



Safety. Detection. Control.

Safety Guide

Safety in the
working environment

Issue 1



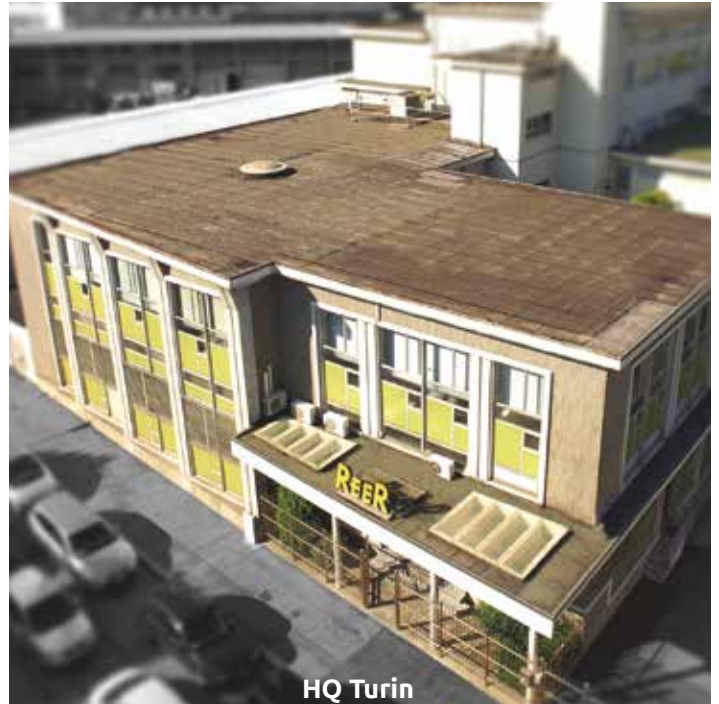
COMPANY

Your technological partner since 1959

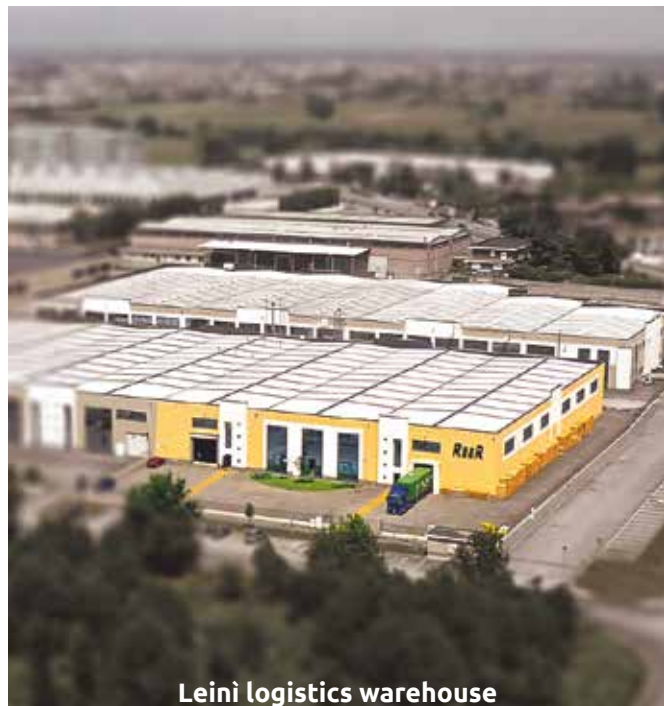
ReeR was established in 1959 to distribute components for industry, lighting and home automation. By the mid-70's the first safety sensors were developed, and afterwards the first light curtains were produced.

Today ReeR is both the Italian leading company and one of the main world manufacturers of optoelectronic sensors for industrial safety.

The export activity of the Safety Division outlines the company's global expertise and its network of skilled distributors provide an accurate support service to their customers based in more than 50 countries.



HQ Turin



Leinì logistics warehouse

Know how

Technological excellence and application know-how embody the spirit of ReeR.

14% of the personnel is employed in the R&D department, with expertise in safety hardware, software and firmware.

Furthermore, ReeR is one of the main players in the standardization process development as it takes part in the most important national and international Organizing Committees on machinery safety requirements.

Safety and Automation

If safety in the workplace is essential, it becomes crucial in highly automated environments.

Thanks to the experience achieved by cooperating with the world leading companies in the machine-tools, automotive, packaging and palletisation industries, ReeR is able to offer a wide range of safety devices, such as: light curtains, programmable controllers, photocells, laser scanners and interfaces able to meet each application demand.

ReeR has always been at the forefront also in the field of optoelectronic curtains for automation, measurement and control.



Key words

Quality



The ReeR product quality is guaranteed by the Quality System certified by TÜV Italia according to the ISO 9001:2008 standard.

- Insourcing of all main working phases
- Process control, quality, delivery times, competitiveness
- Computerised monitoring of every working phase guarantees:
 - part list check
 - traceability



ReeR supports the environment



All internal electrical consumption origins from renewable sources.

