied in an inductive proximity sensor.
The coil of an LC oscillator is inside a unilaterally magnetic half shell core. This oscillator oscillates typically at a frequency in the range of approx. 100 – 1000 kHz.

The LC oscillator generates a high frequency electromagnetic alternating field (HF field), which is emitted on the active surface of the proximity sensor.

The amplitude of oscillation decreases as a metallic conductor approaches the half shell core or oscillation stops completely.

Eddy currents

The cause is the withdrawal of energy as a result of a loss in eddy currents as the object approaches.

If a piece of metal in a constant magnetic field is moved, this induces eddy currents in this piece of metal. The same happens if stationary metal parts are exposed to magnetically alternating fields.

An inductive proximity sensor operates with a low power consumption of several microwatts and this has several advantages:

- No significant magnetising effect
- The HF field does not cause any interference
- No temperature rise in the object to be sensed

Oscillations

Electrical oscillations can be clearly illustrated by means of mechanical oscillations.

In the case of mechanical spring oscillation, a periodical change takes place between potential and kinetic energy (potential energy and motive energy). Analogous to this, electrical and magnetic field energy changes in the case of electromagnetic oscillation.

A comparison of mechanical and electrical values is provided by:

- Deflection x → Charge q
- Load m → Inductance L
- Friction constant k → Resistance R
- Spring constant D → Reciprocal of capacitance 1/C

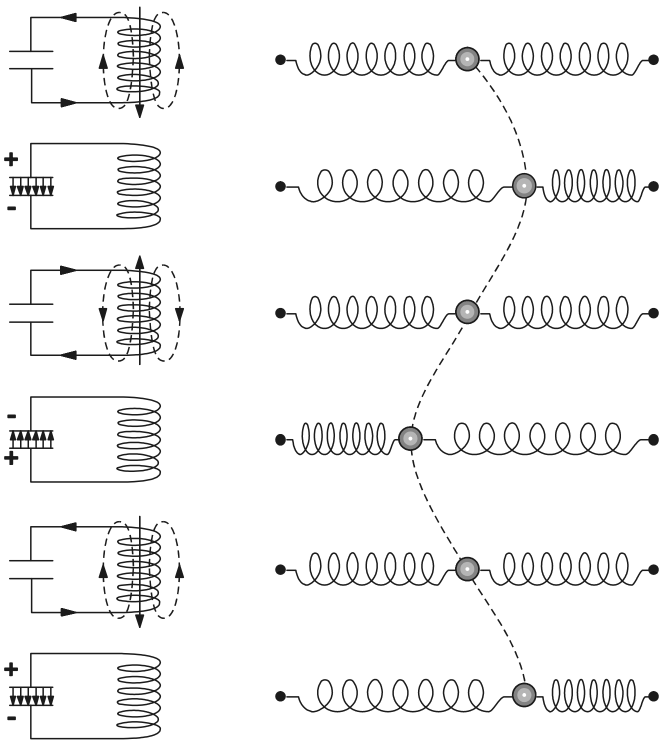


Fig. 11.1.1: Comparison of mechanical and electrical oscillations

The LC resonant circuit

Electromagnetic oscillations are created in a so-called LC resonant circuit consisting of a coil and a capacitor. Once the capacitor is loaded, it discharges via the coil. During this process, current intensity and voltage change periodically.

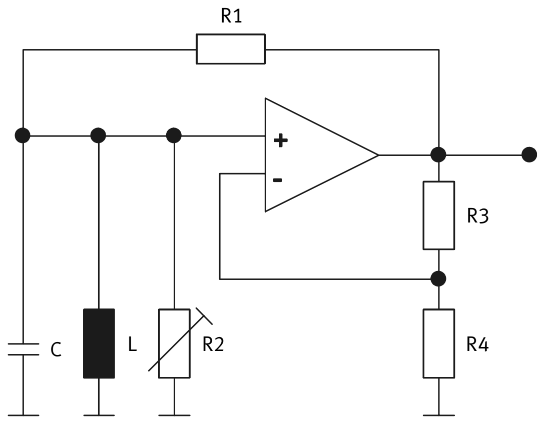


Fig. 11.1.2: LC resonant circuit

Unattenuated oscillation in this instance can however only be obtained if the resonant circuit does not have any ohmic resistance. In practice, it is therefore necessary to use an amplifier, which compensates for the attenuation resulting from the resistance. In Fig. 11.1.2, an operational amplifier is used to illustrate the principles of the circuit.

In order to obtain a value for the frequency of an LC resonant circuit, the time varying charge Q on the capacitor is examined. The following applies in the case of a plate capacitor with capacity C and voltage V:

$$Q = C \cdot V$$

At any given time t, a variable charge q(t) is obtained, which provides a variable voltage v(t).

The derivation of this charge according to time, dq/dt, determines the current i(t), which flows through the coil with inductance L. The voltage obtained on the capacitor is

$vC(t) = q(t)/C$

and the voltage on the coil

$v_L = L\, di/dt = L\, d^2q/dt^2$

The equation for oscillation is

$v_C + v_L = L\, d^2q/dt^2 + q/C = 0$

If this equation is divided by L, the result for unattenuated oscillation is:

$d^2q/dt^2 + q/LC = 0$

The result for the resonant frequency of the resonant circuit without attenuation is:

$\omega^2 = 1/LC$

Example

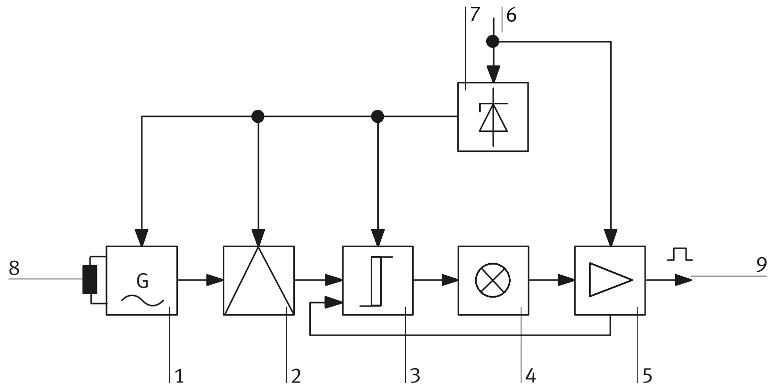
For example, if one assumes

$L = 100\ \mu H$, and $C = 10\ nF$,

then the resonant frequency is

$\omega = 1/\ (100 \cdot 10^{-6} \cdot 10 \cdot 10^{-9})^{1/2} = 1 \cdot 10^6\ Hz = 1\ MHz$

Basic circuit of an inductive proximity sensor



Oscillator (1)
Demodulator (2)
Triggering stage (3)
Switching status display (4)
Output stage with protective circuit (5)
External voltage (6)
Internal constant voltage supply (7)
Active zone (coil) (8)
Switch output (9)

Fig. 11.1.3: Block circuit diagram of an inductive proximity sensor

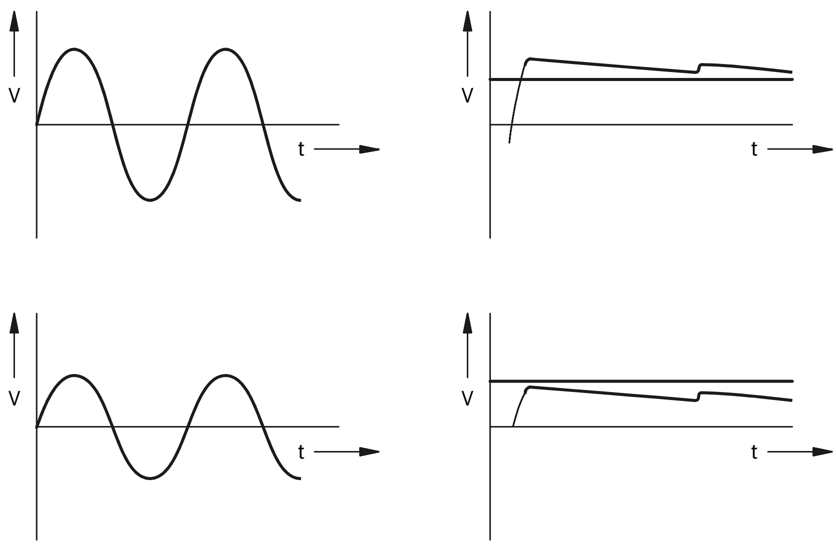


Fig. 11.1.4: Oscillator amplitude and switching threshold of the triggering stage

A demodulator is connected to the oscillator for evaluating changes in amplitude. This is where the output signal for the actuation of the triggering stage is created. In the triggering stage, the analogue signal is converted into a digital signal. The triggering stage does not supply an output signal unless the input signal is above a certain threshold.

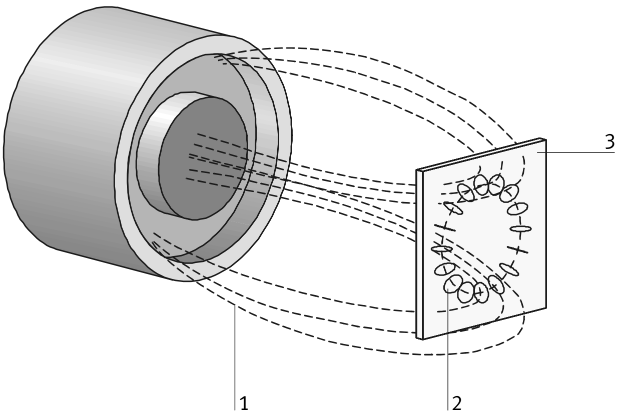
With the signal provided by the triggering stage, the output stage is switched. Depending on the switching status, the threshold of the triggering stage is also slightly changed. Thus, the hysteresis of the proximity sensor is created. An output signal is created if, with the increasing attenuation of the proximity sensor, the rectified amplitude signal falls below the triggering threshold. With the decreasing attenuation, a higher amplitude of oscillation is required to switch off the output signal. In this case the triggering threshold is slightly higher than in the former case and the proximity sensor indicates hysteresis.

Switching distance and conductivity

Amongst other things, the switching distance depends on the electrical conductivity of the metal to be detected. The following table lists the values in respect of the conductivity of different metals and alloys. The third column indicates the reduction factor for the switching distance of an inductive proximity sensor. This simple dependence does not apply in the case of ferromagnetic metals and alloys. With ferromagnetic material, considerably higher losses are created by the eddy currents in the attenuated material than with non-ferromagnetic material.

Conductor	**Conductivity** $\left[\frac{m}{\Omega \cdot mm^2}\right]$	**Reduction factor**
Copper	56.0	0.25 – 0.40
Aluminium	33.0	0.35 – 0.50
Brass	15.0	0.35 – 0.50
Chrome-nickel	1.0	0.70 – 0.90

Table 11.1.1: Conductivity and reduction factors of various materials



Magnetic stray field H_S (1)
Eddy currents through magnetic field H_W (2)
Attenuating material (3)

Fig. 11.1.5: Schematic field pattern of inductive proximity sensors

The field H_W created as a result of the eddy currents acts against the generating field H_S. This effect is described as field displacement. The skin effect has another, however less powerful effect on the various switching distances of different materials with the typical oscillator frequencies used. As a rule, the oscillator frequency for inductive proximity sensors is in the range of 300 – 800 kHz.

Up to now, the dependence of the switching distance of the material to be attenuated could not be calculated explicitly.

Power dissipation in the attenuating material

Losses are created as a result of eddy currents in a metal plate. Assuming that the depth of penetration of the field is small and that the approaching field does not penetrate the metal plate, the following applies:

$$\frac{\text{power dissipation}}{\text{area}} = H_0{}^2 \sqrt{\frac{\pi \cdot f \cdot \mu}{\kappa}}$$

H_0 = r.m.s value of the magnetic field strength of the stray field on the plate surface
μ = $\mu_0 \cdot \mu_r$ = Magnetic permeability,
μ_0 = $1.257 \cdot 10^{-6}$ Vs/Am = Magnetic field constant,
μ_r = Relative permeability
κ = Electrical conductivity
f = Frequency

The value of H_0 depends on the distance of the plate from the proximity sensor and from the field distribution. Power dissipation increases with the square root of the permeability. With the increase in conductivity, power dissipation on the other hand decreases. Power dissipation is decisive as regards attenuation of the oscillator. In the case of materials with high power dissipation, attenuation already occurs at greater distances leading to switching, but in the case of lower power dissipation at small distances only.

Diamagnetism, paramagnetism and ferromagnetism

Materials, which reduce the magnetic field of a measuring coil, are described as diamagnetic, i.e. permeability is less than 1. The reduction is, however, very small. With paramagnetic materials, a slight strengthening of the field occurs, i.e. permeability is higher than 1. Ferromagnetic materials considerably strengthen the magnetic field and as such are given a separate name. Their permeability is considerably higher than 1 and apart from that they depend heavily on pre-treatment of materials.

Paramagnetic materials	**Diamagnetic materials**	**Ferromagnetic materials**
Manganese	Zinc	Iron
Chromium	Lead	Cobalt
Aluminium	Copper	Nickel
Platinum	Silver	

Table 11.1.2: Paramagnetic, diamagnetic and ferromagnetic materials

Skin effect

With a linear conductor carrying a direct current, current density has the same value at all points of the conductor cross section. With alternating currents, however, the current is forced towards the surface. In the case of very high frequencies, the current is practically restricted to a thin layer on the surface of the conductor, hence the name skin effect. Skin effect means that a wire for a high-frequency alternating current has a higher resistance than that for direct current.

If one assumes that the wire is made up of several conductors of lesser cross-section, then the mutual induction of such a conductor in the centre is greater than that of one at the outer edge. The passing alternating current is thus forced to the surface, i.e. the area with least alternating current resistance.

Penetration depth

The skin thickness, within which the current amplitude has decreased by the amount 1/e (= 1/2.718), is described as the penetration depth d. The following formula applies:

$$d = \frac{1}{\sqrt{\pi \cdot \mu_r \cdot \mu_0 \cdot \kappa \cdot f}}$$

Whereby μ_0 = $1.257 \cdot 10^{-6}$ Vs/Am = Magnetic field constant
μ_r = Relative permeability
κ = Conductivity
f = Frequency

It can be seen that the greater the permeability and the conductivity of the material, the smaller the penetration depth. If the material thickness of the object being detected by an inductive proximity sensor is less than the penetration depth of the field, then a part of the field is outside the plate, thus resulting in greater switching distances.

Materials	**Penetration depth [mm]**
Copper	0.073
Aluminium	0.094
Brass	0.16

Table 11.1.3: Field penetration depths at a frequency of f = 800 kHz

11.1.2 Capacitive proximity sensors

The active element of a capacitive proximity sensor consists of a capacitor, which is made up of a disc-shaped metallic electrode and a beaker-shaped half-open metallic shield. If a non-conductive or conductive material is introduced into the active zone in front of the sensor, capacity C of the capacitor changes.

With capacitive proximity sensors, an RC resonant circuit is tuned in such way that a sensor in the unactuated state produces a stray field in front of the active surface. Only if an object enters into this zone, is it possible for the RC-oscillator to respond. The change in capacitance leads to this response.

The capacitance change depends on the following factors:
- Distance and position of the object in front of the electrode
- Dielectric constant of the object
- Dimensions of the object

If a non-conductive object is introduced into the active zone, then capacitance increases with the dielectric constant ε_r of the material and vice versa in proportion with the distance from the disc-shaped capacitor electrode. The greatest switching distance is achieved with either a water surface or with earthed, electrically conductive materials. The smaller the relative dielectric constant of a non-conductive material, the smaller the switching distance.

As with inductive proximity sensors, it is possible to detect moving or stationary objects.

Material	**Relative dielectric constants**
Ethyl alcohol	25.1
Polyvinyle chloride	2.9
Methyl alcohol	33.5
Polyethylene	2.3
Glass	3 – 15
Polystyrene	3.0
Water	81
Transformer oil	2.2 – 2.5
Ice	4
Slate	6 – 10
Air	1
Brick	2.3
Hard rubber	3 – 4
Vaseline	2.1 – 2.3
Paper	1.2 – 3.0
Cable sealing compound	2.5
Paraffin	2.2
Oiled paper	5

Table 11.1.4: Relative dielectric constant of various materials

RC-resonant circuit

An RC circuit is not capable of oscillation of its own accord. An active element is required in order to make up an oscillator.

Circuits are often used which are similar to a Wien-Robinson oscillator.

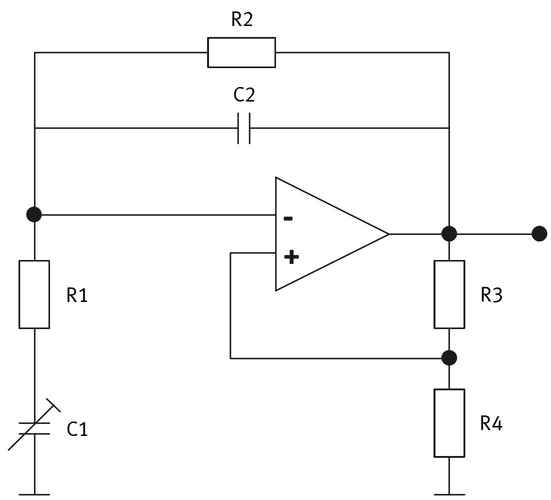


Fig. 11.1.6: RC resonant circuit

For R1 = R2 = R and C1 = C2 = C, the resonant frequency of the RC-oscillator is

$\omega = 1/RC$

11.2 Fundamentals of magnetic proximity sensors

With magnetism, differentiation is made between permanent magnetism and electromagnetism. A simple illustration of magnetic field lines in space can be achieved by means of iron filings. To give an example, iron filings placed on a sheet of paper with a magnet underneath will be activated into the lines of the magnetic field. Even small compass needles can be used for the detection of field lines.

11.2.1 Permanent magnetism

If the dynamic effects of the poles of two separate permanent magnets are compared when they are brought together they can either attract or repel. Similar poles (e.g. two north poles) repel one another, whereas opposite poles (e.g. a north and a south pole) attract one another.

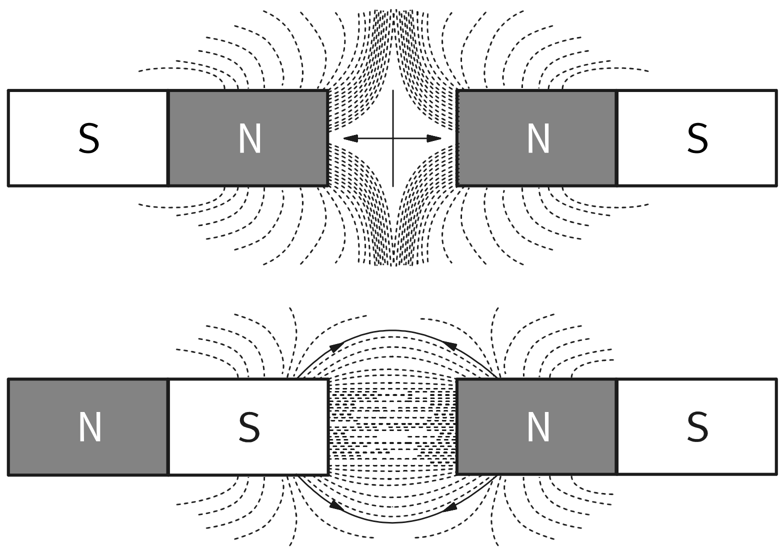


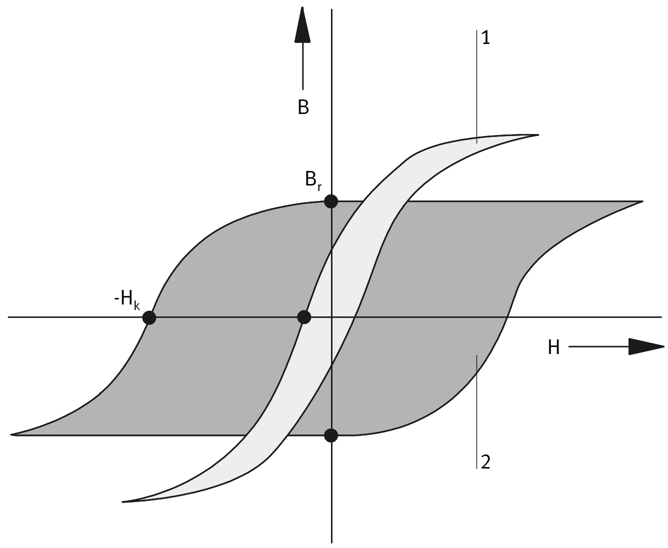
Fig. 11.2.1: Illustration of field line pattern with similar and opposing magnetic poles

The field lines of a magnet are closed lines which run from the north pole to the south pole. South or north poles never occur individually; every magnet always has two poles.

Permanent magnets are made of various materials:

- Hard ferrite magnets
- Metallic alloy magnets
- Magnets made of rare minerals: samarium-cobalt or neodymium-iron-boron.

If a proportion of magnetism remains after the effects of a strong magnetic field, this is called remanence B_r. A reverse magnetic field with the coercive field strength $-H_k$ is required to cancel this magnetisation completely.



Magnetic field strength (H) Soft magnet (1)
Magnetic induction (B) Hard magnet (2)

Fig. 11.2.2: Magnetisation curve

11.2.2 Electromagnetism

The areas surrounding current-carrying conductors always have a magnetic field. The magnetic field lines around a straight conductor are always in concentric circles.

The direction of field lines surrounding a current-carrying conductor is determined by the corkscrew rule. If a corkscrew is screwed using the right hand in the direction of the flowing current, then this direction of rotation indicates the direction of the field lines.

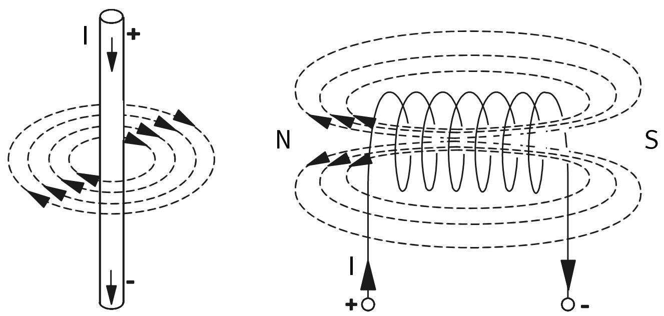


Fig. 11.2.3: Magnetic flux pattern of a conductor and a coil

11.2.3 Detecting a magnetic field

Reed switch

The most simple and usual method of detecting a magnetic field is to use a reed switch. Two soft magnetic metal reeds are brought into contact by means of an external magnetic field and an electrical contact is established. Closing of this contact is however not bounce-free. Fig. 11.2.4 illustrates the switching behaviour of this contact.

