
# Technical Notes

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CONTRINEX

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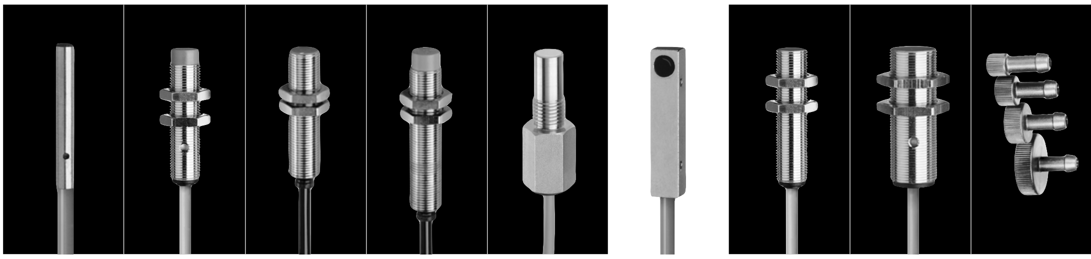

## Table of Contents

## Inductive Proximity Switches with Large Operating Ranges: The Technology, Characteristics and Application Advantages

### Development History of Inductive Proximity Switches

The inductive proximity switches' time came at the beginning of the 1960's. Due to their reliability, high quality to price ratio and ease of installation they have conquered a wide range of applications. Despite many technical improvements, one of the substantial and long standing drawbacks of these devices was the poor ratio of construction size to switching distance. In 1982, however, a two- to threefold increase in the switching distance was achieved using a new oscillator concept for devices using the inductive principle of operation. Since then they have proved themselves effective in many applications. In the following paragraphs we will take a closer look at the essential characteristics and applications of these devices.

### Technology

To attain higher switching distances, the Condist® oscillator was developed. Inductive proximity switches fitted with this oscillator work on the same physical principles as customary market designs: a high frequency electromagnetic field is induced in the region over the sensor surface by a resonance coil. Conductive materials within the area of this magnetic field induce an eddy current loss which consequently changes the operation of the oscillator. The subsequent evaluation electronics measures and calculates this change. Since these fundamental operating principles have not changed the application characteristics of the Condist® oscillator also remain unchanged. The only real distinction is the enlargement of the switching distance, which is made possible by a much better temperature stability of the oscillators.

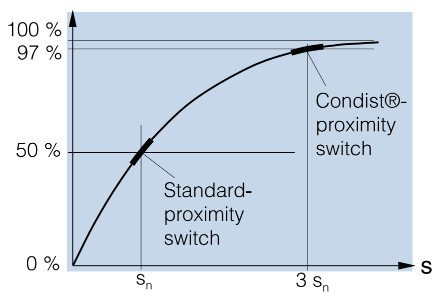


Fig. 1

Fig. 1 shows the correlation between the resonance attenuation and the measuring plate distance from the resonance coil. Devices fitted with the Condist® oscillator show an identical relationship to standard oscillators, except that the switching point is moved to the right in the direction of larger switching distances. Due to the unique stability of these oscillators, this is possible without any otherwise expected degradation of the other proximity switch characteristics.

### Characteristics

The following information shows the important differences for the user between standard proximity switches and those fitted with a Condist® oscillator.

Table 1: Switching Distance

| Size | Condist® | Standard |
|---|---|---|
| **M8** flush mounted | **3 mm** | 1 mm |
| **M8** not flush mounted | **6 mm** | 2 mm |
| **M12** flush mounted | **6 mm** | 2 mm |
| **M12** not flush mounted | **10 mm** | 4 mm |
| **M18** flush mounted | **12 mm** | 5 mm |
| **M18** not flush mounted | **20 mm** | 8 mm |
| **M30** flush mounted | **22 mm** | 10 mm |
| **M30** not flush mounted | **40 mm** | 15 mm |

Table 2: Switching Frequency

| Size | Condist® | Standard |
|---|---|---|
| **M8** flush mounted | **1000 Hz** | 1000 Hz |
| **M8** not flush mounted | **500 Hz** | 500 Hz |
| **M12** flush mounted | **800 Hz** | 800 Hz |
| **M12** not flush mounted | **400 Hz** | 400 Hz |
| **M18** flush mounted | **200 Hz** | 500 Hz |
| **M18** not flush mounted | **200 Hz** | 200 Hz |
| **M30** flush mounted | **150 Hz** | 300 Hz |
| **M30** not flush mounted | **100 Hz** | 100 Hz |

'Flush' mounted devices with large switching distances should not, in fact, be absolutely flush (quasi-flush). That is, in unfavourable cases, the switch should project out by a distance X (as shown in fig. 2). The distance 'X' is dependent on the switch size and is variable within the range of 0.05 to 0.2 times the casing diameter.

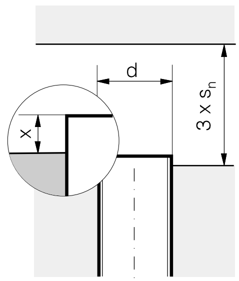


Fig. 2

All of the remaining characteristics also correspond in principle, but in particular:

- Operating voltage and output current
- Current consumption
- Temperature range
- Protection circuit, EMC characteristics
- Resistance to the environment

### Most Useful Applications

The following useful examples have been taken from concrete practical instances, in which the greater switching distance of devices fitted with Condist® oscillators is shown to best advantage.

**Case 1: Requirements for a switching distance of ≥ 10 mm and an outside diameter of ≤ 20 mm**

Further stipulations: quasi-flush and normally dimensioned installation.

The normal device needed for the measurement distance of $s_n \geq 10$ mm requires a switch size of M30, which is far too large.

The next smallest size of standard devices is an M18 which has an insufficient switching distance of 5 mm. The device with the largest switching distance within

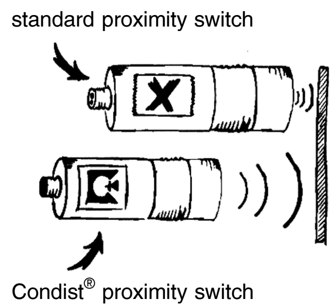


Fig. 3

the size M18 is $s_n$ = 12 mm. The requirement is therefore, easily fulfilled.

**Case 2: Dependence of switching distances on gearwheel teeth size**

The effective working surface, B (see fig. 4) is much smaller than that of a standard measuring plate, A (as specified in any catalogue). However, with a much less effective measuring surface, the switching

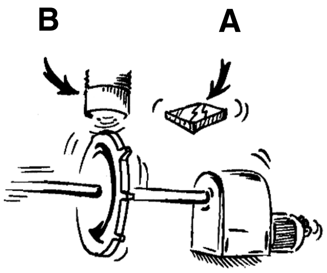


Fig. 4

distance becomes very much reduced. For example in fig. 4, a distance of 2 mm (catalogue value) might be reduced to, say, 0.5 mm (dependent on the cross-sectional size of the gearwheel teeth). The resulting switching distance in these cases is often too small and in the practical installation there is always the danger of mechanical damage to the switching device due to contact with the gearwheel teeth - especially where a lot of adjustment work is required. The installation of a device with a large switching distance gives, in this example, a switching distance of 1.5 mm, which solves the problem.

**Case 3: Detection of electrical cables**

The detection of cables with standard inductive devices is, as a rule, not possible. Firstly, the cable isolation prevents the

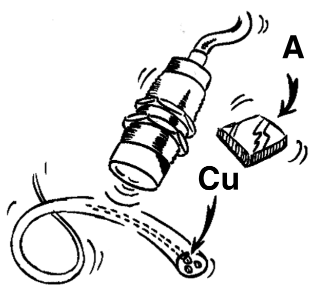


Fig. 5

are very good. A non-flush mounted, installable M30 device is recommended here.

**Case 4: Adjustment of proximity switches on running machinery**

Often the fine adjustment of the switches cannot be accomplished statically (for example with a moving object) and must be achieved while the machine is at operating speed. A small error from the personnel installing the device for the first time can lead to damage to the equipment and in addition can also lead to accidents to personnel. Here, the installation of devices with a large switching distance is an obvious advantage - and the risks of a collision with a moving objects are minimized.

**Case 5: Field maintenance**

While it is good practice to use trained production personnel for the installation and adjustment of switches, maintenance at the user' facility should not require such high standards. Defective standard proximity switches can be replaced using unskilled personnel since the need for high precision installation is not now so important.

**Case 6: Replacement of original proximity switches**

During the initial setting up of an installation, the proximity switches chosen often only just fulfill the requirements of the situation - usually due to cost considerations - which can increase the risk of mechanical damage to the equipment. However, replacement of initially installed switches by switches with a large switching distance, in particular in well-known trouble areas, can improve this situation and reduce costly machine downtime.

**Case 7: Detection of thin wires**

The use of inductive proximity switches for the detection of thin wires is in general difficult due to the small effective surface, and is in reality often impossible. Here, photoelectric devices are much better (laser photoelectric barrier devices or solutions with optical fibers). This solution does involve increased costs, and moreover, installation in polluted environments requires special precautions and skill. In many cases proximity switches with a large switching distance offer an interesting alternative. Non-flush, M30 sized devices are the best suited. Copper wires of diameter 0.5 mm can be, for example, recognized at a distance of 6 mm, whereas with standard devices this recognition is impossible.

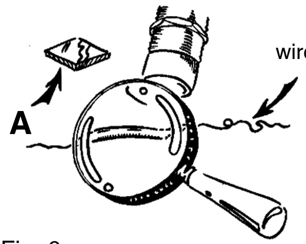


Fig. 6

**Case 8: Application of protection covers**

Additional protection for these devices, such as covers and top caps, is possible for use in hostile environments or as protection against mechanical damage. However, an undesirable reduction in the useable switching distance will be incurred by using this protection. Devices with a large switching distance in this case still maintain an acceptable result.

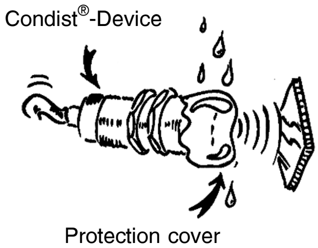


Fig. 7

**Case 9: Sheet metal processing**

Processed and unprocessed sheet metals require larger mechanical tolerances than other metal parts. This leads to, for example, the problem of presence detection. If the switch is installed near to the moving part of sheet metal for reliable switching, the danger always exists of mechanical damage to the switch. If it is installed at a safe distance, the recognition is unreliable which impedes the production run or procedure. Inductive devices with large switching distances by their very nature provide a great advantage.

**Case 10: Conveyor-belt systems**

On one hand, conveyor-belt systems are characterized by the large number of switches required for the control system. On the other hand, the installation of the switches is problematic due to the fact that the chains, conveyor belts and accessories have a considerable amount of mechanical play. Inductive proximity switches using standard switching distances are often unsuitable in these circumstances since the required switching distances demand large diameter proximity switches, which is often in conflict with the available space. Photoelectric devices would do the job, but they are not liked by the operators because there is always a dirty, polluted environment around the conveyors requiring periodic cleaning. Inductive devices with a large switching distance enable an easy, cost-effective and sure solution.

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Dipl. Ing. Peter Heimlicher studied electronics at the ETH in Zurich. In 1972, immediately after his studies, he founded CONTRINEX AG, of which he has been managing director ever since. His company is specialized in the manufacture of high-performance inductive and photoelectric proximity switches.

# Inductive Proximity Switches as Encoders

## Why Inductive?

Inductive proximity switches are enormously popular with end-users. They are

- robust
- good value for money
- insensitive to dirt
- standardized

and, as a result, simple to install.

## Inductive Proximity Switches as Encoders

Today, encoders are mature products, and are available in a variety of designs. However, compared to inductive proximity switches, they are significantly more expensive. In addition, they have rotating axes, and consequently require a certain care during assembly. Finally, encoders are often far too efficient for the requirements of the job to be done.

Substituting the encoder with an inductive proximity switch, which detects already present mechanical parts, such as a gear wheel, is a frequently used alternative. Where no suitable gear wheel is available, an additional one (or any suitably fabricated toothed disk) can be specially added. If need be, extra holes can be drilled in a co-rotating part, or a shaft with milled-on grooves, or equipped with spigots, can be used. In this way, a cheap, simple, and reliable substitute encoder is obtained. However, in practice, this solution often leads to difficulties, and the performance obtained is disappointing. This may be overcome by following the tips for optimum assembly given below.

## Design for Optimum Resolution and Switching Frequency

It should be stated at the outset that the values obtained from encoders with respect to resolution and switching frequency cannot be matched by a long way. However, the obtainable results are greatly influenced by the correct choices of proximity switch and gear wheel, which therefore require great attention.

The test method for the switching frequency of inductive proximity switches according to IEC 60947-5-2/EN 60947-5-2 (Fig.1) gives a good clue to achieving optimum results. In effect, this method, characterized by a tooth/gap mechanical ratio of 1:2, and an operating distance **s** set to half the nominal operating distance **$s_n$**, corresponds approximately to the optimum conditions with respect to resolution and switching frequency.

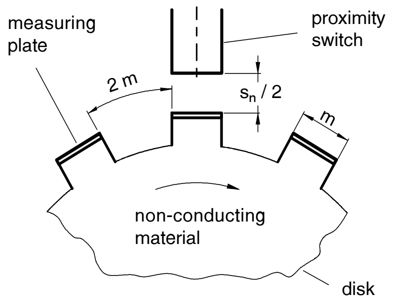


Fig. 1

## Choice of Proximity Switch

On physical grounds, the maximum switching frequency of an inductive proximity switch is approximately inversely proportional to its outside diameter. The smallest possible diameter proximity switch is therefore the most suitable for achieving high switching frequency. However, particularly when dimensions are small, the physically possible upper limit is not fully utilized, because the manufacturers analyzing circuit has not been optimized for the switching frequency. This is even more the case since the CE mark has been required: switching frequency and EMC resistance are opposite quantities. There are considerable differences from manufacturer to manufacturer, which should be taken into account. The best results (close to the physical limits) are obtained with NAMUR proximity switches (DIN/EN 19234), as long as they are built-in discretely (no IC). Here also, appropriate clarification from the manufacturer is worthwhile.

The above is naturally also valid for the resolution: the smaller the proximity switch, the better. Nevertheless, there are differences here also. Variant 1 (Fig.2), with the ferrite core recessed with respect to the housing, gives better resolution than variant 2 (Fig.3), as a result of better field bundling. However, for the manufacturer, variant 2 is simpler, since

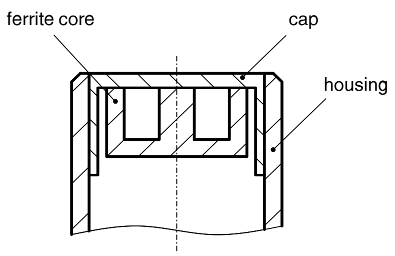


Fig. 2

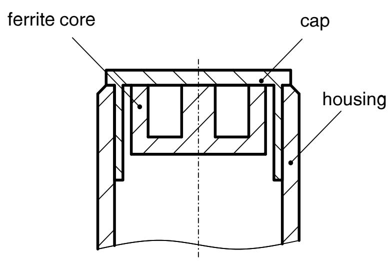


Fig. 3

the pre-damping through the housing is lower, and consequently the operating distance temperature stability requirements are easier to maintain. Whether the instrument is of the type variant 1 or variant 2 can easily be determined visually, but, as a rule, not from the information given in the catalog.

| Size | Module M (1) | Module M (2) |
|---|---|---|
| Ø 3 | 1.5 | 1.25 |
| M4 | 1.5 | 1.25 |
| D4 | 3 | 2 |
| M5 | 3 | 2 |
| D6,5 | 4 | 3 |
| M8 | 4 | 3 |

(1) safe
(2) under favorable conditions

Table 1

| Size | D1 | B |
|---|---|---|
| Ø 3 | 3 | 1.5 |
| M4 | 3 | 1.5 |
| D4 | 4.5 | 2 |
| M5 | 4.5 | 2 |
| D6,5 | 7 | 3.5 |
| M8 | 7 | 3.5 |

D1 hole diameter
B inter-hole spacing

Table 2

## Dimensioning the Gear Wheel or Perforated Disk

The geometry of a standard gear wheel (Fig.4) closely approaches the ideal form (see above under switching frequency). The fact that the tooth flanks are not at right angles to the tooth surfaces makes no significant difference. However, the size of the proximity switch must be properly suited to the gear wheel module (table 1). For a perforated disk (Fig.5), the recommendations given in table 2 are applicable. Better results can be obtained with elongated holes (longitudinal axis) (Fig.6). Other geometric variations must be optimized by trials.