The 2002/95/CE RoHS directive restricts the use of hazardous substances in electric and electronic devices.



Health and safety in the workplace



In order to reduce incident risks in the workplace, ReeR has implemented a management system for the monitoring of all health and safety issues in the workplace, as regulated by BS OHSAS 18001.

Innovative manufacturing process

Constant investment in manufacturing technologies

- Manufacturing process control system regulated by Lean Manufacturing principles
- Continuous improvement
- Slim production
- Waste reduction
- Delivery times improvement
- Fast-moving part-numbers management



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Products

Safety devices

- Type 4 and Type 2 Safety light curtains
- Photocells
- Magnetic and RFID switches
- Incremental encoder

Configurable controllers

Laser scanners

Safety Interfaces

- PL e - SIL 3 Safety speed monitoring interface
- Type 4 interface for light curtains
- Type 4 interface with muting for light curtains
- PL e safety interface for two-hand control
- PL e safety interfaces for emergency stop buttons and safety switches

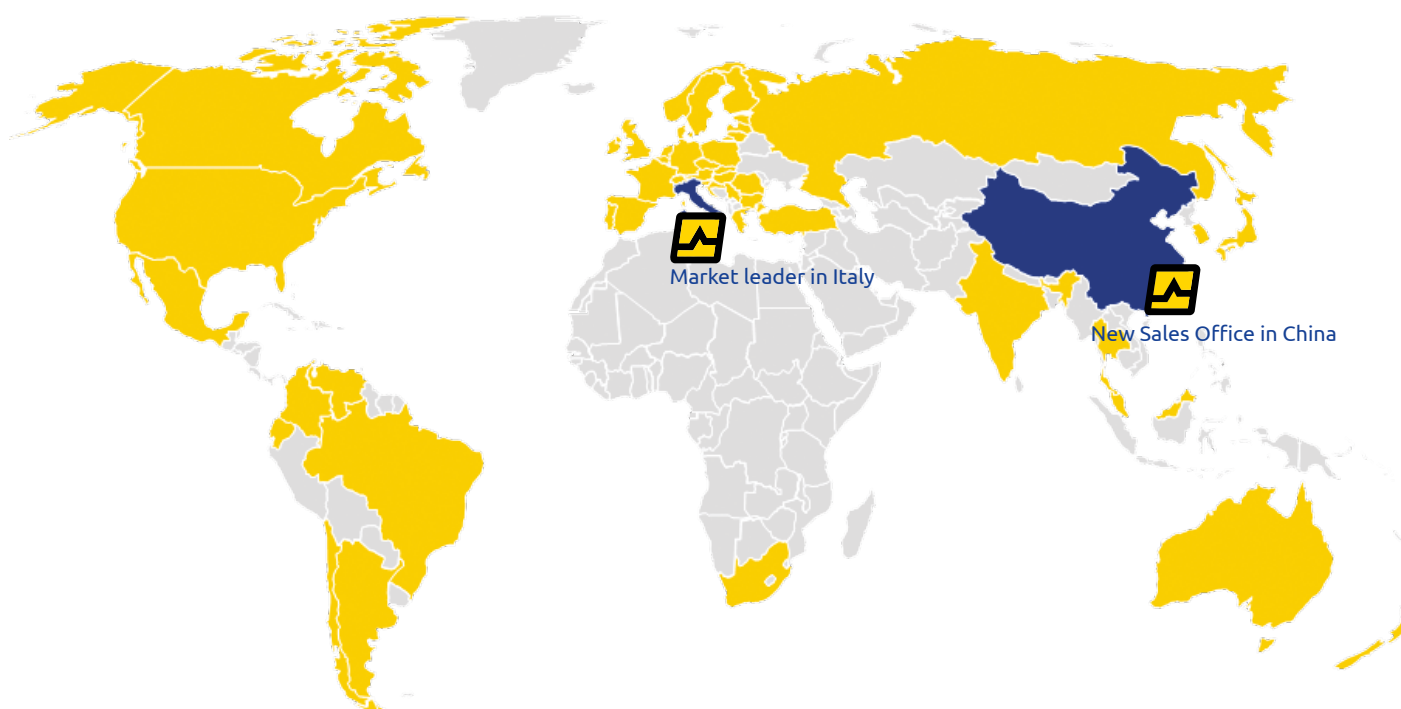
Measuring devices

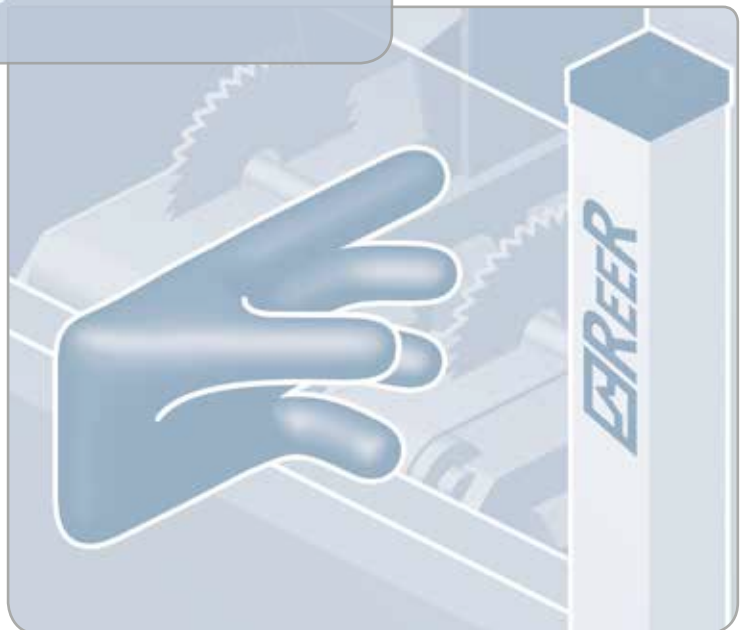