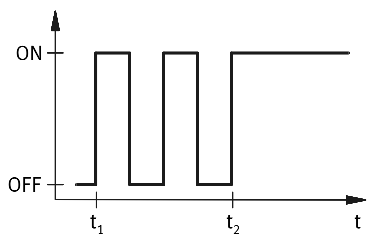
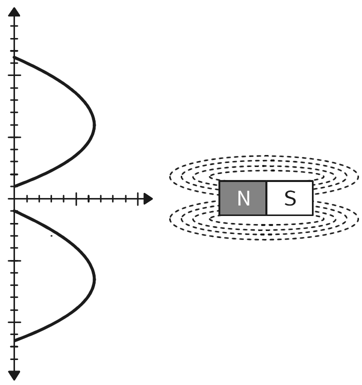


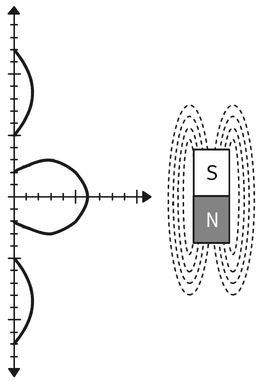
Fig. 11.2.4: Switching characteristic of bouncing mechanical contacts

Furthermore, it should be noted that this switch has two or three switching zones depending on the direction of the magnetic pole axis. If the pole axis points vertically in the plane of the switching reeds, then two switching zones will always be obtained (Fig. 11.2.5). This is due to the shape of the magnetic flux pattern. When the magnet passes, the field strength which is required to trigger the switch is obtained twice. If the pole axis is parallel to the switching reeds, then three switching zones are created for small switching distances, a main switching range plus two minor switching ranges. Minor switching ranges occur due to the magnetic reversal effects of the switching reeds when entering the magnetic field (Fig. 11.2.6).



Polar axis vertical to switching reed plane

Fig. 11.2.5: Switching ranges of a reed switch in relation to the magnetic pole axis



Polar axis parallel to switching reed plane

Fig. 11.2.6: Switching ranges of a reed switch in relation to the magnetic pole axis

Inductive-magnetic proximity sensors

Similar to inductive proximity sensors for the detection of metals, the oscillation status of an electronic oscillator is evaluated as a binary signal. The difference as opposed to a "purely" inductive proximity sensor lies in the fact that the coil of the oscillator is shielded so that no electromagnetic field is emitted. However, an externally active magnetic field leads to additional magnetisation of the core material. This causes the proximity sensor to switch through.

There are designs, where the coil is pre-attenuated by means of a small soft magnetic plate. An externally active magnetic field induces the magnetisation of this small plate. The oscillator then oscillates and the proximity sensor switches through.

With this type of proximity sensor too, the number of switching zones depends on the orientation of the magnetic pole axis. One advantage compared with a reed switch is that only one single switching range occurs if the pole axis of the magnet runs parallel to the active surface.

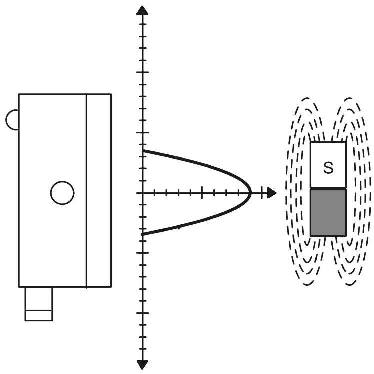


Fig. 11.2.7: Switching ranges of a inductive-magnetic proximity sensors

Hall sensors

The Hall effect was discovered in the last century by E. Hall. He discovered that a voltage difference is created on the opposite sides of a small thin gold plate, through which a current passes, if a magnetic field operates vertically to this. Subsequently, it was discovered that this effect also occurs with many semi-conductors. Certain physical characteristics are required for this. The thickness of the small plate must be less than the dimensions of length and width. Voltages of up to 1.5 V can be created.

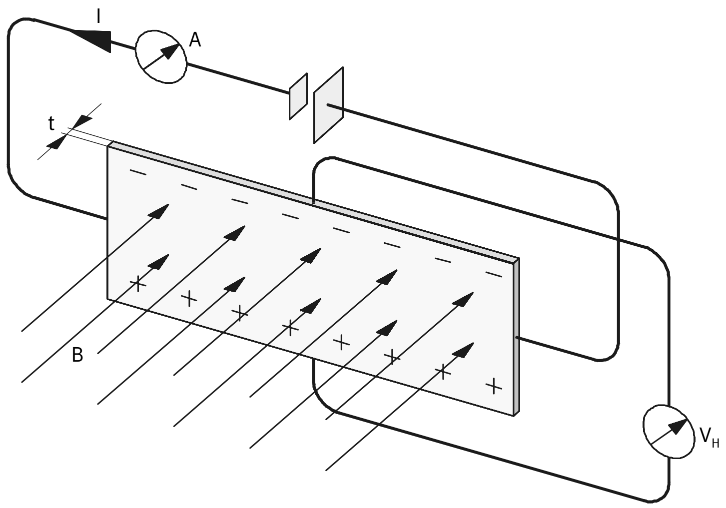


Fig. 11.2.8: Schematic representation of the Hall effect

The formula for Hall voltage is

$$V_H = R_H \cdot I \cdot \frac{B}{t}$$

V_H = Hall voltage
R_H = Hall constant
I = Current
B = Magnetic induction
t = Plate thickness

The reciprocal value in the equation of occurring Hall constants is the density of the charge carrier in the material.

Hall sensor elements are used for the measurement of current and magnetic field or in combination with moving magnets for angle and position.

Magnetoresistive effect

Magneto-resistive sensors operate on the principle of a change in the electrical resistance of ferromagnetic materials under the influence of a magnetic field. Sensors of this type consist of thin foil in strips or a meander structure. The resistance layers consist of nickel-iron alloys (Permalloy), which are arranged in Wheatstone bridge circuits. The bridge voltage changes under the influence of an external magnetic field. The effect is not linear; saturation occurs at a change in resistance of approximately 1 – 2 %. In polycrystalline, ferromagnetic materials the change in resistance also depends on the direction of incidence of the magnetic field.

Magnetoresistive sensor

Magnetoresistive sensors often consist of semi-conductive materials such as indium-antimonide (InSb) or indium-antimonide/nickel-antimonide (InSb-NiSb), which change their electrical resistance in the presence of a magnetic field.

The output resistance of a magnetoresistor without an external magnetic field and at room temperature depends on the dimensions and the conductivity of the material used. The conductivity of the semi-conductor is determined by its dotation. By dotation one understands the deliberate introduction of impurity atoms into a semi-conductor in order to increase its conductivity. In that sense one speaks of extrinsic conduction instead of intrinsic conduction, because the introduced impurity atom (impurities) decisively influence conductivity.

The change in resistance in the case of small magnetic fields is very small, due to the fact that the sensor resistance is a square function of the magnetic field. Increased sensitivity can be achieved through a magnetic bias in the magnetoresistor by means of a permanent magnet. The working point of the magnetoresistor is now in the steeper range of the squared characteristic curve thus creating a greater change in resistance. Sensors of this type are therefore constructed from magnetoresistive semi-conductor material in conjuction with a permanent magnet and flux-guiding soft iron materials.

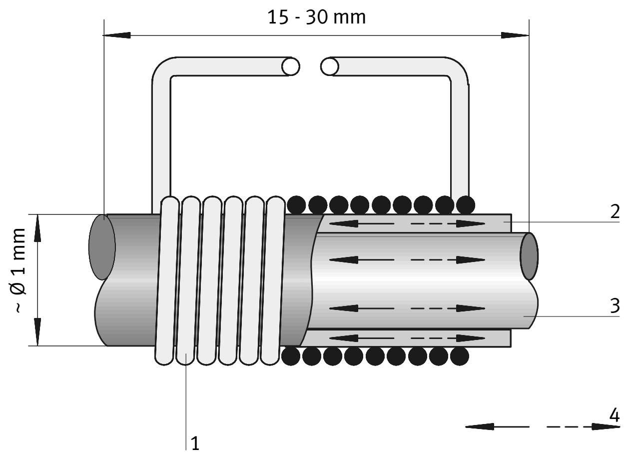
Ferro-sensors

Magnetoresistive sensors can be excited by means of externally approaching permanent magnets or – in the case of magnetically biased sensors – by means of ferromagnetic materials. The latter design is also described as a ferro-sensor. With the approach of a ferromagnetic material, the magnetic field of the permanent magnet contained in the sensor is changed. This field change is detected by the magnetoresistor and converted into an output signal. The sensor responds only to ferromagnetic materials.

Wiegand effect

A wire-shaped ferromagnetic material with one single magnetic domain is used as a sensor medium. Magnetic polarisation can only take up one of the two directions parallel to the wire. The soft magnetic core is enclosed by a hard magnetic shell. In the presence of an external magnetic field, a magnetic reversal takes place along the entire length of the wire. A voltage signal is created in a coil which is wound around the wire. Voltage signals of 2 – 8 V amplitude are provided with a sensor length of 15 – 30 mm.

One characteristic feature of Wiegand sensors is that no external voltage supply is required to operate the sensor. These operate at a temperature range of -196 – +175 °C.



Single or multiple layer coil with concentrated windings per unit length (1)
Hard magnetic shell (2)
Soft magnet core (3)
Directions of magnetisation (4)

Fig. 11.2.9: Wiegand sensor

11.3
Fundamentals of ultrasonic-proximity sensors

Sound frequency which is above the limit of human hearing is described as ultrasound. The lower limit is at approximately 20 kHz. The particular characteristics of ultrasound applied to proximity sensors are the result of the high frequency and the correspondingly short wavelength.

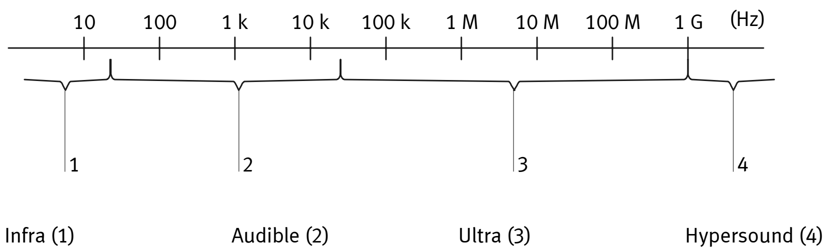


Fig. 11.3.1: Sound frequency range

The propagation of sound is the result of propagation of mechanical long waves, which manifests itself in a periodic density variation in the carrier medium, leading to alternating compressions and dilutions. The propagation of sound waves is dependent on a transmitting medium, it is not possible in a vacuum.

Speed of sound in solid objects

For solid objects, the propagation speed of sound waves equals:

$$v = \sqrt{\frac{E}{\rho}}$$

E = Modulus of elasticity
ρ = Density

The modulus of elasticity of a material is determined by Hooke's law:

$$E = \frac{F \cdot l}{A \cdot \Delta l}$$

Here, F is the force which lengthens or shortens a body of length l by length Δl, and A is the cross-sectional area of the body.

Speed of sound in fluids

The speed of sound in fluids equals:

$$v = \sqrt{\frac{K}{\rho}}$$

K = Compression modulus
ρ = Density

Speed of sound in gases

For the speed of sound in gases the following applies:

$$v = \sqrt{\frac{\kappa \cdot p}{\rho}} = \sqrt{\kappa \cdot R \cdot T}$$

κ = Adiabatic exponent
p = Pressure
ρ = Density
T = Temperature
R = Gas constant

The adiabatic exponent κ describes the quotient of the specific heat capacity at constant pressure c_p, and the specific heat capacity at constant volume c_v.
This equation demonstrates that the speed of propagation of sound waves in gas depends to a large extent solely on the temperature and not on the pressure of the gas.

Speed of sound in air

The following formula applies for the speed of sound in dry air at temperature T:

$$v = v_0 \sqrt{1 + \frac{T/°C}{273.2}}$$

v_0 = 331.6 m/s

or

$$v = v_0 + 0.58 \cdot \frac{m}{s} \cdot \frac{T}{°C}$$

Solids (at 20 °C)	**v [m/s]**
Aluminium	5110
Iron	5180
Gold	2000
Cork	500
Copper	3800
Brass	3500
Steel	5100

Fluids (at 20 °C)	**v [m/s]**
Benzene	1320
Chloroform	1000
Glycerine	1923
Petroleum	1320
Mercury	1415
Water, distilled	1483

Gases (at 0 °C and 101.3 kPa)	**v [m/s]**
Argon	308
Helium	971
Carbon dioxide	258
Carbon monoxide	337
Air	332
Hydrogen	1286

Table 11.3.1: Speed of sound in various materials

Because of the short wavelength, ultrasonic waves behave in a similar way as light waves. Also, the law of optical geometry (angle of incidence = angle of reflection) applies to ultrasonic waves.

The surface structure is of great significance as far as the directed reflection is concerned. If surface roughness is within 1/4 to 1/6 of the sound wavelength, the waves are reflected diffusely, whereas smooth surfaces have a maximum angle of approx. ±5° to the sound cone, roughly structured substances, e.g. bulk goods, can be detected up to an angle of approx. ±45°.

The wavelength λ equals:

$$\lambda = \frac{v}{\nu}$$

λ = Wavelength
ν = Frequency
v = Speed of sound

Example

At a frequency of 200 kHz and a speed of sound in air of approx. 340 m/s, the following value is obtained in respect of the wavelength

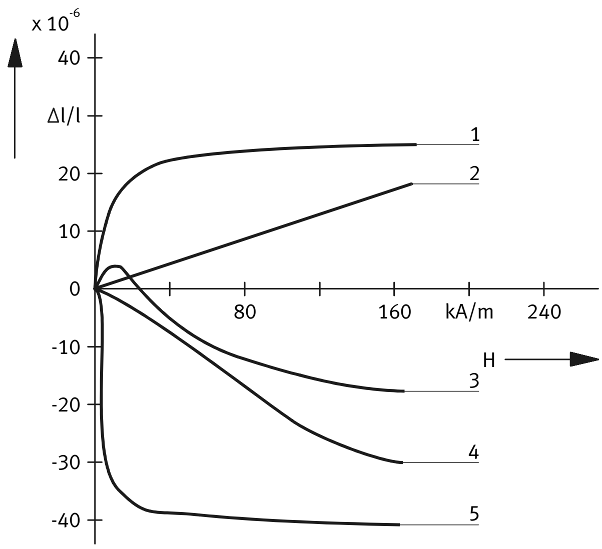
$$\lambda = \frac{v}{\nu} = \frac{340\frac{m}{s}}{200 \cdot 10^{3}\,Hz} = 1.7 \cdot 10^{-3}\,m = 1.7\ mm$$

11.3.1 Generation of ultrasound

There are three different methods of generating ultrasound: mechanical, magnetic and electrical. In this context, mechanical generation of ultrasound is only of minor importance.

Magnetic generation

With the help of magnetorestriction, it is possible to generate ultrasound of up to approx. 50 kHz. Ferromagnetic substances change their length in a magnetic field. The relative change in length is within a maximum range of $4 \cdot 10^{-5}$.

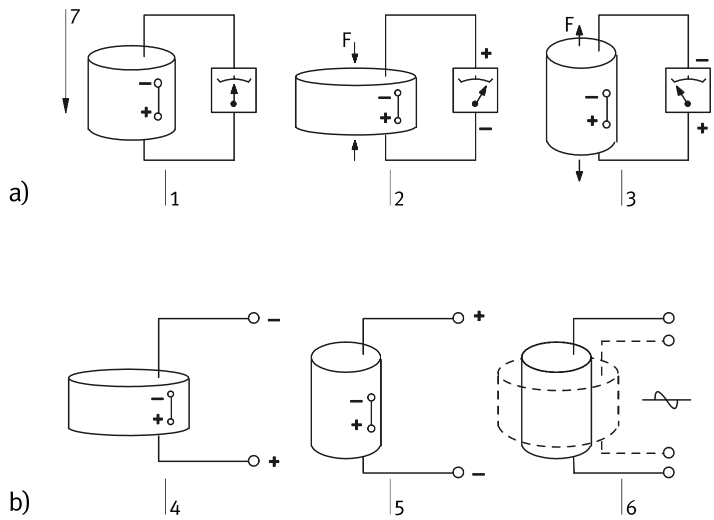


6 % Nickel, 94 % Iron (1)
29 % Nickel, 71 % Iron (2)
Iron (3)
Cobalt (annealed) (4)
Nickel (5)

Fig. 11.3.2: Magnetostrictive strain curves of various materials in relation to field strength H

Electrical generation

With electrorestriction (inverse piezoelectrical effect) an alternating voltage of high frequency is connected to a crystal plate. This plate then carries out the mechanical oscillations of the corresponding frequency, which become particularly strong with resonance. Frequencies of up to approximately 10 000 kHz are achieved.



Unloaded body (1)
Compressive stress (2)
Tensile stress (3)
DC voltage, opposed to polarisation (4)
DC voltage, parallel to polarisation (5)
AC voltage, leads to alternate lengthening and shortening (6)
Polarisation axis (7)

a) Conversion of force into voltage
b) Conversion of voltage into linear change

Fig. 11.3.3: The piezoelectric effect (source: Philips Components)

Nowadays, instead of crystals, piezoelectrical materials, which are widely distributed under the trade name Piezoxide (e.g. by Valvo), are used to generate ultrasound. These materials are made of lead-zirconate-titanate.

Figs. 11.3.4 and 11.3.5 illustrate the dependence of speed of sound in air on the temperature and relative air humidity.

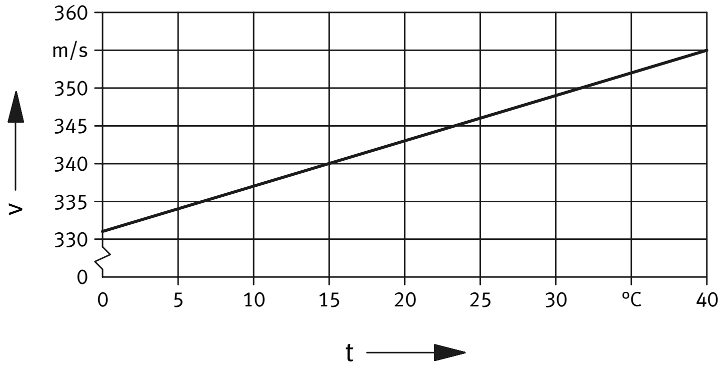


Fig. 11.3.4: Speed of sound in dry air as a function of temperature

$$v = v_0 + 0.58\frac{m}{s}\cdot\frac{T}{°C}$$

$$v_0 = 331.6\frac{m}{s}$$

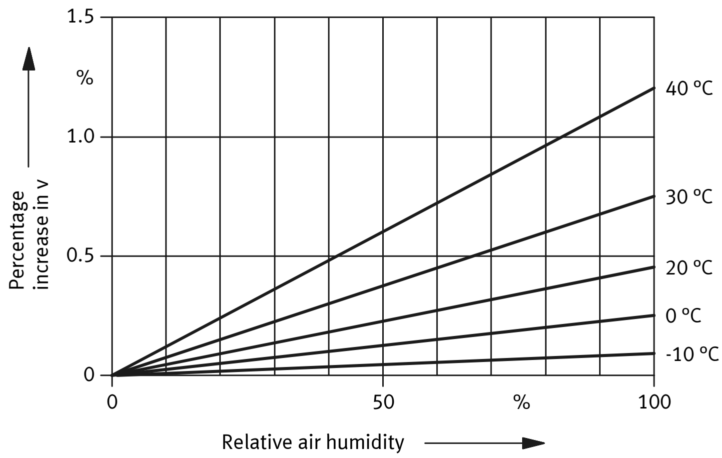


Fig. 11.3.5: Percentage change in speed of sound as a function of relative air humidity

11.3.2 Attenuation of ultrasound in air

When selecting ultrasonic proximity sensors, the frequency of the emitter should be taken into account. The attenuation of ultrasound in air depends on the ultrasonic frequency and as such also the range of an ultrasonic sensor.

Physical law

With the propagation of sound in air, the sound pressure amplitude decreases exponentially with the distance

$$\hat{p} = \hat{p}_0 \cdot e^{-\alpha d}$$

$\hat{p}$ = Peak value of the sinusoidal sound pressure wave on the output of the emitter (d = 0)

$\hat{p}_0$ = Peak value of sound pressure wave at distance d from emitter (assuming that the sound ray does not diverge)

α = Attenuation coefficient (Unit m^{-1})

Correspondingly, the following applies in respect of accoustic power:

$$P = P_0 \cdot e^{-2\alpha d} = P_0 \cdot e^{-\alpha' d}$$

This formulation is often used with $2\alpha = \alpha'$ representing the attenuation coefficient.

Logarithmic attenuation ratio

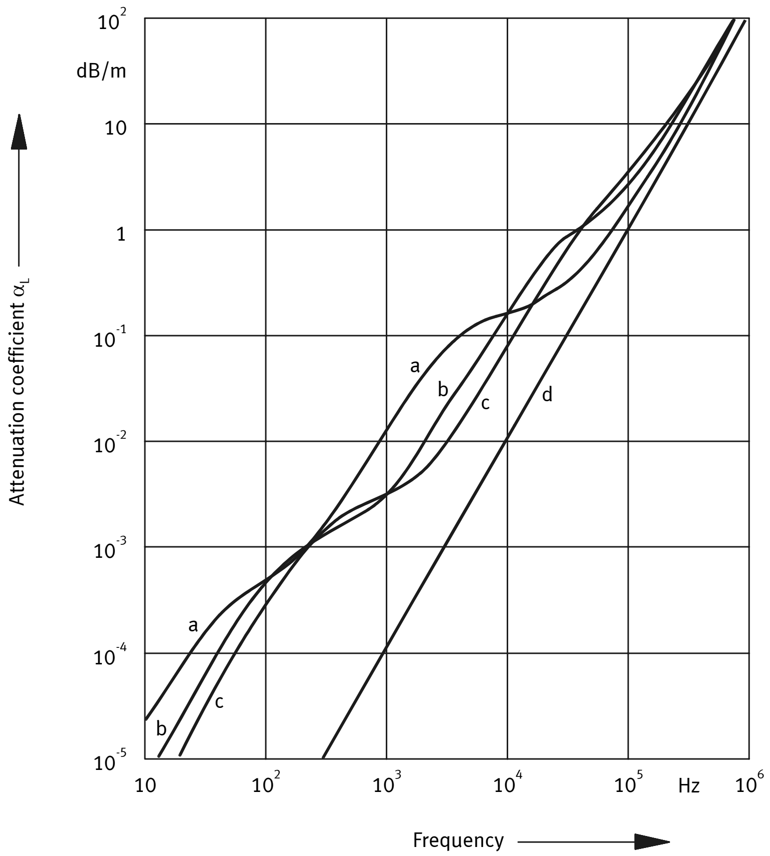
Instead of the (linear) attenuation coefficient α or α', a logarithmic attenuation ratio α_L is also used, which on examination of the sound pressure amplitude is defined by the relation

$$\hat{p} = \hat{p}_0 \cdot 10^{-\frac{\alpha_L d}{20}}$$

or on examination of the accoustic power by the relation

$$P = P_0 \cdot 10^{-\frac{\alpha'_L d}{10}} \qquad \text{with } \alpha'_L = 2\alpha$$

α_L or α'_L are indicated in dB/m (1 dB = 1 decibel).



a) Relative air humidity 10 %

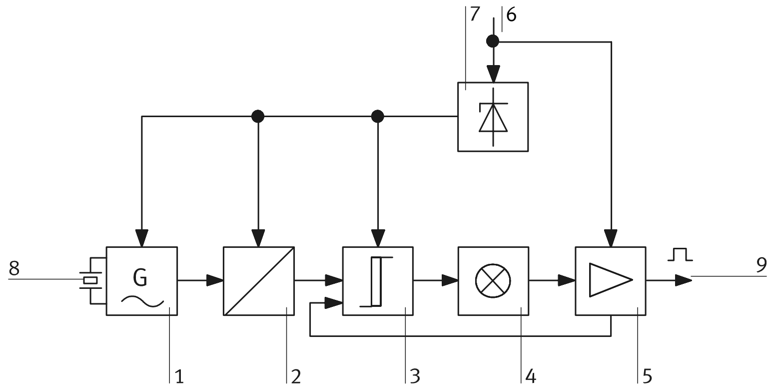
b) Relative air humidity 40 %

c) Relative air humidity 80 %

d) Theoretic attenuation based on standard absorption: Linear attenuation is proportional to the square of the frequency of sound.