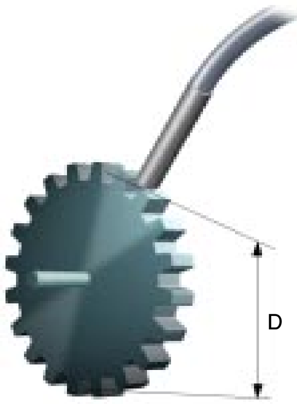

Fig. 4

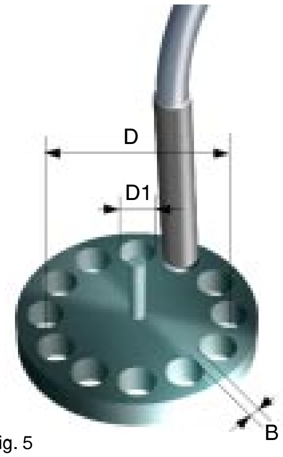

Fig. 5

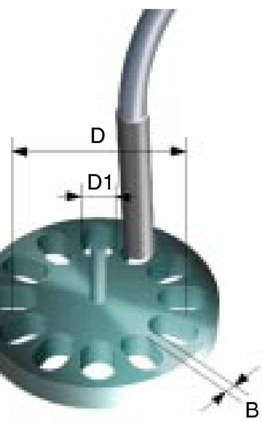

Fig. 6

## Optimum Operating Distance

The optimum operating distance for the "safe solution", according to table 1, is 0.5 x $s_n$. For an "acceptable solution under favorable conditions", it is approximately 0.6 x $s_n$, but during assembly it must be individually adjusted by means of a signal check, using an oscillograph.

Contrary to the recommendations, shorter operating distances lead to lower switching frequencies, lower resolutions, but better operating security. Longer operating distances give lower operating frequencies, higher resolutions, and lower operating security. It should be pointed out here that poor results are often caused by operating distances being too short.

## Maximum Rotational Speed

By adhering to the preceding instructions, it can be assumed that the manufacturer's stated maximum switching frequency will be reached. The following is therefore valid for the maximum rotational speed

$$N = \frac{60 * f_{max}}{Z} \quad \text{[rpm]} \quad (1)$$

or with Z teeth, or holes

$$Z = \frac{D}{M} \quad (2)$$

for the gear wheel, or

$$Z = \frac{\pi * D}{D1 + B} \quad (3)$$

for the perforated disk. At maximum rotational speed N

$$N = \frac{60 * f_{max} * M}{D} \quad \text{[rpm]} \quad (4)$$

for the gear wheel, or

$$N = \frac{60 * f_{max} * (D1 + B)}{\pi * D} \quad \text{[rpm]} \quad (5)$$

for the perforated disk, where

- N = maximum rotational speed
- Z = number of teeth or holes
- $f_{max}$ = maximum switching frequency of the proximity switch
- D = gear wheel or perforated disk diameter (pitch circle)
- M = gear wheel module
- D1 = hole diameter
- B = inter-hole spacing

## Resolution

In the case of a gear wheel, the maximum resolution **A** is fixed by the module, and is calculated by

$$A = \frac{360 * M}{D} \quad \text{[degrees]} \quad (6)$$

for the gear wheel. For a perforated disk, it is

$$A = \frac{360 * (D1 + B)}{\pi * D} \quad \text{[degrees]} \quad (7)$$

## Practical Examples

### Example 1

Given a gear wheel of maximum outside diameter 30mm, find the best possible resolution.

The smallest possible module for the "safe solution" (table 1) is M = 1.5, giving a corresponding proximity switch size of D3 / M4. According to (6), the resolution is

$$A = \frac{360 * 1.5}{30} \quad \text{[degrees]}$$

resulting in

$$\mathbf{A = 18^0}$$

The maximum switching frequency of the chosen 3-wire proximity switch is 5 kHz. The maximum rotational speed according to (4) is therefore

$$N = \frac{60 * f_{max} * M}{D} \quad \text{[rpm]}$$

giving the result

$$\mathbf{N_{max} = 15'000 \text{ rpm}}$$

### Example 2

Given a perforated disk with a pitch circle diameter of 100mm, find the best resolution that can be obtained with a maximum rotational speed of 3000 rpm, together with the most suitable proximity switch.

According to (7), the resolution will be

$$A = \frac{360 * (D1 + B)}{\pi * D} \quad \text{[degrees]}$$

In principle, the best resolution can be obtained with the smallest device, i.e. sizes D3 / M4. The corresponding values are:

D1 = 3
B = 1.5

From this

$$A = \frac{360 * (3 + 1.5)}{\pi * 100} \quad \text{[degrees]}$$

with the result

$$\mathbf{A = 5.2^o}$$

The switching frequency at 3000 rpm is calculated by reformulating (5) to

$$f_{max} = \frac{\pi * D * N}{60 * (D1 + B)} \quad \text{[Hz]}$$

i.e.

$$f_{max} = \frac{\pi * 100 * 3000}{60 * (3 + 1.5)} \quad \text{[Hz]}$$

resulting in

$$\mathbf{f_{max} = 3490 \text{ Hz}}$$

The maximum switching frequency of 5 kHz for the Ø 3 / M4 device will therefore be respected.

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# Miniaturization - The Inductive Proximity Switch Trend

## Why miniaturize?

The ideal detector should be as precise as you want and infinitely fast, but close to zero in price and size. We will show in the following text first of all what it is possible to achieve today regarding size. Due to the ever-increasing intensive use of high-performance electronic machine controls, a larger concentration of sensors can be observed. This should not, if possible, oblige the machine manufacturer to modify the mechanics just to provide space for detectors, it would be in fact illogical that the use of detectors makes the mechanics bulkier, therefore more expensive and even possibly less effective. This automatically results in the requirement for smaller and smaller detectors. This particularly concerns the proximity detectors used in large quantities, which we will deal with in the following text.

## Size reduction

The desired reduction concerns two aspects:

– In addition to the sizes described in the standard IEC 60947-5-2 for cylindrical proximity switches (Ø4, M8, M12, M18 and M30), smaller sizes must be introduced, e.g. M4 and Ø3.
– In addition to the existing sizes in accordance with the aforementioned standard, the operating distance, which as we know is proportional to the diameter, must be enlarged. In this way, for a required operating distance we can use smaller devices. In the following text we will deal with the smaller construction; the enlargement of the operating distance will form the theme of a later publication.

## Requirements

The miniaturization of an existing construction does not seem at first to be a particularly spectacular task. However, this is not the case for a whole series of reasons. One must first of all make sure that the user can install the miniaturized product without difficulty. He often wants to directly replace an existing device with a smaller one. This means that the latest device must display the same electrical characteristics as the larger device, in particular it must have the currently indispensable protection circuits (protection against short-circuits, polarity reversal protection, over-voltage protection, electromagnetic compatibility, etc.). Secondly, the user is generally unwilling to give up the comfort to which he has become accustomed in favor of miniaturization. The LED must be present. A high resistance to unfavorable environmental conditions is inevitable, the degree of protection IP 67 is required. The N.O and N.C. contacts, PNP, NPN and NAMUR configurations must be found in the offer. Highly flexible oil-resistant cables, as well as connector types, are required. Not only that, the devices must have a strong construction. This requires relatively thicker case walls. Further, the use of popular hybrid circuits on ceramic substrate is not recommended because of the increased risk of breakage due to the less favorable ratio between length and width. Miniaturization by reduction of the number of components is reducing the performances and is therefore a path which can not be followed. We still need to consider the economic aspect. The user is certainly ready to pay a little more for a smaller product; but if the large scale use of miniaturized devices is to be possible, these additional costs must be kept within certain limits. The use of expensive components and manufacturing processes is therefore immediately prohibited. On top of all this, despite the additional manufacturing difficulties, the reject rate must stay under control. Taking these explanations into consideration, we notice a miniaturization that takes the particular conditions mentioned into account is a demanding task.

## Technique used

First of all, the circuit in question must be carefully analyzed. Solutions based only on discrete components are eliminated because of lack of space. As many functions as possible must be assured by an appropriate integrated circuit. A large number exist on the market, all of which nevertheless present more or less pronounced inconveniences. Experience shows that there is no hope of passing even one of these disadvantages on to the user in the form of restrictions. They must be eliminated by suitable additional discrete components. The use of ASICs (Application-Specific Integrated Circuit) is most often prevented by the large dimensions of the chip. An entirely specific integrated circuit could eventually be considered, but it can also only eliminate some of the discrete components.

## Components

In a second stage, we must look for an appropriate outline of the components. We consider the smallest components available that can still be manipulated by SMD placers (table 1). The ferrite core presents a particular problem. Given that ordinary commercial cores are not suitable or even not available, we must take the more expensive option of a custom construction.

**Table 1**

*Resistors:*

Chip resistors 0402 (1.0 x 0.5 mm)
Micromelfs (2.0 x 1.0 mm)

*Capacitors:*

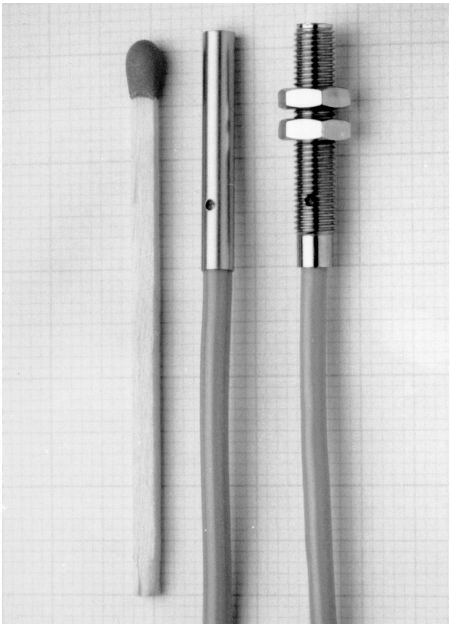
Ceramic capacitors 0402 (1.0 x 0.5 mm), 0504 (1.25 x 1.0 mm), 0603 (1.5 x 075 mm)

*Semiconductors:*

Diode chips (0.4 x 0.4 mm)
Zener diode chips (0.5 x 0.5 mm)
LED chips (0.4 x 0.4 mm)
Transistor chips (0.5 x 0.5 mm)
Integrated circuits as dies

## Substrate

We must start by choosing a substrate, taking the assembly technique into consideration. Thin film substrates provide the highest density, but are abandoned for cost reasons. Thick film substrates could be used in principle; their inconvenience is a limited density (width and distance between the conductors, resistor surface required) and the high sensitivity to breakage of the ceramic. Epoxy substrates have shown themselves to be very appropriate. They unite high density, low costs, a low sensitivity to breakage and the possibility of embedded component mounting (important for the integrated circuit). The resistors cannot be printed as for hybrid thick film substrates; but this no longer plays an important role, with very cost effective SMD resistors available today and reduced assembly costs. An example of such a substrate is shown in figure 1; the dimensions are 17 x 2.5 mm. It is the mounting technique which is critical. For passive components (resistors and capacitors), SMD is unavoidable. Despite this, there is still an important obstacle to overcome from the everyday SMD constructions to a substrate for miniaturized proximity switches. A considerable investment to acquire the additional know-how cannot be avoided.



## Assembly Technique

In order to mount very small SMD components with very close spacing (0.4 mm between components) on soldering surfaces surrounded very closely (0.1 mm) by conductors, the assembly technique must be perfectly mastered. First, the choice of soldering paste is important; because the best resolution and precision of the silkscreen printing must be achieved. The smallest impurity leads to problems, in particular if we must afterwards paste onto the same substrate (Chip-on-Board). Then, a suitable SMD placer must be chosen for the component placement. High speed operation is less important than to assure the precision and the manipulation of very small components. To achieve the best results, the machine must be used exclusively for the type of substrate for which it was originally set. It is unnecessary to emphasize that the soldering that follows is critical.

## Chip-on-Board

Chip-on-Board technology is generally applied for semiconductors. Attention should be given here to the question of cost. The design rules for the substrate are critical; they influence notably the costs and the manufacturing wastage. The choice and the specifications of semi-conductors are also important: the layout and size of the bonding pads, type of metalization front and back, die thickness and packaging (loose, Waffle pack, Blue Film). The bonding procedure must be chosen with care; it's a matter of Goldball (thermo-compression) and Aluminium-Wedge. The shape of the loops and the angle of the bonding head respectively must be defined in a way as to avoid excessive height. If necessary, the chips will be mounted embedded. A separate chapter is devoted to the encapsulation of pasted semiconductors, which

**Table 2**

### Technical characteristics:

(In accordance with IEC 60947-5-2)

| | |
|---|---|
| Sensing range | 0.6 mm ± 10 % |
| Hysteresis | 5 % typ. |
| Polarity | PNP, NPN, NAMUR |
| Contact | N.O., N.C. |
| Voltage range | 10 ... 30 VDC |
| Ripple content | 20 % max. |
| Output current | 100 mA max. |
| Output voltage drop | 2.0 V max. at 100mA |
| Current consumption | 10 mA max. |
| Switching frequency | 5000 Hz max. |
| Operating temperature range | -25 … +70 °C |
| Temperature drift | ± 10 % max. |
| LED | Built-in |
| Voltage reversal | Built-in |
| Power-on reset | Built-in |
| Protection degree | IP 67 |
| EMC - protection: | |
| IEC 60255-5 | 1 kV |
| IEC 61000-4-2 | Level 2 |
| IEC 61000-4-3 | Level 3 |
| IEC 61000-4-4 | Level 2 |

has a substantial influence on the reliability of the assembly.

## Coil

A difficult phase is still the fixation of the ferrite core and the coil, as well as the soldering of the coil wires. Here, it is practically impossible to automate. It is necessary to have an ergonomic workplace and qualified personnel who are well trained and benefit from excellent vision, a steady hand and nerves of steel.

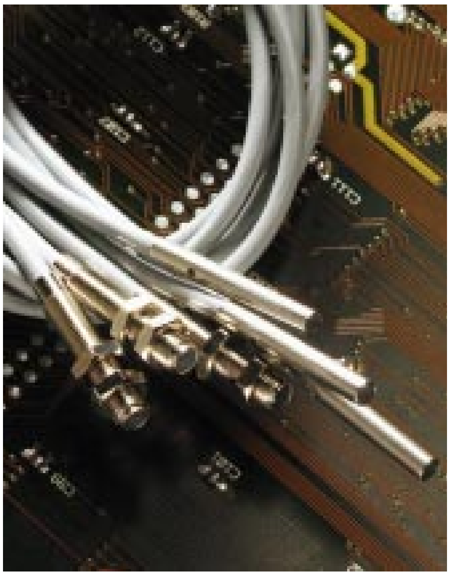
## Potting

The potting of the proximity switches is an always necessary, but not much appreciated operation. It is not any different for miniature devices. In addition, the work must be carried out with great precision and cleanliness. For a good reliability in difficult operational conditions, it is essential to do the potting in a vacuum in order to avoid air bubbles being trapped. This is a condition essential for the desired long-term reliability (formation of micro-climates, corrosion).

## Quality

The production of miniature detectors can only be mastered by the perfect enforcement of a consistent test philosophy. Already at the time of substrate design and the choice of components, the testing aspects must be considered, even if it is a matter of apparently simple elements. In the production, the principle: one operation - one test - next operation - next test, etc., must be absolutely respected. To this effect, complex methods are needed, since due to the small dimensions of the product, current test systems available on the market cannot be used. Everything must be designed and built by the manufacturer himself. To achieve a reduced reject rate, the test must, if possible, immediately follow the operation, in order to intervene as soon as possible. Repairs are often not possible because of the tight construction. The quality control of miniature devices operates on the same principle as for larger devices. To reach the best possible reliability, the devices are additionally subjected to thermal cycling (5 cycles from -25 °C to +80 °C and back again). Furthermore, the functions are also verified at the temperature extremes.

## Results



The smallest complete proximity switches in series production today have an outer diameter of 3 mm or a fine M4 thread and a body length of 22 mm (figure 2). These devices are produced in accordance with the principles set out, and they are indistinguishable from larger types by their performance, apart from their size and operating distance (table 2). A glance at the substrate used is offered by figure 2; the dimensions are 2.5 x 17 mm. These devices have been on the market for a number of years already and are in use in a considerable quantities. Experience until now shows that their use is entirely problem free and they open up new possibilities for manufacturers in cases where space is critical. Over and above their small size, advantage can be taken of some of the following properties: better reproducibility, better resolution (e.g. for scanning toothed wheels with modules going down to 1.5 and coding disks), lightweight and high switching frequency (5 kHz and over).

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# Photoelectric Proximity Switches in Sub-miniature Technology

## Trend, requirements

For some time now there has been a marked trend towards smaller constructions of sensors. This is due to the increased demand for the automation of production processes, resulting in:

- a higher degree of automation;
- continuously controlled production quality at all production stages;
- low reject rate.

The purpose underlining these demands is mainly to improve the quality during manufacture and to reduce manufacturing costs.

With regard to the sensor technology it means that, with basically unchanged criteria (e.g. machines, installations etc.):

- more and more sensors are installed and there is less and less space available for the installation of these sensors;
- sensors also have to be installed in almost inaccessible places;
- the demands for resistance against environmental influences (chemical, EMC etc.) are steadily increasing;
- installation of sensors by personnel not specifically trained in the installation must also be possible;
- it must be possible to exchange defective sensors quickly, simply and without reference to specialists.

All this combines to create an ever growing demand for small, powerful but nevertheless capable, robust and cost-effective sensors.

With this situation in mind the following details will illustrate the process of developing a new line in photoelectric proximity switches and the results achieved.

Picture 1

## Problematic situation

Cylindrical housings are preferred for smaller sensors. Sizes M18, M12 and M8 are at present available on the market for photoelectric equipment (versions in non-standard housings such as M6 and others with separate evaluation electronics are not discussed here). Required, but still not available, were units with a 4 mm diameter or with M5 thread and which are known from inductive versions and used there in large numbers. The following text will describe the process adopted to realize this type of equipment.

## Solution

The most straightforward solution to the problem and used in this case is to start with the technology employed for existing, larger units and to try to reduce the dimensions of the various modules.

