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Waldkirch, September 27, 2010

Is it possible to use standard components for safety functions?
or
how good is a good MTTFd value?

Dear Madam or Sir,

Following the appearance of the new safety standards EN ISO 13849-1 and EN 62061, more and more machine manufacturers are asking about the use of standard sensors for safety functions.

Component manufacturers such as SICK usually quote only the MTTFd or MTTF value.

Is this value alone enough to determine usage, and is it permissible to use standard components for safety functions in the first place?

Why don't the component manufacturers quote parameters like Performance Level or Safety Integrity Level for standard components?

This article is intended to provide an answer to these questions and some insight into important aspects of the use of standard sensors for safety functions. Two example applications are used to illustrate the difference in use between standard components and safety components.

Yours sincerely,

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Otto Görnemann
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Is it possible to use standard components in machine safety applications?

In principle, yes.

On the one hand, the new safety standards EN ISO 13849-1 and EN 62061 provide greater flexibility for the machine manufacturer, allowing savings in materials costs by the use of standard components in safety circuits.
On the other hand, system designers have more work to do in evaluating the reliability and effects of optimization measures.

The reliability value MTTF (Mean Time To Failure) is one of the factors that feature in such an assessment.
This value is increasingly requested from machine manufacturers for standard components so that those components can be used for safety functions. The MTTF value is, however, only one part of the data and protective measures that need to be taken into account for safety functions.

What do you need to keep in mind when designing safety functions in accordance with the new safety standards EN ISO 13849-1 and EN 62061?

The following list of criteria is a general overview:

- The hardware and software structure (architecture)
- The reliability of the components, in terms of safety
- The effectiveness of fault detection mechanisms
- The measures taken to combat common cause failures
- The design process of the hardware and software
- Suitability for the stresses of operation and for the ambient conditions

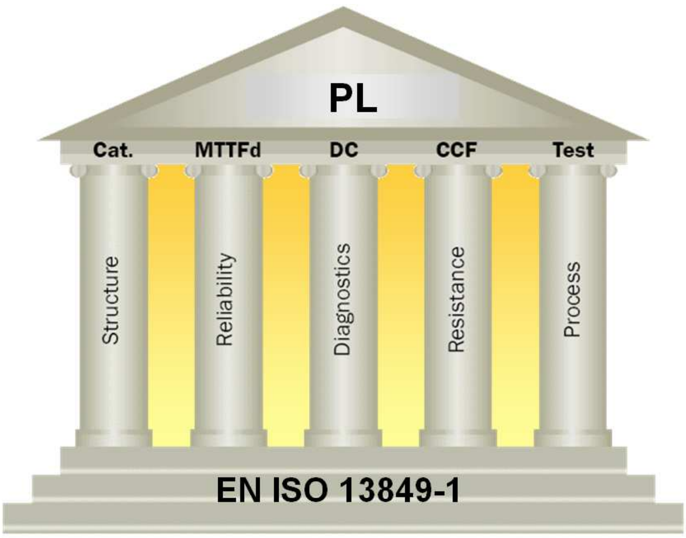


Fig. 1: The pillars for determining the safety performance of a subsystem in accordance with EN ISO 13849-1

So-called "subsystems" (e.g. safety light curtains or safety controllers) are identified for the purpose of computing and evaluating a safety function (see Fig. 2).

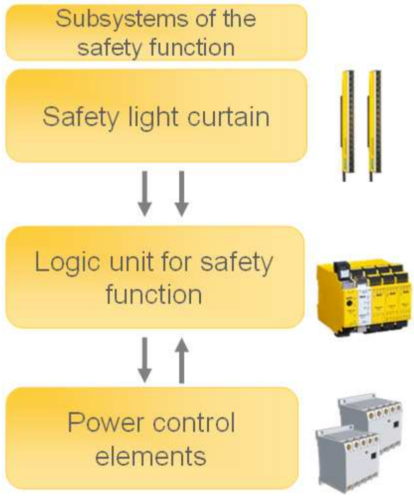


Fig. 2: Subsystems in a safety system

The Performance Level (PL) in accordance with EN ISO 13849-1 or the Safety Integrity Level (SIL) in accordance with EN 62061 is determined for these subsystems.

Fault detection for certain discrete components in the safety-related control system – such as contactors, standard valves, or electromechanical switches (locks) – requires additional measures to be taken through the higher-level control system.

In the case of subsystems with optical sensors, it is vital to consider not only the functional safety aspects but also the optical characteristics that determine the necessary sensor detection capability.
These characteristics vary depending on whether the safety function requires the detection of persons or objects. Table 1 on page 13 shows additional optical characteristics for the detection of persons.

What is the role of MTTFd?

MTTFd is the expected mean time to dangerous failure, in years.
It is a statistical value determined through life testing or reliability predictions based on the probability of failure of the components used.
MTTFd has nothing to do with “guaranteed useful life” or “failure-free time.”
Dangerous failure of a component in the safety-related part of the control system can result in a safety function not being carried out as desired, so that a potential hazard for the operating personnel is not eliminated.

For example, the effect could be that a machine does not stop when its guard is opened.
MTTFd is just one of the factors which describe the quality of the components used.

Components for which only an MTTFd or B_{10d} value is stated and which satisfy the basic safety principles (see “Explanation of terms” box on p. 4) can be considered for use as elements in subsystems (e.g. the contactors in Figure 2).

What other criteria need to be considered as well?

In order to completely and correctly evaluate a safety function for which standard components are used, so that any possible dangerous faults can be brought under control, the user also needs to consider the following:

- The structure of the hardware (its category) and the software
- The specification of the system's capacity to detect or identify internal faults (diagnostic coverage, DC)
- Documented evidence of measures taken for the avoidance of common cause failures (CCF) in the application
- The design process
- The application conditions

and

- The systematic failures (see “Explanation of terms” box)

EN 954-1 classified the structural measures (the architectures) into categories; these same categories are contained in EN ISO 13849-1.