Fig. 11.3.6: Dependence of attenuation coefficient on ultrasonic frequency (air temperature 20 °C)

11.3.3 Ultrasonic proximity sensors



Oscillator (1) Switching status display (4) Internal constant voltage supply (7)
Evaluation unit (2) Output stage with protective circuit (5) Ultrasonic transducer (8)
Triggering stage (3) Switch output (6) External voltage (9)

Fig. 11.3.7: Block circuit diagram of an ultrasonic proximity sensor

A high frequency alternating voltage is generated to excite the piezoceramic module into oscillation. This AC voltage is switched through to the ceramic module by means of a pulse generator, when the transmitting pulse is to be emitted. Distance measurement is calculated according to the ultrasound propagation time. A ramp generator is triggered at the time of transmission, which generates a time-dependent voltage. Thereupon, the piezoceramic module is switched over to receiving. The ultrasonic signal is reflected if an object is present in the active range of the proximity sensor. The proximity sensor receives the signal and the ramp generator is stopped. The voltage level is evaluated at this point and an output signal emitted.

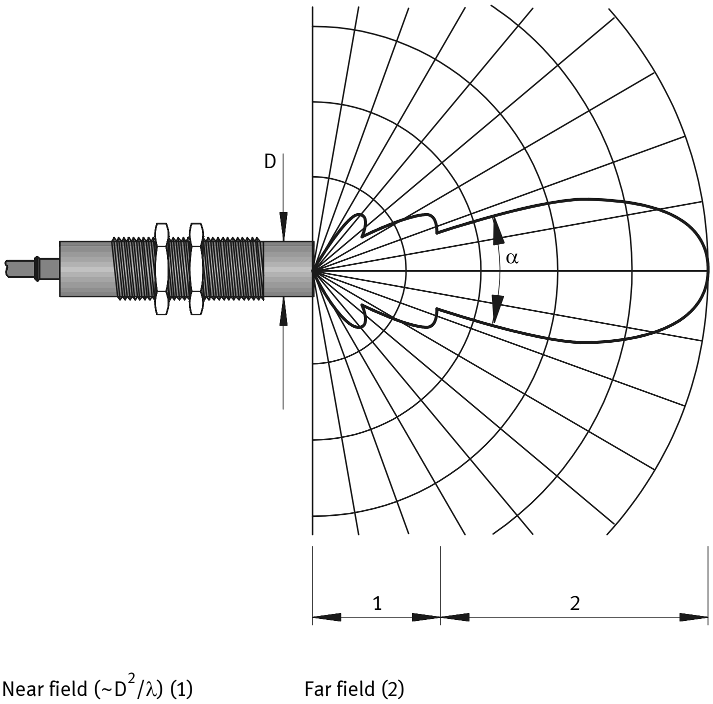
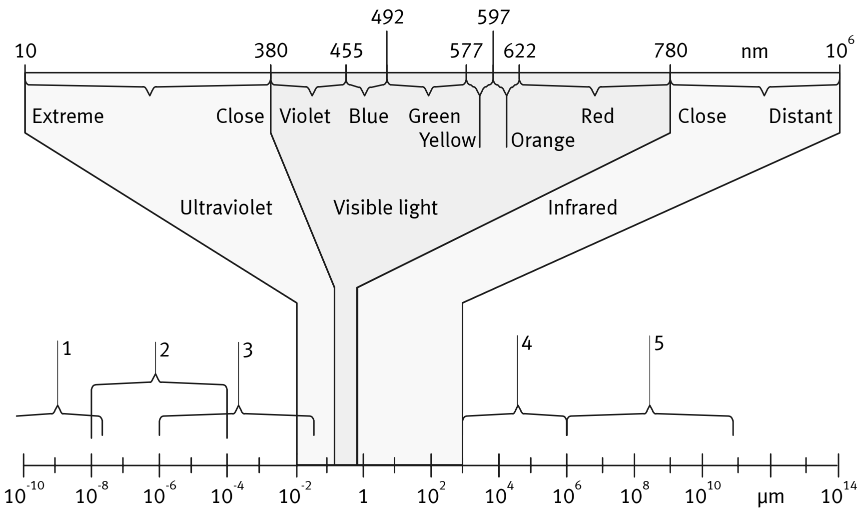


Fig. 11.3.8: Sound emission characteristic of an ultrasonic transducer

An object must not be present in the sound field of the proximity sensor within the so-called near field, as this can lead to error pulses at the proximity sensor output. For an ultrasonic proximity sensor with a transducer diameter of 15 mm and an emitting frequency of 200 kHz, the range of the near field is approximately 130 mm.

11.4 Fundamentals of optical proximity sensors

Optical proximity sensors are devices which convert signals generated by light emission into electrical signals. The response of optical receivers varies according to different ranges of wavelength. Fig. 11.4.1 indicates the spectral ranges of electromagnetic emission.



Cosmic rays (1) X-rays (3) Radio waves (5)
Gamma rays (2) Radar waves (4)

Fig. 11.4.1: Spectral ranges of electromagnetic light emissions

The range of visible light is just a small section of the overall spectral range reaching from violet (approx. 380 nm) to red (approx. 780 nm). The frequencies of light are in the range of 10^{15} Hz.

Light spreads in a straight line. A consequence of this statement lies in the formation of a shadow. A pin sized light source produces a core shadow. In the case of extended (or several pin sized) light sources, core and half-shadows are superimposed.

Light beams, which radiate from one point, are divergent (the beam cross-section increases as the distance grows). Beams which focus on one point are convergent (the beam cross-section decreases towards the crossover point). Beams without a common output or point of direction are known as diffuse.

The speed of light in a vacuum is roughly 300,000 km/s. The table below lists some values for the speed of light in respect of different materials.

Medium	v [km/s]	Refractive index
Vacuum	300,000	1
Air	300,000	1.0003
Water	225,000	1.33
Crown glass (Dependent on type)	198,000	1.51
Flint glass (Dependent on type)	186,000	1.61
Diamond	124,000	2.42
Polymethylmethacrylate (PMMA)	200,000	1.49

Table 11.4.1: Speed of light and refractive index

11.4.1 Reflection

The following principle applies with regard to reflection of light:

Angle of incidence = Angle of reflection

Here the angles are measured between the vertical and the angle of incidence.

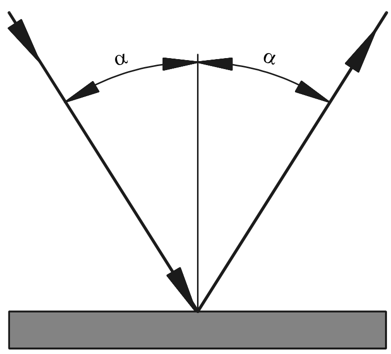


Fig. 11.4.2: Reflection of light beams

11.4.2 Refraction

At the interface of two transparent media a light beam is not only reflected, but part of its energy overspills in a different direction in the new medium, i.e. it is refracted.

Here, a medium with reduced speed of light propagation is known as optically denser and that which is greater as optically thinner.

With the transition from an optically thinner to an optically denser medium, the angle of refraction is smaller than the angle of incidence, the beam is refracted towards the vertical.

With the transition from an optically denser to an optically thinner medium, the angle of refraction is greater than the angle of incidence, the beam is refracted away from the vertical.

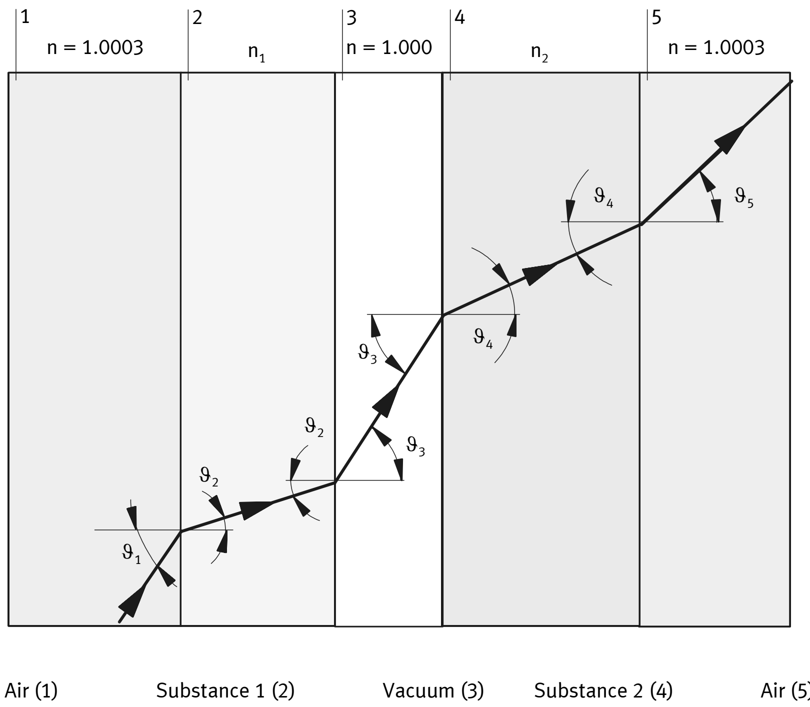


Fig. 11.4.3: Refraction of light beams in various media

11.4.3 Total reflection

With the transition from an optically dense medium into an optically thin medium, the angle of incidence cannot exceed a certain limit value. In the case of angles greater than this, total reflection occurs, i.e. the entire light energy is reflected into the optically dense medium.

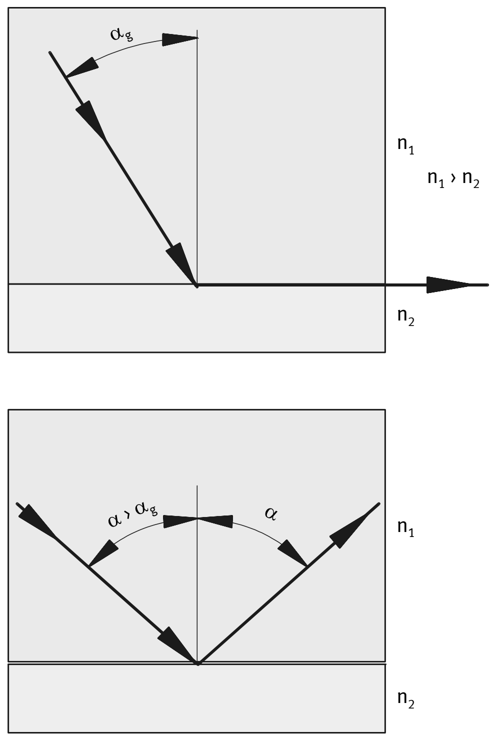


Fig. 11.4.4: Total reflection

11.4.4 Photoelectric components

In optoelectronic proximity sensors, photoelectronic emitting components are used to create light emission and photoelectronic receiving components for receiving light emission.

The most commonly used emitter elements are luminescent diodes, which are also known as LEDs (light emitting diode). For special applications, laser diodes are also used.

For receiving elements, photodiodes or phototransistors are generally used. In addition, photoresistors are also of some signficance, e.g. in photoelectric exposure meters.

Luminescent diodes

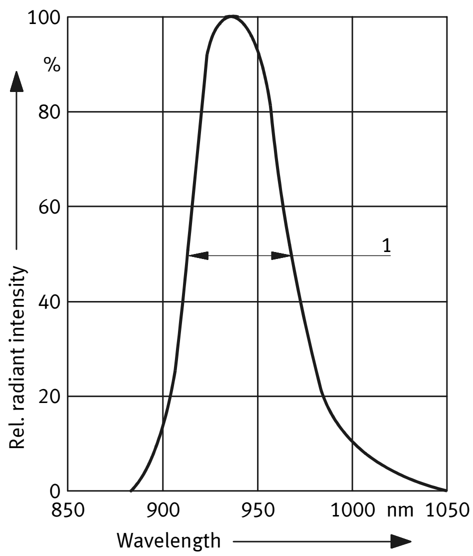
Luminescent diodes (LED) are semiconductor diodes which emit light beams when an electrical current passes through. Depending on the composition of the semi-conductor material, light beams of varying wavelength are created, see Table 11.4.2.

Material	**Colour**	**Wave length [nm]**
Gallium arsenide	infrared	950
Gallium aluminium arsenide	infrared	880
Gallium aluminium arsenide	red	660
Gallium arsenide phosphide	red	660
Gallium arsenide phosphide	red	635
Gallium arsenide phosphide	yellow	590
Gallium phosphide	green	565
Gallium nitride	blue	480

Table 11.4.2: Typical materials and wavelengths of luminscent diodes

Luminescent diodes in the infrared and red spectral range are mainly used in sensors, because this produces good adaption to the sensitivity of photodiodes when receiving light emissions.

Luminescent diodes represent a relatively small spectral width of the emitted light, which is generally between 30 – 140 nm (spectral halfwidth), see Fig. 11.4.5.



Spectral halfwidth (1)

Fig. 11.4.5: Emission spectrum of a GaAs-LED

Photodiodes

Photodiodes are semi-conductor components which are based on the principle of single-crystaline silicone or germanium. They are constructed in the same way as ordinary semiconductor diodes and have a barrier layer which is however very closely arranged underneath the crystal surface. If the diode is exposed to light emission, then the photons penetrating the crystal (quantum of the optical radiation) are absorbed and electrical charge carrier pairs are created. This effect is known as the photoelectric effect. The charge carrier pairs are separated in the barrier layer and an electrical current is created, i.e. the photocurrent.

Photodiodes are basically divided into the following types:
- PN photodiodes
- PIN photodiodes
- Schottky photodiodes
- Avalanche photodiodes

PN photodiodes have two differently doped areas in the crystal material, the so-called P-area and N-area, which are separated by a thin barrier layer. (Dotation refers to the process of integrating atoms from other materials, e.g. of boron or gallium into the crystal material. By means of dotation it is possible to influence the conductivity of a semiconductor).

With PIN photodiodes the P-area and the N-area is separated by a relatively wide layer of intrinsically conductive semiconductor material (I = intrinsic). This creates a layer of low insulating capacity and a fast switching time of the PIN photodiode.

PN silicone photodiodes and PIN silicone photodiodes are the most widely used types of photodiodes.

Schottky photodiodes are named after the Schottky effect and renowned for their excellent sensitivity in the ultraviolet spectral range.

Silicone avalanche diodes are based on the avalanche effect in barrier layer semiconductors. They operate at a high reverse voltage and are suitable for the detection of very small light output with reduced reaction times.

A typical characteristic curve of spectral sensitivity within a silicone photodiode is shown in Fig. 11.4.6. One important property is the maximum value of spectral sensitivity, which for silicone photodiodes can range between approx. 600 nm and 1000 nm, depending on type.

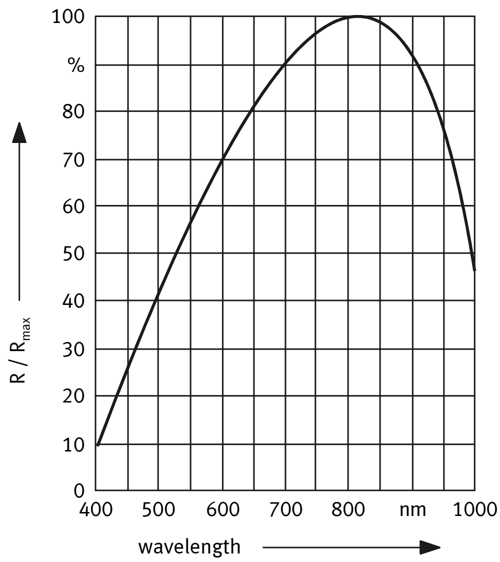


Fig. 11.4.6: Relative spectral sensitivity R/R_{max} of a silicon photodiode

The sensitivity of silicone photodiodes in the spectral maximum is typically at 0.5 A/W, i.e. at a received light emission power of 1 mW for instance, a photocurrent of 0.5 mA is created.

Responsivity R of a photodiode is the quotient of the photocurrent I and the optical radiant power P, which impinges on the photodiode:

$$R = \frac{I}{P}$$

11.4.5 Fibre-optic cables

Fibre-optic cables (glass or plastic fibre cables) are used in sensor technology for the purpose of conveying light to inaccessible or particularly exposed areas, where there is no room for an emitter and/or receiver or where difficult environmental conditions prevail.

The operation of an optical fibre is based on the total reflection of incoming radiated light inside the fibre.

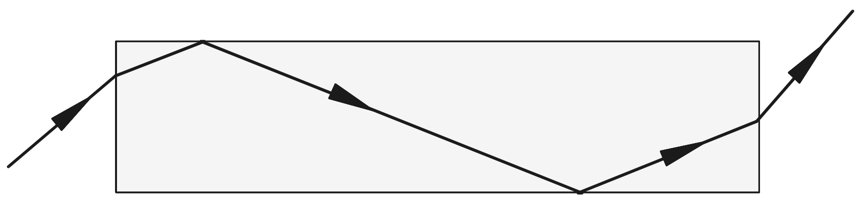
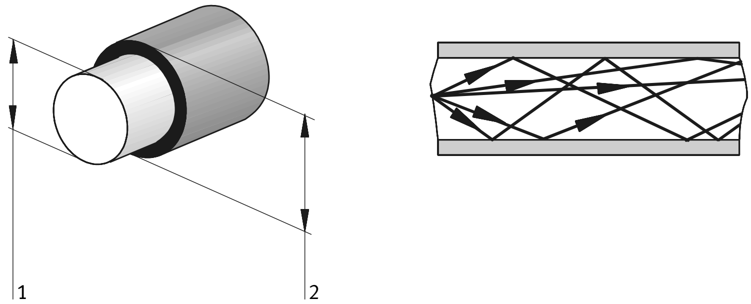


Fig. 11.4.7: Total reflection of light beams in the core of an optical fibre

In order to achieve total reflection, the high-refracting core is surrounded by a low-refracting cladding.

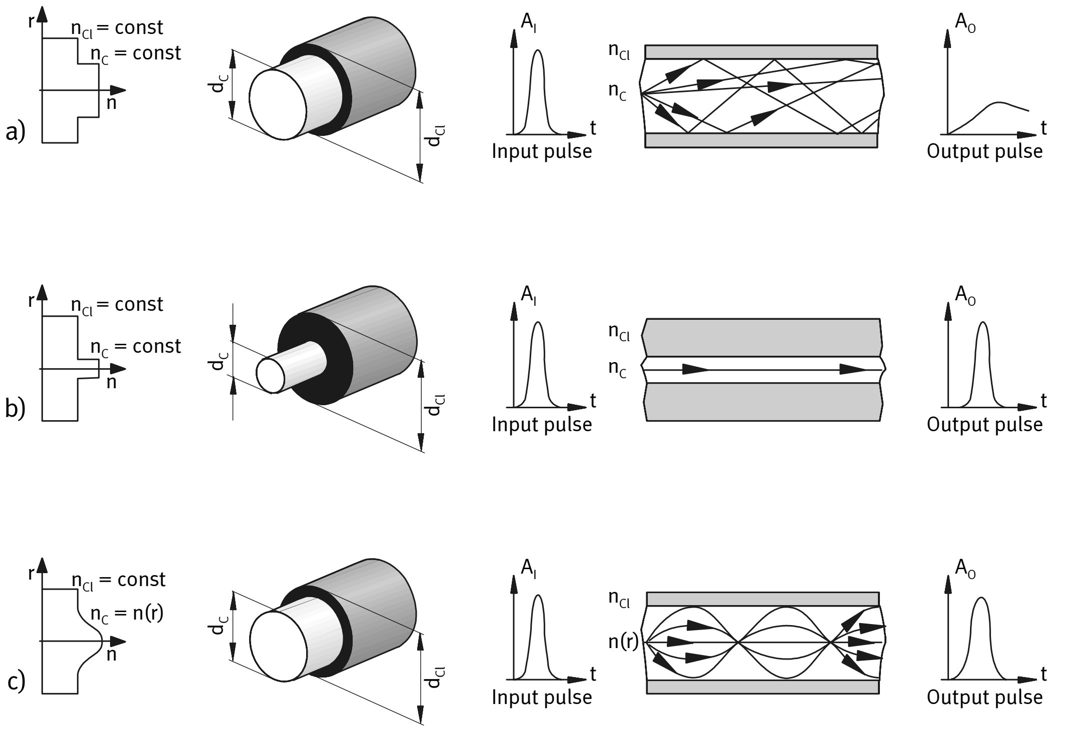


d_{Core} (1) $d_{Cladding}$ (2)

Fig. 11.4.8: Principle of a fibre-optic cable

There are three different types of fibre:
- Step index, Multimode
- Step index, Monomode
- Gradient index, Multimode

"Modes" refers to the particular forms of propagation of a light beam inside the fibre optic cable, which differ according to their individual direction of propagation.



a) Profile section of step index (Multimode)

b) Profile section of step index (Monomode)

c) Profile section of gradient index

Fig. 11.4.9: Types of optical fibres

Step index fibre

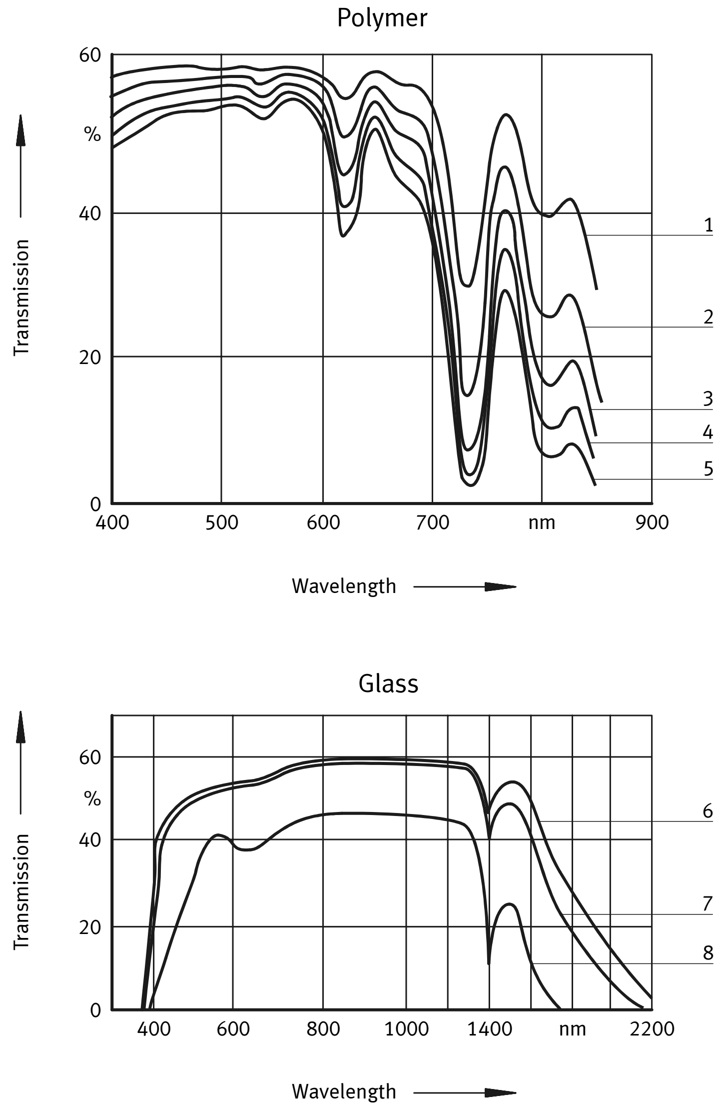
A step index fibre has a sharp limit between the core and cladding refraction index, the light beams can pass through the fibre in several ways (Multimode). A small input pulse is widened on passing through this fibre, because different acceptance angles produce different distances. In the case of the step index monomode fibre, only one path is possible for the light beam. The pulse retains its form to a large degree.