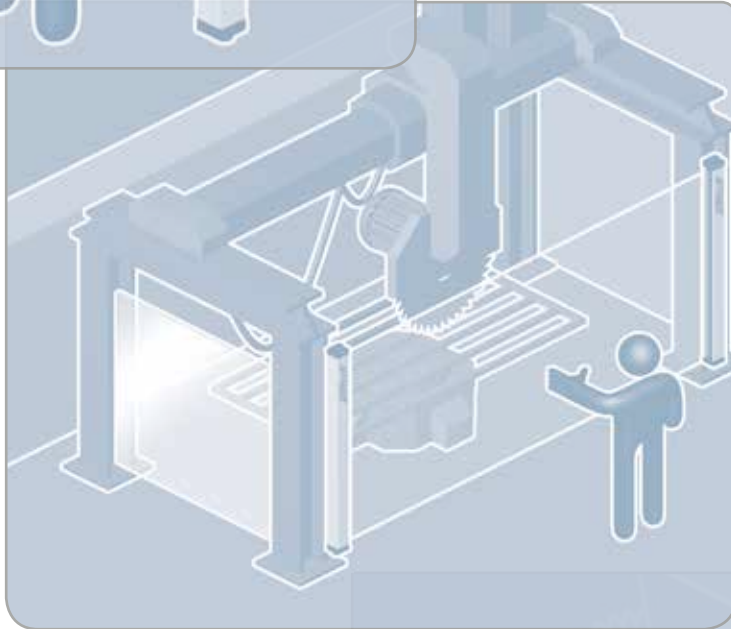
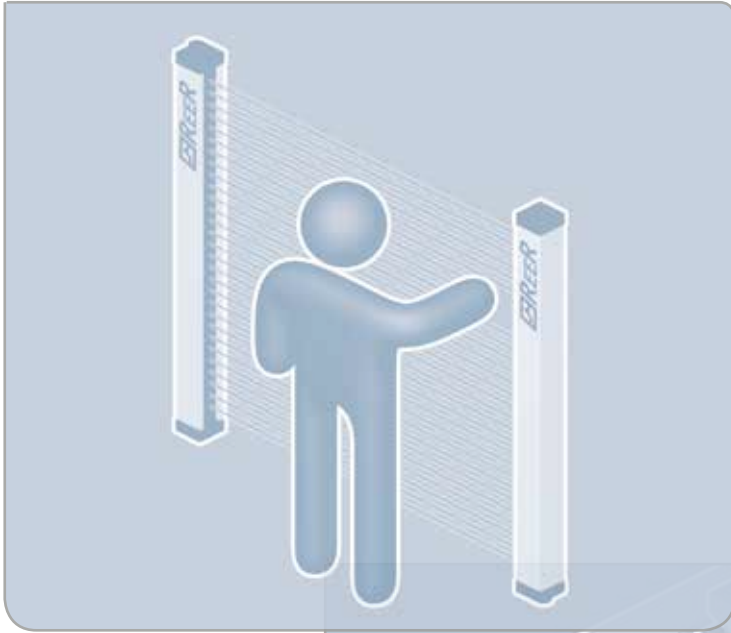
Accessories



Sales network

Direct sales network in Italy and China and 65 distributors in the world





SAFETY GUIDE

Introduction

This safety guide refers to the set of rules governing the control system on safety of machinery. In particular, this concerns the crucial family of standards under the umbrella of:

- ISO 13849 "Safety of machinery" (ISO)
- IEC 61508 "Functional safety of electrical / electronic / programmable electronic safety related systems" (IEC). IEC 61508 which impacts safety of machinery especially through IEC 62061 "Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems"
- IEC 61496 "Safety of machinery - Electro sensitive protective equipment"

Important statistical concepts related, in varying degrees, to probability of dangerous failure, are covered by machine safety, resulting in new classifications of safety-related control systems for machinery and protection devices. These include PLs (Performance Levels, for ISO) and SILs (Safety Integrity Levels, for IEC). PL and SIL come next to and in many ways replace the now familiar concept of Category featuring in the 'old' EN 954-1.