In addition to the structural criteria, the new standards place considerable emphasis on diagnostics and fault avoidance measures.

The other items listed focus on EN ISO 13849-1 with the Performance Level (PL), but are similarly valid when applying EN 62061.

Explanation of terms

Conformity with **basic safety principles** is a prerequisite for safety functions of category B and higher. They incorporate generally recognized sound engineering practices for the component manufacturer, such as those described in product standards (including ambient conditions, principles of operation, ...). Measures for bringing systematic errors under control have been taken during development and production.
The user is also subject to obligations, such as conforming to specifications and ensuring proper fastening (see EN ISO 13849-2, sections A.2, B.2, C.2, D.2).
A component should be selected so that it works correctly under all expected **application conditions and ambient influences** (e.g. temperature, humidity, vibrations, electromagnetic interference, optical disturbance), or so that the machine remains in or goes into a safe state if the component fails under those conditions.

Conformity with **well-tried safety principles** is a prerequisite for category 1 and higher. This refers to principles which make it possible to exclude certain faults through the use or configuration of components, for example by the use of components with a defined (known) failure mode or with positively guided contacts or by techniques such as redundancy and diversity (EN ISO 13849-2, sections A.3 and D.3).

The use of **well-tried components** is a prerequisite for category 1. Well-tried component are components which have been widely used in the past with successful results in specific safety-related applications, or which have been made and verified using principles which demonstrate their suitability and reliability for safety-related applications. Examples are listed in EN ISO 13849-2, sections B.4, D.4. Some components, such as standard PLCs or standard photoelectric switches, are not included in this definition.

The **MTTFd value (Mean Time To dangerous Failure)** is the expected mean time to dangerous failure of the component, in years. It is greater than or equal to the MTTF (Mean Time To Failure) and takes into account only those faults that would result in a dangerous failure.
If the component manufacturer quotes only the MTTF value, users must either decide for themselves what proportion of the faults in their application are dangerous, or they must consult the manufacturer. It is also possible to apply the MTTF value as the MTTFd value. Annexes C and D of EN ISO13849-1 describe other approaches.

Systematic failures are those failures that can be traced back to faults arising during specific states, stresses, and input conditions. These faults are the result of errors made during development, manufacture, operation, or maintenance.

The **B_{10d} value** is a statistical value for components subject to wear. It states the average number of switching operations where 10% of the components fail to danger. The corresponding MTTFd value is calculated from the B_{10d} value and the switching cycles of the component (see EN ISO 13849-1).

Measures to take to combat common cause failures (CCF) are described in EN ISO 13849-1, such as:
- Physical separation between the signal paths
- Diversity
- Protection against overvoltage
- Incorporating the results of an FMEA into the development process
- Protection from electromagnetic interference
- Protection from all relevant ambient influences

The standard offers a points system for evaluating the measures.

How is the required safety performance level determined?

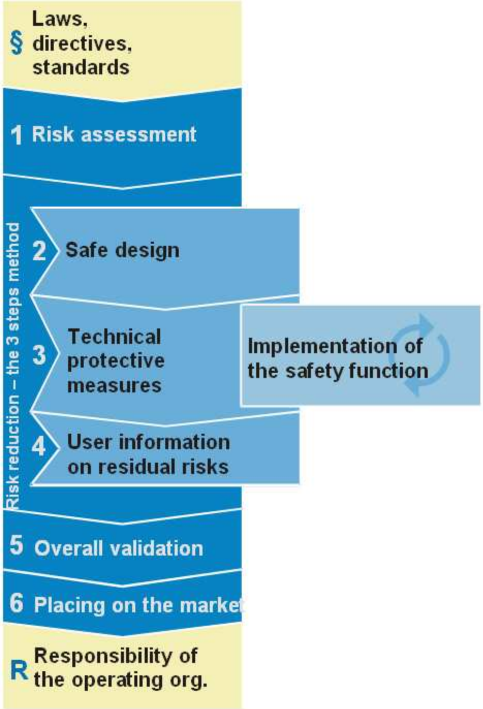


Fig. 3: Six steps to a safe machine

SICK's "Guidelines for Safe Machinery" describe the laws, standards, and rules to be observed by the user and possible protective measures in six steps.
Part of Step 3 is determining the required safety performance level.
In EN ISO 13849-1 a risk graph is used to determine this Performance Level required – PLr (see Figure 4).
The system designer first evaluates the hazards of the machine without any protective measures, based on:

- The severity of injury
- The frequency and/or the duration of the hazard
- The possibility of avoiding the hazard or limiting the damage/injury

This gives a Performance Level PLr = "a" to "e" for the required quality of the protective measures, where "e" represents the greatest risk reduction.

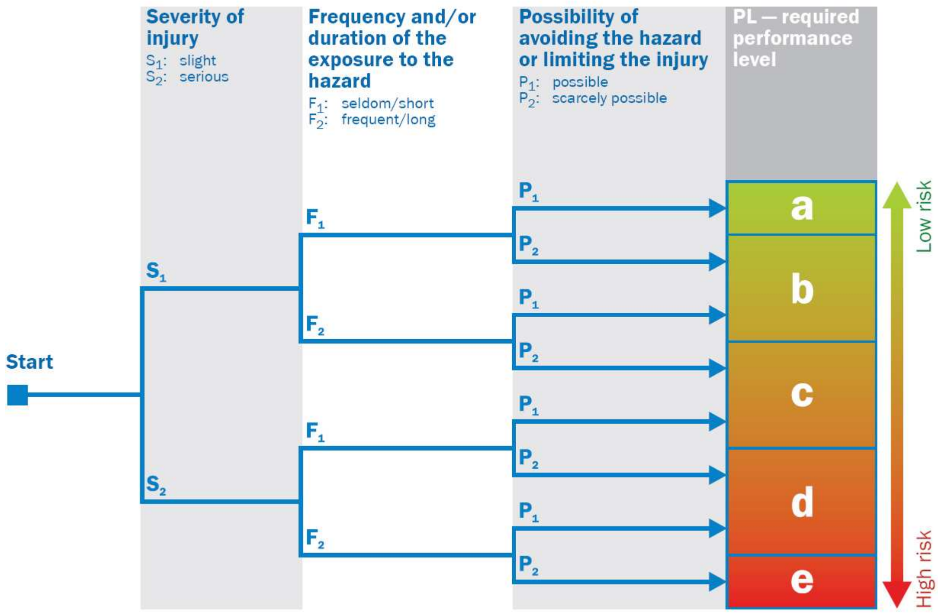


Fig. 4: Determining the required Performance Level in accordance with EN ISO 13849-1 (risk graph)

Does the technical protective measure provide the required safety performance?