Gradient index

With the gradient index fibre a continuous transition of the refraction index is achieved. The pulse width is not particularly strongly widened.

Polymer and glass fibre-optic cables

Polymer fibre-optic cables are used preferably in the red range (660 nm) and glass fibre-optic cables predominantly in the infrared range. Glass fibre-optic cables absorb considerably less light in this wavelength range than polymer fibre-optic cables. In contrast, polymer fibre-optic cables are particularly flexible and can be cut to a required length.



polymer fibre, length: 1 m (1), 2 m (2), 3 m (3), 4 m (4), 5 m (5)

glass fibre, length: 500 mm (6), 1000 mm (7), 3600 mm (8)

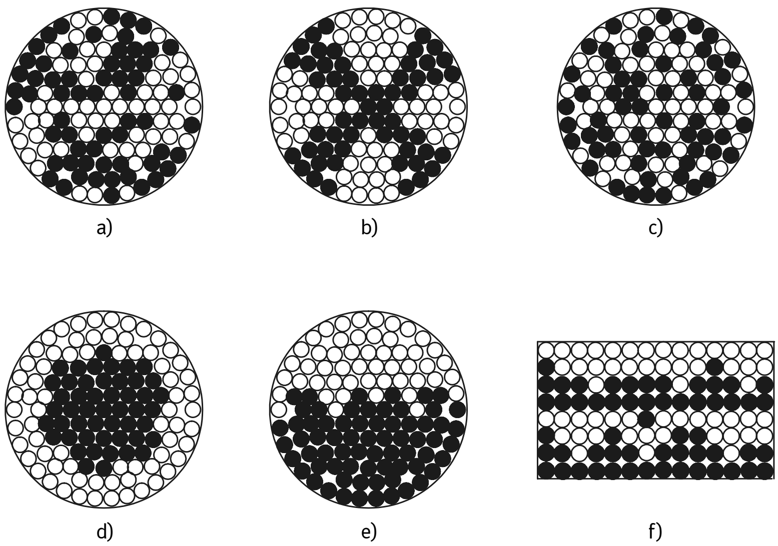
Fig. 11.4.10: Optical transmission of polymer and glass fibre as a function of the wavelength

The following are possible fibre materials:

- Multicomponent glass with a silicone-dioxide content of approx. 70 %
- Glass with a very high silicone-dioxide content of nearly 100 %
- Plastics
- Fluids

Basically, two cables are used in conjunction with proximity sensors. One cable transmits the light emitted by the light source, while the other cable conducts the light to the receiver of the proximity sensor. Diffuse sensors as well as through-beam sensors can be realized using optical fibre. In order to increase the relatively short sensing range of diffuse sensors with fibre-optic cables, they may be used in conjunction with reflectors to form a retro-reflective sensor.

For sensor applications, fibre optic cables include bundles of individual fibres. The arrangement of the optical fibre in emitter and receiver cables can be done in a wide variety of manners. The chosen arrangement depends on the individual case of application.



a) arbitrary
b) segmented
c) uniform
d) concentric
e) semi-circular
f) in-line

Fig. 11.4.11: Schematic design forms of fibre-optic cables (Source: Schott)

12. Circuit symbols for proximity sensors

12.1 Circuit symbols to standard DIN 40900

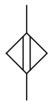
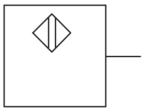
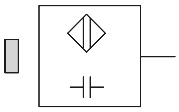
Circuit symbols	Description
	Proximity sensor
 	Approach-sensitive device, block symbol Note: Method of operation to be specified Example: Approach-sensitive device, capacitive, reacts to approach of a solid object
	Contact sensor

Table 12.1.1: Circuit symbols for sensors to standard DIN40 900, Part 7

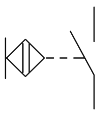
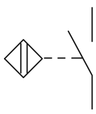
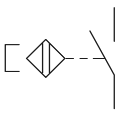
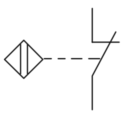
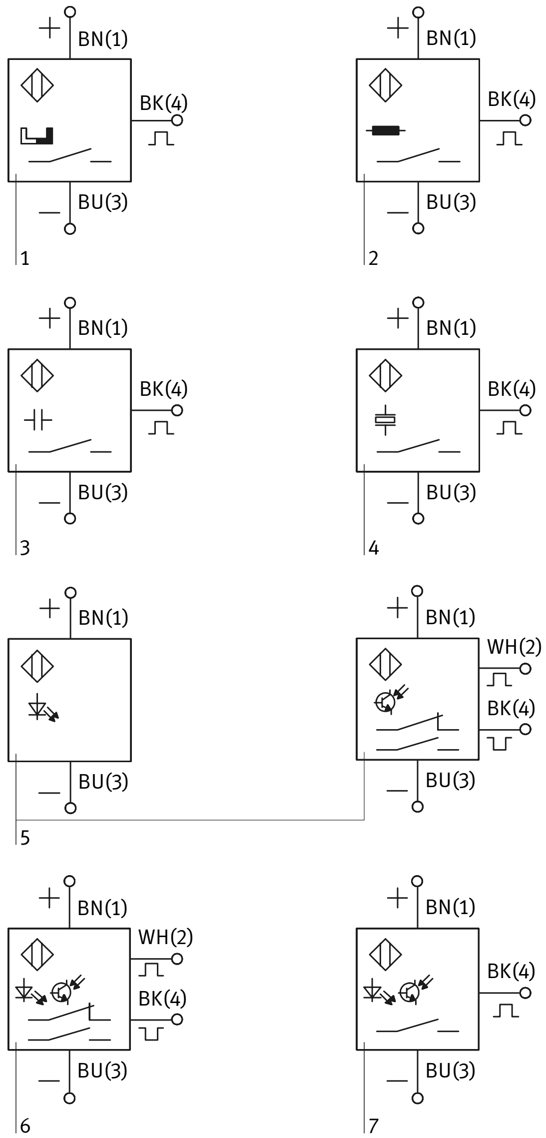
Circuit symbols	Description
	Contact-sensitive sensor (normally open contact)
	Proximity-sensitive sensor (normally open contact)
	Proximity-sensitive sensor (normally open contact), actuated by approach of a magnet
Fe 	Proximity-sensitive sensor (normally closed contact), actuated by approach of ferrous object

Table 12.1.2: Circuit symbols for sensors to standard DIN 40 900, Part 7

12.2 Examples of circuit symbols



Magnetic proximity sensor (1)
Inductive proximity sensor (2)
Capacitive proximity sensor (3)
Ultrasonic proximity sensor (4)
Through-beam optical sensor, Emitter and receiver in separate housing, Receiver with 2 switching outputs (5)
Optical proximity sensor, Emitter and receiver in one housing, 2 switching outputs (6)
Optical proximity sensor, Receiver and emitter in one housing, 1 switching output (7)

Fig. 12.2.1: Examples of circuit symbols for proximity sensors

13. Technical terms relating to proximity sensors

13.1 General terms

Active surface
The surface which emits the electrical field and on which a contactless proximity sensor reacts to an approaching object.

Constant light operation
The light beam is not modulated and is evaluated only in respect of the intensity of constant light.

Diffuse sensor
An optical proximity sensor whose light is scattered by the surface of an object (diffusion).

Diffusion
Diffuse reflection of light from the surface of an object.

Directed reflection
Directed reflection of light emission by means of reflecting surfaces.

Fibre-optic cables
Material, through which light can be conducted other than in a straight line and with minimum losses.

Flush fitting proximity sensors
The proximity sensor can be surrounded by metal or other materials up to the point of its active surface, without the characteristic values of the sensor being affected.

Free zone
The area surrounding the proximity sensor, which must be kept free of materials affecting the characteristic values of the proximity sensor.

Inductive proximity sensors
A device which creates a high frequency electro-magnetic field by means of an LC resonant circuit and emits a signal at the output in the event of certain attenuating conditions being fulfilled.

IR-Light
Infrared light is an invisible light form which has a greater wavelength than visible light (780 nm to approx. 100 μm).

Modulated light operation
The utilisation of a modulated light beam.

Non-attenuating material
Any material which does not significantly affect the characteristic values of an inductive proximity sensor.

Non-flush fitting proximity sensors
Sensors that require a free zone when fitted in metal or other materials in order to maintain the characteristic values of the proximity sensor.

Operating reserve factor
With optical proximity sensors the operating reserve factor β is derived from the quotient of the actual received optical signal power P_E in relation to the necessary optical signal power P_S at the switching level: $\beta = P_E/P_S$

Photoelectronic sensor, optoelectronic sensor
A term generally used for all devices which detect objects via a light source, i.e. ranging from infrared emissions and visible emission (wavelength range of 380 – 780 nm) to ultraviolet emission (UV).

Photoreceiver
The light receiving part of a light barrier or of a diffuse sensor.

Phototransmitter
Light emitting part of a light barrier or a diffuse sensor.

Reference axis
The axis vertically through the centre of the active surface of a proximity sensor.

Reflection
Deflection and reflection of light emissions on the boundary surfaces of various media.

Reflector
Optical aid for reflecting optical emissions, often in the form of triple reflectors.

Retro-reflection
Directed reflection of light emission to the source of the emission.

Retro-reflective sensor
The light of an optical emitter is reflected by means of a reflector (retro-reflection).

Standard test plate
A mild steel test plate, of square shape and 1 mm thick used for the purpose of carrying out comparative measurements of the switching distance of inductive sensors.

The lateral length equals:
- Diameter of the inscribed circle of the active surface.

or
- three times the value of the nominal switching gap.

The higher of the two values is to be applied.

Through-beam sensor
An optical sensor arrangement with separate emitter and receiver, which reacts to an interruption of the light beam directed between the emitter and the receiver.

Triple reflector
Optical aid, whereby retro-reflection is created by means of multiple reflection on its pyramid shaped inner surfaces.

UV light
Ultraviolet light in the wavelength range of 380 – 10 nm.

Visible light
Light ranging from red to violet (approx. 780 – 380 nm wavelength).

13.2 Terms for dimensional characteristic values

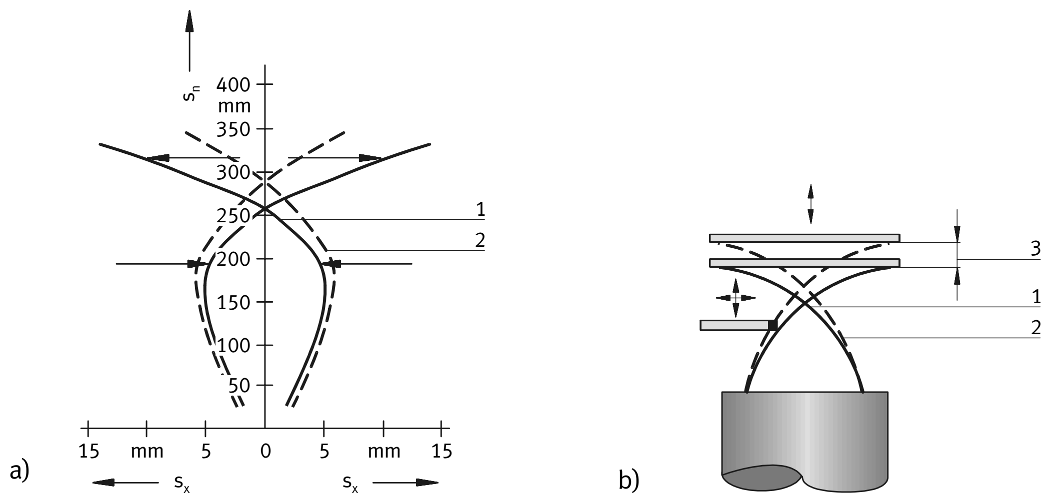
Axial approach
Approaching of calibrating plate centrally to the reference axis.

Nominal range
Standard specified range of light barriers. This range is established in a dry and clean environment and includes a reserve range to cover sundry tolerances. In the case of retro-reflective sensors this range refers to the reflector specified for the sensor.

Nominal switching distance
Standard specified sensing range of a diffuse optical proximity sensor.

Nominal sensing range
The switching distance of a proximity sensor at nominal supply voltage and nominal temperature without compensation for production tolerances.

Radial approach
Approach of the calibrating plate at a right angle and in the direction of the reference axis of the active surface of the proximity sensor.



Switch-on point (1) Switch-off point (2) Hysteresis (3)

a) Optical proximity sensor, object approached from side
b) Inductive proximity sensor

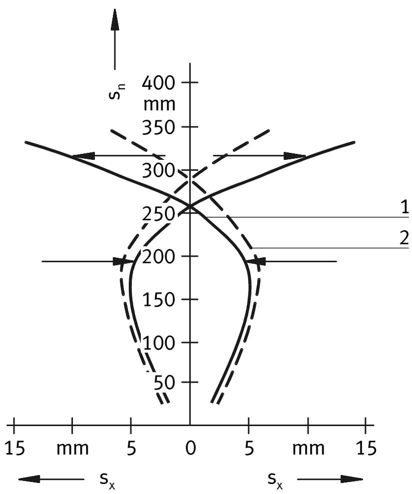
Fig. 13.2.1: Response characteristic

Range
Maximum distance between the emitter and receiver of a through-beam sensor or between the emitting and receiving device and the reflector of a retro-reflective sensor.

Real switching distance
The switching distance of an inductive proximity sensor measured at nominal voltage and nominal temperature, taking into account manufacturing tolerance. Maximum deviation from the nominal switching distance is ±10 %.

Reproducibility
Switching point difference which occurs within 8 hrs at a temperature of 15 – 30 °C and a nominal voltage deviation of ±5 %.

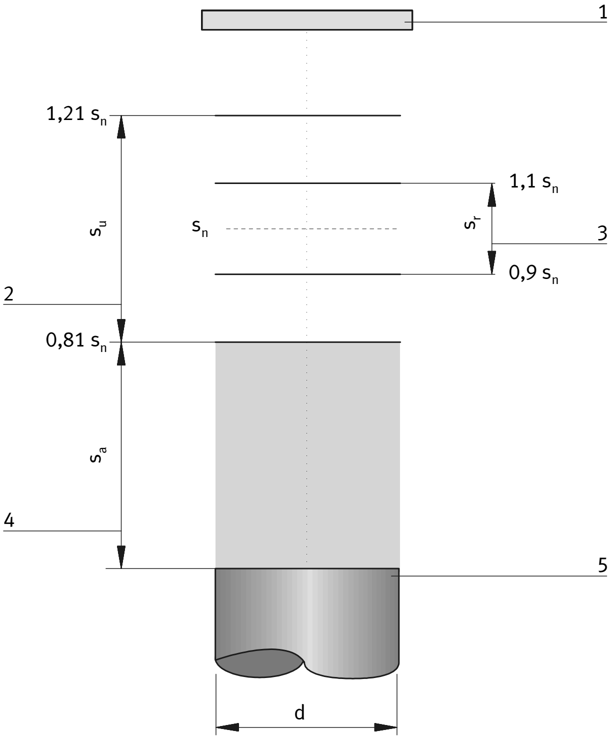
Sensing range
Distance between a diffuse sensor and a reference surface of specified dimensions (matt white paper) as it approaches the device in the direction of the axis until a signal change takes place.



Switch-on point (1) Switch-off point (2)

Fig. 13.2.2: Response characteristics of diffuse sensors

Switching distance
The distance at which a standard target approaching the active surface of a proximity sensor generates a signal change.



Actuating element (1)
Total tolerance range (2)
Manufacturing tolerance (3)
Reliable operating range (4)
Proximity sensor (5)

s_n = Nominal switching distance
s_r = Real switching distance
s_u = Useful switching distance
s_W = Working distance

Fig. 13.2.3: Switching distances

The real switching distance is specified by $0.9\ s_n < s_r < 1.1\ s_n$.
The useful switching distance is generally specified by $0.9\ s_r < s_u < 1.1\ s_r$, or partly as above by $0.81\ s_n < s_u < 1.21\ s_n$, which is the same.

Switching hysteresis
The difference between the switch-on point and switch-off point during the axial or radial approach of the calibrating plate to the active surface of a proximity sensor.

Useful switching distance
The switching distance of an inductive proximity sensor within the full rated supply voltage and temperature ranges. Maximum deviation from the real switching distance is ±10 %.

Working switching distance
Switching distance of an inductive proximity sensor within which reliable operation is guaranteed, independent of manufacturing tolerances or environmental factors. The values are between 0 and the lowest value of the useful switching distance.

13.3 Terms of electrical characteristic values

Nominal voltage V_n
A value within the operating voltage range, to which technical data refer.

Operating voltage V_s
Range of supply voltage which must not be exceeded or fallen below.

Permanent current I_a
Current flowing during continuous operation.

Residual current I_r
Current which flows when output is switched off.

Residual ripple
Alternating current superimposed on direct current. The residual ripple from peak to peak must not exceed the operating voltage limits.

Residual voltage V_r
Voltage, which is measured via load when the proximity sensor is not actuated.

Short-time current I_k
Short-time current which flows for a specified period and frequency.

Voltage drop V_d
Voltage measured between the switch output and the supply voltage (pnp type) or between the switch output and ground (npn type) at maximum current load and when the proximity sensor is actuated.

13.4 Terms for time and function characteristics

Adjustable switching (N/O – N/C)
Converting the device from normally open to normally closed operation.

Analogue output
The change in the physical quantity detected causes a continual change in the output signal.

Changeover function (anti-valent switching function)
An output with N/O function and an output with N/C function are available simultaneously.

Dark switching
The output is switched through if the photoreceiver is unilluminated.

Digital output
A digital output occurs if a change of a detected physical quantity results in a step response of the output signal.

Light switching
The output is switched through if the photoreceiver is illuminated.

Normally closed function (N/C)
The output is open if an object is detected and switched through if an object is not detected.

Normally open function (N/O)
The output is switched through if an object is detected and open if an object is not detected.

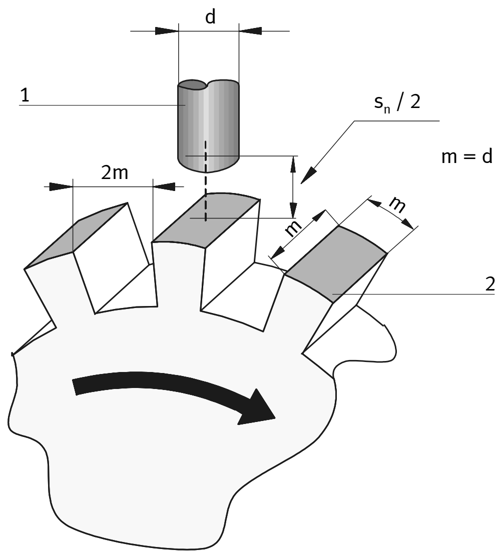
Reset time
Delay time between the actuating element leaving the active zone and the signal change at the output. The minimum required distance between two elements is determined by this time taking into account the travel time.

Response time
Delay time between the actuating element entering into the active zone of a proximity sensor and the signal change at the output. The speed at which the actuating element could pass through the active zone is limited in relation to the width of the actuating element.

Signal duration
Duration of the output signal with dynamic actuation. This must correspond to the input delay of the connected load.

Switching frequency

According to European Standard EN 50 010, the maximum switching frequency of an inductive proximity sensor is measured as shown in Fig. 13.4.1.



Proximity sensor (1) Test plate (2)

Fig. 13.4.1: Measurement of switching frequency

Switch-on delay

Time between switching on the operating voltage and the ready status of the device

13.5 Actuating characteristics of mechanical-electrical position switches

Actuating force (AF)
The final stage of the actuating force which triggers the switchover of the contacts.

Changeover displacement (COD)
The displacement of the actuator between the switching and reset point.

Final position (FP)
The position taken up by the actuator when it reaches the final position.

Forward displacement (FD)
The travel of the stem or actuator from its free position to the switching point.

Free position (FP)
The position taken up by the actuator when it is not contacted by a drive element.

Overtravel displacement (OD)
The displacement beyond the switching point up to the final position; the minimum permissible overtravel displacement is specified. Exceeding of this value reduces the specified mechanical service life of the switch.

Positive opening displacement (POD)
The travel of the actuator from its free position to the position, where the mechanical forced opening of the contacts is effected.

Reset force (RF)
The remaining actuator spring force, which effects the automatic reset of the spring contact.

Reset position (RSP)
The position of the actuator, in which the released spring contact returns to its normal position.

Switching point (SP)
The position of the actuator, in which the switch-over of the loaded spring contact takes place.

Total displacement (TD)
The displacement of the actuator from its free position to the final position.

Total force (TF)
The force to be applied to the actuator in order to get from the release to the final position.

13.6 Terms relating to environmental conditions

Chemical resistance
Behaviour in aggressive environment.

Climatic resistance
Behaviour in specified climatic conditions.

Nominal ambient temperature
Ambient temperature to which the technical operating data refers

Operating temperature (Ambient)
Temperature range in which the device operates reliably.

Protection class IP
Protection against contact and penetration by foreign matter (dust) as well as water under specified conditions to IEC 529 (DIN 40 050).

Shock stress
Behaviour under conditions pertaining to IEC 68-2-6.

Storage temperature
Temperature range of device when not in use.

Vibration stress
Behaviour under specified conditions pertaining to IEC 68-2-27.

14. Standards and protection classes

14.1 Standards

EN 50 008
"Inductive proximity sensors Form A for direct current, 3 or 4 terminals"
(European standard for three- and four-wire proximity sensors in cylindrical housings for direct current.)

EN 50 010
"Inductive proximity sensors. Methods for measuring the operating distance (switching distance) and the operating frequency (switching frequency)"
(European standard for measuring techniques to establish the switching distance and the switching frequency for proximity sensors in DC or AC design.)

EN 50 025
"Inductive proximity sensors Form C, for direct current, 3 or 4 terminals"
(European standard for three and four wire proximity sensors for direct current in block shape with rectangular section.)

EN 50 026
"Inductive proximity sensors Form D, for direct current, 3 or 4 terminals"
(European standard for three- and four-wire proximity sensors for direct current in block shape with rectangular section.)

EN 50 032
"Inductive proximity sensors. Definitions, classification, designation."
(European standard for terms and designations used in European standards for proximity sensors.)

EN 50 036
"Inductive proximity sensors Form A, for alternative current, 2 terminals"
(European standard for two-wire proximity sensors in cylindrical housings for alternating current.)

EN 50 037
"Inductive proximity sensors Form C, for alternating current, 2 terminals"
(European standard for two-wire proximity sensors in block shape with square cross section.)

EN 50 038
"Inductive proximity sensors Form D, for alternating current, 2 terminals"
(European standard for two-wire proximity sensors for alternating current in block shape with rectangular cross section.)

EN 50 040
"Inductive proximity sensors Form A, for direct current, 2 terminals"
(European standards for two-wire proximity sensors in cylindrical housings for direct current.)

EN 50 044
"Inductive proximity sensors. Identification of terminals."
(European standard for designations of terminals for proximity sensors with cable connection, plug connection or terminal wiring facility.)