The second edition of the Technical Specification IEC TS 62046 "Application of protective devices for the detection of the person", is a useful guide for players who want to use protective devices for the realization of control systems for machine safety.

European directives

The aim of the EC Directives is to harmonize the national legislation of the Member States so as to have common regulations concerning technical, economic, social aspects, etc. and to facilitate the free circulation of goods, service and people within the European Union.

In particular, where the safety of workers is concerned, the harmonization of legal provisions has resulted in the formulation and approval of Directives and Standards of great importance.

DIRECTIVES

Define the objectives to be achieved.

STANDARDS

Define the means and methods by which to achieve the objectives established by the Directives.

A product/service that complies with the harmonized Standards is presumed to conform to the Directives.

Stages for the realization of a Standard:

- Creation of a Working Group (WG) made by experts of the subject to be treated, which represents the Member States
- Preparation of a draft version of the Standard (prEN) to be examined by the various national Committees involved, for comments, proposals and the subsequent final approval
- Drafting of the definitive formulation of the text of the Standard (EN), official publication, and acceptance by the individual Member States.

The Directives concerning the protection of workers are:

- 89/391/EC "Health and safety at work - Framework directive"
- 2009/104/EC "Use of work equipment" and amendments / additions

The Directives governing safety components are:

- 2006/42/EC "Machinery directive"
- 2014/35/EU "Low Voltage Directive"
- 2014/34/EU "Electromagnetic Compatibility Directive"
- 2014/34/EU "ATEX directive"

Social directives

“Social Directives” 2009/104/EC and 89/391/EC, are aimed at the improvement of safety in working environment.

The Directives:

- Determine the preventive measures to be adopted in the working environment.
- Supply information on:
 - risk analysis
 - program of prevention and achievement of compliance of the machines
 - procedures concerning the compliance of machines
 - responsibilities of the employer
 - education and training of the people in charge of system operation
- Imposes the adaptation of existing machinery in compliance with the provisions of the Machinery Directive.

The machinery directive

The “Machinery Directive” 2006/42/EC is meant for the manufacturers of machines and safety components, and has the following objectives:

- The definition of safety and health protection requirements for the improvement of the degree of protection offered to the operators of hazardous machinery
- The design, construction and marketing in the European Union of safety machines and components complying with the minimum safety requirements laid down by the Directive itself
- The free circulation in the Member States of machines and safety components complying with the Directive

The Machinery Directive:

- It applies to all new machines and safety components that are sold, lent or hired, and to used machinery in the event of sale, rental or loan
- It sets forth the essential safety requirements relating to the design and construction of machines and safety components and it defines the respective certification procedures.
- It is mandatory for machines and for safety components.
- Only products conforming to the Directive can be marketed or commissioned in the European Union

Certification procedures

The Directive:

- Lays down stringent procedures for safety components and highly hazardous machines which are listed in Annex 4
- Lays down simplified procedures for low and medium risk machines not included in annex 4
- Requires that manufacturers prepare a technical dossier for each product stating the safety principles adopted in the design, manufacture, transport, use and maintenance of the machine or the safety component

Declaration of conformity

In order to certify the conformity of a product to the Directive, the manufacturer must:

- Affix the CE mark to the product
- Attach the CE declaration of conformity attesting compliance to the Directive

Certifications

The CE type certificates is valid for 5 years (Annex IX para. 9.3), the five-year period starting from the revision date of the certificate. After which a new verification will be required to maintain the certification.

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Low voltage directive

2014/35/EU is aimed at ensuring that electrical materials are designed and manufactured so as to guarantee the protection of people against any risk of injury arising from the use of such materials.

This Directive applies to all electrical materials meant for use at a nominal voltage of between:

- 50V and 1000V for alternating current
- 75V and 1500V for direct current

Electromagnetic compatibility directive

The aim of “Electromagnetic Compatibility Directive” 2014/30/EU is to ensure that electrical devices are designed and manufactured so that:

- Electromagnetic emissions are limited and low enough to permit other electrical devices to operate according to their intended purpose
- The level of built-in immunity to external disturbances enables them to operate according to their intended purpose

This Directive applies to all electrical and electronic devices able to cause electromagnetic disturbances and whose operation can be affected by external factors.

ATEX directive

The ATEX Directive 2014/34/EU applies to all equipment intended for use in potentially explosive. It is in force since 30 March 2014.

The ATEX Directive 2014/34/EU specifies minimum safety requirements for electrical devices used in environments classified as dangerous regarding the aspect of risk of explosion due to the presence of gas or dust.

The Directive divides equipment into groups and categories.

The manufacturer must decide, according to the use, the group and the category of belonging.