### The electronic unit

In order to reduce the size of the electronic module it is sufficient to use known processes (Chip-on-Board technology, SMD technology, extra-fine PCBs). It is, however, mandatory that always the smallest available components be used. The application of an integrated circuit combining the most important electronic functions is unavoidable.

Picture 2

### The optical unit

Existing, larger versions are not suitable for reducing the optical unit.

This is due to a variety of reasons:

- There are no sufficiently small transmitter and receiver components (LED's and photodiodes) installed in housings.
- When using transmitter and receiver components in Chip form their surfaces, which transmit or receive light, are vertical to the required direction (Fig. 1).
- Lenses and deflector mirrors cannot be used for reasons of space.

In order to circumvent these obstacles a recognized optical component was used: the convex mirror. The divided or undivided version provides the desired solution. Fig.1 shows the construction of such an optical device as an example of the reflex light sensor.

The light, either being transmitted or received, is diverted by 90° and bundled at the same time by the divided convex mirror plates. The required optical separation between transmitter and receiver is achieved through the interspaced PCB. By means of a suitable design of the PCB it is also possible to avoid the undesired electrical coupling between the two PCB layers.

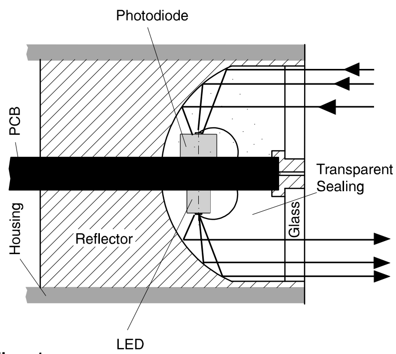


Fig. 1

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### EMC

In order to obtain sufficient EMC characteristics it is obviously necessary to effectively screen at least the receiver part of the unit (Photo diode and amplifier). However, with small components there really is no space available for the installation of shields. In order for the units to be suitable for use and to be authorized to carry the CE mark, they must demonstrate excellent EMC strength.

The convex mirror used is ideally suitable. In any case, it is preferably produced as a metal coated, plastic component. The desired EMC characteristics can be achieved quite simply by the electrical connection of the metal coating with a suitable point of the circuit and correct design of the PCB.

### Environmental conditions

Good resistance against environmental conditions and influences is of paramount importance for problem-free use of sensors over a wide field of applications. Here the photoelectric equipment, in comparison with inductive equipment, has a definite physical disadvantage:

– The light path is negatively influenced by contamination;
– Contrary to other types of sensors, they cannot be sealed completely with casting resin. Even when using transparent resins their refractive characteristics have a serious and detrimental effect on the functions of light optics.

Here the new unit has decided advantages. By means of a suitable integrated circuit it was possible to include an excess light indication and/or an indication of contamination (in case of insufficient light reception the output state LED will flash). On the other hand, the optical system obtained with a convex mirror can be fully sealed with transparent resin without affecting its characteristics at all. It is well known that reflection is independent from the refraction index of the medium.

## Construction and data

Examples of the equipment described is illustrated by Picture 1.

The housings, with a diameter of 4 mm smooth or M 5 threaded, have a length of only 35 mm (cable version) or 57.5 mm (plug versions in plugged-in condition, including the plug). Picture 2 illustrates a view of the electronic module and Figs. 2 and 3 are scale drawings of the complete parts.

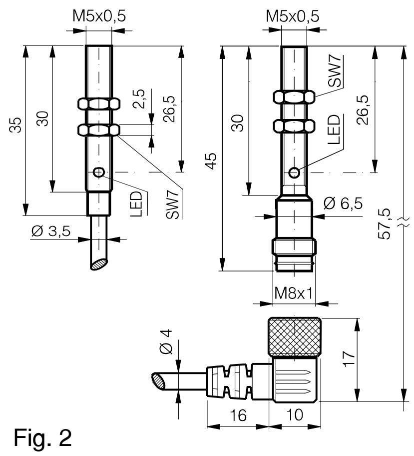


Fig. 2

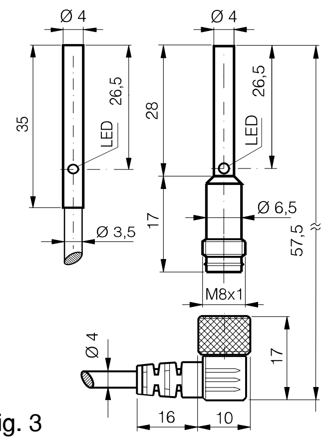


Fig. 3

The equipment is completely sealed under vacuum with casting resin, without any form of air inclusions. Otherwise, in the long-term this could lead to reliability problems, e.g. through condensation. The light intake and exit surfaces are made from glass, so that they are scratch and solvent resistant (important for cleaning). The equipment does not contain any ceramic hybrid substrate and is therefore less liable to fracture.

### Technical data:

(according to IEC 60947-5-2)

| | |
|---|---|
| Sensing range | 50 / 500 mm |
| Supply voltage range $U_B$ | 10 ... 30 VDC |
| Output current | 100 mA |
| Current input | 10 mA |
| Switching frequency | 250 Hz |
| Switching times | 2,5 msec |
| Max. ambient light: | |
| incandescent | 3'000 Lux |
| sun | 10'000 Lux |
| Ambient temperature range | 0 ... + 55 °C |
| Protection class | IP 67 |
| EMC - protection: | |
| IEC 60255-5 | 1 kV |
| IEC 61000-4-2 | Level 2 |
| IEC 61000-4-3 | Level 3 |
| IEC 61000-4-4 | Level 2 |

The sensing ranges are 50 mm for the reflex sensor and 500 mm for the through-beam sensor. Short-circuit protection, all-round voltage reversal protection, over-voltage protection and switch-on pulse suppression is also incorporated. A LED signals the control state and insufficient light reception.

## Price

The selected processes permit cost-effective manufacture and therefore an attractive price. The costs are certainly less than, for instance, those for a fiber optic amplifier and the associated optical fibers.

## Applications

The new photoelectric proximity switches have not been developed for specific applications. On the contrary, they were consciously designed as a universally adaptable unit for rough industrial use. As already mentioned, they satisfy the general trend and meet the requirements of optical systems. The subsequent information can therefore only reflect an incomplete selection of the many applications possible:

– Replacement for larger units with restricted installation space;
– Replacement for inductive units with insufficient sensing range;

– Installation in place of optical fibers. This would obviate the necessary and careful routing of the optical fibers. It is also a more economic solution to the problem of costs of optical fiber, fiber optic amplifier and their installation.

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# New Pressure-Resistant Switches for Highly Dynamic Uses

Pressure-resistant inductive proximity switches were developed for a multitude of uses: from all applications in the area of hydraulic technology to many uses within the domain of pressure (up to 500 bars). Pressure resistance of the switch is dependent on the thickness of the casing walls particularly in the region of the sensing face. Herein lies a problem: to guarantee an acceptable switching distance with these thicker walls.

**Pressure Resistance**

These new proximity switches are built exclusively in the 'direct way', with enough case strengthening for high pressure resistance up to and over 500 bars. A ceramic disk is used on the sensing face which has enough thickness to withstand the pressures without further reinforcement measures. There is also no need for any further auxiliary construction, for example, the use of internal supports. The entire electronic module, including the ferrite core and the coil, are installed as an internal component in the pressure free environment of the casing. However, as a result of the thickness of the ceramic disk 2.5 mm (P20), when the proximity switch module with a normal operating distance (in this example, 2 mm) is installed, the useful measuring distance is less than zero. The solutions to these problems are described below.

**Fixing and sealing of the front face.**

Pressure resistance, out of pure necessity, requires a seal of some sort so that at maximum operating pressures there is no infiltration of harmful mixtures of liquid or gas. Such a seal is particularly necessary between the 'squared up' side of the ceramic disk and the metallic casing.

Picture 1

With new proximity switches, success has been achieved by shrinking the casing around the ceramic disk. Picture 1 shows the casing and the ceramic disk before and after assembly, and Fig. 1 shows the part in cross-section. Assembly is made by heating the casing in the joining area (which can be achieved, for example, in a few seconds using induction heating). While the casing is still hot, the ceramic disk is placed in position without using any mechanical force. The whole assembly is then left to slowly cool. The metal casing will shrink much more than the ceramic disk, due to the higher temperature coefficient of metal. With suitable choices, the dimensions $d_1$ and $d_2$ will result in a powerful and tight seal. However, even with this, the joint is not satisfactorily tight. The gas impermeable sealing is achieved with the insertion of a thin layer of copper between the casing and the ceramic disk (see Fig. 2). For this, the entire casing is copper plated before shrinking, and then the copper plating is removed after shrinking. At the joint the copper is not removed, which brings about a connection which, with the shrinking process, produces a mechanical pressure of up to 200 N / mm$^2$ on the surfaces, which produces a superior sealing.

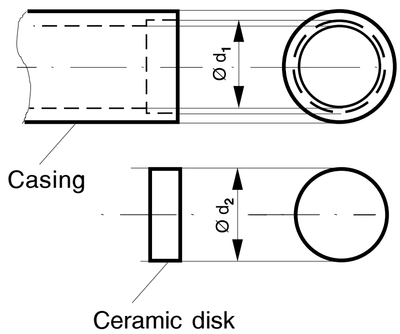


Fig. 1

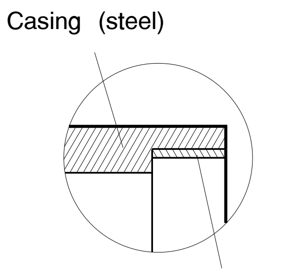


Fig. 2

**Operating Distance**

As described above, a large amount of useful operating distance is lost due to the thickness of the ceramic disk. All the same, a satisfactory operating distance is produced by installing an electronic module with a large operating distance (approx. 3 times Condist® Oscillator) in place of a normal electronic module. The resulting operating distance for type P20 is 3 mm, which is even higher than a simple unit without a ceramic disk (2 mm).

**Dynamic Requirements**

Conventional pressure-resistant proximity switches are only conditionally suited to dynamic pressure uses. When used in the normal way the support system and the teflon seal will wear out after a certain number of pressure cycles. Experience of this comes through experience with practical applications, in particular with hydraulic systems. These new proximity sensors in this respect are completely different. With their simple installation in combination with the higher mechanical surface pressure of the casing on the ceramic disk, they are highly insensitive in dynamic situations and against pressure peaks.

### Design

The following devices are available as described (Figs. 3 and 4).

### Costs

The devices make do with fewer and simpler mechanical parts. The installation is made in fewer steps and without any special skills. The electronic modules are the same as those already mass-produced for long-range switches. These devices are therefore, despite their advantageous properties, unusually economical in their manufacture.

### Advantages

- A practically unlimited number of pressure cycles permissible over the full pressure range
- Large operating distances
- Gas tight joining in the area of the sensing face
- Simple mounting. Install against a limiter: and finished! No adjustment is required (P20).
- Favourable cost

### Applications

The new devices are available on the market as advantageous replacements - especially considering their easy attachment, their long operating distance and low price.

Their application is however, especially reputable where dynamic pressure stress is expected, for example:

- Interrogation of the piston end position in hydraulic cylinders;
- Control and monitoring of the switches of hydraulic valves;
- rpm counting and monitoring of hydraulic motors;

**P20**


Fig. 3

**P12**

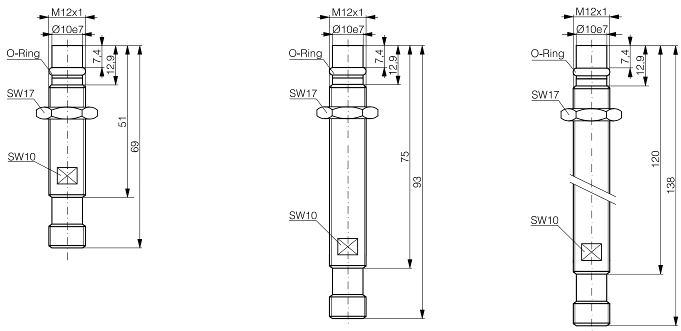


Fig. 4

Picture 2

- Control and monitoring valve switching in gas distribution systems (the devices are gas impermeable);
- Applications within high-vacuum installations.

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**Technical Data:**

(According to IEC 60947-5-2)

| | P20 | P12 |
|---|---|---|
| Max. operating pressure | 500 bars | 500 bars |
| Max. peak pressure | 800 bars | 800 bars |
| Operating distance | 3.0 mm | 1.5 mm |
| Hysteresis | 10 % typ. | 10 % typ. |
| Supply voltage range $U_B$ | 10 ... 30 VDC | 10 ... 30 VDC |
| Maximum ripple content | 20 % | 20 % |
| Output current | ≤ 200 mA | ≤ 200 mA |
| Output voltage drop | 2.0 V max. at 200 mA | 2.0 V max. at 200 mA |
| Switching frequency | 500 Hz | 2,000 Hz |
| Operating temp. range | -25 ... + 80 °C | -25 ... + 80 °C |
| Protection degree | | |
| at active face: | IP 68 | IP 68 |
| connection side: | IP 67 | IP 67 |
| Housing material | Stainless steel | Stainless steel |
| Sensing face | Ceramic $Al_2O_3$ | Ceramic $Al_2O_3$ |
| EMC protection: | | |
| IEC 60255-5 | 1 kV | 1 kV |
| IEC 61000-4-2 | Level 2 | Level 2 |
| IEC 61000-4-3 | Level 3 | Level 3 |
| IEC 61000-4-4 | Level 2 | Level 2 |

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# Tips for Mounting Inductive Proximity Switches

## Why inductive?

Inductive proximity switches are highly popular with end-users. They are

- robust
- good value for money
- insensitive to dirt
- standardized

and, as a result, simple to employ.

### 1. Type of mounting embeddable / non-embeddable

In his documentation, the manufacturer indicates whether a particular device is intended for embeddable or non-embeddable mounting. This information relates to the permissible location of the device's sensing face in relation to the mounting surface, and is only of concern where there are metal surroundings. Insulating parts do not influence the functioning of inductive proximity switches. Metal parts in the vicinity of the sensing face on the other hand, influence the operating distance, though in various ways:

- Ferromagnetic metals (iron, nickel, cobalt, etc) increase the operating distance;
- Non-ferromagnetic, but good conducting metals (aluminum, brass, copper, etc.) reduce the operating distance;
- Non-ferromagnetic, poor conducting metals (stainless steels, zinc, etc.) can, according to the situation, increase or decrease the operating distance to a greater or lesser extent. The actual behavior must be determined from case to case.

As a matter of principle, mounting should not alter the operating distance by more than 10%. As a rule, the manufacturer's indication concerning embeddable / non-embeddable mounting also refers to this value.

Some information concerning various mounting situations is given below:

**1.1. Embeddable mounting** (Fig. 1)

The sensing face of the proximity switch can be located in the same plane as the metallic mounting surface (naturally, it may also protrude if so desired). The mounting surface is allowed to fit tightly around the device; it may for instance also have a tapped fixing thread. Technically, this feature is made possible due to the fact that the field emitted from the device is formed by appropriate tailoring of the magnetic field and shielding into a hemisphere, which does not, or only minimally at least, extend beyond the outside diameter of the device. As a result, the achievable operating distance is consequently reduced. However, in addition to the possibility of embeddable mounting, the user obtains a better defined, well-limited profile of the sensitive area compared to other designs. These devices can be recognized by the fact that the plastic cap of the sensing face does not protrude beyond the metal housing. Consequently, the sensing face is better protected against mechanical damage. Considering these advantages, embeddable mounting devices should therefore be chosen wherever possible.

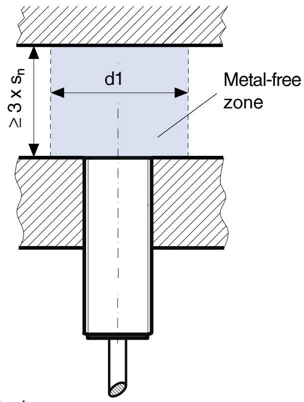



Fig. 1

**1.2. Recessed mounting** (Fig. 2)

No proximity switch specified as "embeddable mounting" should just be simply mounted in a recessed position. When this method of mounting is envisaged, additional clarification is essential. It is generally valid that small sizes rather than large ones may be recess mounted. In any case, it is recommendable to take a measurement, so as to ensure that the operating distance is not altered by more than 10% when mounted. In case of doubt, it is worthwhile questioning the manufacturer, enclosing a mounting sketch.

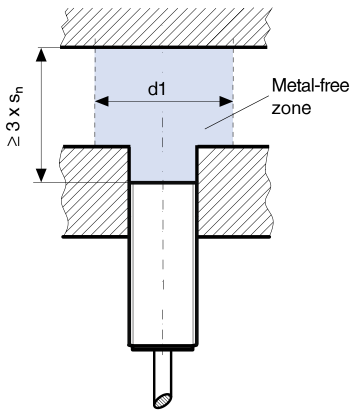



Fig. 2

**1.3. Non-embeddable mounting** (Fig. 3)

The sensing face of the proximity switch must protrude significantly beyond the metallic mounting surfaces, namely by the value X (it can naturally protrude more if required). Further, with off-set mounting, value Y has to be taken into account. X and Y are generally indicated in the manufacturer's documentation; failing this, the values given in the standard (IEC 60947-5-2 or EN 60947-5-2I) may be consulted. These devices can be recognized by the fact that they have a protruding plastic cap. In comparison to embeddable executions, their operating distance is greater. However, the mechanical

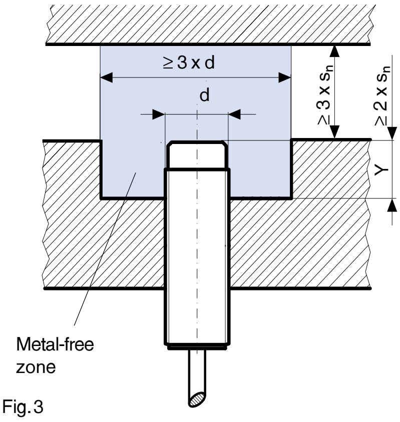



Fig. 3

protection is, in all cases, worse, and the sensitive zone extends significantly beyond the diameter of the device. In general, there is no difference in price.