DIN 40 050
"IP protection classes"
(Standard for the definition of protection classes for protection against contact, foreign matter and water for electrical equipment.)

IEC 529
"Classification of degrees of protection provided by enclosures"
(equivalent to DIN 40 050.)

DIN IEC 757
"Code for designation of colours"
(Definition of a colour code for the identification of specific colours in electrical engineering.)

DIN 44 030
"Light barriers and sensors"
(Definition of terms.)

14.2 Protection classes

The protective classes are indicated by a symbol, which is made up of the two code letters IP (= International Protection) and two codes for the degree of protection.

Example IP 67

The first code (0-6) specifies the degree of protection against contact and penetration of foreign matter, the second code (0-8) the degree of protection against penetration of water. The protection class is stated on the housing or the rating plate.

First code	Degree of protection (contact and foreign matter protection)
0	No specified protection
1	Protection against penetration of solid foreign bodies with a diameter greater than 50 mm (large foreign bodies)[1)] No protection against intentional access, e.g. of a hand, but protection against large-area contact
2	Protection against penetration of solid foreign bodies with a diameter greater than 12 mm (medium-sized foreign bodies)[1)] Protection against finger contact or similar
3	Protection against penetration of solid foreign bodies with a diameter greater than 2.5 mm (small foreign bodies)[1)2)] Protection against tools, wires et al. with a diameter grater than 2.5 mm
4	Protection against penetration of solid foreign bodies with a diameter greater than 1 mm (granular material)[1)2)] Protection against tools, wires et al. with a diameter grater than 1 mm
5	Protection against harmful dust deposits. The penetration of dust is not totally prevented: but dust is not able to penetrate in sufficient quantities to impair operation (protected against dust)[3)] Complete protection against contact
6	Protection against penetration of dust (dust-proof) Complete protection against contact

1) With equipment of protection classes 1 to 4, foreign bodies of even or uneven shape of three vertically aligned dimensions greater than the corresponding numerical value of the diameter are prevented from penetrating.

2) For protection classes 3 and 4, the implementation of this table with regard to equipment with drain holes or cooling air apertures falls within the responsibility of the individual technical committee responsible.

3) For protection class 5, the implementation of this table with regard to equipment with drain holes falls within the responsibility of the individual technical committee responsible.

Table 14.2.1: Classes of protection against contact and foreign bodies

Second code	Protection class (water protection)
0	No particular protection
1	Protection against dripping water falling vertically. Drops of water must not have any harmful effects.
2	Protection against dripping water falling vertically. Water drops falling at any angle up to 15° from the normal position of tilted equipment (housing) must not have any harmful effects. (water drops falling diagonally).
3	Protection against water falling at any angle up to 60° from the vertical. Spraying water must not have any harmful effects.
4	Protection against water splashing against equipment (housing) from all directions. Splashing water must not have any harmful effects.
5	Protection against jets of water from a nozzle directed against the equipment (housing) from all directions. Jets of water must not have any harmful effects.
6	Protection against heavy seas or strong jets of water. Water must not penetrate the equipment (housing) in harmful quantities (flooding).
7	Protection against water when the equipment (housing) is immersed in water under the specified pressure and time conditions. Water must not penetrate in harmful quantities (immersion).
8	The equipment (housing) is suitable for permanent submersion under conditions to be described by the manufacturer (submersion)[1)]
1) This protection class normally refers to equipment which is sealed hermetically. With certain types of equipment it is however possible for water to penetrate insofar as this has no harmful effect.	

Table 14.2.2: Classes of protection against water

14.3 Colour coding

14.3.1 Colour symbols to DIN IEC 757

This standard defines the standard colour coding in electrical engineering.

Abbreviation	English	Deutsch
BK	black	schwarz
BN	brown	braun
RD	red	rot
OG	orange	orange
YE	yellow	gelb
GN	green	grün
BU	blue	blau
VT	violet	violett
GY	grey	grau
WH	white	weiß
PK	pink	rosa
GD	gold	gold
TQ	turquoise	türkis
SR	silver	silber
GNYE	greenyellow	grüngelb

Table 14.3.1: Colour abbreviations

14.3.2 Colour coding to EN 50 044

This standard covers all inductive proximity sensors to standards EN 50 008, EN 50 025, EN 50 026, EN 50 036, EN 50 037, EN 50 038 and EN 50 040.

The standard differentiates between polarised and non-polarised proximity sensors. In the case of non-polarised proximity sensors with two connecting wires for DC or AC operation, the wires can be any colour except green/yellow.

In the case of polarised proximity sensors for direct current and two connecting wires, the connecting wire for the positive terminal must be brown and blue for the negative terminal.

Where proximity sensors have three or four connecting wires, the wires must be identified as follows

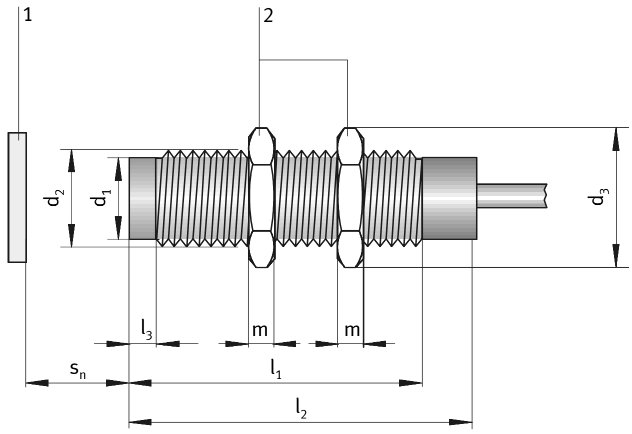
Operating voltage	Positive terminal →	Brown	
	Negative terminal →	Blue	
Load output	for three connecting wires	Black	independent of function;
	for four connecting wires	Black	for the normally open contact function,
		White	for normally closed contact operation.

14.3.3 Numerical designation to EN 50 044
This differentiates between polarised and non-polarised proximity sensors.

For non-polarised proximity sensors, terminals 3 and 4 have the normally open contact function and terminals 1 and 2 the normally closed function. For polarised proximity sensors for direct current with two terminals, the positive terminal must be identified with 1, the negative terminal with number 3. Number 4 is for the normally open contact function and number 2 for the normally closed function.

14.4 Designs of proximity sensors

The designs for inductive proximity sensors are laid down in European standards. Many manufacturers offer all of these design types as well as their own designs which differ from these standards. Standard EN 50 008 specifies the dimensions for cylindrical proximity sensors (design A). In addition, the minimum values for nominal switching distances and switching frequencies which must be achieved are indicated below.



Calibrating plate (1) Width across flates sw (2)

Fig. 14.4.1: Cylindrical, inductive proximity sensors (design A)

Design		**Dimension**					
A1 • flush fitting	A2 • non-flush fitting	Body			Nut		
Size	Size	d_1	l_1 min.	l_2 min.	sw h12	m 0.15	d_3 max.[1)]
• • 1	–	M 8 x 1	40	60	13	4	15
• • 2	• • 2	M12 x 1	40	80	17	4	20
• • 3	• • 3	M18 x 1	50	100	24	4	28
• • 4	• • 4	M30 x 1.5	50	100	36	5	42

1) d_3 = 1.13 sw

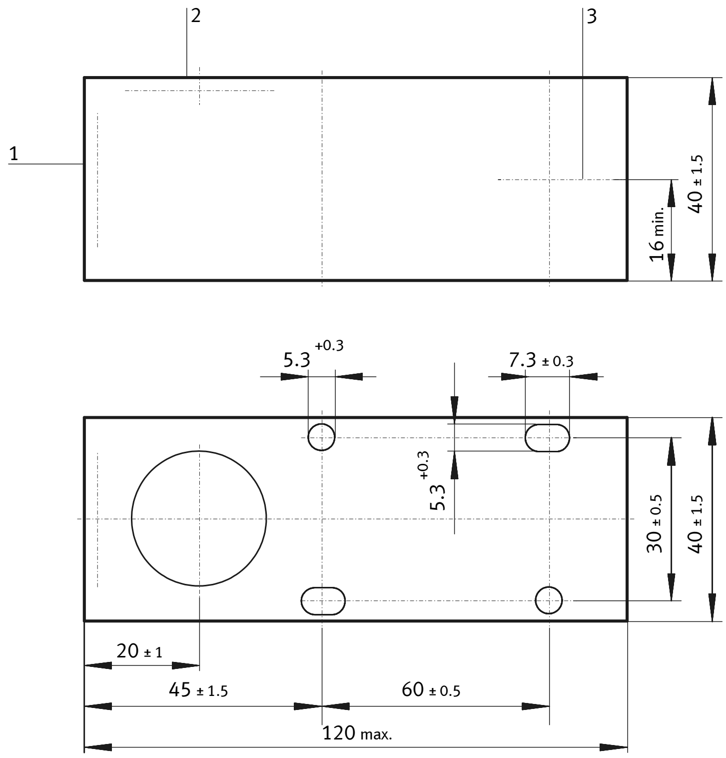
Table 14.4.1: Dimensions for cylindrical, inductive proximity sensors (design A) in millimetres

Design A1 • flush mounted		**Design A2 • non-flush mounted**	
Size	Nominal switching-distance s_n [mm]	Size	Nominal switching-distance s_n [mm]
• • 1	1	–	–
• • 2	2	• • 2	4
• • 3	5	• • 3	8
• • 4	10	• • 4	15

Design	**Minimum Switching frequency f [Hz]**
A11	1000
A12	800
A13	500
A14	300
A22	400
A23	200
A24	100

Table 14.4.2: Nominal switching distances in millimetres and minimum switching frequencies

The relevant data for inductive proximity sensors of form C (block-shaped, with square cross section) and D (block-shaped, with rectangular cross section) is specified in standards EN 50 025 and EN 50 026.



Active surface with design form C 21.1 (1)

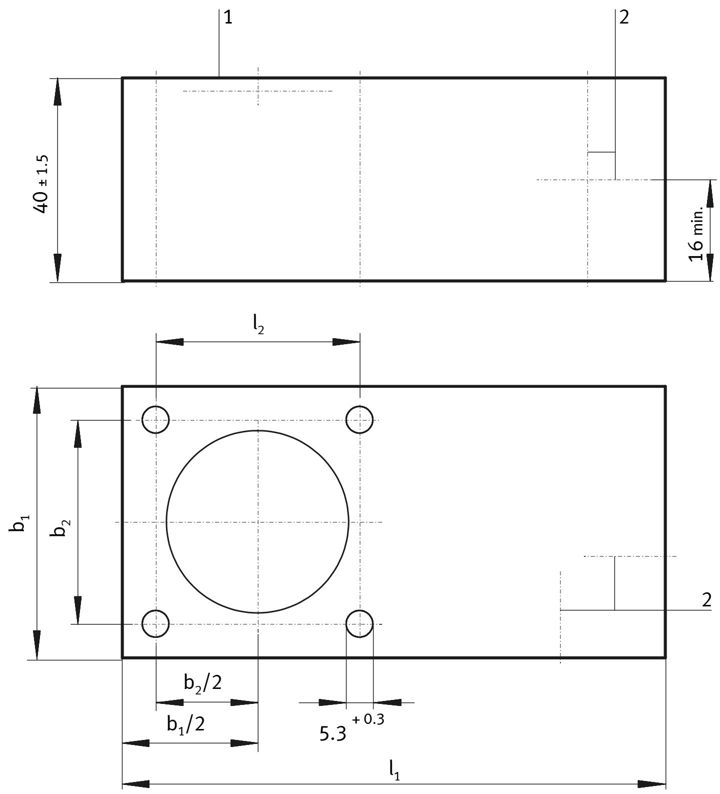
Active surface with design form C 21.2 (2)

Cable entry (3)

Bild 14.4.2: Dimensions of inductive proximity sensors (Design C) in millimeters

The nominal switching distance is 15 mm, the switching frequency must be at least 100 Hz.

As far as inductive proximity sensors of form D (block-shaped, with rectangular cross section) are concerned, these cannot be flush mounted in metal. Standard EN 50 026 specifies the data in respect of dimensions, nominal switching distances and switching frequencies.



Active surface (1) Cable entry (2)

Fig. 14.4.3: Block-shaped inductive proximity sensors (design D)

Size	**l_{1max}**	**$l_2 = b_2$**	**b_{1max}**
• • 1	120	45 ± 0.5	60
• • 2	135	65 ± 0.5	80
	$l_1 \geq b_1$		

Table 14.4.3: Dimensions for block-shaped inductive proximity sensors (design D) in millimetres

Design	**Nominal switching distance s_n [mm]**
D 21	25
D 22	40

Design	**Switching frequency f_{min} [Hz]**
D 21	50
D 22	10

Table 14.4.4:
Nominal switching distances in millimetres and minimum attainable switching frequencies (design D)

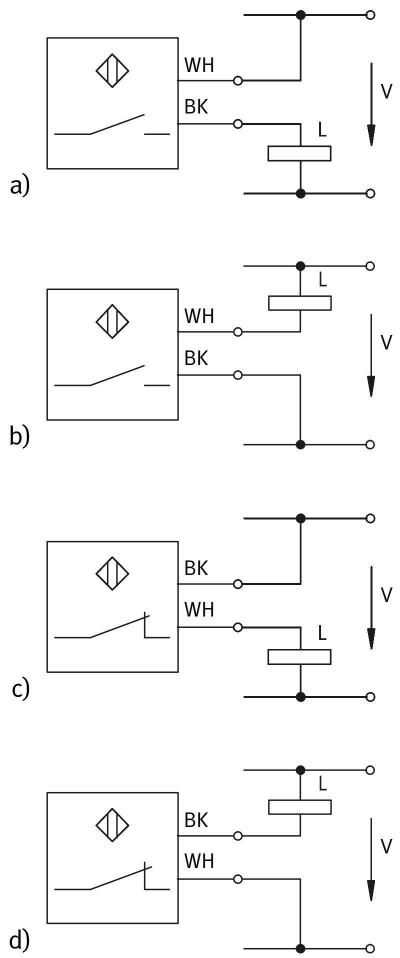
15. Special designs and variants of proximity sensors

15.1
Variants of inductive proximity sensors

- Universal two-wire design
- Designs for welding environment
- Designs for higher temperature range
- Designs for higher pressure range
- Designs with large switching gaps
- Designs with high switching frequency
- Designs with directional orientation (idle return function)
- Designs with safety technology
  – Self-monitoring safety switches
  – NAMUR-Switch for use in areas with explosion hazard
- Designs with selective action according to material
- Designs with switching distance independent of material
- Ring and slot shaped designs
- Special designs for checking of broken drills

15.1.1 Example of a universal two-wire design: Quadronorm by IFM

With the QUADRONORM inductive two-wire DC proximity sensor, 4 output functions can be accomplished in one proximity sensor:



a) Normally open contact, negative switching

b) Normally open contact, positive switching

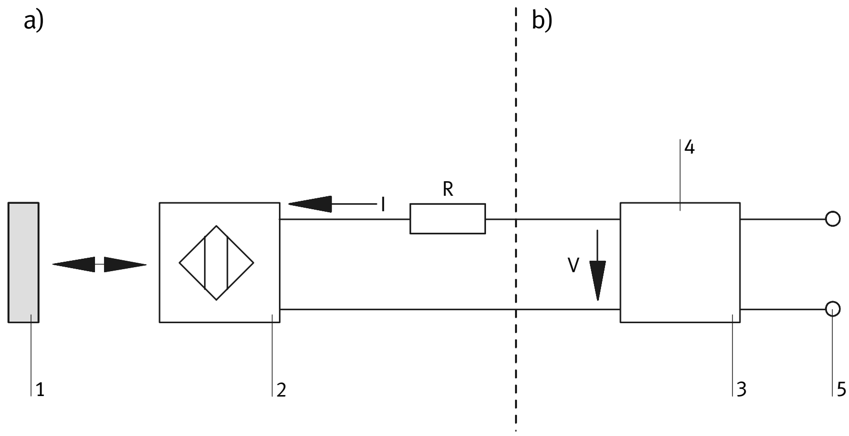
c) Normally closed contact, negative switching

d) Normally closed contact, positive switching

Fig. 15.1.1: Two-wire proximity sensor

15.1.2 Proximity sensors for use in installations with explosion hazard

Special proximity sensors are available for use in areas with explosion hazard, which conform to DIN Standard 19 234. This type of proximity sensor is also known as a NAMUR switch (NAMUR is an abbreviation for the German Standards Committee for Measuring and Control Technology in the Chemical Industry, Working Group for Contactless Controllers).



a) Area with explosion hazard

b) Area without explosion hazard

Object (1)

Proximity sensor (Two-wire DC sensor consisting essentially of an oscillator circuit) (2)

Circuit amplifier (3)

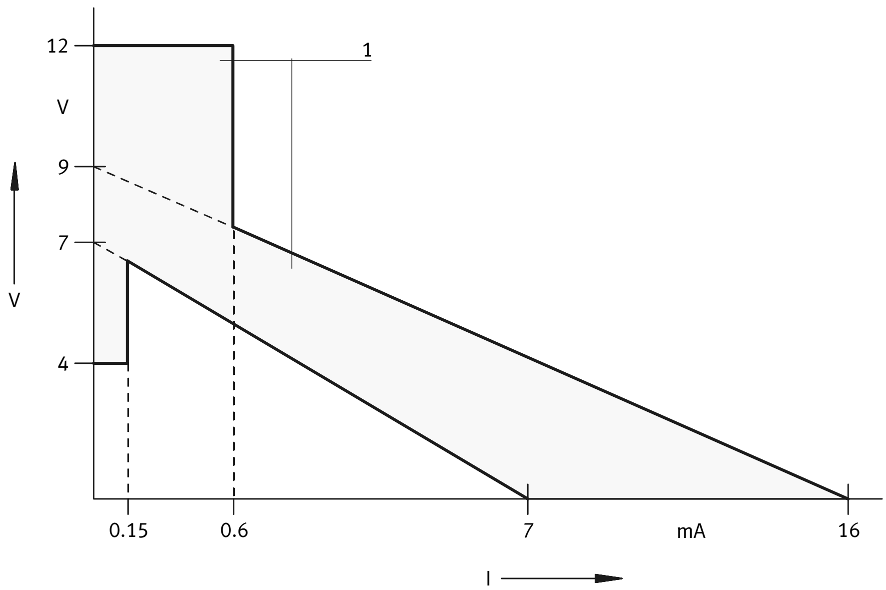
Supply voltage (4)

Binary output signal (5)

Fig. 15.1.2: Circuit principle of NAMUR proximity sensors

The following requirements are characteristics of NAMUR switches (in simplified terms):

- The current-voltage characteristic curve V(I) must be within the specified range to DIN 19 234. This guarantees that there is no sparking to trigger off explosion. The characteristic curve is effected during the transition between the switching statuses "inhibiting" and "conducting".



Permissible range of characteristic curve V(I) (1)

Fig. 15.1.3: Current voltage characteristic curve

- The response range for changing the switching status is between 1.2 mA and 2.1 mA.
- The safe switching status "inhibiting" is between 0.4 mA and 1.0 mA.
- The safe switching status "conducting" is above 2.2 mA.
- Monitoring and response ranges are defined for the interruption of the circuit (line break monitoring).
- A short circuit response is defined within the circuit (short circuit monitoring).
- Certain test conditions and data sheet specifications must be adhered to.

Note

For protection type "Intrinsically safe" the following additional standards apply (for instance in Germany):
- DIN VDE 0165
- DIN 50014-1977 / VDE 0170 / 0171 Part 1 / 5.78
- DIN 50020-1977 / VDE 0170 / 0171 Part 7 / 5.78

Furthermore, the DIN standard 57 165 defines three zones with explosion hazard for flammable gases, fumes and vapours (zone 0, zone 1 and zone 2) as well as two zones (zone 10, zone 11) for flammable dust. For each of these zones certain requirements have been defined for electrical installations, whereby the "intrinsic safety" requirement represents just one of several requirements. It is for example also possible to achieve explosion protection by means of encapsulation.

The above details merely serve as a rough guide; definitive information is available through relevant standards. NAMUR proximity sensors (inductive, capacitive and magnetic) and NAMUR circuit amplifiers are available from a large number of manufacturers.

15.1.3 Magnetic field proof (welding plant) inductive proximity sensors

Inductive proximity sensors resistant to magnetic fields are used in the vicinity of welding equipment. Their mechanical and electrical properties by far exceed those of ordinary proximity sensors.

The overall surface of the proximity sensor must be resistant against any occuring welding sparks.

Particularly high demands are made on the electronics due to the fact that in the vicinity of such welding equipment currents flow in the kA range. These currents cause a very strong magnetic field and would interfere with the function of an ordinary proximity sensor because the proximity sensor coil represents a good antenna for such strong magnetic fields and saturates the resonant oscillator circuit.

By using a special core material for the oscillator coil and an electronic circuit which recognises the presence of a welding field and blocks the switch output during the short welding pulse, it is possible to use these sensors in welding lines such as in the automotive industry. Just how large these magnetic fields are, can for instance be seen by the fact that a steel wrist watch at a distance of approximately 30 cm from the current-carrying conductor is easily attracted by this.

Examples

- Sizes M 12 x 1, M 18 x 1 and M 30 x 1.5 with switching distances of 2 mm, 5 mm and 10 mm. These proximity sensors are magnetic field proof in continuous and alternating fields with magnetic currents of up to 25 kA. A Teflon protective screwed cover is available for the protection of active surface against welding splashes.
- Magnetic field proof inductive proximity sensors in stainless steel design with a ceramic front surface. A version in PBTP housing material is available for welding currents of up to 100 kA.

Welding currents	**Distance [mm]**			
I [kA]	**12.5**	**25**	**50**	**100**
5	80 mT	40 mT	20 mT	10 mT
10	160 mT	80 mT	40 mT	20 mT
20	320 mT	160 mT	80 mT	40 mT
50	800 mT	400 mT	200 mT	100 mT
100	1600 mT	800 mT	400 mT	200 mT

Table 15.1.1: Reference values for magnetic induction

The proximity-related calculation of magnetic induction B in mT can be made using the following formula:

$$\frac{B}{mT} \approx 0.2 \cdot \frac{I/A}{a/mm}$$

I = Current in amps
a = Distance in mm

15.1.4 Inductive proximity sensors for higher temperature range

While normal inductive sensors cover a temperature range of -25 – 70 °C, there are sensors to cover requirements at the higher temperature limit of 100 – 250 °C.

15.1.5 Inductive proximity sensors for higher pressure range

For use in hydraulic systems and for underwater research at deep sea levels, sensors are required which can withstand high pressure.

Sensors are available to a pressure level of up to 80 MPa (800 bar). Standard type sensors are used for a range of approx. 500 kPa – 1 MPa (5 – 10 bar).

15.1.6 Inductive proximity sensors with large switching distance

The potential switching distance is determined primarily by the size of the resonant circuit coil. Large switching distances therefore require larger coils.

Proximity sensors with large switching distances are for instance of advantage in cases where alternating distances occur between the object to be detected and the proximity sensor, e.g. as a result of position tolerances or different object sizes.

Example

Inductive proximity sensors in plastic housings of 80 mm, 90 mm or 100 mm dia. with switching distances of 50 mm, 70 mm or 100 mm. Switching distances of 45 mm and 90 mm can be achieved with metal housings of 100 mm and 200 mm dia. for flush mounting.