EN ISO 13849-1 gives a guide to determining whether the technical protective measure would provide the required level of safety performance (PLr).
The standard also offers a bar graph as a simplified overview, which summarizes required criteria (see Figure 5). Not shown in ths bar graph are: the requirements for the design process, the application conditions and the measures against systematic failures (see “Explanation of terms” box).

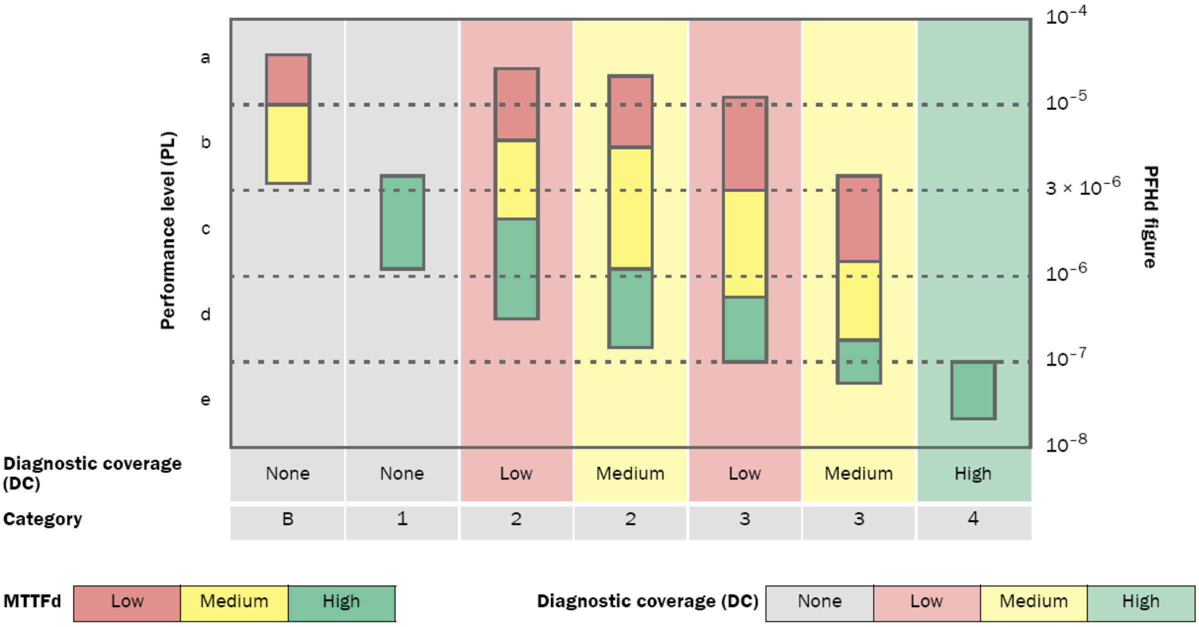


Fig. 5: Determining the PL of a subsystem according to the simplified method of EN ISO 13849-1

Example applications to illustrate the most important aspects

Two tasks and a variety of possible solutions are used to evaluate the use of standard sensors for safety functions.

Task 1 – Monitoring the guard door on a grinding mill.

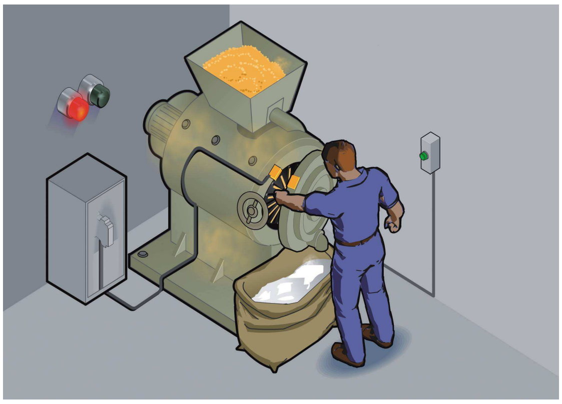


Fig. 6: Safeguarding a grinding mill with guard door lock in Task 1

The guard door of the grinding mill is opened and closed about four times per hour. The safety function has to ensure immediate shutdown of the mill motor when the door is opened.
The risk assessment resulted in a required Performance Level PLr = "d."

Solution 1.1 – A magnetic switch for safety functions

A proximity switch designed for safety functions is used as a sensor.
The safety system consists of the safety sensor, a logic unit, and the power control elements for shutting down the dangerous movement.

The PL achieved is determined for each of these subsystems.
The component manufacturer provides the necessary data and applied standards for the components used, including safety components (see Figure 7).