**1.4. Quasi-embeddable mounting** (Fig. 4)

The sensing face of the proximity switch must protrude only insignificantly beyond the metallic mounting surfaces, namely by the value X (it can naturally protrude more, if required). In addition, a gap d1 must be maintained. X and d1 should always be given in the manufacturer's information. As in the case of fully

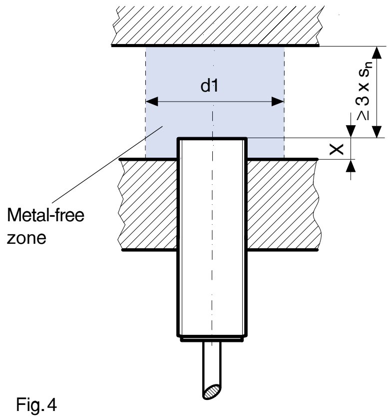



Fig. 4

embeddable types, these devices are recognizable by the fact that the plastic cap of the sensing face does not protrude beyond the metal housing, and are therefore better protected against mechanical damage.

Inasmuch as protrusion of the proximity switch beyond the mounting surface is undesirable, off-set mounting according to Fig.5 can be used. In this case, the off-set mounting distance Z and the mounting diameter d2 must be taken into consideration, and these may exceed but never fall below the given values. In general, these measurements should be obtained from the manufacturer.

According to the application, with a further variation (Fig.6), a more economical machining of the support can possibly be achieved.

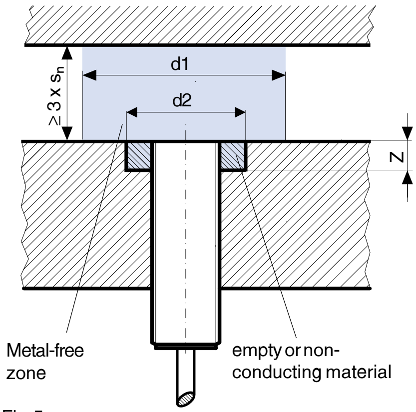



Fig. 5

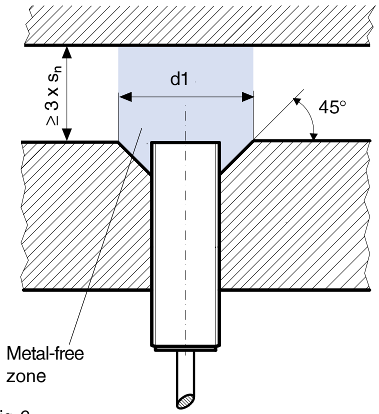



Fig. 6

## 2. Surrounding metal parts

Not only metal parts in the plane of the sensing face, but also those alongside or in front, influence the field and consequently the response of the device. As far as the type of metal is concerned, the information given in section 1 is also valid in this case. As a result of the vast number of mounting possibilities, useful information from the manufacturer is limited. When the spaces referred to in Figs.1 to 6 as "metal-free zones" can really be kept free of metal, then problem-free operation can be assumed. In principle, in this case, the following is also valid: as a result of embedding conditions, the operating distance should not vary by more than 10% relative to its value in free surroundings. If there is any doubt, this must be checked by means of a measurement.

## 3. Operating distance adjustment

The rated operating distance of a device can be obtained from the manufacturer's documentation, and is measured according to the relevant standard (EN 60947-5-2). In practice however, the actual operating distance is unfortunately dependent on numerous influences, the most important of which are described below:

**3.1. Manufacturing scatter**

The standard allows the manufacturer a rated operating distance scatter of ±10%, which must be taken into account in the design (Fig. 7).

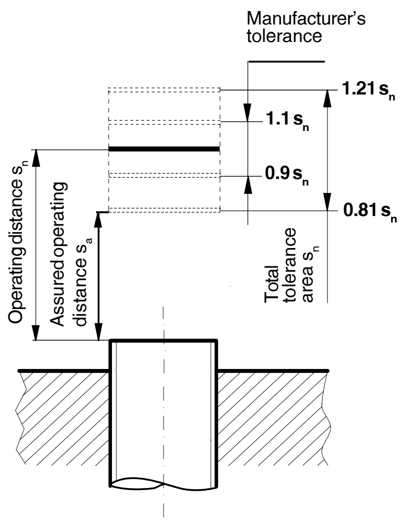



Fig. 7

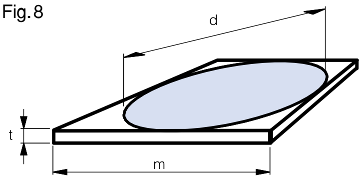
### 3.2. Influence of temperature and voltage

The standard requires that within the indicated temperature range (normally –25 … +70°C) and supply voltage, the operating distance does not vary by more than 10% of the value at 23°C and nominal supply voltage. Under factory conditions (+15 … +30°C), a temperature influence of ≤ ±2% can be assumed.

### 3.3. Geometrical influence

The given rated operating distance relates to the standard target defined in the above-mentioned standard. This target is made of steel, e.g. type FE 360 according to ISO 630, having a smooth surface, a square shape, and a thickness of 1mm (Fig.8). The side of the square is equal to

Fig. 8




the diameter of the inscribed circle of the sensing face or to three times the rated operating distance $s_n$ of the proximity switch, whichever is the greater. Larger measuring plates result in only slightly higher operating distances. On the other hand, other real operating distances, unfortunately in practice nearly always smaller, arise as a result of different objects (smaller surface, elongated shape, bending, surface condition), as a result of device-typical field flows. Only with foils can the attainable operating distances be greater. The following graph shows the **geometrical influence** for flat objects:

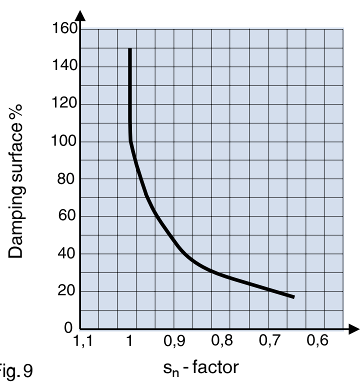



Fig. 9

### 3.4. Material influence

The specified rated operating distance refers to steel objects, according to ISO 630. For other metals, this value must be adjusted using a correction factor. Below are given a few typical **correction factors:**

- Brass $s_n$ x 0.50
- Aluminum $s_n$ x 0.45
- Copper $s_n$ x 0.40
- Nickel-Chrome $s_n$ x 0.90
- Stainless steel V2A $s_n$ x 0.85

These correction factors are only indicative; the actual values must be taken from case to case from the technical information, or determined. They are dependant on the size of the device, whether mounted embeddable or non-embeddable, the exact alloy, etc.

For some time moreover, there have been devices in the market that boast a correction factor of 1 for all metals.

### 3.5. Aging

With inductive proximity switches, aging effects, except when used under extreme service conditions, are negligible.

**Practical rule**

The following procedure has proven itself in practice:

- Mount the device in the designated position.
- By moving the device or the object, ascertain the effective operating distance.
- Position the proximity switch at 0.9 times the measured effective operating distance and secure it.

By this means, the assured operating distance in the actual application is reliably maintained.

## 4. Mutual influence with aligned devices

The mounting of several proximity switches with limited spacing (Fig. 10) can, as a result of inductive coupling between the oscillator coils, lead to mutual influence and as a result, to signal fallout. This case deserves particularly careful clarification, since the disturbances are not always immediately conspicuous, but may only occur sporadically. For such installations, the corresponding information from the manufacturer concerning the minimum spacing to be observed should first be consulted, and whenever possible adhered to. If in a specific case it cannot be adhered to, there are various possibilities:

- Install embeddable devices, since the required spacing compared to the housing diameter is significantly smaller;
- Use smaller proximity switches; the required spacing is disproportionately smaller;
- As far as the application permits, switch the supply voltage to the device on and off in such a way that neighboring units are never under tension at the same time. For instance, with processes that are not too fast, a kind of multiplex operation that removes disturbances in an elegant manner can be arranged;
- Use devices with different oscillator frequencies. These are available from most manufacturers as special versions. Two frequencies are often enough, provided the devices with these frequencies are

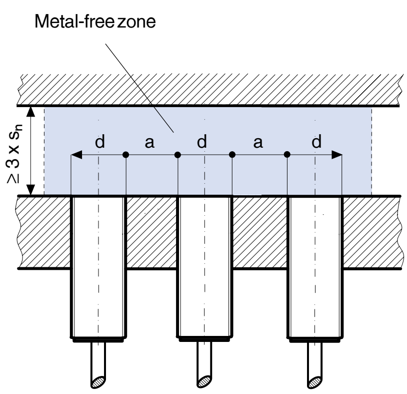



Fig. 10

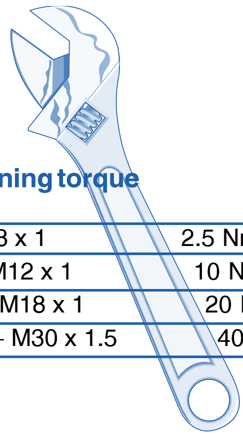
installed alternately. This solution is however problematic for several reasons:
  – special devices, which are more expensive and not stock items, are required;
  – the risk of mix-ups during mounting is considerable;
  – the logistical cost (spare parts stock, additional article, stock lists) increases;
  – problems during the field replacement of spare parts can hardly be avoided.
– Use devices with the same dimensions, but from different suppliers. In this case, the oscillating frequencies are generally different, but this must first be clarified. Since oscillator frequencies are not given in catalogs, they must be requested from the manufacturer. The frequency difference should be at least 10%. For mounting, the information given further above is valid.

It is strongly advised to avoid any action just on the off chance that it may work. The oscillator frequency scatter between devices of the same type and the same manufacturer can often be enough to achieve a seemingly good result without further measures. Though whether next time it still works is a question of pure luck, to say nothing of mounting spare parts in the field.

## 5. Fixing

### 5.1. Threaded cylindrical devices

In compliance with the manufacturer's instructions, the maximum tightening torque of the nuts must be respected; the housing is hollow inside and therefore supports less load than a screw with the same diameter (Fig. 11). This is particularly important for small sizes. Moreover, it must be borne in mind that the wall thickness of the housing can be thinner for a few millimeters at each end, and that therefore the given tightening torque may perhaps not be attainable at these points. Where vibrations are present, the use of an additional safety-locking washer is recommended.



**Tightening torque**

| | |
|---|---|
| – M8 x 1 | 2.5 Nm |
| – M12 x 1 | 10 Nm |
| – M18 x 1 | 20 Nm |
| – M30 x 1.5 | 40 Nm |

Fig. 11

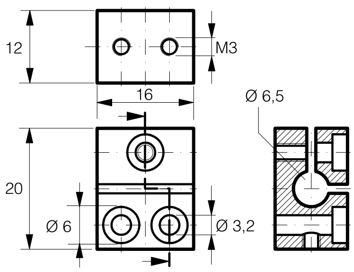



Fig. 12

### 5.2. Smooth cylindrical devices

Smooth-walled devices are best fixed by means of clamps (Fig. 12). Cementing may also be possible. The use of adjusting screws should be avoided; they lead to deformation of the housing, and can lead to total device failure.

### 5.3. Square devices

It must be ensured that the mounting surface is sufficiently smooth, so that when tightening the fixing screws, the device is deformed to a negligible extent only. In this case also, where vibrations are present, the use of an additional safety-locking washer is recommended.

## 6. Connector / cable assemblies

In a number of cases, particular attention should be paid to the choice of connecting cable:

### 6.1. Use in oily environments

PVC-based cable insulation in permanent contact with any kind of oil will become brittle in time. This must also be avoided in static installations, since bending, e.g. during maintenance work can never be completely excluded. Cables with PUR insulation offer a good alternative in such cases. However, it is perfectly sufficient for only the sleeve coat to be of this material.

### 6.2. Use in chemically aggressive environments

The suitability of insulating materials such as PVC and PUR must be clarified from case to case since, according to the chemicals in question, there can be large differences in resistance. It is advisable to consult the plastic manufacturer's resistance tables. When absolute security is required, Teflon insulation is without equal. However, a few disadvantages must be accepted:

– Special execution of the proximity switches with the corresponding effects on logistics;
– Significantly higher price;
– Difficult processing.

### 6.3. Use with periodical flex-bending of the cable

For this type of stress, elementary construction rules must be considered:

– Keep the bending radius as large as possible;
– Avoid sharp bends at edges, especially at the cable exit from the proximity switch housing (Fig. 13). The use of fixing straps may be considered;

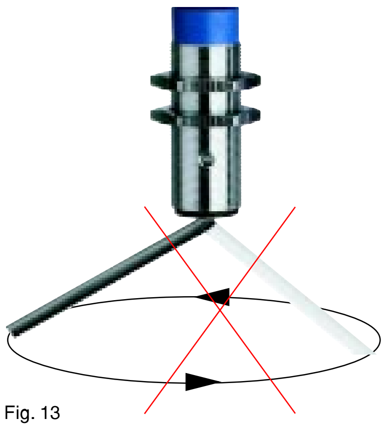


Fig. 13

– Avoid self-vibration of the cable loops, or provide damping;
– Install grommets to protect against bending.

As a further measure, the use of cables with improved flex-bending strength is recommended, e.g. according to DIN VDE 0472, part 603, test method H/F (Fig. 14), minimum 20,000 cycles. Fine wire flex does not always give the best flex-bending strength. The flex-bending strength is rarely indicated in the manufacturer's documentation; in this case, inquire direct.

**6.4. Use in low temperature environments**

Normal PVC insulation becomes stiff at a temperature of 0°C, and brittle below -25°C. This is no problem for static mounting, since maintenance work is not normally carried out at these temperatures. If static mounting cannot be guaranteed, cables with PUR insulation offer a suitable alternative down to -40°C. For lower temperatures, silicone rubber insulation is without equal.

## 7. LED

If possible, the LED should be visible after mounting, for which the commissioning and maintenance personnel will be thankful. It is often sufficient to turn the device in the right direction. For devices with cable connections, a rearwards oriented LED is advantageous for visibility; on the other hand, this is often a disadvantage for the quality and durability of the seal between the housing and cable. For devices with socket connections, the use of a connecting lead with a built-in LED can guarantee a better visibility.

## 8. Labeling

In the case of spare part mounting, the importance of the device label should not be underestimated. For this reason, it is not of primary importance to place a high value on an aesthetically satisfactory label, but rather more on a permanent one. This is especially valid in a mounting situation where the device is in permanent contact with liquids. Less recommendable is the application of the label on the sensing face.

Bending tester according to VDE 0472

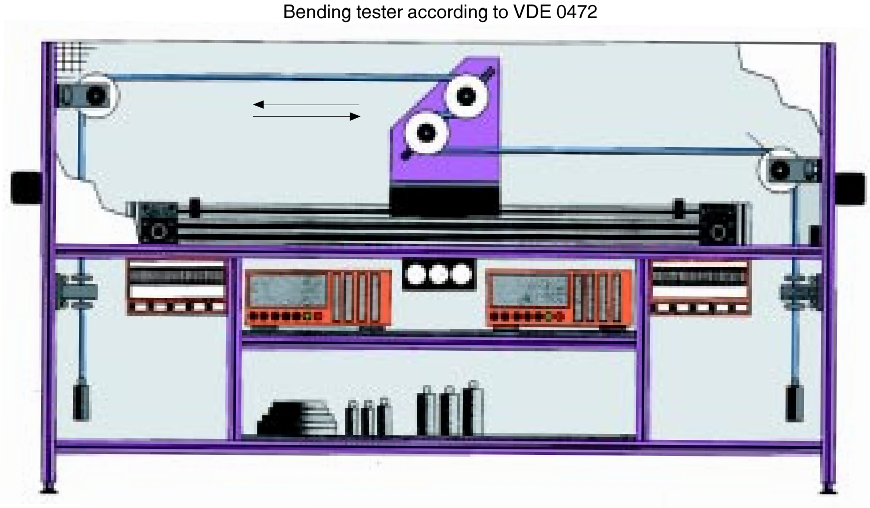


Fig. 14

As is well known, despite all precautions, abrasion (which in addition also endangers the life of the device) must be reckoned with. It must be borne in mind that, in case of failure, the label may no longer be readable.

The manufacturer's original labeling is nearly always carefully optimized, and therefore of good quality. The problem frequently only arises when the user applies company-specific additional labeling, e.g. part numbers. The additional cost required to provide first-class durability is easily dispensed with and, as a result, problems when replacement parts need installing are involuntarily provided.