Note

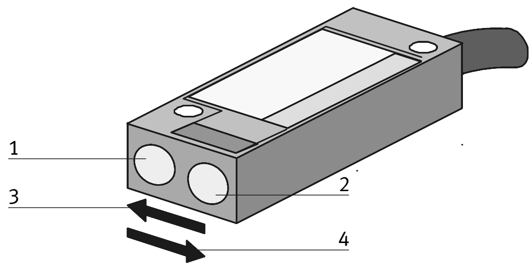
- In conformance with Standard EN 50 010, large switching distances require correspondingly large standard calibrating plates or correspondingly large object surfaces.

15.1.7 Inductive proximity sensors with high switching frequency

Inductive proximity sensors generally have a maximum switching frequency which is in the range between 500 Hz and 5 kHz, whereby the smaller designs operate at the highest frequencies. Large designs with switching distances in excess of 20 mm can have switching frequencies of less than 50 Hz. High switching frequencies are for instance required for the sensing of fast rotating parts. Products are available with switching frequencies of up to 20 kHz.

15.1.8 Inductive proximity sensors with idle return function

Directional inductive sensors have two adjacent active zones. If an object passes these two zones, then the proximity sensor only registers the object moving in a certain direction, but not in the opposite direction. The basic requirement for this is that the object to be sensed fully traverses the active zones both in the counting and idle return directions.



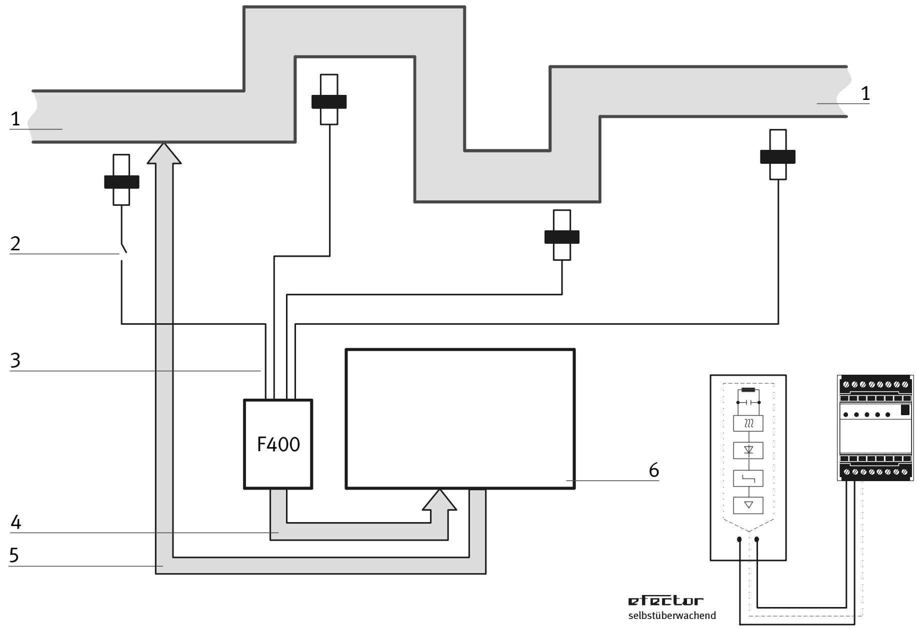
Active zones (1, 2) Counting direction (3) Idle return direction (4)

Fig. 15.1.4: Inductive proximity sensor with idle return function

15.1.9 Self-monitoring proximity sensors

The self-monitoring proximity sensor (safety switch) is used in all those instances where a high degree of reliability is required. A fault occurring with the switch is detected by the evaluation unit and triggers the required actions. Generally the entire installation is switched to safe status.

With some safety systems, not only the switch itself, but also the voltage supply lines, the voltage supply and the evaluation electronics are continually checked.



Production process (1)
Fault (2)
Error message (3)
Error signal (4)
Intervention in production process (5)
Control (6)

Fig. 15.1.5: Design example: Self-monitoring inductive sensor system (source: IFM)

The connected sensors, including the connection cables are constantly monitored for correct function.

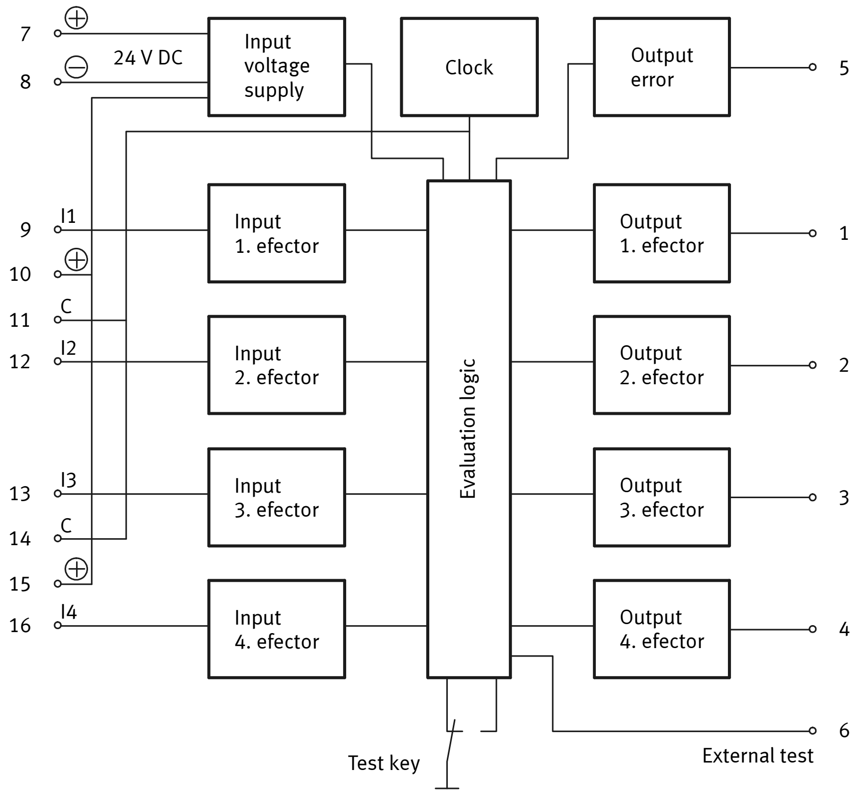


Fig. 15.1.6: Block diagram of a function monitoring circuit (Source: IFM)

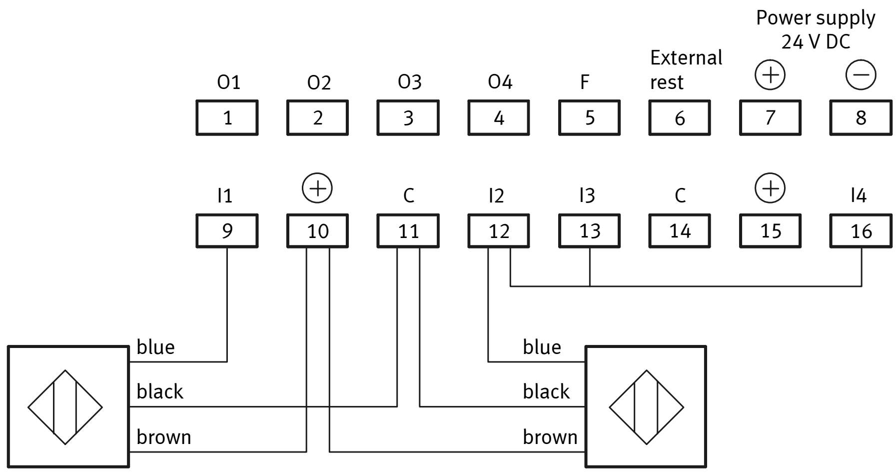


Fig. 15.1.7: Connection of a function monitor, Example using 2 sensors (Source: IFM)

The function monitor generates sensing pulses to monitor the sensors which are connected to it. The pulses reach the black signal connections of the sensors via a common timing circuit. Special sensor designs are used, where the black connection is not, as in the case of standard sensors, for the output of the switching signal, but in this case for receiving the testing clock. The sensors are supplied with voltage by the function monitor via the brown connections. The blue connections serve as the outputs of the sensors to the function monitor.

The sensors are continually reprogrammed from normally open to normally closed function in accordance with the rhythm of the clock frequency. The pulses from the pulse line (BK) and the signal line (BU) are connected in the function monitor in such a way that the clock pulses are filtered out logically and the appropriate switching status of the sensors is available at the signal outputs.

The fault-free status is signalled via a positive output signal on a common error message output. In the case of a fault, e.g. line break, short circuit or damage to a sensor, the error message output and the signal output of the sensor concerned are closed and the error can be located by means of a test key.

15.1.10 Inductive proximity sensors for specific material detection

For certain applications, it is desirable that an inductive proximity sensor should react to specific materials only. Ordinary inductive sensors respond to all metallic objects. The largest switching distance is achieved with steel.

On the other hand, there are proximity sensors which respond to specific materials achieving the greatest switching distance using iron-free materials ("proximity sensors for non-ferrous metal"). Ferrous metals have a reduced effect and therefore flush-fitting installation in steel is possible.

Examples

- Selective proximity sensors of cylindrical M 30 design, as well as block shaped with nominal switching distances in relation to aluminium of 10 mm and 20 mm. These proximity sensors are suitable for objects made of copper, aluminium, tin, brass, bronze, zinc, silver, gold, manganese and lead.
- Selective proximity sensors with switching distances of 8 mm, 10 mm and 20 mm of types M 30 x 1.5, block shaped 34 mm x 50 mm x 65 mm and 40 mm x 40 mm x 114 mm.

15.1.11 Inductive proximity sensors with material independent switching distance

Proximity sensors with constant switching distances, irrespective of material, have the advantage that in the case of changing material no re-adjustment is required, and a single switching distance is continually maintained, as in the case of standard proximity sensors with the standard steel plate in steel S 235 JR.

Example

Inductive proximity sensors with switching distances of 5 mm, 10 mm and 15 mm, each independent of type of metal.

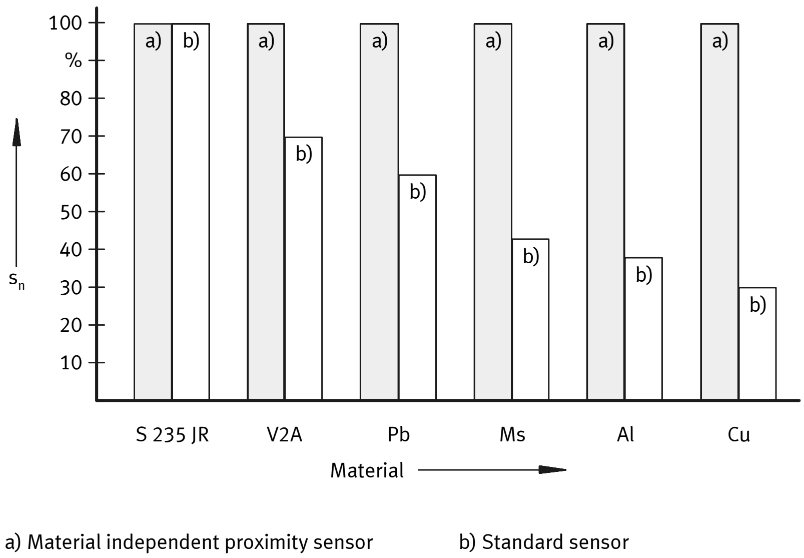


Fig. 15.1.8:
Comparison of switching distance between material independent proximity sensors and standard sensors

15.1.12 Ring type inductive proximity sensors

The oscillator coil consists of a ferrite ring core with internal coil. The oscillator is attenuated as soon as an electrically conductive object enters the ring.

Ring proximity sensors are suitable for instance for contactless sensing of small metal parts, which are transported via a conveyor tube, whereby the conveyor tube passes through the ring sensor.

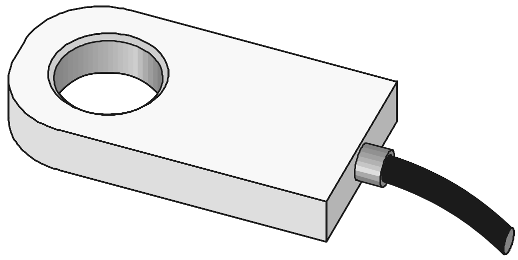


Fig. 15.1.9: Ring type proximity sensor

Example

Proximity sensors with an internal diameter of 10 mm, 15 mm, 21 mm and 43 mm.

15.1.13 Slot type inductive proximity sensors

Slot proximity sensors are in the shape of a fork, where two oscillator coils are placed opposite one another. The proximity sensor responds to metallic objects in the space between the fork, similar to a light barrier sensor. Proximity sensors of this type are used in applications where constant accurate reproducibility of the switching point is required even if the line of movement of the object varies slightly.

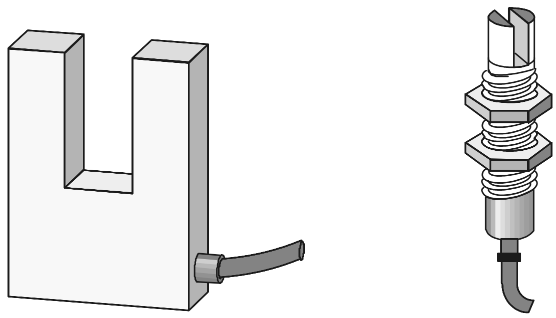


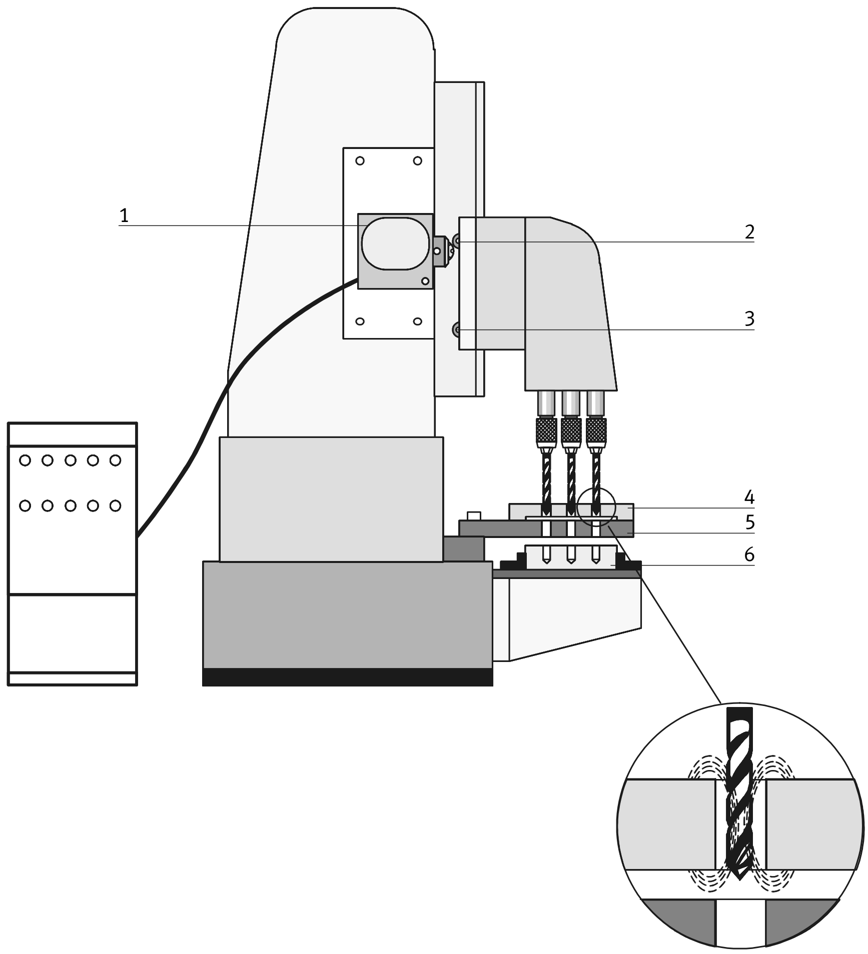
Fig. 15.1.10: Slot type proximity sensors

Example

Proximity sensors with slot widths of 2 – 30 mm

15.1.14 Inductive proximity sensors for broken drill monitoring

Inductive sensors are also available for monitoring drill breakage, whereby drills, taps or reamers are monitored for fracture during the working process. The principle is based on the induced linkage of the sensor coils when a tool is introduced. Diameters from 1 – 25 mm can be monitored. Tools are checked for availability on actuation of the upper or lower sensing level.



Incorporated limit valve (1) Lower sensing point (2) Upper sensing point (3) Sensors (4) Mounting plate (5) Workpiece (6)

Fig. 15.1.11: Proximity sensors to monitor drill breakage (Source: Euchner)

15.2 Variants of optical proximity sensors

The following briefly describes a number of variants:

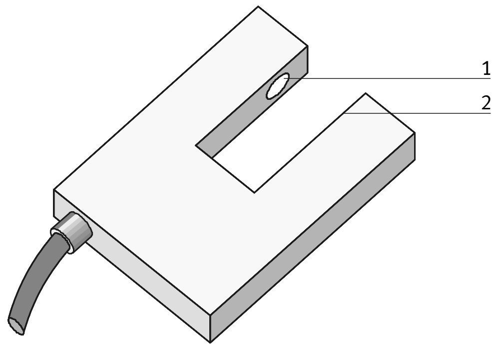
- Slot type barrier sensors
- Frame sensors
- Laser sensors
- Retro-reflective sensors with polarisation filter
- Printing mark sensors
- Luminescence sensors
- Angled light barrier sensors
- Sensors for accident prevention
- Dynamic sensors

There are many more variants in addition to the above, for example:

- Colour distinguishing sensors
- Sensors with integrated contamination signal
- Light grid sensor (using several through-beam sensors)
- Light curtain sensor with glass fibre optics
- Wide beam diffuse sensor for the detection of cling film or glass
- Special sensors for monitoring drill breakage (starting from a drill diameter of 1.5 mm)
- Sensors for data transmission
- Diffuse sensors for reading bar codes
- Explosion-proof designs, NAMUR versions
- Designs for connecting up to 2 or 3 fibre optic adaptors to a sensor module

15.2.1 Slotted light barrier sensors

Slotted barrier sensors are through-beam sensors, in which the emitter and the receiver are mounted opposite each other in a single U-shaped housing. They are often available in low cost versions in plastic housings.



Emitter (1)   Receiver (2)

Fig. 15.2.1: Slotted light barrier sensor

The interruption of the light beam within the fork is evaluated as the switching signal.

Slotted barrier sensors are available in a range of slot widths between 3 mm and 50 mm.

These sensors are for instance used for measuring rotary or linear movements, whereby a slotted disc or a linear scale is sensed. In this way, it is possible to achieve a digital potentiometer without sliding contact. Relatively high switching frequencies are possible, for example up to 1 MHz. Also light barrier sensors are available, which can detect the direction of movement of an object.

15.2.2 Frame barrier sensors

Frame barrier sensors operate according to the principle of a light curtain. On two opposite sides of the frame a large number of emitters and receivers are fitted in close alignment, completely covering the inside of the frame with a light curtain.

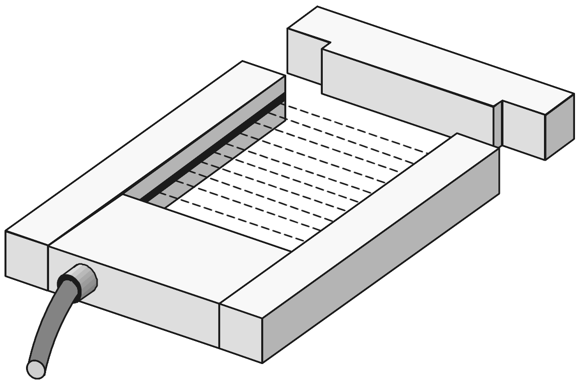


Fig. 15.2.2: Frame light barrier

Frame sensors are used preferably to detect small parts falling through the frame, for example for ejection monitoring of punched or pressed parts. Because of their application in dynamic processes, frame sensors generally only have a dynamic switching behaviour. Permanently existing parts, such as a transparent conveyor tube which may be contaminated by dust and oil are therefore not detected. The response time of frame sensors, for example, can be 150 µs and parts of up to 2 mm in diameter can be resolved.

15.2.3 Laser barrier sensors

Light emitting diodes (LED) are mostly used as the light source for optical sensors. However, by using laser diodes, it is possible to construct laser sensors, which have the following advantages:

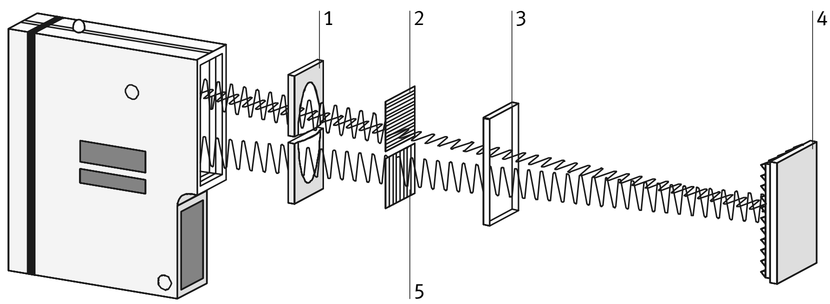
- Extremely wide range by means of concentrating the laser beams
- Very narrow and precise response range over great distances

With laser beams having a cross section of 18 mm x 10 mm, it is possible to detect objects at ranges of more than 200 m for instance. With shorter ranges of for example 2 m, it is possible to detect an object of only 0.3 mm diameter. Such extremely small response areas are particularly useful for accurate approaching and setting of tools and workpieces.

15.2.4 Polarised retro-reflective sensors

Where retro-reflective sensors are used to detect highly reflective objects, the proximity sensor is unable to distinguish whether the reflection originates from the reflector or the object, i.e. it does not recognise the object. One solution to this problem is to use polarisation filters.

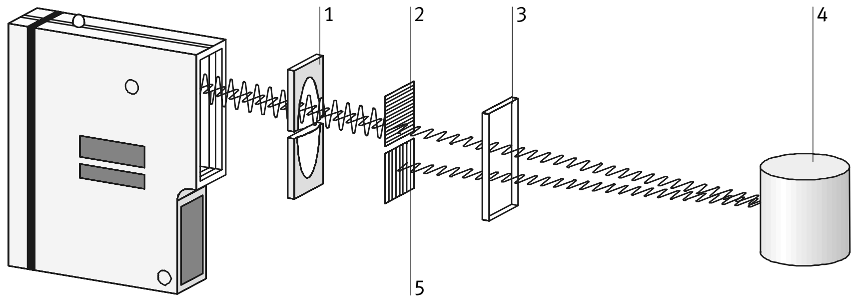
Operating principle



No object in lightbeam

Lenses (1) Front cover (3) Analyzer (5)
Polarisor (2) Reflector (4)

Fig. 15.2.3: Polarised retro-reflective sensors (source: Sick)



The reflecting object does not produce the same polarised light beam as the reflector and is detected.

Lenses (1)
Polarisor (2)
Front cover (3)
Reflecting objector (4)
Analyzer (5)

Fig. 15.2.4: Polarised retro-reflective sensors (Source: Sick)

The two polarisation filters for emitter and receiver are built-in between the lens of the proximity sensor and an additional glass cover on the front of the proximity sensor. A feature of the polarisation filter is that it only lets through light waves which oscillate at a certain level. The light generated by the optical sensor (e.g. red light LED) oscillates on several levels of polarisation.