- Group 1: equipment intended for use in underground works, mines and their surface installations
- Group 2: equipment intended for use in environments where it is likely to occur explosive atmospheres

These product groups are then categorized according to the level of protection from the risk of ignition of potentially explosive atmospheres.

The products in the group 2 are divided into three categories:

- Category 1: equipment intended for high-risk areas where an explosive atmosphere is present long periods
- Category 2: equipment intended for medium-risk areas where an explosive atmosphere may occur under normal operating conditions
- Category 3: equipment intended for areas where an explosive atmosphere is only likely under abnormal circumstances

Accredited bodies

In each Member State, the role of the accredited Bodies is to assess and verify the compliance and the application of the European Directives.

Each State is responsible for the appointment and control of its own Bodies.

In Italy the authorized body to carry out accreditation activities is: Accredia. Accredia maintains a database with a list of all Italian organizations accredited for the various directives.

Notified bodies

Notified Bodies are authorized to examine and certify machines and safety components in compliance with the applicable Directives.

Each Member State of the European Union is required to:

- Appoint the Notified Bodies by specifying their tasks
- Submit a list of the Notified Bodies to the European Commission and to the other Member States

The European Commission publishes a Directory of all the Notified Bodies on the Official Journal of the European Commission, together with a list of the services, the machines and/or the safety components on which they are authorised to intervene.

The Member States of the European Union must make sure that these Bodies respect specified ethical and technical criteria.



Harmonized standards

- They are technical Standards conceived to meet the essential requirements of the Directives
- They are written by the various technical committees on a mandate by the Commission of the European Union
- They are approved and adopted:
 - by the CEN (European Committee for Standardization)
 - or the CENELEC (European Committee for Electrotechnical Standardization)
- Then they are translated and published in the Official Journal of the European Committee and the Official Gazette of each Member State.

Status of the Standards

prEN a proposed standard (draft) which has not yet been definitely approved

EN an approved standard already in force

TS a technical specification

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The European Standards concerning safety are subdivided into 3 groups:

TYPE A STANDARDS

They specify the general design principles applying to all types of machine:

e.g... [EN ISO 12100](#) Safety of machinery - General principles for design - Risk assessment and risk reduction

TYPE B STANDARDS

They are divided into two classes:

type B1 Standards: concerning a specific aspect of safety

e.g... [EN ISO 13855](#) Positioning of safeguards with respect to approach speeds of parts of the human body
[EN ISO 13857 - 1](#) Safety distances for the protection of the upper limbs
[EN 60204](#) Safety of machinery. Electrical equipment of machine
[EN ISO 13849 - 1,2](#) Safety related parts of control systems

type B2 Standards: concerning safety devices

e.g... [EN 61496-1](#) Electro-sensitive protective equipment - general requirements and tests -
[EN 61496-2](#) Electro-sensitive protective equipment-Particular requirements for equipment using active optoelectronics protective devices (i.e. light curtains)
[EN 61496-3](#) Electro-sensitive protective equipment-Particular requirements for Active Optoelectronics Devices responsive to diffuse reflection (i.e. laser scanner) -
[EN ISO 13850](#) Emergency stop - Principles for design

TYPE C STANDARDS

They concern specific types of machine:

e.g... [EN 692](#) Mechanical presses
[EN 693](#) Hydraulic presses
[EN 415](#) Packaging machines
[EN 415-4](#) Palletizing and de-palletizing systems
[EN ISO 10218](#) Industrial robot

A type C Standard takes priority over type A and B Standards.

If no C type Standards exist, compliance with the Directive can be attained on the basis of type A and type B Standards.



Northern American standard and test bodies

The Body overseeing health and safety in the workplace in the USA is the **Occupational Health and Safety Administration (OSHA)**. Individual States may have their own safety regulatory organizations which may enforce stricter regulations than OSHA. OSHA oversees the application of laws and regulations in force at the Federal level, and in turn issues safety standards covering the use and construction of safety devices and/or machine tools.

An important example of such activity is Standard OSHA 1910.217 – Mechanical Power Presses.

The **American National Standard Institute (ANSI)** issues standards on the safety of machine tools or particular aspects of their construction or operation. For the preparation of these standards ANSI often relies on the contribution of non-profit organizations such as the **Robotic Industry Association (RIA)**, or the **Association for Manufacturing Technology (AMT)**.

Examples of major ANSI standards:

B11 standards, including:

B11.1 Mechanical Power Presses

B11.2 Hydraulic Power Presses

B11.3 Power Press Brakes

B11.4 Shears

B11.19 Performance Criteria for the Design, Construction, Care and Operation of Safeguarding When Referenced by other B11 Machine Tool Safety Standards (design, construction, maintenance and operation criteria for protection devices specified in Std. B11 covering machine tools)

Other ANSI standards:

B20.1 Conveyor Belts

ANSI/RIA R15.06 Safety Requirements for Industrial Robots

Contrary to Europe, North America does not accept a certificate of conformity as an approval to sell and install electrical equipment.