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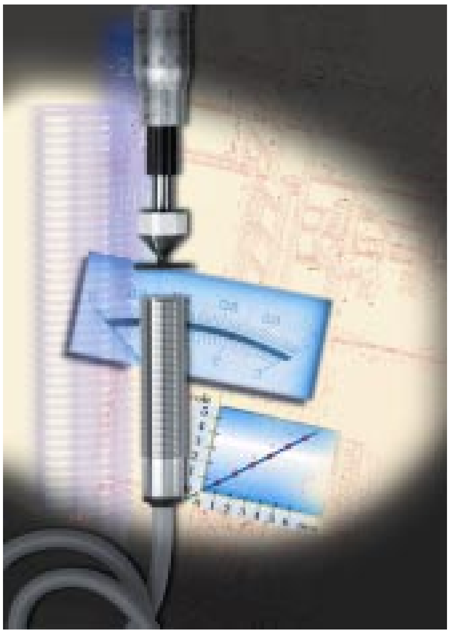
# New Inductive Proximity Switch with Analog Output

## Why inductive?

Inductive proximity switches are highly popular with end-users, since they are
- robust
- cost effective
- insensitive to dirt
- standardized

and therefore simple to use.



## Why analog?

Classical (switching) inductive proximity switches in fact work internally as analog devices, although they produce a binary signal at the output, which is often desired. A large part of the available internal information, though, is lost. Switches with analog outputs provide the user with full information, permitting a variety of possible applications.

## Previous technology

As mentioned above, proximity switches already work as analog devices. However, a signal shaper before the output stage changes the rectified analog oscillator signal into a digital one (Fig. 1). This signal shaper also exists in switches with analog outputs, but there it serves an entirely different purpose. Instead of producing a switching point, it converts the signal emitted by the rectifier (4) into a more usable, but still analog, form. Its main purpose is the generation of defined starting and end points of the output function, as well as a defined flow in between. Such switches have been available on the market for some time. The scope of their application has, however, so far remained very small, principally due to severe limitations of their usable sensing range.

## New technology

To a large extent, the new switch presented here works in a similar way to the well-known switching versions. The essential difference lies in the type of oscillator (3). Instead of conventional technology, a Condist® oscillator, of completely different design, is used. CONTRINEX has already been using this oscillator for a number of years in the large scale manufacture of proximity switches with long operating distances. As a result, a much larger sensing range is obtained, with excellent stability and repeat accuracy. Since intermediate digitization has been dispensed with, the switch resolution is furthermore virtually unlimited.

## Advantages of the new proximity switch

- Very large sensing range
- Available in an economical non-linearized execution with favorable transfer function (Fig. 2) and in linearized execution (in preparation)
- Low specimen scattering
- Short design
- Current and voltage output in the same switch

At present, the switches are available in the size M12 (Fig. 3) series. Further sizes are in preparation.

## Applications

- ***Proximity switches with multiple switching points:***
  The output signal is transmitted to the analog input of a PLC. Any number of switching points can then be produced by means of software. Another possibility would be to employ a suitable analog switching device with multiple switching points.

- ***Start-up control***
  The classical procedure consists of simply turning the drive off after it has passed an end-point (detected, for instance, by a binary proximity switch). The end-point position is, however, relatively uncertain, due to the uncontrolled mechanical run-out. By using an analog output proximity "switch" with, for example, a PLC, a highly accurate start-up control can be achieved at little cost.

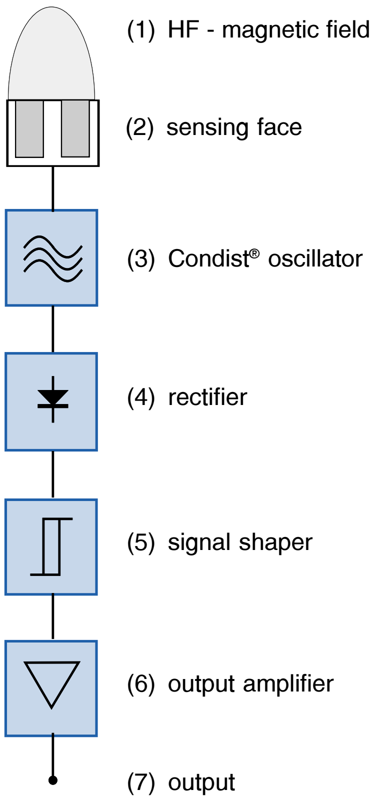



Fig. 1

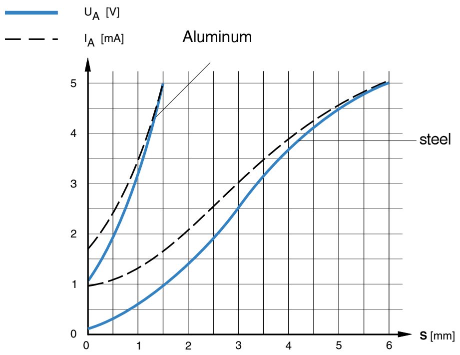



Fig. 2

– ***Non-contact potentiometer***
The use of a standard contact potentiometer for the detection of mechanical values (e.g. pedal position in vehicles) is frequently unsatisfactory. Vibrations, environmental influences, wear, etc. lead to unacceptably high maintenance costs and reliability problems. In these cases, use of the new proximity switch fundamentally improves the situation, without incurring a high investment cost. Conversion of mechanical movement, e.g. turning, into a form suitable for the proximity switch, can be carried out by means of eccentric disks, wedges, etc. If necessary, switches can be supplied to customer specifications.

– ***Self-teaching function***
The mechanical adjustment of proximity switches in the plant is a well-known, and until now, inevitable installation problem, requiring reliable personnel and time. The problem is greater still when installing a spare part in the field. The use of an analog output proximity "switch" offers an elegant possibility of overcoming this problem. In effect, the switch is positioned only approximately, e.g. on the basis of a marker. Next, the PLC causes the target object to move mechanically to the desired switching position, determines the corresponding output signal of the proximity "switch", and stores the value as a future switching point.

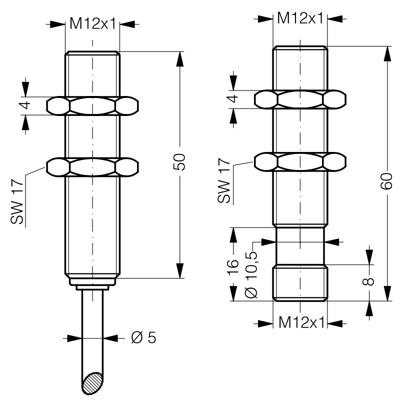



Fig. 3

– ***Concentricity monitoring***
Accurate concentricity of rotating machine parts is a prerequisite for trouble-free operation and long life. Concentricity can deteriorate unpredictably with time, e.g. due to bearing wear, and this consequently leads to unexpected and often catastrophic breakdowns, incurring expensive repairs and downtime. On cost grounds, the installation of available concentricity monitoring devices is frequently avoided. In such cases, an analog output proximity "switch", together with a PLC, frequently already installed, provides a simple, economical, and very efficient solution.

– ***Vibration monitoring***
Vibration can also be an indication of a machine's condition. Amplitude monitoring over time allows preventive maintenance to be carried out, and so helps to avoid unexpected and often catastrophic breakdowns with the ensuing expensive repairs and downtime. Here also, an analog output proximity "switch", together with a PLC, frequently already installed, offers a simple, economical and, in many cases, adequate solution.

## Cost comparison

To a great extent, the non-linearized switch is assembled from the same parts as the corresponding switching device. Additionally, end point trimming is basically not more expensive. This results in an economically interesting cost situation, since the switch presented here (non-linearized execution) is only about 20% more expensive than the corresponding switching device.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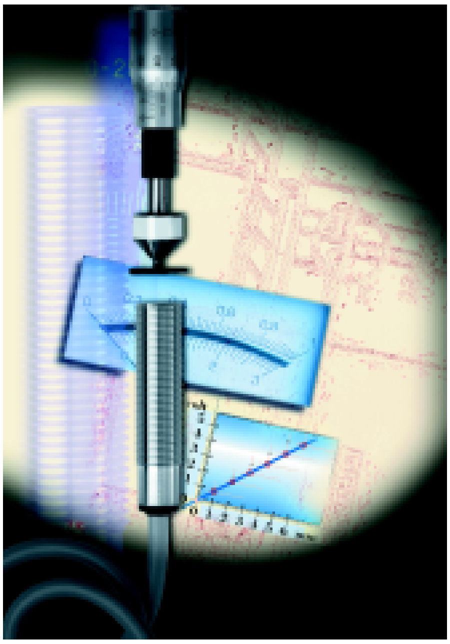
# The Application of Inductive Proximity Switches with Analog Output

## General application advice

In general, the same application rules as for the well-known inductive switching devices apply. However, there are, in addition, a number of extra features, which are discussed in the application report "New Inductive Proximity Switch with Analog Output".



The following application examples have all been taken from practice. Due to space availability, only a selected few are described here, the possibilities being virtually unlimited.

## Application examples

### 1. Several switching points with a single proximity switch

One often comes across the case that, during the movement of the target to be detected, a particular action should not be triggered at just one position. More often, relevant specific actions should take place at various positions. Thus, in a program switching station, the task can be resolved using a single disk and a single analog device (Fig. 1), instead of several disk cams and an equal number of normal switches. Evaluation in the case of a PLC application is carried out via a PLC input module with analog inputs (e.g. Siemens S5, type 6ES5 464-8MC11). For current PLCs, these modules are available at reasonable prices. Alternatively, appropriate signal evaluation devices, available from various suppliers, can be used.

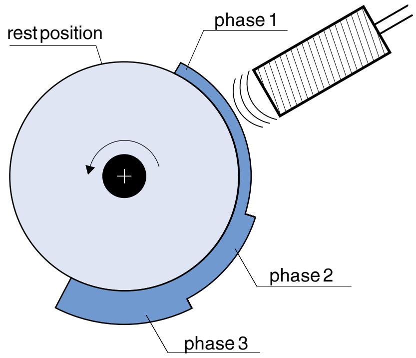



Fig. 1

### 2. Conversion of a linear movement into an electrical signal

In the simplest case, a linear movement can be directly converted, as shown in Fig. 2. In this case, it only has to be ensured that the device is not physically touched. In practice however, the sensing range of the devices is often not enough for such a direct detection. However, using a wedge-shaped intermediate piece, it can be modified at will (Fig. 3). Moreover, interesting possibilities arise when this piece is non-planar. For instance in this way, linearization of the transfer function can be achieved (Fig. 4).

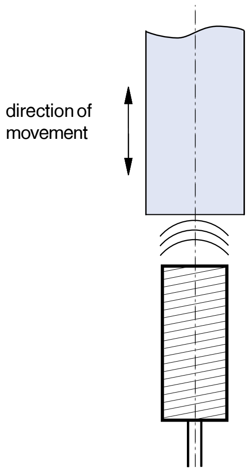



Fig. 2

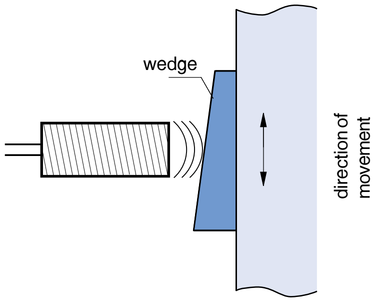



Fig. 3

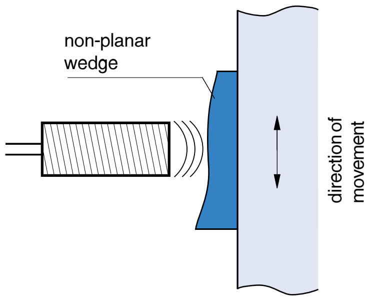



Fig. 4

### 3. Conversion of a rotational movement into an electrical signal

Delivery of a rotational movement or an angle to the analog device can be made by using an eccentric disk (Fig. 5). As in example no. 2, by a suitable choice of the disk form, the angle range can be modified within wide limits, and / or a linearization of the transfer function can be effected in this case too.

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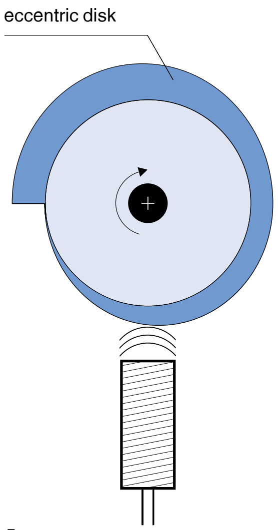


Fig. 5

## 4. Start-up adjustment

The classical procedure of motion control consists of simply switching off the drive after passing over an end point (detected for instance by means of a binary proximity switch). The mechanical end-point position is however quite vague as a result of uncontrolled runout. By using a proximity "switch" with analog output, together with a PLC for instance, it is possible to carry out high-precision start-up adjustment at negligible cost (Fig. 6).

## 5. Elevator start-up adjustment

An interesting case of start-up adjustment is found in the field of elevators. A conventional elevator generally switches to crawling shortly before reaching its destination, and then stops abruptly without overshooting to any great extent. This is certainly very simple from the technical viewpoint, but there are two drawbacks. Firstly, the crawling phase prolongs the total traveling time, and secondly, despite crawling, the accuracy of the end position is both limited as well as load dependent. By using an analog inductive proximity switch as a transmitter for detecting the cabin position, combined with a start-up adjustment (analogous to Fig. 6), these disadvantages are elegantly resolved, with no appreciable increase in the sensor cost. The requirement for an adjustable drive creates an additional expense, but today, these no longer cost the earth.

## 6. Detecting the pedal position in vehicles

The pedal positions in modern vehicles are required as information sources for numerous processes. Their detection requires sensing devices that convert a path or angle into an electrical quantity, which can then be fed to the control system. In the simplest case, these converters consist of a potentiometer; in addition, magnetic field semiconductors are used. Moreover, the use of displacement sensors, which work according to the differential transformer principle, is conceivable.

However, there are applications where previously no satisfactory solution had been found, i.e. construction equipment. Here, a high level of vibration is combined with the worst possible environmental conditions, such as dirt, extreme operating temperatures and humidity. Moreover, permanent magnets are not well viewed, since they collect metal parts and shavings. Unacceptable reliability problems are the inevitable result.

Analog inductive proximity switches meet all the above requirements to a great extent, and moreover, at a favorable cost. Constructional realization is very simple, as Fig. 7 shows.

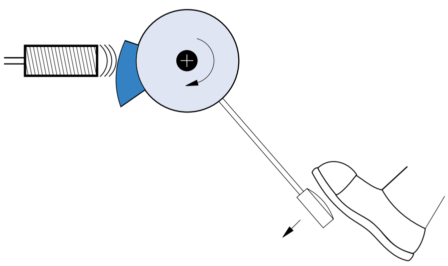

Fig. 7

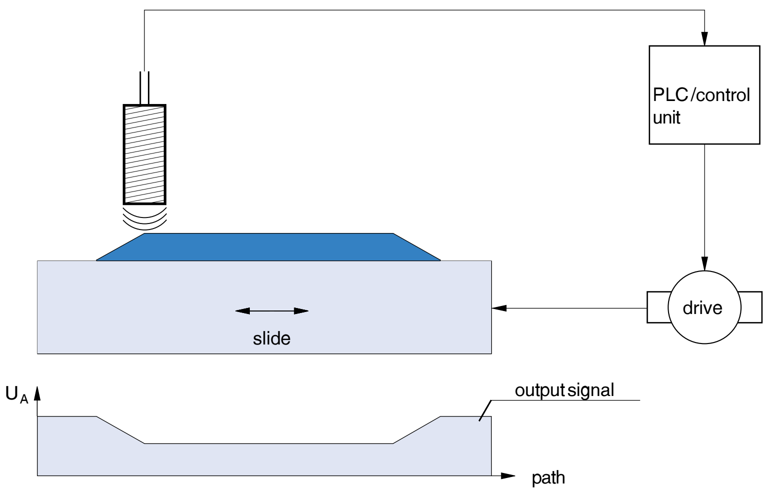


Fig. 6

## 7. Non-contact potentiometer

What has been said above concerning vehicle pedal position is of course also valid for other applications where mechanical values have to be converted into electrical ones. The use of a proximity switch as a potentiometer is not obvious at first sight, but however it permits a constructively simple solution to the problem, e.g. following Fig. 5. Multiturn potentiometers can also be simply realized (with spindles).

## 8. Parts control

Monitoring of the correct position of parts on conveyor belts is a classic application for photoelectric proximity switches, above all in combination with optical fibers. In the case of metallic parts, analog inductive proximity switches offer an interesting alternative, particularly as far as sensitivity to dirt and costs are concerned. An example is shown in Fig. 8.