The polarisation filter of the emitter lets through only that part of light which oscillates at a specific polarisation level. In this way only the polarised light beam reaches the reflector (there is no need for the ambient light level to be taken into account, because this will be suppressed in the receiver anyway). The reflector which is in the shape of a triple mirror then rotates the polarisation level by 90°. In order that the light reflected by the triple mirror can be received by the receiver, the series-connected polarisation filter is rotated by 90° opposite to the emitter polarisation filter.

If there is a reflecting object in the lightbeam then in contrast to the triple mirror, polarisation is maintained. In this way, the light from the object which hits the receiver polarisation filter is not allowed to pass through to the receiver and the receiver evaluates the absence of the light signal as "object available".

15.2.5 Printing mark sensors

Printing mark sensors are used for the detection of printed contrast markings, e.g. of printed black-white or coloured marks on packaging materials, identification codes on storage containers. Other examples include positioning with printing, for applying glue or for cutting material widths according to patterns, or for cutting labels or bags.

Printing mark sensors are also described as marking readers/scanners.

Printing mark sensors operate similarly to diffuse sensors, except for one difference in that the emitting beam is focussed on a specific sensing distance. Printing mark sensors are able to detect very slight contrast differences, whereby differences in colour can also be interpreted as contrast differences.

The object must be within certain tolerances of the switching distance of the proximity sensor. The strength of radiation reflected by the object is compared in the receiver with an adjustable critical value. The threshold corresponds to a specific grey-scale value on the object. If the threshold of the grey-scale value is fallen below of or exceeded, the printing mark sensor changes its switching status.

Depending on the different types of application (varying reflection with different colour contrasts), printing mark sensors are often equipped with optical sensors whose wavelengths can be changed by using different light emitting diodes. Even bulbs in conjunction with selectable colour filters are used.

Printing mark sensors can be used with fibre optic adaptors. However, in such cases, luminous radiation is as a rule unfocussed and the sensing width may vary; however contrast sensitivity quickly diminishes as the distance increases.

Printing mark sensors are also able to detect very small marks. Designs incorporating an LED light source are for instance able to detect printing marks of a dimension of 0.5 mm at switching distances of 20 mm, whereas designs using laser radiation source are able to detect far smaller marks.

15.2.6 Luminescence sensors

Markings can no longer be reliably detected by means of printing mark sensors, if the markings are amongst other similar textures, e.g. printed labels. Also, in many cases the printing mark is not meant to be seen. In such cases, luminescence sensors, which respond to invisible, luminescent markings are suitable.

The emitter of a luminescence sensor emits ultraviolet light at a wavelength of 365 nm for example. The ultraviolet light excites a fluorescent marking substance, which emits at a higher wave length range (e.g. between blue and red).

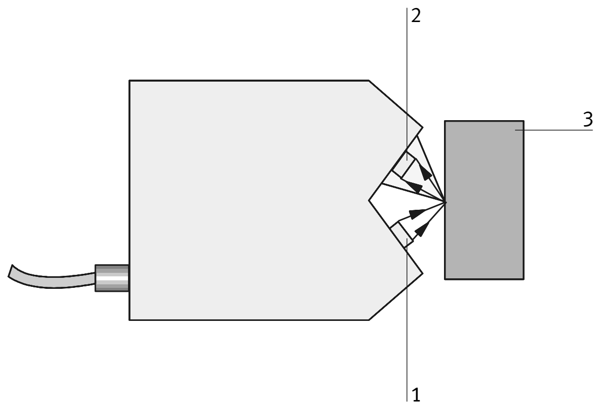
The luminescence radiation excited is detected by the receiver, which generates a switching signal. The emitter and receiver are modulated so that the receiver only responds to the modulated light of the emitter. In addition, optical filters are used to prevent the influence of external light effects.

Luminescent sensors also work perfectly with reflecting surfaces. Devices with sensing ranges of up to 500 mm are available. Luminescent sensors can also be used in conjunction with fibre optic cables.

15.2.7 Angled light barrier sensors

An angled light barrier sensor is a through-beam sensor with an angled light emission. The optical emitter and receiver are focussed on a common point. If an object appears at this focal point, the receiver detects the light reflected by the object and generates a switching signal.

Angled light barrier sensors are used for the accurate detection of objects at smaller distances whereby in contrast to retro-reflective sensors the switching distance is independent of the degree of reflection.



Emitter (1)   Receiver (2)   Object (3)

Fig. 15.2.5: Angled light barrier sensor

15.2.8 Sensors for accident prevention

Sensors for accident prevention are used to protect access to danger zones where power driven equipment is used, e.g. presses, automatic metal-cutting and shaping tools, cutters, winding machines, foundries, robots, rollers and stirrers. Sensors which are used for the purpose of accident prevention must meet the national safety regulations as laid down by individual regulatory bodies.

Depending on these regulations, sensors for accident protection come under the category of contactless protective devices, which can mean through-beam sensors or systems connected to these, such as light curtains or light grids. Protection devices must give a switching command if parts of the body enter the protected area. The purpose of the switching command is to prevent or interrupt a potentially dangerous movement.

The following requirements must be fulfilled (we do not claim completeness, appropriate local regulations take precedence):

- Specification of response time and size of obstacle on rating plate.
- Indication of at least two operating statuses.
- Prevention of any risk in case of interrupted operation of the protective device.
- Sufficient protection against external influences such as vibration, dirt, stray fields, mains interference, short circuit, line break.
- Self test, start-up test, self monitoring. Operative malfunctions in the protective device must be detected and signalled to the potentially dangerous equipment in the form of a cut-off command.
- Inhibit re-start following the interruption of a hazardous movement.
- Observation and identification of a specified safety distance between the protective area and the danger zone as well as identification of overtravel time.
- Protection against encroachment of or reaching into the protective area from below or above as well as against remaining between the protective area and the danger zone.
- Tests (prior to initial commissioning and additional regular routine testing also after retooling and repairs).

Industrial designs of accident protection sensors for example have the following features compared to ordinary sensors:

- Several indicator lights for operating and function display, e.g. for "emitter switched on", "light path free", "Light path interrupted", "light reception", "Light reception good" and "Light reception poor".
- For sensors with relay output, two positive action relay contacts for the connection of both outputs to the machine control.
- Front lens heating, lens contamination indicator.
- Permanent self-monitoring.
- High optical and electrical noise immunity.

Accident protection grid sensors consist of a system of parallel acting sensors, which create a dense grid of parallel infrared emission zones. The individual sensors of the grid are actuated in quick succession according to the multiplex method. A beam from the receiver to the emitter serves the purpose of synchronisation. Resolution is for example 35 mm between parallel beams (Minimum obstacle size).
Various designs are available to achieve different height levels,
e.g. from 400 – 1000 mm.

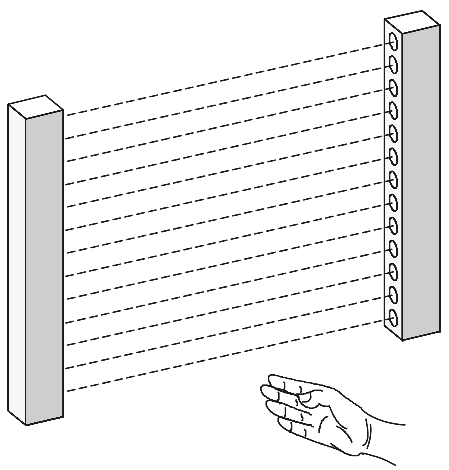


Fig. 15.2.6: Safety screen of through-beam sensors

15.2.9 Dynamic sensors

Standard sensors react to static build-up in the light beam. The switching signal reacts as long as the build-up is present.

Dynamic sensors, in contrast, react to rapid changes in the emission strength received. Slow changes such as for instance as a result of gradual contamination or slowly occurring objects are not registered because the switching threshold in the receiver is continually adjusted.

Dynamic sensors are often used as thread breakage monitors in the textile industry. The thread passes through the sensor. A thread breakage creates a slight, brief change in the light being passed and is detected. Breakages in the finest threads (e.g. up to 0.05 mm) can be detected. The minimum brightness variation can be adjusted.

16. Solutions

16.1
Solutions to exercises from Chapter 2

Exercise 2.1

Protective circuits for electro-mechanical limit switches
Differentiation must be made between ohmic, inductive and capacitive loads. Depending on the type of load, a suitable protective circuit is to be designed in order to achieve a longer service life for the switching contacts.

Ohmic load

If the load is purely ohmic, no additional protective measures need to be taken to observe the limit values of the respective data sheet.

Capacitive load

A great amount of current flows briefly if a capacitive load is switched on. If this current exceeds the value specified in the data sheets, external measures must be taken to restrict it. A protective resistor is connected in series with the switch. The design of the protective circuit is in accordance with the formula

$R = V / I_{max}$

with switching voltage V and maximum switching current I_{max}. The resistance is to be selected so that it can accept the required electrical power.

Inductive load

If there is a coil in the circuit, it stores magnetic energy while the circuit is closed. When switched off, this magnetic energy is reduced suddenly thus producing an arc across the two switching contacts which causes them damage. Different protective measures are required depending on voltage type.

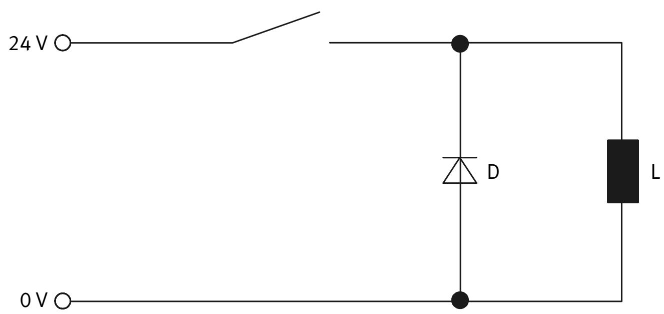


Fig. 16.1.1: Protective circuits for DC

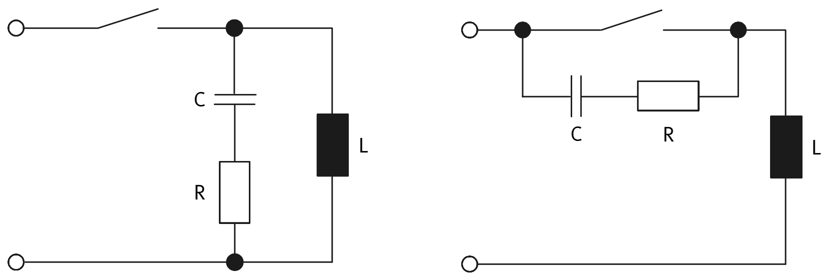


Fig. 16.1.2: Protective circuits for DC and AC

$$\frac{C}{nF} \approx 100\frac{I}{A}$$

$$\frac{R}{\Omega} \approx \text{Ohmic resistance of coil}$$

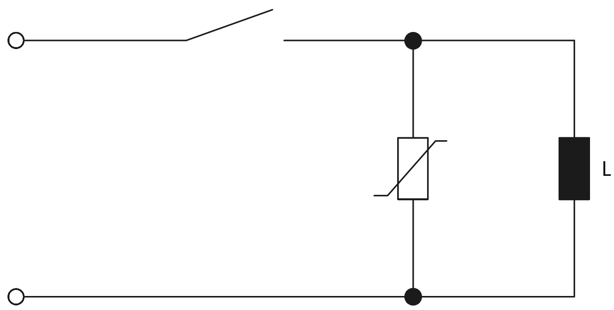


Fig. 16.1.3: Protective circuit for AC current using a varistor

Exercise 2.2

Switching of low electrical capacity
The switching reliability of a limit switch can be considerably improved by fitting a resistor to the load.

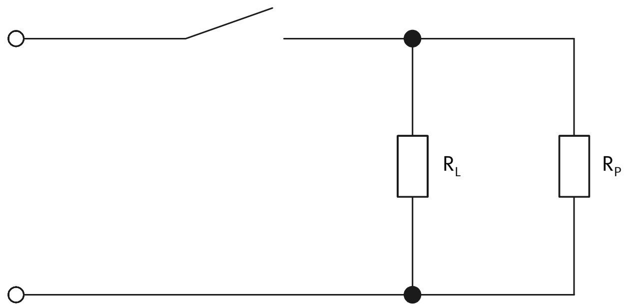


Fig. 16.1.4: Circuit for low contact rating

16.2 Solutions to exercises from Chapter 3

Exercise 3.1

Maximum passing speed of a cylinder piston across a reed proximity sensor
The maximum passing speed for a piston is calculated using formula:

$v_{max} = S_{min} / T_S$

S_{min} is the smallest possible response range of the proximity switch when overtravelled by the cylinder piston. T_S is the switching time of the proximity sensor or of another affected part, e.g. a valve. In this instance, the result obtained from the data sheet of the reed proximity sensor (SME) is the value T_S = 2 ms for the response time of this component.

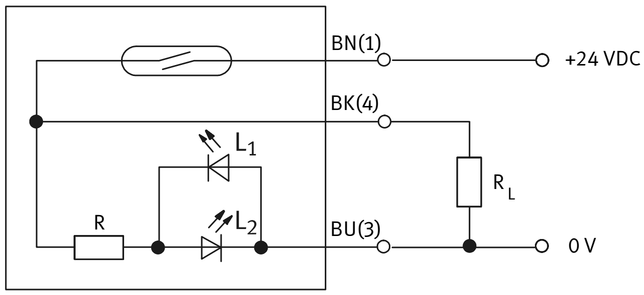
A value of 7 mm is obtained from table 16.2.1 in respect of the Festo cylinder DNNZ with a diameter of 32 mm for the response travel. For v_{max} a value of 3.5 m/s is obtained.

Piston diameter [mm]	Typ	Hysteresis H_{max} [mm]		Response travel S_{min} [mm]	
		SME	**SMP**	**SME**	**SMP**
8	ESN, DSN	2	1.5	7	9
10	ESN, DSN	2	1.5	5	9
12	ESN, DSN	2	2	8	11
16	ESN, DSN	2	2	6	9
20	ESN, DSN	2	2.5	7	9
	DGS				
25	ESN, DSN	1.5	2	6	17
	DGS	2	1.5	7	10
32	ESW, DSW	2	1.5	10	12
	DN, DNZ	2.5	4	7	15
	DNNZ	2.5	4	7	15
40	ESW, DSW	2	2	9.5	12
	DN, DNZ	2.5	4.5	8	15
	DNNZ	2.5	4.5	8	15
50	ESW, DSW	2	2	10.5	12
	DN, DNZ	3	5	8	17
	DNNZ	3	5	8	17

Table 16.2.1: Hysteris and response range of various cylinders (example)

Again for the Festo cylinder DNNZ with a diameter of 32 mm, a value for v_{max} of 0.467 m/s is obtained for a valve with a response time of 15 ms.

Exercise 3.2 **Electrical connection of a reed proximity sensor**



Series resistor (R) Load (R_L) Light emitting diodes (L_1, L_2)

Fig. 16.2.1: Circuit diagram of reed proximity sensor

In the case of a proximity sensor with reed contacts, a circuit is built-in for protection against inductive switch-off peaks, which at the same time acts as a bipolar switching status display.

The protection diodes are connected parallel to load L via the series resistance, similar to the protective circuit shown in Fig. 16.1.1. The protective circuit also works with an alternative supply voltage.

When a load is connected, care should be taken that the load resistance is sufficiently great so that the maximum permissible switching current of the proximity sensor is not exceeded. Provided this requirement is met, the polarity of the supply voltage can be exchanged without causing any damage.

It should be noted that particularly during testing, a sensor can easily be damaged if the load output BK (4) is accidentally short-circuited to terminal BU (3).

Exercise 3.3

Resolution of a reed proximity sensor
The minimum possible stroke that can be detected for a cylinder fitted with two reed proximity sensors is calculated by:

$H_{min} = 2 \cdot H_{max}$

H_{max} is the maximum hysteresis of the cylinder switch combination.

The relevant values can be taken from table 16.2.1. The value for a Festo cylinder of type DNNZ with a diameter of 32 mm, fitted with a reed switch (SME) is H_{max} = 2.5 mm. This results in a minimum possible stroke of 5 mm.

16.3 Solutions to exercises from Chapter 4

Exercise 4.1

Application of an inductive proximity sensor
The number of parts containers is established by means of counting the output pulses of proximity sensors.

If one assumes that the transport speed is constant, the time difference between two consecutive proximity sensor pulses can be converted into the distance between the parts containers.

A second proximity sensor is required for direction detection. It is necessary to establish the sequence in which the two proximity sensors emit an output signal to obtain the information in respect of direction.

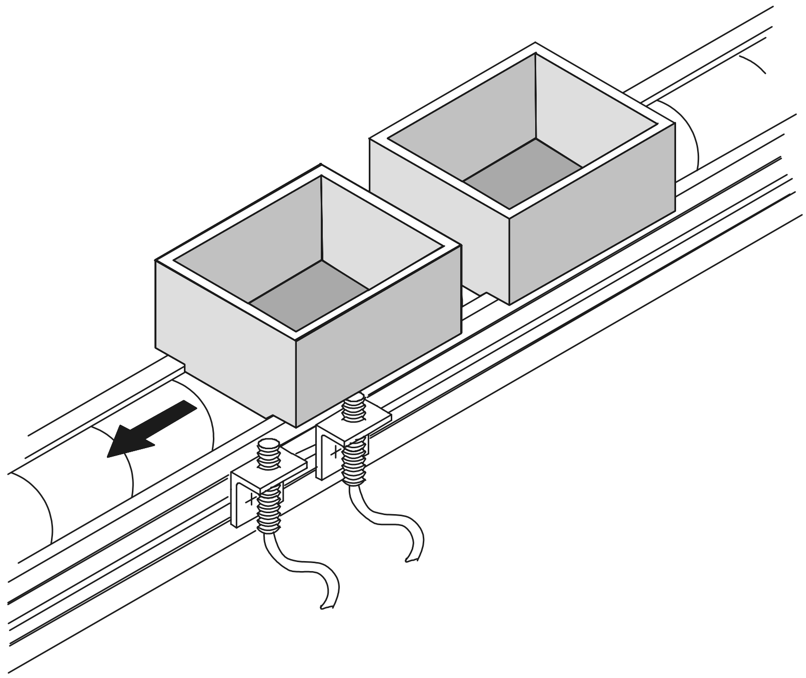
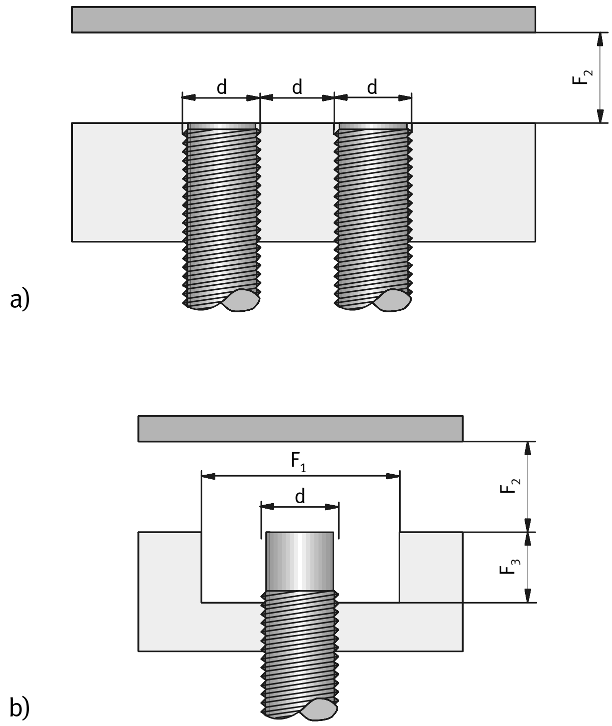


Fig. 16.3.1: Schematic assembly of transport device

With inductive proximity sensors the switching distance is dependent on the material to be detected. In this case, the nominal switching distance specified in the data sheets must be multiplied by the value 0.5 (reduction factor for aluminium). This results in a value which is only half as great as the nominal switching distance specified in the data sheet. Because the distance between the aluminium container and the proximity sensor can fluctuate, it is important to select a proximity sensor with a switching distance which is not too small. In addition, a greater nominal switching distance facilitates the adjustment of the proximity sensor on the transporting device.

In the case of specified built-in diameters, the greatest switching distance is achieved if a non-flush fitting type of proximity sensor is used. In this case, however, care must be taken to ensure that the active zone of the proximity sensor is free of metal.



a) Flush mounted
b) Non-flush mounted

Diameter of proximity sensor (d) Nomial switching distance (s_n)
Free zone 1 = 3 x s_n (F_1) Free zone 2 ≥ 3 x s_n (F_2) Free zone 3 ≥ 2 x s_n (F_3)

Fig. 16.3.2: Installation specifications for proximity sensors

Hysteresis is the term used to describe the difference between the switch-on point and the switch-off point of a proximity sensor. This is essential to guarantee the safe switching of the proximity sensor. Should the two switching points coincide, this would result in fluttering of the output signal when the object is passed in front of the proximity sensor precisely at the switching distance.

Exercise 4.2

Detection of vibrating steel cylinders

1. Movement of the steel cylinders may lead to several counting pulses being triggered off per steel cylinder if the reaction time of the control is less than the vibration period and if steps have not been taken to suppress the multiple pulses by means of software.
2. 1 % of 8 mm = 0.08 mm

16.4 Solutions to exercises from Chapter 5

Exercise 5.1

Filling level measurement in a grain silo
To detect the filling mounds of granular materials, material-specific characteristics must be taken into account. When the silo is filled, a mound of bulk material is created. The angle of settlement is a characteristic which depends on the material used. When being emptied a depression is created. These two characteristics must be taken into consideration when selecting the place of installation of the proximity sensor. If this is not done, it can lead to error measurements.

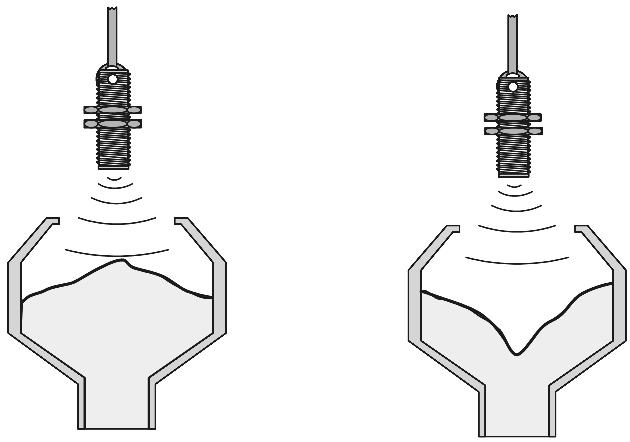


Fig. 16.4.1: Level sensing by detecting the filling mound and emptying depression in granular material

Furthermore, it should be noted that the switching distance to be attained with capacitive proximity sensors heavily depends on the water content of bulk materials. Damp bulk materials result in a greater switching distance than dry materials.

Exercise 5.2

Environmental effects on capacitive proximity sensors
A capacitive proximity sensor measures a change of capacitance in the active zone and evaluates this change. If humidity settles on the proximity sensor housing (dew, fog), this can lead to an error signal. Because water has a high dielectricity constant ($\varepsilon = 81$), small droplets of moisture are sufficient to interfere with the proximity sensor. Capacitive proximity sensors are available which can compensate the effects of humidity by means of an auxiliary electrode.

Exercise 5.3

Detection of cardboard boxes

Because the capacitance change caused by a thin cardboard box is relatively small, it may be that the capacitive sensor is unable to detect the boxes. In this instance, each individual case must be checked as to whether the proximity sensor responds to all objects which it is to detect. A change in sensitivity can usually be made by adjusting the potentiometer screw on the capacitive proximity sensor. Please take into consideration that the humidity content of cardboard may have an influence on the switching distance.