Prior to installation the device or system in question must be inspected by the Authorities Having Jurisdiction (AHJ).

If the device in question is already listed by a Nationally Recognized Testing Laboratory (NRTL), the competent authority is dispensed from inspecting the product.

The mark of a NRTL assures product conformity to safety standards in force.

Although not mandatory in North America, certification facilitates marketing as retailers, inspectors, users and local authorities readily approve any product bearing a NRTL mark. Certified installations enjoy advantages in terms of insurance benefits and freedom from potential industrial disputes, as workers unions might prevent members from operating non-certified, and therefore possibly dangerous, machinery.

OSHA is the body authorized to approve NRTLs.

NRTLs shall obtain approval for all national and foreign facilities for all products for which they are authorized to award certification.

To obtain accreditation, the applicant shall also, but not only, prove to be independent of any users, suppliers or retailers of the products for which certification is sought.

NRTLs may develop and apply for approval of its own developed standards or adopt standards produced by other NRTLs.

Each NRTL has its own unique mark.

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Underwriters Laboratories Inc. (UL) is a leading NRTL among those authorized to issue certification of electrical systems and equipment. UL is a non-profit organization listing industrial components which have been tested and proven to be safe and reliable in terms of electrical safety and fire resistance.



UL Listed Certification Mark means that the product in question was tested and verified to be in line with USA safety requirements. UL Listed General Mark certifies conformance to fire resistance and electrical safety requirements.



UL certification also includes components such as safety light curtains which are covered by Std. UL 61496-1 and Std. UL 61496-2 derived from international Std. IEC 61496-1,2. Systems incorporating safety software can be also certified as per Std. ANSI/UL 1998. Safety light curtains (ESPE) are covered by a specific marking certifying compliance with the appropriate product standard and with Std. ANSI/1998. ReeR safety curtains are in line with all these requirements and bear the associated mark of approval.



UL may also certify conformity to CSA Canadian Standards (through C-UL mark or C-UL-US mark for products to be marketed in Canada and in the USA).

The Canadian Standard Association (CSA) is the main Canadian standardization body and acting certification authority competent for verification of conformance of safety components to Canadian regulations.

As Nationally Recognized Test Laboratory (NRTL) for the USA, CSA is authorized to verify conformance of all products under OSHA jurisdiction and award the CSA mark of NRTL/C, equivalent to C-US UL, which applies for example to safety light curtains.



Risk assessment

The Technical report [ISO/TR 14121-2](#) puts forward a practical guide for the examination of the hazards (EN ISO 12100 complied) with the aim of selecting and adopting the most suitable safety measures to reduce or eliminate the risks.

For USA an equivalent procedure is described in the [ANSI Technical Report B11.TR3-2000](#).

The risk assessment can thus be broken down into 4 stages:



Fig. 1. Stages of risk assessment

1. Determination of the limits of the machine

Consists in the examining of the intended use and of all the reasonably foreseeable misuses in relation to the level of training, experience and attitude of the user.

2. Identification of the hazards

Consists in the systematic identification of:

- the risks and the hazardous elements (mechanical, electrical, chemical, etc.)
- hazardous situations (manual loading-unloading, access to the system, etc.)
- events that might cause damages (machine failures or anomalies)

3. Risk estimation

Each hazardous situation identified is derived from a combination of the following elements:

- Severity of injuries or damage to health (reversible, irreversible, fatal)
- Probability of occurrence of that injury, which is a function of frequency and duration of exposure to danger
- Possibility of avoiding danger with reference to:
 - rapidity of occurrence of the event,
 - possibility by the operator to perceive hazards and react promptly,
 - possibility to escape.

4. Risk evaluation

It examines the suitability of the safety measures adopted.

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Safety-related control system for machinery

Where safety is based on the proper operation of the machine control system, it shall be designed so that to ensure a minimal probability of functional errors. Otherwise, any errors shall not lead to the loss of the safety function. In Europe, to meet these requirements it is highly recommended to use the harmonized standards developed by mandate of the European Commission (assumption of conformity). Using the harmonized standards saves extra time and costs where proof of conformity of the safety-related control system to the essential requirements of the Machinery Directive shall be demonstrated.

Given hereunder are the basic concepts of the new standards ISO 13849-1 and IEC 62061 which supersede EN954-1 as regulatory instruments covering machine control systems.

Note: categories are not necessarily totally hierarchical

Functional safety standards

ISO 13849-1 and **IEC 62061** - Within the limits of scope and scope, these two norms provide presumption of compliance with essential requirements 1.2.1 of Annex I to Directive 2006/46/EC.

ISO 13849-1 Safety Related Parts of Control Systems, Part 1: General principles for design

ISO 13849-1 is a revised version of EN 954-1

The complex mathematical formulas of the system reliability theory were replaced with pre-calculated tables.

Some concepts of EN 954 were retained, i.e. categories, redundancy, monitoring.

A number of EN 954 were modified, i.e. risk graph, selection of Categories.