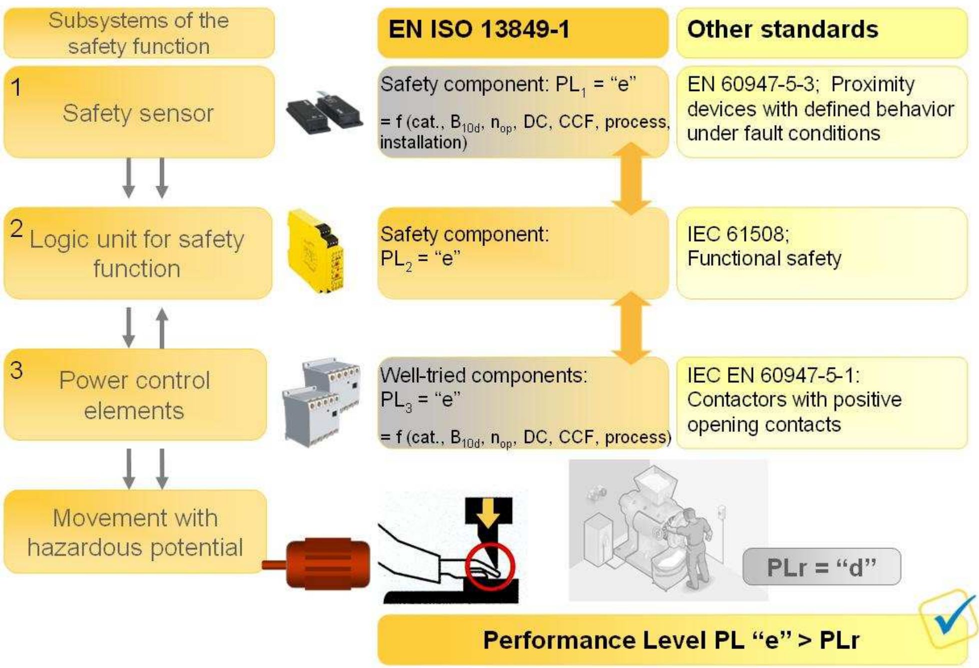


Fig. 7: Safety system with subsystems for Solution 1.1 of Task 1, its evaluation according to EN ISO 13849-1, and the relevant product standards

As Figure 7 shows, a Performance Level (PL) is not stated by the manufacturer for all the components used.
In order to determine the PL, the user has to evaluate the structure (the category), the diagnostic and testing measures (DC) such as those implemented by the logic unit, and the measures taken to combat common cause failures (CCF).

The sensor should be positioned on the machine so as to prevent anyone from bypassing the protective measure (in other words, tamper-proof positioning).
The safety performance level determined in Solution 1.1 is PL = “e” which is even higher than the required PLr = “d.”

Result:
The safety function can be used for safeguarding.

Solution 1.2 – One standard inductive sensor

A single standard inductive sensor is to be used for the safety function (Figure 8).
The manufacturer gives an MTTFd of 83 years for the sensor (MTTFd = “High” according to EN ISO 13849-1).

The sensor was developed in accordance with product standard EN 60947-5-2. Conformity with the basic safety principles for that specific type of manufacturer can therefore be assumed (see “Explanation of terms” box).

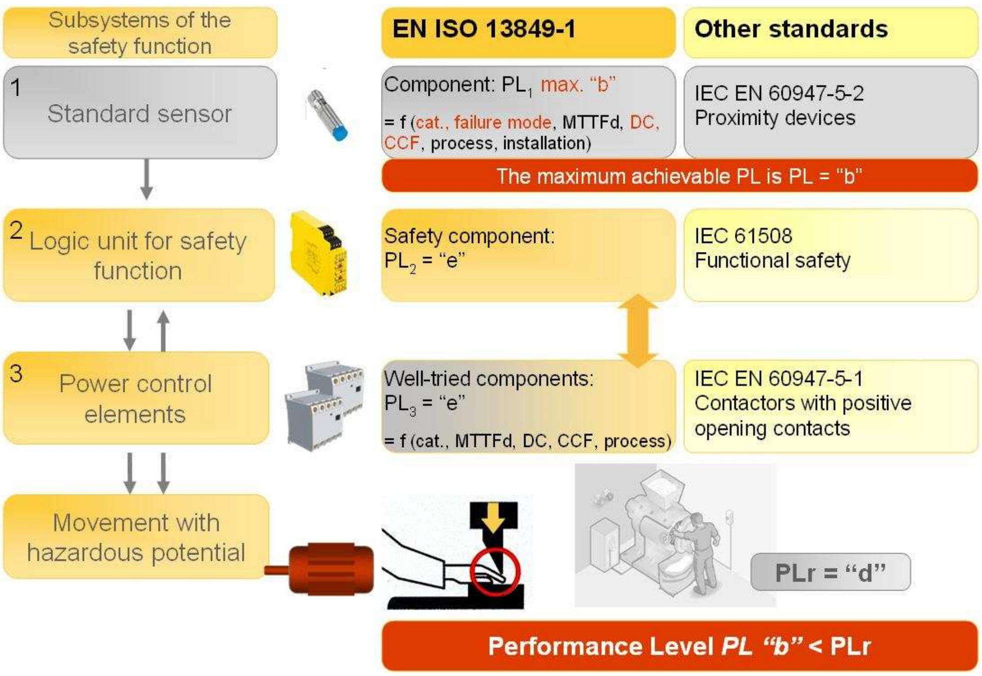


Fig. 8: Safety system with subsystems for Solution 1.2, its evaluation according to EN ISO 13849-1, and the relevant product standards

This standard sensor is usually equipped with complex electronic components (e.g. µC, ASIC, transistor arrays). The manufacturer does not specify the failure mode in the event of an internal fault.
That means this sensor is not a well-tried component with well-tried safety principles as defined by EN ISO 13849-2 – it is simply a standard component (see “Explanation of terms” box).
This restriction means that the safety evaluation cannot result in anything higher than category B or Performance Level b, assuming that the component can withstand the expected ambient influences in the application (see “Explanation of terms” box).

Result

With Solution 1.2 the required Performance Level d is not achieved, despite the high MTTFd–value of the sensor (see Figure 5).

An additional, external, electrical test mechanism would be able to detect some of the safety-related faults, but it is not possible to quantify the full diagnostic coverage (DC) because the internal structure and the failure modes of the sensor are unknown.

Therefore the test mechanism would not change the result of the safety evaluation.