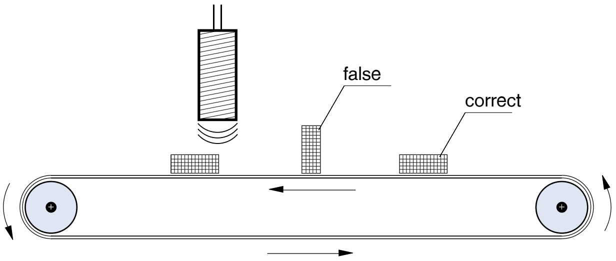

Fig. 8

## 9. Monitoring of axle concentricity

In the concept of preventive maintenance, the monitoring of axle concentricity plays an important role. During the course of time, concentricity can deteriorate in an unpredictable fashion, e.g. due to bearing wear, leading to unexpected and often catastrophic breakdowns with costly repairs and downtime. Continuous concentricity monitoring allows immediate information concerning the state of the bearings. It is true that there have been efficient devices on the market for some time for this purpose but, however, their price has hindered wide application. It is quite the opposite with analog inductive proximity switches, their price being only a fraction of that of conventional systems, and their use and signal evaluation are child's play (Fig. 9). Their capacity, on the other hand, is exceptionally high, and can measure up to systems many times more expensive. The definition and short-term repeat accuracy reach such high values (in the region of < 0.1 µm) that, as a rule, they cannot be measured with normal workshop equipment. Attention must only be paid to ensure that the electronic analyzer can keep pace!

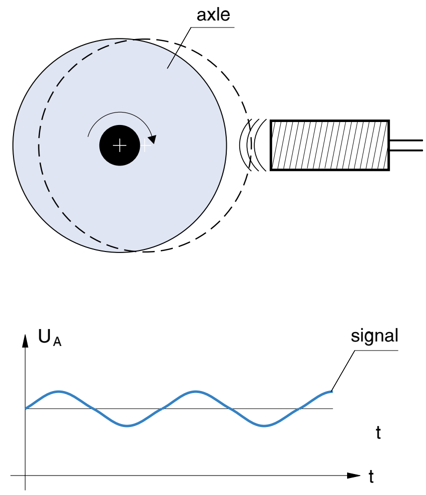

Fig. 9

## 10. Vibration monitoring

Vibration can also be an indication of a machine's condition. Monitoring of its amplitude over a period of time makes preventive maintenance possible, and helps eliminate unexpected and often catastrophic breakdowns with costly repairs and downtime. In this case also, a proximity "switch" with analog output, in combination with a PLC, frequently already installed, offers a simple, cost-effective and, in many cases, adequate solution (Fig. 10). Monitoring can take place axially, biaxially or triaxially, one proximity switch being necessary for each axle. In this application, attention must be paid to the device's upper frequency limit.

## 11. Automatic adjustment of the switching point (Teach-in)

In many cases, the switching point of proximity switches must be maintained with extreme accuracy, and for this reason, it is mechanically adjusted during installation by means of twisting the device in the thread. This certainly involves supplementary labor, but at least it does not give rise to problems with the original equipment. The situation is completely different during field replacement. Here, the manufacturer is at the mercy of the qualifications and competence of his customer's maintenance personnel.

For this application, the analog inductive proximity switch offers a relatively low-cost and interesting alternative. The reasoning behind this is that during installation, the proximity switch is adjusted only approximately, e.g. by eye using a mark or label. Next, an initialization cycle, which is anyway in most cases already available in the software, is started. It merely has to be extended with a suitable, low-cost module. In the course of initialization, the control system brings the machine part to be detected to the exact point where the corresponding proximity switch must react. The signal at the output of the analog inductive proximity switch is now read by the PLC, and digitally stored as switching point information in the memory. This value will only be overwritten during an eventual future initialization cycle. In such a cycle, any number of proximity switches can be installed accurately, speedily and independently of the skill and reliability of the maintenance personnel.

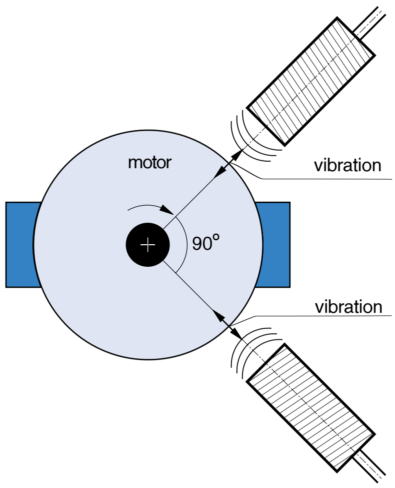

Fig. 10

## 12. Automatic correction of specimen scatter

Like all components, analog inductive proximity switches are inevitably subject to specimen scatter, whose value given in the manufacturer's data sheets is for the most part only rudimentary. CONTRINEX data sheets, however, indicate this value at three points on the curve, which nevertheless does not alter the fact that scatter can be too high for certain applications. This means that manual adjustment is necessary, which is a considerable disadvantage when fitting exchange parts in the field. Here, the procedure described in the previous paragraph can be used, and the problem thus elegantly resolved.

## 13. Electronic linearization of the response curve

Inductive technology produces a rough curve (for instance as in Fig. 11), which is not particularly linear, especially at the ends of the range. Certainly, the proximity switch manufacturer could build an additional linearizing circuit into his device, but this would, however, make it larger and more expensive. This need not be the case of electronically controlled applications. On the contrary, the curve should be digitally linearized. To achieve this, a procedure that inserts the device's transfer function into the PLC memory during an initialization cycle is used. Instead of a single switching point as in example number 11, the whole response curve of the device, with an application-specific resolution, i.e. with sufficient numbers and positions of measuring points, is memorized during the initialization cycle. After digitalization of the measured values, the ratio between the measured and ideally expected value is calculated for each measuring point, and stored in the form of a correction table in the PLC. During operation, this table is then interposed between the values registered and the further signal treatment.

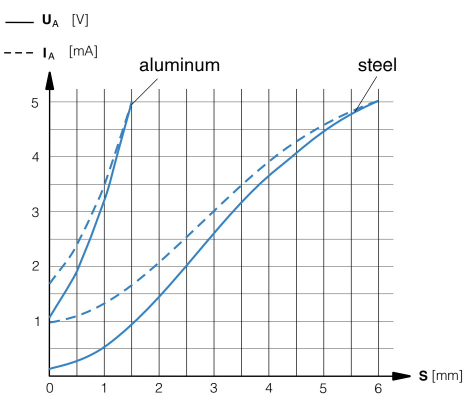

Fig.11

## 14. Identification of direction of rotation with only one proximity switch

By a suitable arrangement of the toothed or perforated disk (see also the application report "Inductive Proximity Switches as Encoders"), identification of the direction of rotation is possible with only one, in this case analog, proximity switch. For this, there are a number of possibilities, of which one example is shown in Fig. 12. At the electronic analyzer, three switching points are set, two of which must lie in the area of the teeth surfaces and one outside. From the sequence in which they move past, the direction of rotation of the toothed or perforated disk can be derived. It goes without saying that the rotational speed can thus be measured at the same time.

## Summary


With the series of analog inductive proximity switches with large sensing ranges introduced by CONTRINEX, an abundance of technically interesting and economically advantageous possibilities for converting mechanical quantities into electrical ones have become available to constructors. The devices combine the well-known advantages of tried and tested inductive proximity switches with those of mechanically susceptible potentiometers, magnetic field sensors with permanent magnets and far more complex length measuring systems.



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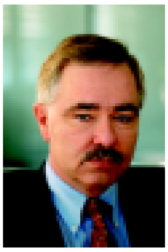


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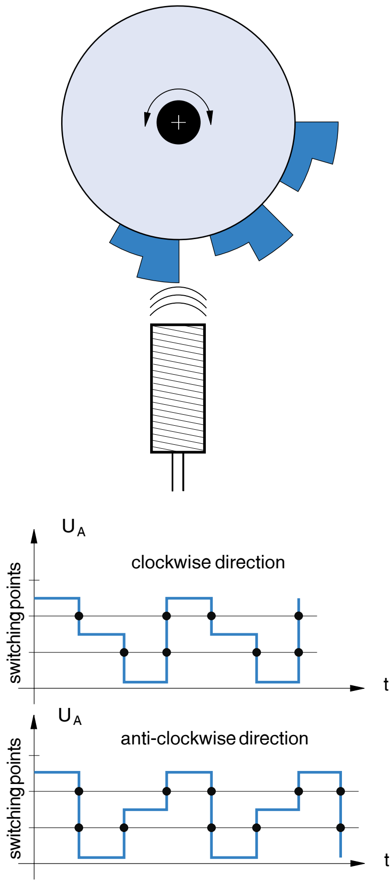

Fig. 12

# Condet® Proximity Switches

## Why inductive?

Inductive proximity switches are highly popular with end-users. They are:

– robust
– good value for money
– insensitive to dirt
– standardized

and, as a result, simple to employ. Although this type of device has been manufactured for decades, development has not stood still. Contrinex now offers inductive proximity switches which function using the completely new Condet® technology and have interesting properties.

## Advantages of Condet® Technology

– The devices (including sensing face) are built into a one-piece stainless steel housing and are therefore extremely robust.
– They achieve long operating distances on steel.
– Similar long operating distances on aluminum, brass, etc.

In short, these are the essential advantages of the new proximity switches relative to the standard ones currently used in large numbers. They therefore fulfil the most important, long outstanding end-user desires.

## Operating Principle

The new technology varies considerably from that used previously. It permits innovative proximity switches that have previously been inconceivable.

The devices of the previous generation contain a front-mounted coil, which forms part of the oscillator circuit of a high-frequency oscillator. The coil produces a high-frequency magnetic field in front of the sensing face; conducting objects brought into this area increase the oscillator circuit losses, which are detected and evaluated by the built-in electronics. Unfortunately, the oscillating circuit is also affected by other, undesirable influences, in particular temperature and time dependent losses. As a result, the oscillator stability, and with it the achievable operating distance, are limited.

A new type of device, working essentially like a differential transformer, exhibits none of the above-mentioned disadvantages. This, however, has only been achieved at great technical expense, since at least two coils, an emitter and a receiver, have to be used. Today's most widely used device of this type even has three coils.

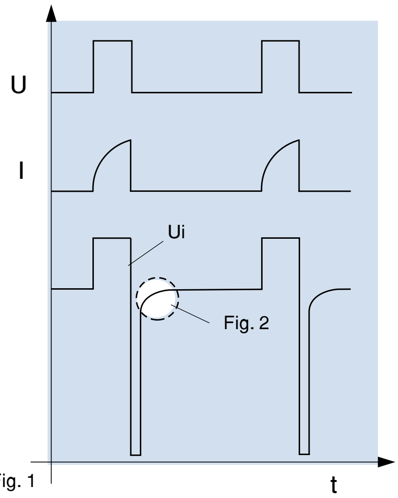

Fig. 1

By contrast, the Condet® technology works in principle like a conventional transformer. In this case, only a single coil is found behind the sensing face. To start off with, this serves as the primary coil during the transmitter current pulse (Fig.1). This transmitter current pulse sets up a magnetic field in front of the coil. As in the case of a secondary coil, a voltage is induced in the conducting target, provoking a current flow. When the transmitter current pulse is abruptly switched off, the object becomes the primary coil. The residual current flowing in it at that moment fades away, thereby inducing a voltage in the device coil, which is now the secondary coil (Fig.2). This reverse induced voltage is evaluated by the device. In the underlying induction principle, as is well known, neither temperature nor losses occur, which has a correspondingly positive effect on Condet® technology behavior.

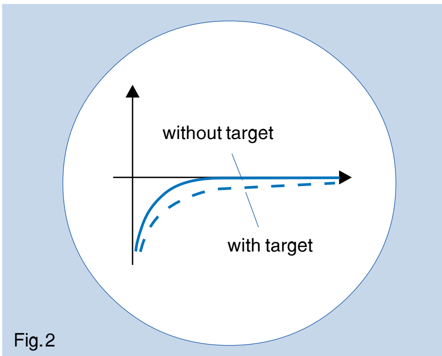

Fig.2

The cycle time (comprising of emission, delay, and reception times) is in the order of 100 to 200 µsec. This corresponds to a frequency range some 20 to 100 times lower than with conventional devices. Interestingly, as a result, the penetration depth of the magnetic field in conducting materials increases sharply. Moreover, if a non-magnetic material with a relatively high specific resistance is chosen, e.g. stainless steel, the penetration depth can reach 1 to 2 mm. This property can be put to good use: the sensing face of the proximity switch can be made from such a metal.

## Construction

The internal construction of the new proximity switches scarcely differs from those usually found in the market. There is only one, albeit fundamental, difference: the housing is made from one single piece, front face (sensing face) included (Fig.3). For the normal

Fig. 3

version, the material used is stainless steel. The usual plastic cap on the front face is no longer required. In addition, the stainless-steel cover over the sensing face now present has a substantial wall thickness. In all other respects, the inside of such a device corresponds completely to conventional technology (Fig.4): a coil inserted into a ferrite core, an electronic module, a LED, connecting leads or connectors ac-

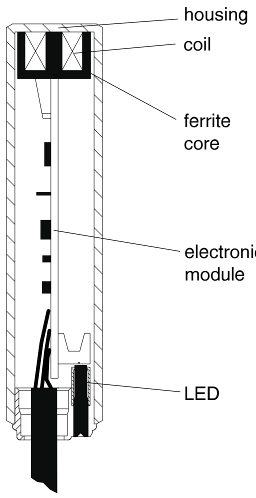

Fig. 4

cording to the type, the whole being resin potted.

## Properties

The devices are basically what their name implies: proximity switches, as have been known for a long time. Only the three most important differences with respect to devices normally available in the market are therefore described below.

### 1. Housing in one single piece

Leaving off the previously necessary plastic cap over the sensing face removes the most important weakness of proximity switches used up till now. Unfortunately, conventional devices are mechanically weak precisely at the place where the danger of overstraining is highest: at the front, opposite the target, which is generally moving. Here, the new devices, with a wall thickness of 0.5 to 1 mm (stainless steel), have outstanding mechanical resistance. In addition, a joint, which has until now frequently caused permeability problems, followed by early failure, has been eliminated: between the metal sleeve and the plastic front cap. Naturally, there is no seal with a one-piece housing. Impermeability is therefore guaranteed without restriction. Additionally, devices in standard executions are also already suitable for use under severe pressure conditions (up to approx. 20 bar). The exact values can be obtained from the data sheets.

### 2. Long operating distances

The operating distances reach very high values. The advantages of long operating distances are sufficiently well known:

- Increased distance from moving parts, thereby reduced danger of mechanical damage, and consequently increased operating reliability.
- Reduced demands with respect to mechanical installation tolerances, thereby reduced costs.
- Simpler adjustment during mounting.
- Safer replacement by maintenance personnel.

Table 1 shows a comparison with previous technology.

The values refer to a standard steel (type FE 360) target. The devices for embeddable mounting are moreover fully flush-mountable without restriction (Fig.5).

| **Size** | **Operating distance** [mm] Standard | Condet® |
|---|---|---|
| M8 embeddable | 1 | **3** |
| M8 non-embeddable | - | **6** |
| M12 embeddable | 2 | **6** |
| M12 non-embeddable | 4 | **10** |
| M18 embeddable | 5 | **10** |
| M18 non-embeddable | 8 | **20** |
| M30 embeddable | 10 | **20** |
| M30 non-embeddable | 15 | **40** |

Table 1

### 3. Long operating distances on aluminum, brass, etc.

Conventional proximity switches achieve their greatest operating distance on steel. The stated operating distances given by manufacturers, as well as the corresponding standard, always refer to this material. In the case of other metals, the operating distance is reduced by a correction factor. Typical values are shown in Table 2.

| Target **material** | **Operating distance** |
|---|---|
| Steel type FE 360 | $s_n$ x 1.00 |
| Brass | $s_n$ x 0.44 |
| Aluminum | $s_n$ x 0.36 |
| Copper | $s_n$ x 0.32 |
| Stainless steel (V2A) | $s_n$ x 0.69 |

Table 2

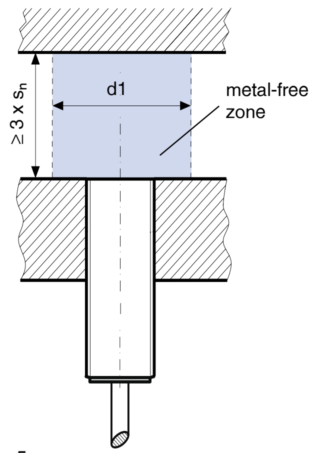

Fig. 5

This means a considerable reduction of application possibilities. For a few years, as mentioned above, additional devices have therefore been available with a correction factor of virtually one, i.e. the identical operating distance on all common non-ferrous metals.

Similarly, devices made using Condet® technology give very good results on non-ferrous metals. However, the correction factor is not always exactly equal to one. Table 3 shows typical values for the most frequently used metals (size M12 non-embeddable).

| Target material (1 mm thick) | Operating distance |
|---|---|
| Steel type FE 360 | $s_n$ x 1.0 |
| Aluminum | $s_n$ x 1.0 |
| Brass | $s_n$ x 1.3 |
| Copper | $s_n$ x 0.8 |
| Stainless steel (1 mm thick) | $s_n$ x 0.5 |
| Stainless steel (2 mm thick) | $s_n$ x 0.9 |

Table 3

The correction factor between steel and aluminum is set at the factory to one, since aluminum, next to steel, is the most frequently used metal. As a result of the high penetration depth of the magnetic field in stainless steel and other non-magnetic, poorly conducting metals (see above), the operating distance on thin sections of these materials is reduced. In fact, it is this effect which makes a one-piece housing possible. The given values refer to a standard 1 mm thick target. In this case also, excellent results are obtained with greater material thicknesses (Table 4, values for size M12 non-embeddable).

| Material | | Operating distance |
|---|---|---|
| Type | Thickness [mm] | [mm] |
| V2A | 0.5 | 1 |
| | 1 | 5 |
| | 2 | 9 |
| | 3 | 11 |
| Zinc | 0.5 | 14 |
| | 1 | 13 |
| | 2 | 11 |
| | 3 | 10 |

Table 4

## Applications

The new proximity switches are suitable for nearly all uses where inductive proximity switches have been used up till now. Their long operating distance and robustness in the area of the sensing face are always important pluses into the bargain. The very special advantages of the new device, however, really only come fully into play in a few well-known difficult application fields:

- Metal working machines: completely insensitive to permanent contact with aggressive cutting oils and drilling emulsions; high resistance to sharp-edged, hot slivers.
- Food industry: no hygiene problem at the joints, no plastic, unlimited resistance to cleaning with aggressive, hot cleaning agents, even in high-pressure jets.
- Chemical industry: degree of protection IP 68 already achieved with the standard version (cable connection). Resistant to many reagents. Special versions with housings of acid-resistant steels are possible without problem.
- Automobile industry: very good results for the detection of aluminum parts, a metal which is used more and more in vehicle construction for weight considerations.