The role of Categories is no longer crucial as in EN 954-1.

To assess the resistance to dangerous failure, the Category concept is replaced by Performance Level (PL) as the ability of the safety-related machine control system (hereinafter called SRP/CS) to assure protection in specified operating conditions.

The parameter used to evaluate the PL of the safety-function is the Average probability of dangerous failure/hour. A failure is considered to be dangerous where it inhibits the system protection function if undetected.

There are 5 levels, PLa to PL e.

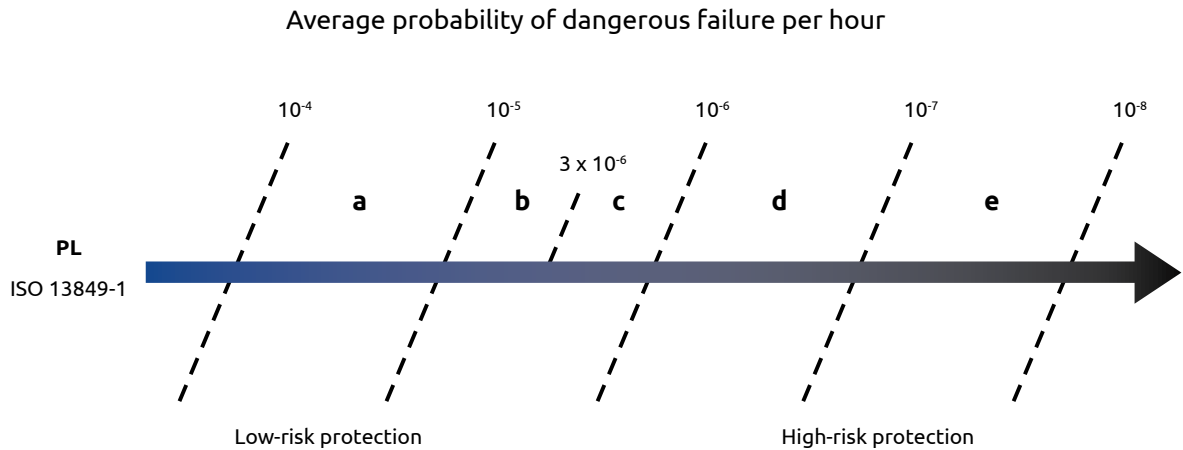


Fig. 2. Table of ISO 13849-1

The greater the contribution to reducing risk the lower must be the average probability of dangerous failure of the SRP/CS.

PL is a function of control system architecture, component reliability, ability to promptly detect internal failure potentially affecting the safety function and quality of the design.

The table below summarizes mandatory qualitative and quantitative requirements to be met for safe control system design to ISO 13849-1.

See also glossary on page 33

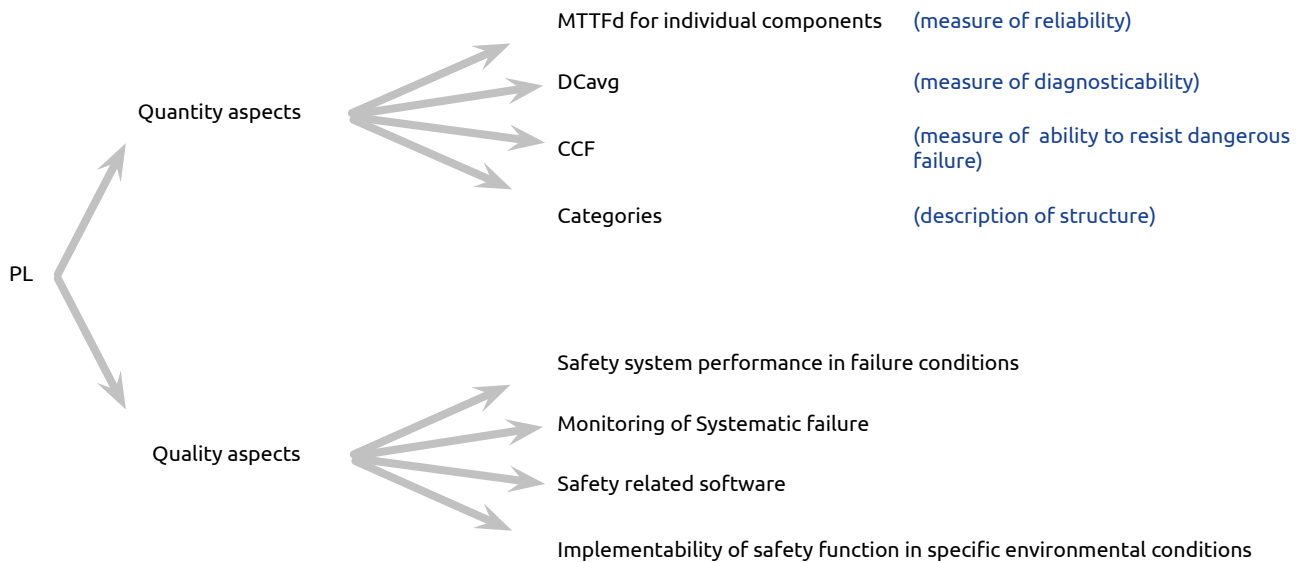


Fig. 3. Mandatory qualitative and quantitative requirements to be met for safe control system design to ISO 13849-1

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To claim a given PL, in addition to evaluating the Average probability of dangerous failure/hour for the SRP/CS in question, it will also be necessary to prove compliance with quality requirements specified by the standard.