Solution 1.3 – Two identical, standard inductive sensors

Two of the sensors from Solution 1.2 are used as a dual-channel input circuit. The logic unit provides the diagnostics and checks the input circuit for the plausibility of the input signals (both channels must always have identical signal levels).

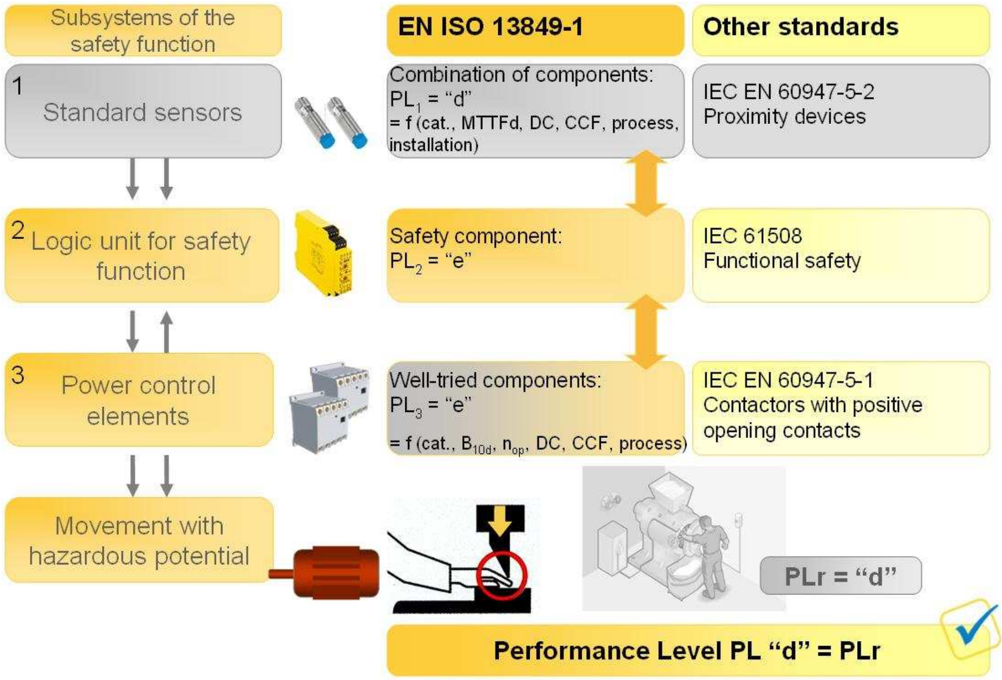


Fig. 9: Two identical standard sensors in a dual-channel input circuit in Solution 1.3

This dual-channel architecture, with the plausibility check by the logic unit, offers an improvement in diagnostic coverage over the single-channel solution. The check is performed every time the guard door is opened and closed (about four times per hour).

Since there is no dynamic testing and no cross-circuit detection (detection of a short-circuit between the two input channels), the subsystem of sensors + logic unit achieves medium diagnostic coverage (DC 90%).

Result:

With the category 3 architecture and the medium DC, it may be possible to achieve PL d (see Figure 5).

However, measures would need to be taken to prevent the occurrence of unknown faults in both channels of the input circuit at the same time which could lead to failure of the safety function (see CCF in the "Explanation of terms" box).

For example, overvoltage surges on the sensor lines, due to high inductive loads switching nearby, could cause the simultaneous destruction of the switching outputs of the sensors (both channels would remain at "high" level).

If the CCF measures are not sufficient or the local conditions cannot be assessed, the dual-channel architecture must be evaluated as if it were single-channel.
In that case, just as for Solution 1.2, the achievable category would be no higher than B, as the combination of two standard sensors also cannot be considered to be a well-tried safety principle.
The required Performance Level d can be achieved with Solution 1.3, however the user has to know the application conditions and evaluate the failure effects.

Solution 1.4 – Two different standard sensors

In contrast to Solution 1.3, the powerful technique of diverse redundancy is used.
Two standard sensors of different types (with different internal structures) and with inverse output levels are monitored on a dual-channel basis by the logic unit (Figure 10). The MTTFd values of the two sensors combine to give a high total MTTFd value.

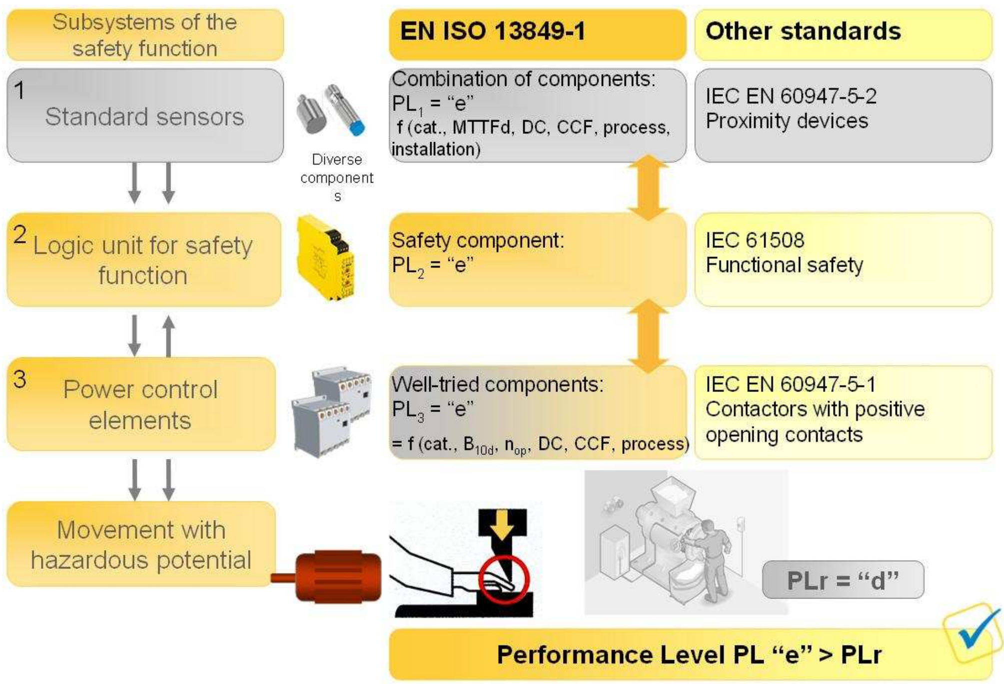


Fig. 10: Two diverse standard sensors as a dual-channel input circuit in Solution 1.4

The input circuit has a dual-channel architecture with plausibility check and short-circuit detection by the logic unit.
The diagnostic coverage improves to 99% (DC = "High") and the diversity helps greatly to combat CCF.