Tip: With suitable choices of materials and wall thicknesses, metallic objects can also be detected through metal barriers!

## Limitations

As described above, Condet® proximity switches work in a similar way to transformers. The target must therefore have a certain surface area. For detecting one-dimensional parts, e.g. thin wires, the process is less suitable. In such cases, devices using Condist® technology (also from Contrinex) are superior.

For detecting parts of non-magnetic, poorly conducting metals (stainless steel, zinc, lead, chromium, titanium, etc.), care must be taken to ensure sufficient object thickness (see Table 4 above).

Condet® proximity switches can (as is also the case for conventional devices) be disturbed by magnetic fields with frequencies in the order of magnitude of the operating frequency of the device. This results in inaccurate switching behavior. It should therefore be borne in mind that the operating frequency of Condet® switches, as mentioned above, is substantially lower than that of conventional devices.

## Economic Aspects

On the grounds of its simple concept, Condet® technology makes economic manufacture of the devices possible:

- The one-piece stainless steel housing is not more expensive than a conventional brass one when the additional costs for galvanization, the plastic cap, and their assembly are taken into consideration.
- The device needs only a single, simple coil; no high-frequency braiding, no tapping.
- The electronic module consists of a simple ASIC and a few unobtrusive SMDs, just like standard devices found in the market.

## Summary

Proximity switches made according to Condet® technology exhibit all the properties that have helped the inductive proximity switches available in the market to achieve their popularity and wide usage. On top of these, there are a few important characteristics which broaden the application area, simplify use, and increase operation reliability: a robust, one-piece, impervious, stainless-steel housing, and long operating distances that in addition are also achieved on aluminum, brass, etc. Furthermore, the economic efficiency of previous devices is completely preserved.

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# Application Tips Series 700

## Comparison with standard devices

Compared to standard inductive proximity switches, Condet® devices feature numerous advantages, in particular:

- The devices are built into a one-piece, stainless-steel housing (sensing face included) and, as a result, are extremely robust as well as absolutely impervious at the front.
- They achieve very long operating distances on steel.
- Similarly long operating distances are also obtained on non-ferrous metals (aluminum, brass etc.).

picture 1

Even though Condet® devices are inductive proximity switches, their way of functioning, as described in detail in the Contrinex technical note no. 9 “Condet® Proximity Switches”, differs from that of conventional executions. In consequence, their detection properties are only the same at first glance. Closer examination, however, shows a few differences that could be important, depending on the application. These differences are only partially apparent from the data sheets. A detailed examination, with no claim to completeness, is presented below. Attention to these points will help to take optimum advantage of the new devices, and to avoid problems and failures.

## Target influence

### Target material

In principle, Condet® devices give approximately the same operating distances on non-ferrous metals as on steel (with standard devices, an important reduction must be reckoned with on non-ferrous metals). The correction factor is, however, not exactly 1 (table 1). It is, moreover, dependent on the device’s size, execution (embeddable / non-embeddable) and the target geometry (dimensions and thickness). Consequently, it is not possible to give data for all conceivable cases in this paper. However, the devices are factory adjusted so that, using a standard target (according to IEC / EN 60947-5-2), they have the same operating distance on both steel and aluminum.

| **Metal** (for M12 embeddable) | **Correction factor** |
|---|---|
| Steel (FE 360) | **1.00** |
| Aluminum | **1.00** |
| Brass | **1.30** |
| Zinc | **1.15** |
| Magnesium | **1.05** |
| Titanium | **0.90** |
| Copper | **0.85** |
| Stainless steel (1.4301) | **0.45** |

Table 1a

| **Metal** (for M30 non-embeddable) | **Correction factor** |
|---|---|
| Steel (FE 360) | **1.00** |
| Aluminum | **1.00** |
| Brass | **1.20** |
| Zinc | **1.10** |
| Magnesium | **1.25** |
| Titanium | **0.00*** |
| Copper | **0.85** |
| Stainless steel (1.4301) | **0.00*** |

Table 1b ***no detection**

Stainless steel is a special case. Because of its low magnetic permeability and high specific electrical resistance, the depth of penetration for the alternating magnetic field generated by the proximity switch is relatively high. It is, incidentally, this property that makes the use of a closed stainless-steel housing possible. In practice, this means that the operating distance on this material is considerably influenced by its thickness (see below). Although the term stainless steel encompasses a great variety of alloys, the behavior of all non-magnetic variants is very similar.

High penetration depths are also observed with other metals and alloys; however, these are of negligible technical importance.

### Target thickness

The sensing behavior of conventional standard inductive devices is only slightly influenced by the thickness of the target. Foils, in particular those of aluminum, are an exception. In comparison to thicker objects, they produce a much higher (2 to 3 times) operating distance.

Condet® devices, on the other hand, behave differently. As a rule of thumb, the operating distance for a material thickness of over about 1 mm remains constant for the metals (stainless steel excepted) generally used in machine construction. Below 1 mm, it decreases. Foils, as a rule, cannot be detected.

In the case of stainless steel, a much greater material thickness must be reckoned with in order to achieve the full operating distance (fig. 1). Additionally, the behavior is dependent on the device diameter (because of the various working frequencies), and on the execution (embeddable / non-embeddable). This property of stainless steel can be used to advantage (see next section but one).

### Target dimensions

Condet® proximity switches are outstanding for the detection of flat objects (fig. 2). The angle of the surface to the device is not particularly important.

The operating distances with rod-like objects or wires are, in comparison, lower (fig. 3). In such cases, devices using Condist® technology give far better results.

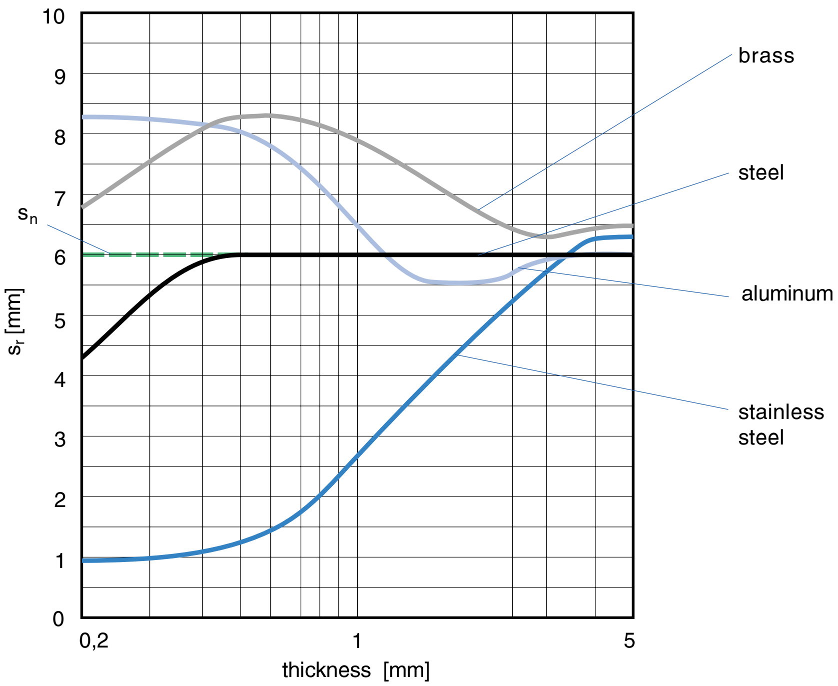


fig. 1a : Operating distance as a function of material thickness (M12 embeddable)

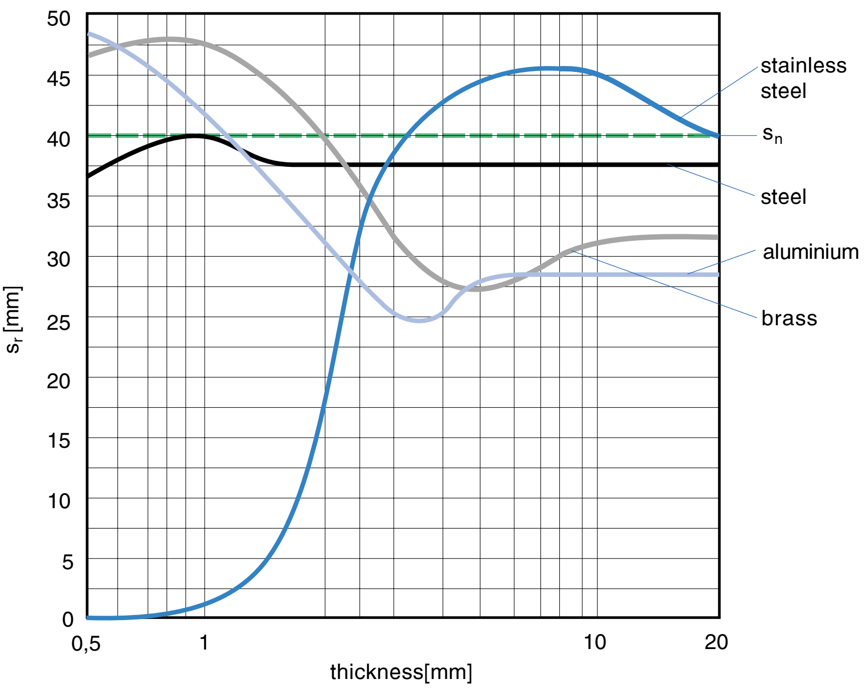


fig. 1b: Operating distance as a function of material thickness (M30 non-embeddable)

### Detection through metal walls

The relatively high penetration depth of the field generated by Condet® oscillators can be used to advantage. In effect, it permits the detection of metallic objects through metal walls (fig. 4). With its high

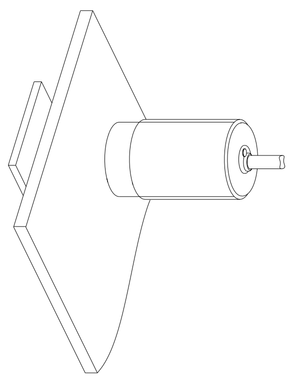

fig. 4 (Detection through a metal wall)

penetration depth, stainless steel is best. However, with the necessary precautions, detection is also possible through other metals. There are no generally valid rules for the choice of the most suitable type of proximity switch, or for the dimensions of the wall and target. The best configuration must be determined from case to case by trials, for which Contrinex will gladly provide help.

## Mounting

### Surrounding metals

Mounting of the embeddable execution is not at all critical, and scarcely differs from the procedure with conventional devices. However, the usual free spaces must, of course, be respected. On the other hand, with non-embeddable versions, the considerably greater tendency to be influenced by non-ferrous metals must be considered. Contrary to standard devices, this is roughly the same as that of steel. It should further be noted that, due to the technology used, the zone of influence extends further back and over a wider diameter than usual, although the maximum values are strictly maintained according to the standard. With large, non-embeddable devices especially, it is important to pay proper attention to the necessary free spaces.

These minimum free spaces are given in the data sheets and the instruction leaflets accompanying the products. The distances to be respected with non-embeddable devices of large diameters are considerable in comparison to standard devices. However, use can be made of the fact that these distances are material dependent (see information on the data sheets of the respective devices).

**Fixing**

The fixing of Condet® proximity switches is basically the same as for standard devices. With non-embeddable devices, especially size M30, the aptitude of the device to be influenced by the fixation parts should be borne in mind (see above, "Surrounding metals"). The use of plastic fixing clamps, commonly found in the market (picture 2 – also obtainable from

picture 2

Contrinex), is an effective possibility in this case. It is further recommended to pay attention to the choice of fixing nuts. The influence of the stainless steel nuts delivered with the device is much smaller than that of brass or steel nuts. This can lead to problems, since the visual distinction between stainless-steel and nickel- or chrome-plated surfaces is not easy to make, even for professionals.

**Alignment**

As with all proximity switches, in order to avoid mutual interference, a minimum distance must be maintained between neighboring devices. These are given in the data sheets. Compared to standard devices, due to the technology used, these are larger with Condet® proximity switches. It should further be observed that for axially

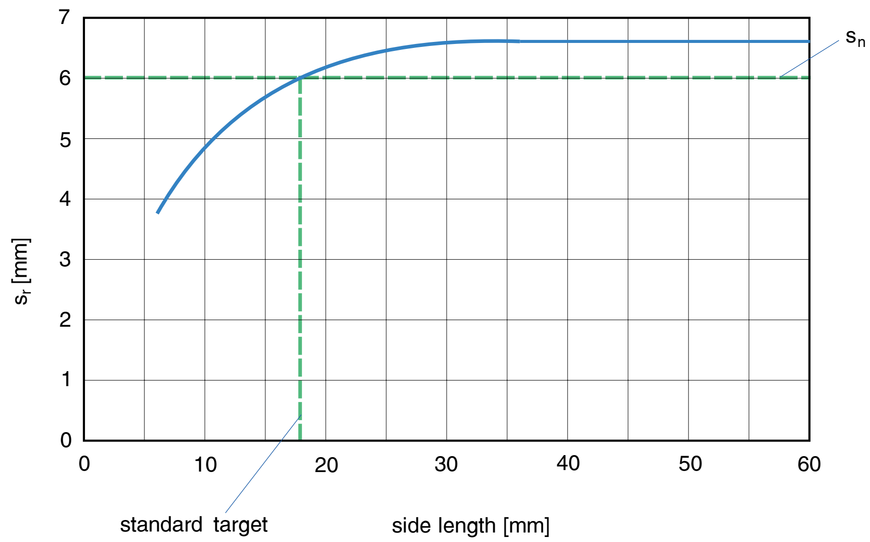


fig. 2a: Operating distance as a function of the surface (M12 embeddable)

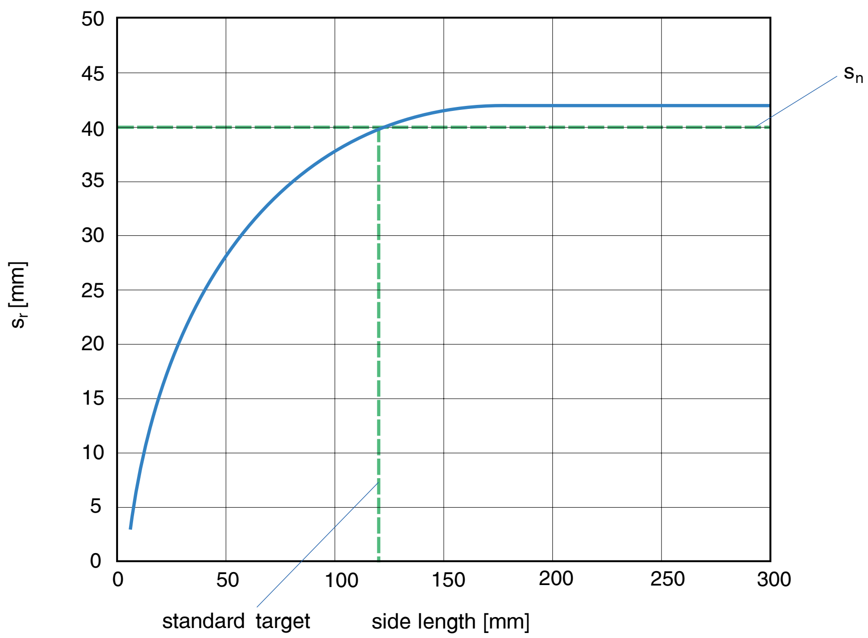


fig. 2b: Operating distance as a function of the surface (M30 non-embeddable)

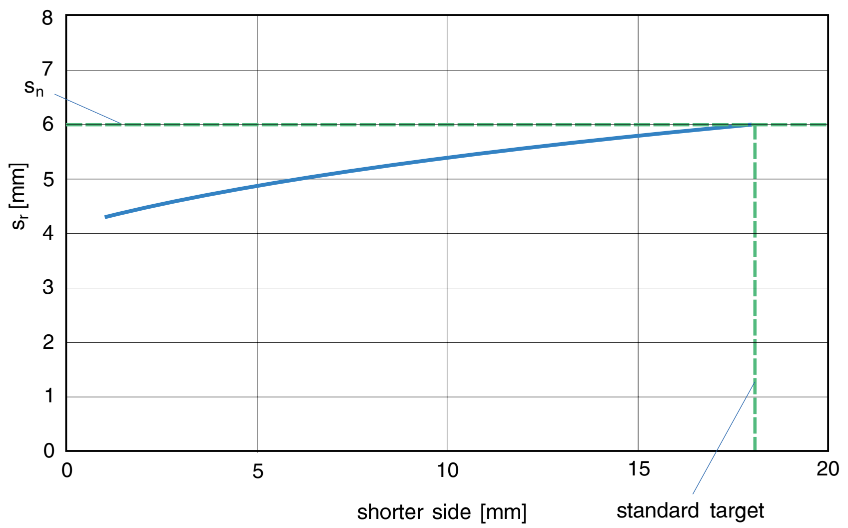

fig. 3a: Operating distance as a function of length/width ratio (M12 embeddable)

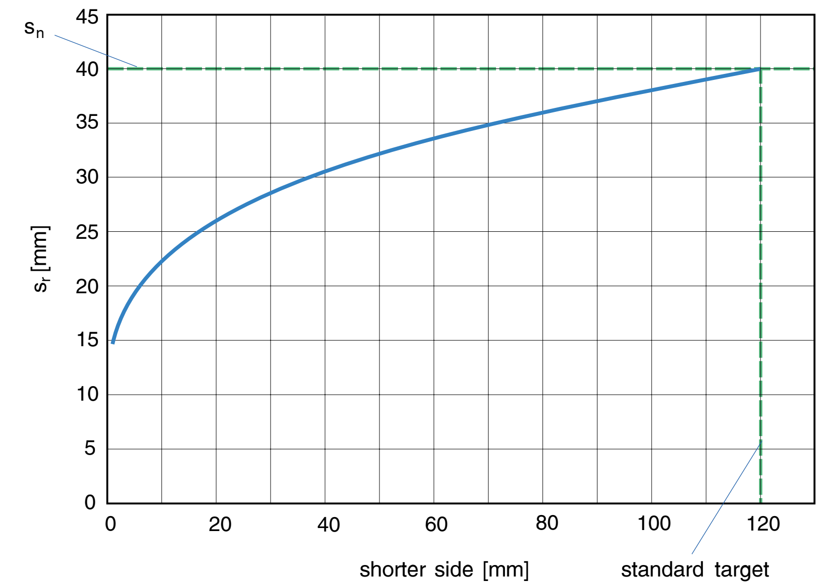

fig. 3b: Operating distance as a function of length/width ratio (M30 non-embeddable)

opposed devices, a relatively large distance is necessary.