Exercise 5.4

Detection of a transparent panel

Capacitive proximity sensor

A capacitive proximity sensor reacts to capacitance changes. The capacitance change which is caused by 0.1 mm thick plastic film is insufficient to actuate the sensor. Wall thicknesses of more than 1 mm are generally required for materials made of plastic in order to actuate a capacitive proximity sensor.

Optical proximity sensor

A diffuse sensor is suitable for use as an optical solution. Sensitivity can be adjusted by means of the setting potentiometer in such a way that the diffuse sensor reacts to the plastic film and not to the inside of the packaging on the other side. The diffuse sensor must be aimed vertically at the reflecting transparent panel.

Ultrasonic proximity sensor

This solution requires a concentration of ultrasonic emission on to the transparent panel. A test is recommended without a transparent panel to check that the ultrasonic proximity sensor does not respond to the packaging itself. This may happen in the case of a large distance and proximity sensors with an ultrasonic cone which is opened too wide. In certain circumstances, the use of a sound absorbing aperture plate is required. This proximity sensor too must be directed vertically at the transparent panel.

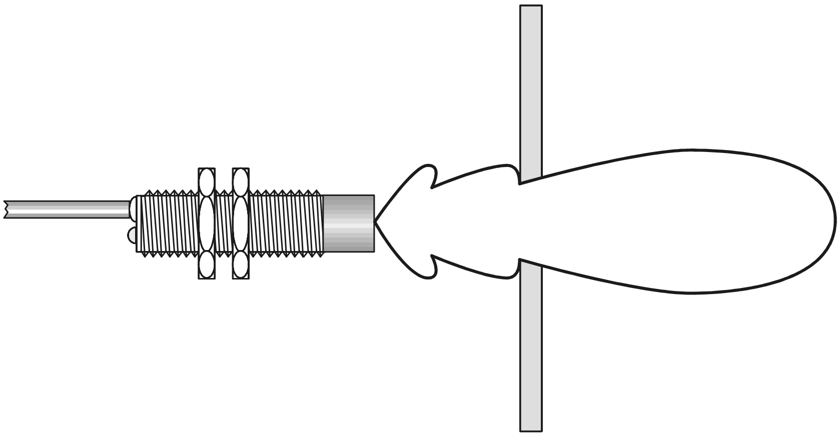


Fig. 16.4.2: Ultrasonic proximity sensor with a sound-absorbing shield (material: e.g. felt)

16.5 Solutions to exercises from Chapter 6

Exercise 6.1

Environmental effects on optical proximity sensors

In a dusty environment, it is to be expected that the lenses of optical proximity sensors and reflectors may become contaminated.

Example

By means of the following example using a retro-reflective sensor, you will discover how much the function of a optical proximity sensor depends on whether its lens and reflecting device are clean. Let us assume that the lens and the reflector are dimmed by deposits of dirt by 10 %. This is a value which is easily achieved. This level of pollution is barely detectable by visual means. Because the light beam of a retro-reflective sensor has to penetrate this contamination four times, the irradiated light is weakened from 100 % to approx. 66 %. Almost a third of the effective emission capacity is used up as a result of this slight contamination.

With optical systems, it is always important to ensure that the lenses and/or reflectors are clean. If required, additional measures must be taken to prevent rapid or high build-up of contamination (e.g. blowing by compressed air, installing a dust trap). The maximum contamination permissible depends on the capacity margin of the proximity sensor; see chapter 6.1 for further details.

Exercise 6.2

Selection of optical proximity sensors

If insufficient mounting space is available at the point where the proximity sensor is to be employed for object detection, optical proximity sensors with fibre-optic cables are particularly suitable. Because of the small dimensions of the sensor heads, fibre-optic cables can be used in inaccessible places.

The choice of fibre-optic cable material has to be made on the basis of environmental conditions. Whilst polymer fibre-optic cables generally can only be used in a temperature range of -25 – +70 °C, these values range between -20 – +200 °C for glass fibre-optic cables. Special designs are available for different temperature ranges. Resistance to chemicals also has to be taken into account when selecting fibre-optic cables.

An important advantage of this arrangement is that the actual proximity sensor with its electrical connections does not have to be installed near the point of detection and can be mounted outside possible danger areas.

Exercise 6.3

Operating reliability of optical proximity sensors

By means of modulating light emission, it is possible to improve the protection of optical proximity sensors against the influence of surrounding light. This means that their sensitivity to interference as a result of ambient light is reduced.

The light emitter pulses the emissions at a specified frequency actuated by a signal generator. The generator signal is transmitted to the logic module of the signal receiver. The signals are checked as to their compatibility and an output signal is generated only if this condition is met.

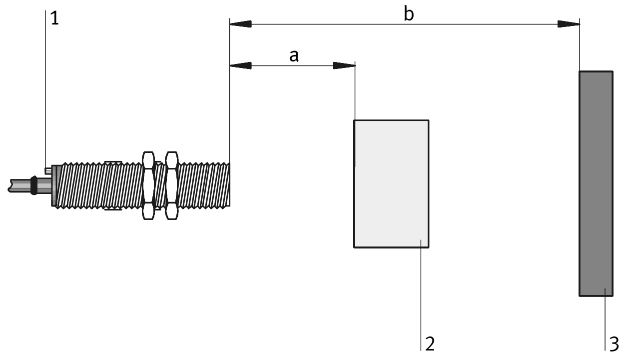
Another possibility is to suppress the ambient light by means of a bandpass, which only allows the emission frequency of the emitter to be passed.

In the case of optical proximity sensors operating in the infrared zone, additional daylight filters are installed. This further reduces the effects of the surrounding light.

Exercise 6.4

Detection of burnished steel

The response of this optical sensor is determined by the environment. The background or wall towards which it is directed, reflects sufficient light to trigger a response. Anodised aluminium, for instance, reflects very strongly. The reason why the sensor switches off is because burnished steel has a low degree of reflection.



Distance between proximity sensor and object (a)
Distance between proximity sensor and background (b)

Setting potentiometer (1) Object (2) Background (3)

Fig. 16.5.1: Background fade-out

To begin with, efforts should be made to adjust the diffuse sensor by means of a setting potentiometer so that it responds to the burnished steel part at distance "a" only and not to the background at distance "b". If this is not possible, then the background must be covered with less reflecting material.

Exercise 6.5

Electrical connection of proximity sensors

In the case of unregulated power supplies with filter, it is possible for voltage peaks to occur during switching on. These may be above the permissible operating voltage of the proximity sensor used and can lead to its failure.

A simultaneous "connecting to ground" of the normally open and normally closed contact can also lead to failure. To provide short-circuit protection, the output of the proximity sensor is pulsed. With simultaneous "connecting to ground" of the two inverted outputs, the short circuit is constantly cancelled on one output and created again on the other. This causes overloading and thus failure of the proximity sensor.

Exercise 6.6

Filling level measurement by means of optical proximity sensors

1. Through-beam sensors, retro-reflective sensors, through-beam sensors with fibre-optic cables.
2. yes

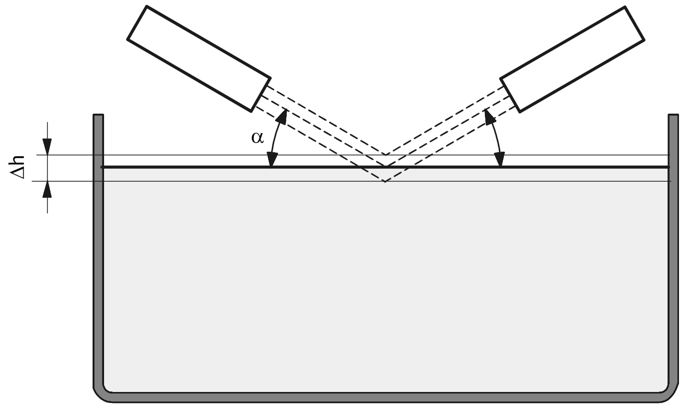


Fig. 16.5.2: Response accuracy

The proximity sensor responds when the height of the filling level is within a certain range. The width of the response range Δh is dependent on the diameter of the active surface "a" of the proximity sensor and on the angle α:

$$\Delta h = a \cdot \sin\alpha / \sin 2\alpha$$

With a = 1 mm (using a polymer fibre-optic cable) and an angle of α = 10° – 45°:

Δh = 0.5 – 0.7 mm

3. If the liquid in the container moves, for example, if foam is on the liquid or if the proximity sensors are splashed during filling.
4. Molten candle wax is prone to hardening on the outer edges, if the container is emptied quickly and heated from the base only. For this reason, filling level measurement cannot be carried out at the edge of the container. If set for the centre, this solution is suitable if it can be guaranteed that no unmelted remnants are floating in the melted wax.
5. Vertically onto the surface of the liquid or through the container wall (for example, with correspondingly thin container side made of plastic) by means of capacitive proximity sensors.
   By means of float switches, potentiometer sensors, hydrostatic pressure measurement at the base of the container, resting the container on load cells, microwave filling level sensors, vibration filling level sensors.

Exercise 6.7

Detection of workpieces

1. Yes, however the values specified in the data sheets regarding maximum range must be observed.
2. From above by means of retro-reflective sensors (using fibre-optic cables if space is restricted or if it is difficult to fade out the background).

Exercise 6.8

Use of optical proximity sensors in car washes

Through-beam sensor

Protection class IP 65 is sufficient (protection against penetration of dust and splashing water). Care must be taken that the lenses do not become dirty (blowing with compressed air, installing a dust trap). A minimum of two lines of light barriers is required, which are staggered so that the gantry does not touch the body of the car when moving back and forth.

Exercise 6.9

Use of optical proximity sensors with fibre-optic cables

This solution works. In this way, the response range can for example be increased from 10 – 60 mm, whereby it should be noted that white or reflecting objects cannot be detected reliably at a small distance via the fibre-optic cable. This solution is suitable for the detection of matt, dark (black) objects. Also, it should be noted that compared to operating without a reflector, the switch output (and the LED) of the proximity sensor is inverted compared to operating without a reflector.

Exercise 6.10

Checking of bottles

The nominal switching distance of an inductive proximity sensor is 8 mm (for steel S 235 JR). For aluminium, the switching distance is reduced to 4 mm. Due to variable height h, an inductive proximity sensor cannot be considered as a solution. The sealing caps can be detected by means of an optical diffuse sensor, whereby the sensitivity of the proximity sensor must be set in such a way that it does not react to the bottle necks. It is an essential requirement that the bottle positions on the conveyor belt always remain within the sensing range of the proximity sensor.

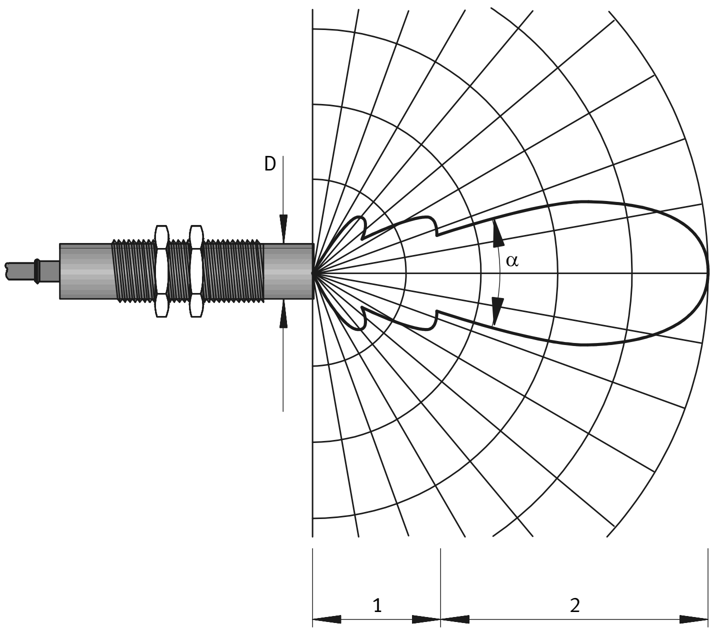
16.6 Solutions to exercises from Chapter 7

Exercise 7.1

Smallest measurable distance

Ultrasonic proximity sensors which have only one ultrasonic transducer, operate alternatively as an emitter and as a receiver. The ultrasonic transducer creates oscillations by means of a connected alternating voltage and emits ultrasonic waves. If the voltage is switched off, then the oscillation of the transducer dies out exponentially. The transducer must stop oscillating before a reflecting signal can be received. The final oscillation time is dependent on the size of the transducer. This does not occur with designs which have separate emitter and receiver transducers.

However, neither type of proximity sensor should be used to detect objects at small distances for another reason. Characteristically, the ultrasonic emission from these proximity sensors produces secondary lobes in the near field adjacent to the main emitting zone. If an object approaches laterally within the range of the near field, sensing becomes highly irregular so that no predictable response is possible.



Near field (~D^2/λ) (1) Far field (2)

Fig. 16.6.1: Sound emission characteristic of an ultrasonic proximity sensor

Exercise 7.2

Deflection of ultra-sonic sound waves

Because the same principle applies for ultrasonic waves as for light beams, i.e. the angle of incidence equals the angle of reflection, a deflection of ultrasonic waves by 90° is possible.

The reflector must be carefully adjusted. As deflection causes dissipation, multiple deflection should be avoided.

Exercise 7.3

Sensing of boxes on a conveyor belt

The device used (range 20 – 100 cm) is adjusted in such a way that it just fails to detect the base of an empty box. In this way, a signal is generated when a filled box passes. The signal is independent of the height of the box or the filling level. The presence of a box is signalled by means of a short signal as the sound cone passes through the side of the box.

16.7 Solutions to exercises from Chapter 8

Exercise 8.1

Range of air barrier sensors

The components to be detected have a width of 90 mm. From the characteristic curve of a Festo through-beam sensor SFL-100 can be seen that a signal pressure of 0.7 mbar is reached by applying a sender pressure of 20 kPa (0.2 bar) at a distance of 100 mm and 5 mm either side of the object). If the supply pressure is increased to 50 kPa (0.5 bar), a signal pressure of nearly 0.3 kPa (3 mbar) is attained under otherwise identical conditions. This output signal can be amplified with the help of suitable pressure amplifiers. An air barrier is suitable for detection of the parts.

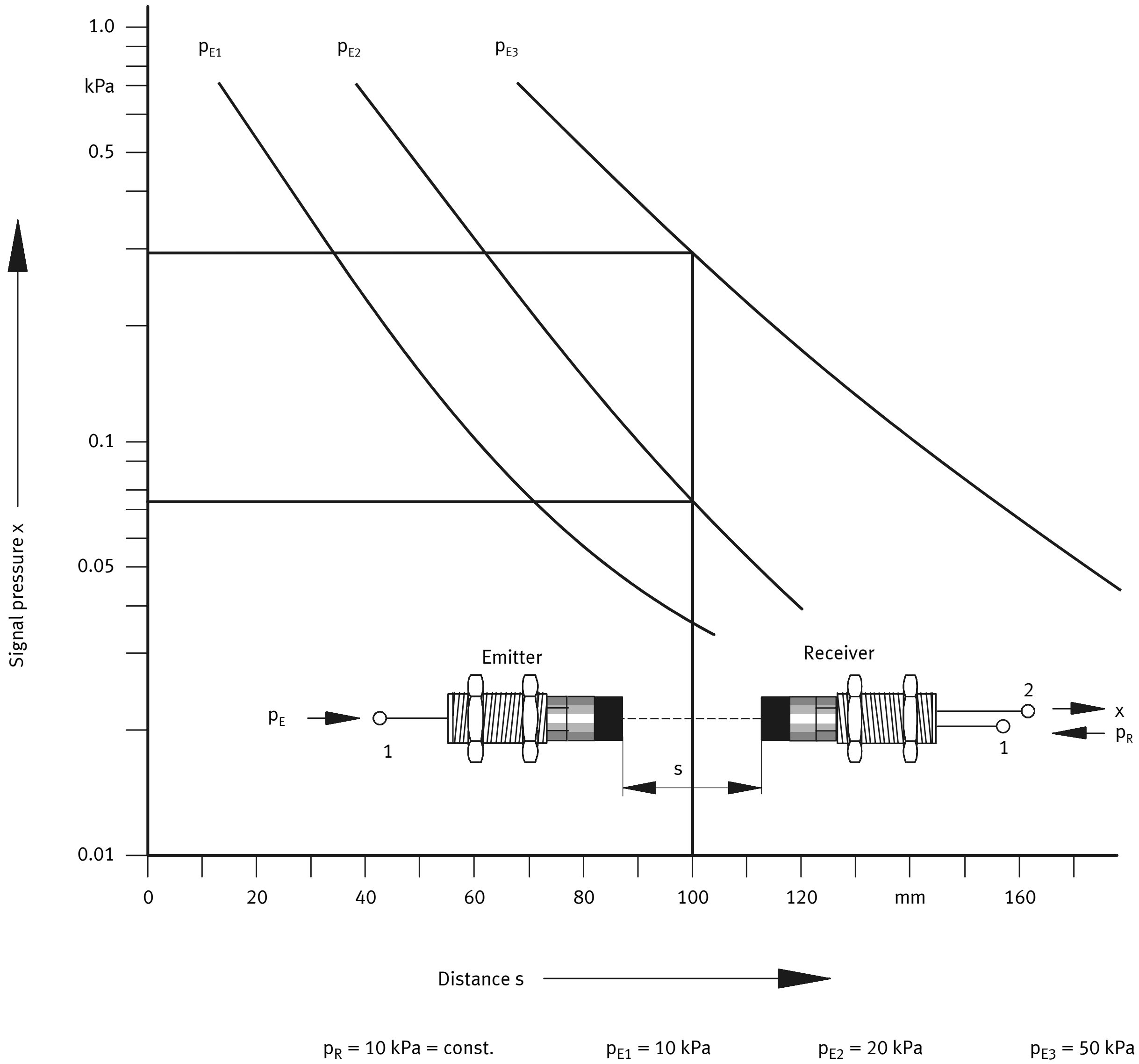


Fig. 16.7.1: Characteristic curves of the Festo SFL-100 air barrier

Exercise 8.2

Checking lids by means of a reflex sensor
The characteristic curve of a reflex sensor specifies values which apply at a supply pressure of 15 kPa (150 mbar). One possible value for the distance between sensor and lid is between 2 – 4 mm. At this distance, a signal pressure of 0,3 – 0,4 kPa (3 – 4 mbar) is produced. This output signal can be amplified with the help of suitable pressure amplifiers.

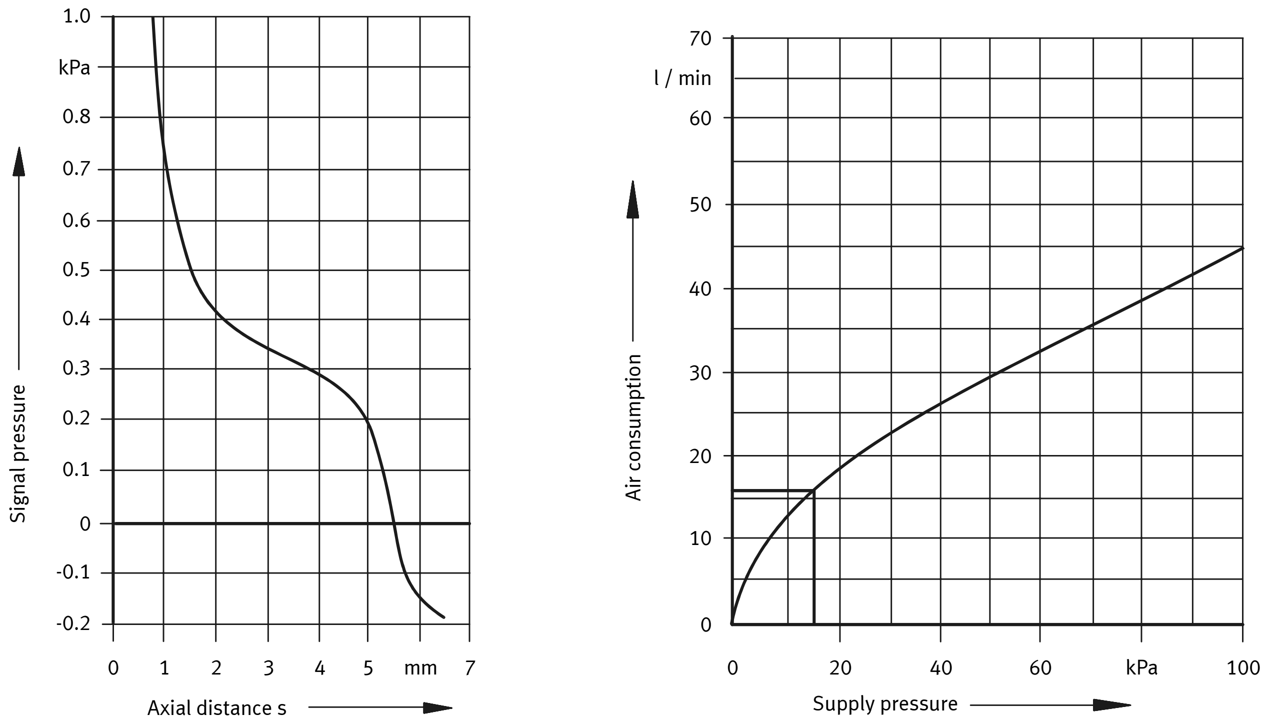


Fig. 16.7.2: Characteristic curves of the Festo RML-5 reflex sensor

At a pressure of 15 kPa (150 mbar), the air consumption of this sensor is approximately 16 l/min if exhausted directly to atmosphere.

17. Bibliography of illustrations

Fig. 4.4.3	Sensing of a cam switching mechanism by means of inductive proximity sensors excerpt from: "Sensor technology", Hans Turck GmbH & Co KG, Mülheim an der Ruhr, catalogue, 1st edition, 1989
Fig. 4.4.4	Measurement of speed and direction of rotation excerpt from: "Sensor technology", Hans Turck GmbH & Co KG, Mülheim an der Ruhr, catalogue, 1st edition, 1989
Fig. 5.4.5	Checking the presence of bulbs inside cardboard boxes excerpt from: "Sensor technology", Hans Turck GmbH & Co KG, Mülheim an der Ruhr, catalogue, 1st edition, 1989
Fig 11.3.3	The piezoelectric effect excerpt from: "Piezoxide (PXE) Characteristics and applications", Philips Components, Hamburg, by Hüthig Verlag, Heidelberg, 1st edition, 1988
Fig. 11.4.11	Illustrations of fibre-optic cables excerpt from: "Fibre-optic components by Schott", Schott Glaswerke, Wiesbaden, catalogue, 1990
Fig. 15.1.5	Design example: Self monitoring inductive sensor system excerpt from: "Product range catalogue", ifm electronic GmbH, Essen, catalogue, 1990
Fig. 15.1.6	Block diagram of a function monitoring system excerpt from: "Product range catalogue", ifm electronic GmbH, Essen, catalogue, 1990
Fig. 15.1.7	Connection of a function monitoring system, example of 2 sensors excerpt from: "Product range catalogue", ifm electronic GmbH, Essen, catalogue, 1990
Fig. 15.1.11	Proximity sensor to check for broken drills excerpt from: "Program overview", Euchner & Co., Leinfelden, catalogue, 1989
Fig. 15.14	No object present in the lightbeam excerpt from: "Light barriers", Erwin Sick GmbH, Freiburg, catalogue, 1989

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