Result:
With the category 4 architecture, DC = "HIgh," adequate measures to combat CCF, and MTTFd = "High," it is even possible to reach total PL = "e" (see Figure 5).

Task 2 – Hazardous point protection for a batch collector

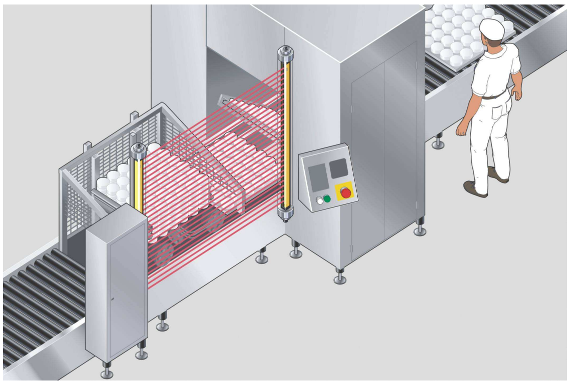


Fig. 11: Protection for a batch collector with PLr = “c” for Task 2

Task 2 describes protection of a hazardous point at a batch collector in a bakery production line, using a light curtain.
The required Performance Level, PLr, is “c”. Other factors to consider for the light curtain in addition to the Performance Level are optical properties such as the effects of ambient light, reflections, etc. on detection reliability (see Table 1).

Solution 2.1 – Safety light curtain

The components are selected according to the necessary level of safety performance (Figure 12).

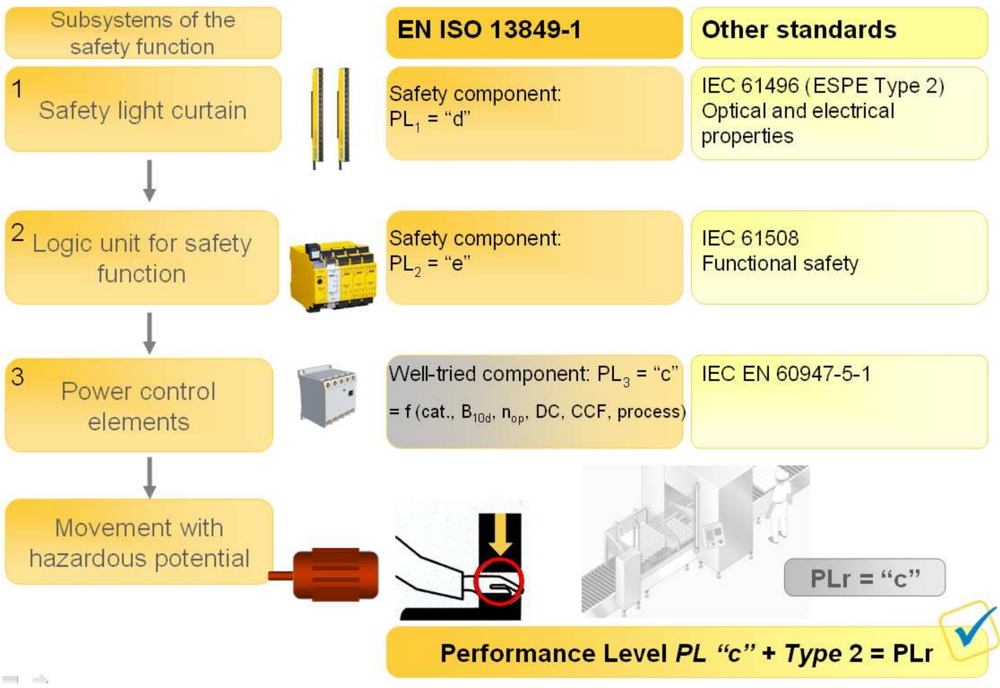


Fig. 12: Safety system with subsystems for Solution 2.1 of Task 2, its evaluation according to EN ISO 13849-1, and the relevant product standards

In some cases the subsystems shown in Figure 12 satisfy a higher Performance Level than necessary.
A safety light curtain of Type 2 as defined by IEC 61496 is used as the sensor. For optical protective devices, Type 2 is the “optical equivalent” of Performance Level c.
The used components and the single-channel architecture fulfill the category 1.

Result:
The required Performance Level and the requirements for optical properties are met with Solution 2.1.

This is subject to the condition that the application software of the logic unit (the programmable safety control) meets the requirements of safety-related logic programming according to EN ISO 13849-1.

The single-channel actuation of the contactors without feedback, shown in Figure 12 in the “power control elements” subsystem, has DC = “Zero.” CCF is not relevant as the output circuit has a single-channel architecture.

However, the required PLr = “c” is achieved if the contactor is a well-tried component with a high MTTFd (≥ 30 years).
The MTTFd value can be calculated from the B10d value and the switching frequency (see “Explanation of terms” box).

Solution 2.2 – Standard light curtain

A standard light curtain is used for the safety function instead of a safety light curtain (Figure 13).