The devices react normally, even if the distances are too small, but the switching edges are irregular (flutter). Nevertheless, objects can be detected without problem, provided that this fluttering does not interfere or can be filtered by software.

There are various possibilities to reduce this mutual interference. The most important of these are described in the Contrinex technical note no. 6, “Tips for Mounting Inductive Proximity Switches”. In addition, shielding can be employed.

## Magnetic fields

All inductive proximity switches are disturbed by external alternating magnetic fields whose frequencies lie close to the device’s operating frequency. Contrary to standard proximity switches, whose operating frequencies lie in the region of a few 100 kHz, Condet devices work in the region of a few kHz. Consequently, the potential to be influenced differs.

Experience shows that, in particular, 50 Hz magnetic fields with a high harmonics content, such as stray fields from mains transformers as well as nearby stepping motors can lead to problems with Condet® devices. On the other hand, the potential to be influenced by switching power supplies, induction heaters etc. is markedly lower.

Permanent magnetic fields and low frequency alternating fields (50 / 60 Hz) with low harmonics content are permissible up to a field strength of 1,000 A/m (size M30: 80 A/m).

## Liquids

Thanks to their one-piece stainless-steel housing (picture 3), Condet® proximity switches are by nature particularly suitable for use in environments where liquids are present. The chemical resistance of stainless steel itself sets the limits, except for the connection side, where attention has to be paid. With cable executions, impermeability is excellent from the construction point of view, but the chemical resistance of the plastics used (PBTP, PUR) can set limits. With connector versions, this is evidently also the case, but in addition, there is a further critical point over which the proximity switch manufacturer has no control: the junction between the connector


picture 3

and the device. A missing or unsuitably dimensioned O-ring on the connector side, or a notch in the connection area on the device side, can considerably interfere with sealing. It is thus recommended to use cable versions in applications where sealing is critical.

## EMC

Condet® proximity switches meet all EMC requirements according to EN 60947-5-2 and the standards mentioned therein. They are thus also usable in heavily disturbed industrial environments without problem. It should merely be observed that in comparison to standard devices, they behave differently with respect to magnetic frequencies in the range of their operating frequencies (see above "Magnetic fields").

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# Diffuse sensors with cylindrical detection zone

## The problem

Diffuse sensors enjoy great popularity with users and are consequently often employed. With these devices, the pulsed light from the emitting diode falls on an object of any shape or color, from which it is reflected in a diffuse manner. In turn, part of this reflected light reaches the light-receiving device, which is located in the same device (fig.1). If the intensity of the

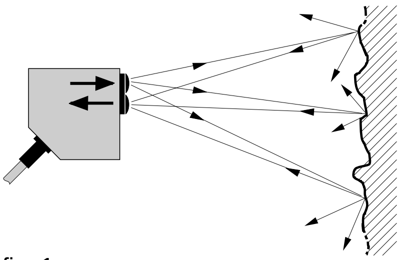

fig. 1

received light is sufficient, the output is switched. Operating distances depend on target size, color and surface structure.

The use of diffuse sensors is generally trouble-free. However, an almost insoluble problem appears when devices with very small diameters, short operating distances and/or narrow total beam angle are called for. Very small diameter devices are to be understood as M5 or less. Below is an example:

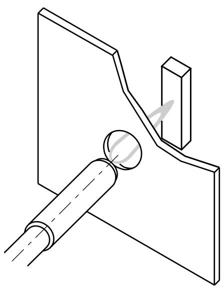

fig. 2

## Technical situation

Conventional diffuse sensors work using optical lenses. It should be noted here that, in the same device, two optical systems are required, namely one each for the emitter and the receiver.

No appreciable problems arise when scaling down these optical systems where small devices have to be made. However, there are fundamental limitations. The lenses themselves can be reduced in size almost indefinitely, but the dimensions of the transmitter and receiver components cannot. Light emitting diodes (LEDs), which are available down to very small housing sizes, are generally used as the transmitters. Nevertheless, these housings are still much too large for really small reflex sensors. Thus, the only solution remaining is a change to unhoused chips, whose use is, however, linked to considerable additional costs. Only now can the basic problem be recognized. By way of illustration, such an optical system is shown to scale in fig. 4. It can immediately be seen that the LED chip is extremely large in relation to the lens diameter. Inevitably, a very poor beam quality results. Both the quantity of output-coupled light and the total beam angle on the

picture 1

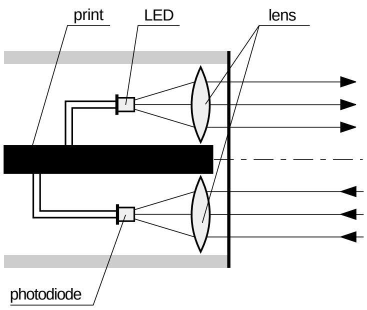


fig. 3

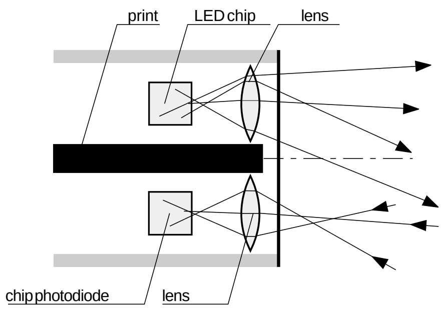


fig. 4

transmitter and receiver sides leave much to be desired. Smaller LED chips would, of course, be the solution, but these unfortunately do not exist. An additional disadvantage is that the roughly cubic LED chips emit their light more or less uniformly in all directions. On the receiver side, incidentally, the situation is no better.

An elegant and effective solution for light coupling and shaping has been realized by Contrinex in the form of its cylindrical miniature devices (series 1040 / 1050), in which the lenses have been replaced by concave mirrors.

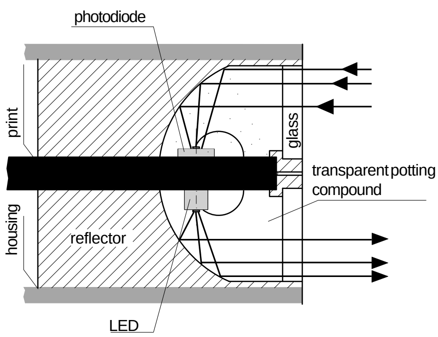


fig. 5

The result clearly is impressive, at least as far as the operating distance (50 mm) is concerned. The total beam angle of ± 22° is however quite large, in fact too large for many applications.

For light-based detection assignments on a miniature scale, optical fibers are very well suited. There is no need to enter into their numerous advantages here. However, all optical fiber solutions likewise suffer from the disadvantage of a large total beam angle, so that the problem mentioned above is still not resolved. The total beam angle of optical fibers is essentially given by the numerical aperture of the optical fiber material, and cannot therefore be influenced.

picture 2

From a technical point of view, the obvious solution is to choose lasers where narrow total beam angles are required. However, laser devices today cannot even nearly be inserted into such small housings as users would wish. In addition, there are economic considerations that currently limit the more widespread use of laser devices.

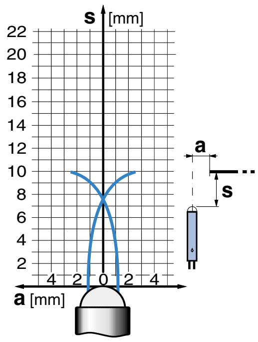


fig. 7

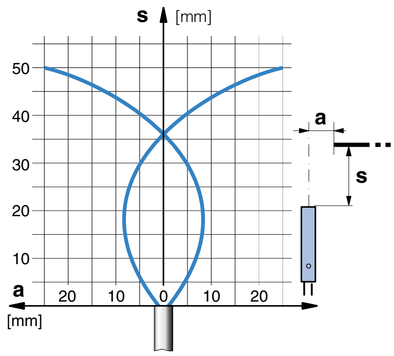


fig. 8

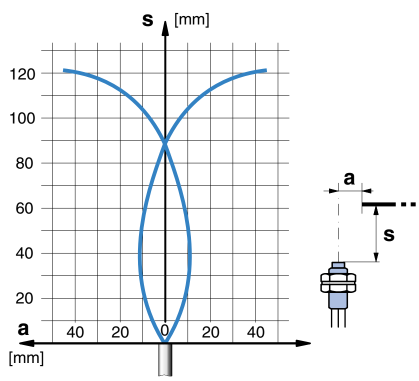


fig. 9

## New technique: Spherical optics

### Principle of the technology

In view of many unresolved detection problems in the miniature field, Contrinex decided to look for new solutions. Not without success! Our work has shown that, surprisingly, amazing results can be achieved with spherical optics.

In order to separate the transmitter and receiver parts, a sapphire sphere is cut in two. Between the two halves of the sphere, there is an opaque layer to prevent an optical short-circuit. The transmitter and receiver semiconductor chips are mounted as closely as possible to the surface of the sphere. As can be seen in fig. 6, the chips (LED and photodiode) are somewhat off the optical axis. This is normally a disadvantage in optics, but not in this case, since the transmission beam and the detection zone of the receiver part "squint" somewhat, i.e. they cross at a certain distance from the device. As a result, the detection zone is approximately cylindrical. Understandably, this arrangement does not give optimum light efficiency. In this case, however, this can be easily accepted.

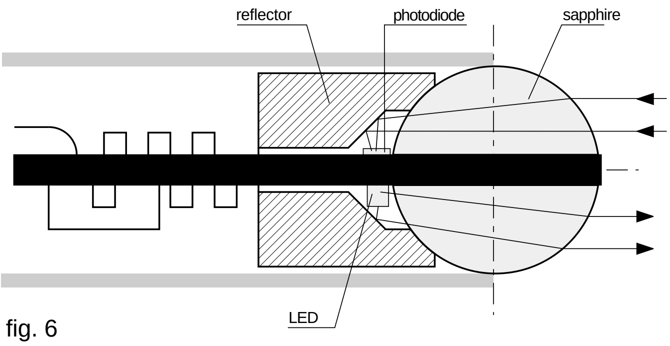


fig. 6

The optical system described above is vacuum potted together with the electronics module in transparent resin.

### Notes on performance

Fig. 7 shows the response curve of the new device (execution with 10 mm operating distance). For comparison, the response curves of previous Contrinex miniature devices (fig. 8) and a typical optical fiber (fig. 9) are also shown.

The remaining performance data is unchanged. Product data sheets can be downloaded from the Contrinex website (www.contrinex.com).

**CONTRINEX**

## Technical data:

(according to IEC 60947-5-2)

| | |
|---|---|
| Operating distance | 10 / 20 mm |
| Supply voltage range $U_B$ | 10 ... 30 VDC |
| Output current | 100 mA |
| No-load supply current | 15 mA |
| Switching frequency | 250 Hz |
| Switching times | 2.5 msec |
| Max. ambient light: | |
| Halogen light | 5,000 Lux |
| Sunlight | 10,000 Lux |
| Ambient temperature range | 0 ... + 55 $^oC$ |
| Degree of protection | IP 67 |
| EMC protection: | |
| IEC 60255-5 | 1 kV |
| IEC 61000-4-2 | Level 2 |
| IEC 61000-4-3 | Level 3 |
| IEC 61000-4-4 | Level 2 |

### Products

Two groups of the new devices are presently available:

- one group with a 10 mm operating distance and narrowest total beam angle;
- a second group with a 20 mm operating distance and a somewhat wider total beam angle.

For both groups, there are cable executions in D4 and M5 housings, PNP and NPN switching. All the usual functions are built into the devices and, thanks to the stainless steel housings and vacuum potting, they are highly resistant to environmental influences. The electrical data corresponds to that of larger executions.

## Application examples

### Detection through holes and gaps

The detection of objects through holes and gaps is only possible in a very limited way with diffuse sensors currently available in the market. However, the new devices succeed in such applications, even in the case of small diameters or gap widths (fig. 10).

### Operating-distance independent approach

With laterally approaching objects, whose distance from the switch cannot be kept constant, there used to be considerable variations in the switching point with previously known models. Here, the new devices yield much better results (fig. 11).

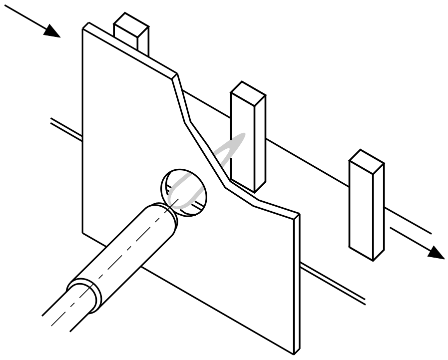

Fig. 10

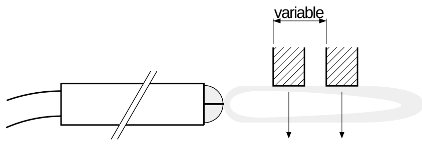


fig. 11

### Longer operating distances than inductive devices

Inductive proximity switches are also available in the above-mentioned sizes and, strictly speaking, would be very suitable for solving the problems described above (as long as the objects to be detected were electrically conducting). However, their operating distances are very short (0.8 … 1.5 mm) and, as a result, frequently insufficient. The closest alternatives are photoelectric devices. However, until now, the smallest operating distance with these was about 50 mm. For operating distances between 1.5 mm and 50 mm, nothing has been available until now. The new devices fill this gap.

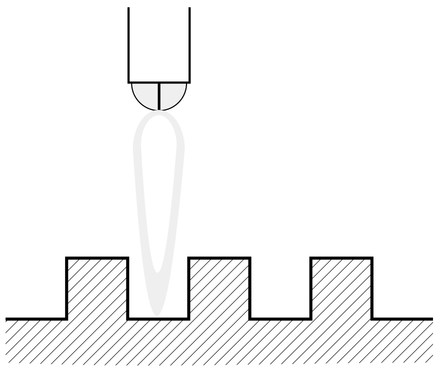

Fig. 12

### Detection of closely lined-up objects

The wide beam of conventional photoelectric devices makes the detection of closely lined-up objects, gear wheels, grids etc. almost impossible. The new technology, on the other hand, gives very good results here (fig. 12).

## Dimensional drawings

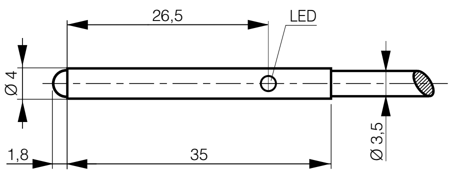


Fig. 13

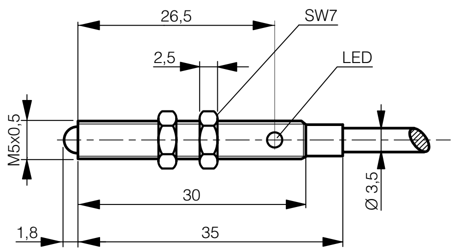


Fig. 14

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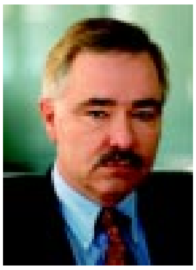

Dipl.-Ing. Peter Heimlicher studied electronics at the ETH in Zurich. In 1972, immediately after his studies, he founded CONTRINEX AG, of which he has been Managing Director ever since. His company is specialized in the manufacture of high-performance inductive and photoelectric proximity switches.