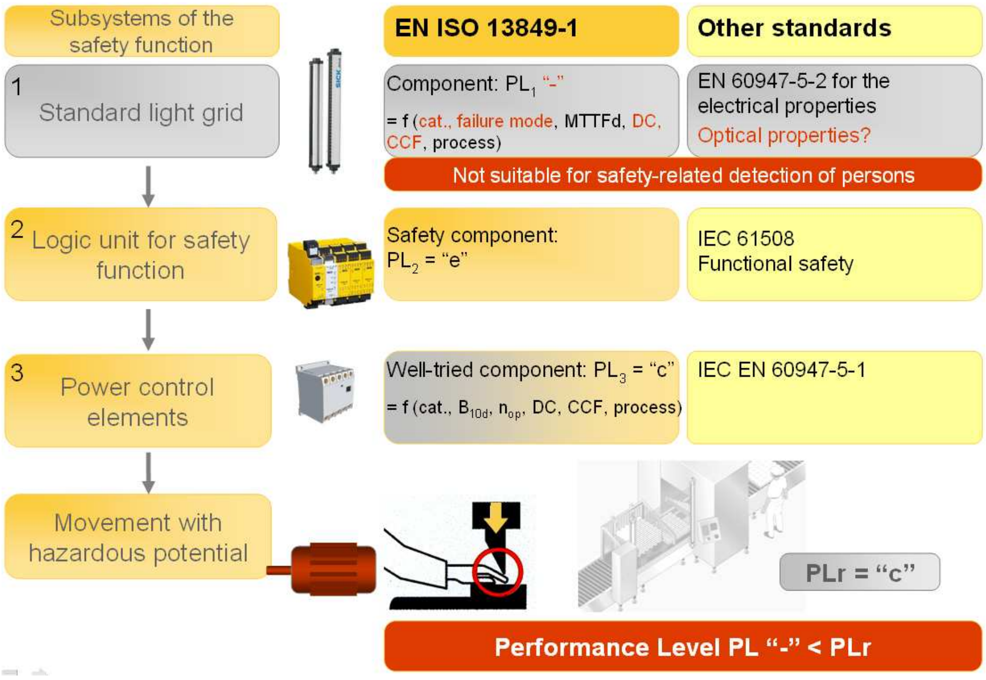


Fig. 13: Subsystems for Solution 2.2, their evaluation according to EN ISO 13849-1, and the relevant product standards

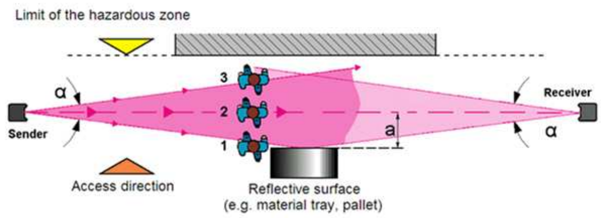
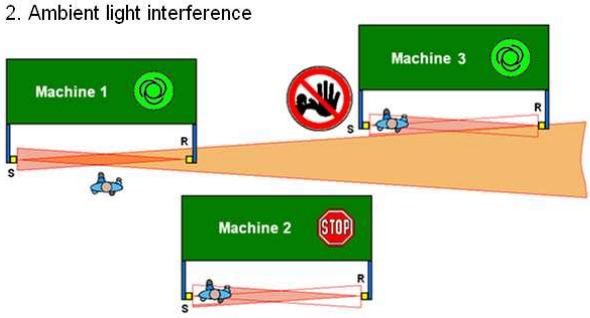
There is no product standard for the optical properties of the standard light curtain.
The criteria for the detection of persons and for functional safety as defined in IEC 61496 were not followed by the manufacturer during development.

The manufacturer cannot specify the failure mode in the event of an internal fault because this standard component is equipped with complex electronic components (e.g. µC, ASIC). That means this sensor too is not a well-tried component with well-tried safety principles as defined by EN ISO 13849-2.

The optical properties of this standard sensor do not satisfy the requirements of the IEC 61496 series of standards for opto-electronic protective devices for personal protection (see Table 1).

Result:
The required Performance Level c is not achieved with Solution 2.2.
As with the standard inductive sensor (Solution 1.2), the addition of an external test mechanism does not improve this result.

Table 1: Some of the requirements of opto-electronic protective devices for the detection of persons

<table>
<tr><th>Some of the requirements of AOPD according to IEC 61496</th><th>Background</th><th>Examples of the loss of detection capability for persons if the requirements are ignored</th></tr>
<tr><td>Conform to functional safety (category)</td><td rowspan="2">Use for personal protection functions</td><td rowspan="3">1. Reflection

</td></tr>
<tr><td>Test of resolution</td></tr>
<tr><td>Increased EMC requirements</td><td>Increased resistance to safety-related faults and improved system availability</td></tr>
<tr><td>Maximum effective aperture angle of optics: 10° / 5°</td><td rowspan="3">Safeguarding of detection capability in case of reflections and ambient light interference</td><td rowspan="3">2. Ambient light interference

</td></tr>
<tr><td>Minimum distance away from reflective surfaces</td></tr>
<tr><td>No disruption of multiple senders of the same type of construction in one plant</td></tr>
</table>

In the case of ESPE (electro-sensitive protective equipment), it is always vital to consider not only the functional safety aspects but also the optical characteristics that determine detection capability.

Advantages and disadvantages of using standard sensors for safety functions

It is possible to save on materials costs by using standard components in safety applications.
However, when it comes to personal protection, the user must have thorough knowledge of all application conditions, the necessary measures to be taken, and of the safety mechanisms – in other words, knowledge of the suitability of the component for use in safety circuits.
If just one standard sensor is used in applications with PL = "c" or higher, the user even needs to have knowledge of the internal error detection mechanisms, which is usually not realistic in the case of complex components.

As a fundamental rule, it is not possible to use standard optical sensors for the detection of persons unless a special conformity assessment procedure is followed in accordance with the Machinery Directive. This applies to both manufacturers and users.

Manufacturers do not follow the standards relevant for safety applications when producing standard components, and unlike safety components as defined by the Machinery Directive, additional safety parameters might not be specified (PL, SIL, PFHd, DC, …).

Advantages of safety components:

- The safety component has been developed and produced by the manufacturer in accordance with the latest technological developments, following the relevant safety standards, and taking into account any influencing factors in the safety application.
- The failure mode of a safety component is defined by the manufacturer.
- For many kinds of safety components, an EC prototype test by an authorized body (such as TÜV or IFA) is commissioned by the manufacturer.
- The manufacturer pays special attention to how products perform in the field.
- The safety parameters for evaluating safety circuits, such as PL, SIL, PFHd, B_{10d}, and the category, are supplied by the manufacturer.
- An EC Declaration of Conformity in accordance with the Machinery Directive accompanies the component.

Conclusion

The examples shown illustrate the basic and most important aspects of the use of standard sensors for safety functions.
It can be seen that even with a good (high) MTTFd value, only a small part of the necessary criteria and measures are covered.
Optimization and other measures for the use of standard sensors such as measures which support testing, or measures to facilitate use by the exclusion of faults, are possible and are already being put into practice.
Component manufacturers such as SICK and authorized bodies such as the German IFA (formerly BGIA) or TÜV are available to provide advice and guidance.

Machine manufacturers certainly have the option of using standard components for safety functions.
Providing documented evidence of the suitability of all components used for safety functions is one of the obligations of the machine manufacturer.
It can be seen that providing this documented evidence of suitability is considerably more difficult for standard components.

Table 2 shows a rough summary of the basic possible uses of standard sensors for safety functions and the measures required for such use.

Table 2: Recommendation for the use of standard sensors for safety functions in accordance with EN ISO 13849-1[1)]

<table>
<tr><th>Standard component</th><th>Up to PL = „a“</th><th>Up to PL = „b“</th><th>Up to PL = „c“</th><th>Up to PL = „d“</th><th>Up to PL = „e“</th></tr>
<tr><td>Proximity sensors

e.g. inductive, capacitive</td><td colspan="2">Specifications from the manufacturer:
▪ Conformity with basicsafety principles[2)]
▪ Data sheet
▪ Specification of MTTFd or B_{10d}

Important for the user:
▪ Conformity with basicsafety principles[2)] for implementation
▪ Effect of ambient conditions (temperature, humidity, water, dust, electromagnetic interference, …) on the safety function[4)]
▪ Documentation[4)]</td><td colspan="3">Specifications from the manufacturer:
▪ Conformity with basicsafety principles[2)]
▪ Data sheet
▪ Specification of MTTFd or B_{10d}

Important for the user:
▪ Conformity with basic[2)] and well-tried[3)] safety principles for implementation
▪ Category requirements, e.g. dual-channel architecture with two sensors[4)]
▪ Determining/safeguarding the DC and measures to combat CCF[4)]
▪ Effect of ambient conditions (temperature, humidity, water, dust, electromagnetic interference, …) on the safety function[4)]
▪ Documentation[4)]</td></tr>
<tr><td rowspan="2">Single-beam photo-electric safety switches

Photo-electric proximity switches

Light grids

Laser scanners</td><td colspan="5">Not to be used for the detection of persons[5)]; otherwise as for proximity sensors (above) with optical ambient influences taken into consideration as well.</td></tr>
<tr><td colspan="2">Specifications from the manufacturer:
▪ Conformity with basicsafety principles[2)]
▪ Data sheet
▪ Specification of MTTFd

Important for the user:
▪ Conformity with basicsafety principles[2)] for implementation
▪ Effect of ambient conditions (temperature, humidity, water, dust, electromagnetic interference, light …) on the safety function[4)]
▪ Documentation[4)]</td><td colspan="3">Specifications from the manufacturer:
▪ Conformity with basic[2)] and well-tried[3)] safety principles for implementation
▪ Data sheet
▪ Specification of MTTFd

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▪ Conformity with basic[2)] and well-tried[3)] safety principles for implementation
▪ Category requirements, e.g. dual-channel architecture with two sensors[4)]
▪ Determining/safeguarding the DC and measures to combat CCF[4)]
▪ Effect of ambient conditions (temperature, humidity, water, dust, electromagnetic interference, light …) on the safety function[4)]
▪ Documentation[4)]</td></tr>
<tr><td colspan="6">1) In all cases, providing documented evidence of the suitability of all components used for safety functions is one of the obligations of the machine manufacturer. Authorized bodies such as the German IFA or TÜV (technical testing authority) can be consulted when evaluating the use of standard components in applications not covered by these recommendations, and in the case of optimizations.
2) Basic safety principles incorporate generally recognized sound engineering practices for the component manufacturer, such as those described in product standards (including ambient conditions, principles of operation, ...). Measures for bringing systematic errors under control have been taken during development and production. The user is also subject to obligations, such as conforming to specifications and ensuring proper fastening (see EN ISO 13849-2, sections A.2, B.2, C.2, D.2).
3) Well-tried safety principles are principles which make it possible to exclude certain faults through the use or configuration of components, for example by the use of components with a defined (known) failure mode or with positive action/opening or by techniques such as redundancy and diversity (EN ISO 13849-2, sections A.3 and D.3).
4) See EN ISO 13849-1, section 10 or Annex G.
5) IEC 61496 sets out specific addition requirements for the detection of persons, including requirements for EMC and optical performance characteristics. In the EU, a special conformity assessment procedure is required in accordance with the Machinery Directive 2006/42/EC.</td></tr>
</table>

Sources and literature:

EN ISO 13849-1: Safety of machinery **–** Safety-related parts of control systems **–**
Part 1: General principles for design (ISO 13849-1:2006)

EN ISO 13849-2: Safety of machinery **–** Safety-related parts of control systems **–**
Part 2: Validation (ISO 13849-2:2003)

EN 62061: Safety of machinery **–** Functional safety of safety-related electrical, electronic and programmable electronic control systems (IEC 62061:2005)

IEC 61496 series of standards: Safety of machinery **–** Electro-sensitive protective equipment

Guidelines for Safe Machinery, "Six steps to a safe machine"
EN version, part No. 807988,
North America version, part No. 7028282
Can be downloaded or ordered from www.sick-safetyplus.com

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