The claimed PL must be validated using ISO 13849-2 Safety Related Parts of Control Systems - Validation defining procedures tests and analysis, for the assessment of:

- safety function provided
- category attained
- performance level reached.

IMPORTANT!

Average Probability of Dangerous Failure/Hour is only one of the parameters contributing to assignment of PL. To obtain a PL rating, it is also mandatory to prove and substantiate having considered and complied with all requirements, including:

- *Monitoring of systematic failures*
- *Using robust and reliable components (in line with Product Standards if available)*
- *Working according good engineering practice*
- *Considering environmental conditions in which the safety-related system will operate*
- *In the case of new software, adopting all organisational aspects of V-type development model shown in Figure 6 of the Standard ISO 13849-1 and meeting development requirements for applications and built-in SW.*

Design of an SRP/CS as per ISO 13849-1 may be summarized in the following eight steps:

1. Identification of safety-related function through risk analysis
2. Assignment of Performance Level requested (PL r) through risk graph
3. Selection of system structure (architectures) and self-diagnostic techniques
4. Technical development of control system
5. Calculation of MTTFd, DCavg and verification of CCF
6. Calculation of PL using Table 5
7. Verification of PL (if calculated PL is below PL r return to Step 3)
8. Validation.

Identification of safety related item and assignment of Performance Level required - PL r

For each safety-related function identified (e.g. through the use of ISO/TR14121-2 - Risk Assessment) the designer of the SRP/CS decides the contribution to reduction of risk to be provided, i.e. PL r.

This contribution does not cover overall machine risk but only the part of risk related to the application of the safety function in question.

Parameter PL r represents the Performance Level required for the safety-related function in question.

Parameter PL represents the Performance Level reached by the implementation hardware. PL of hardware must be equal to or higher than specified PL r.

A tree type graph of decisions is used to find the contribution to risk reduction that must be provided by the safety-related function, leading to univocal identification of PL r. If more than one safety-related function are identified, PL r shall be identified for each of them.

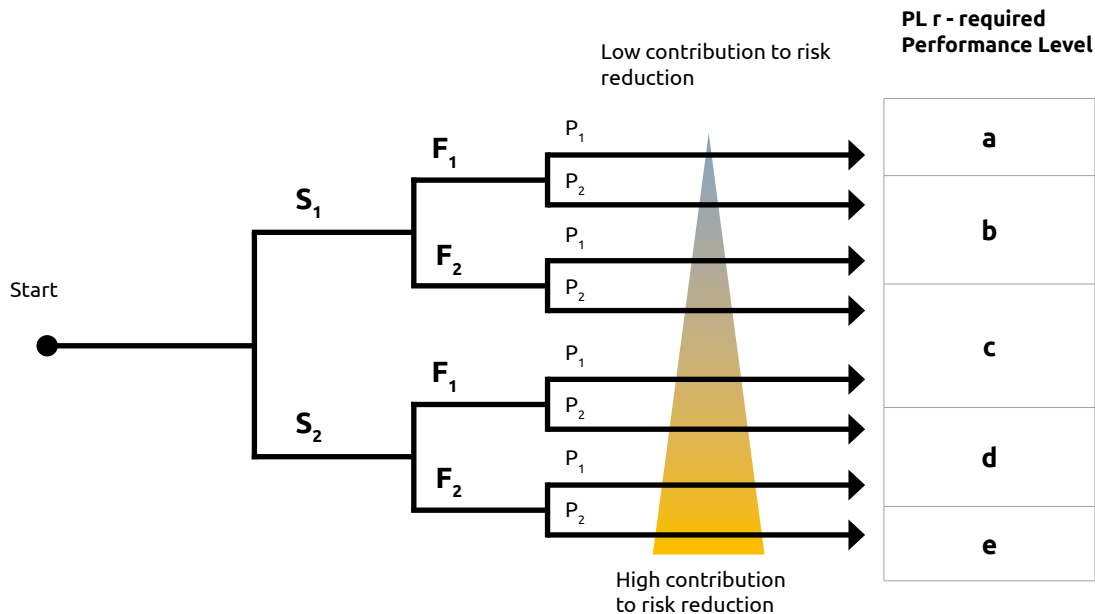


Fig. 4. Tree type graph of decisions

S: severity of injury

S1: reversible

S2: irreversible

F: frequency or time exposure to hazard

F1: rare / short

F2: continuous / prolonged

P: avoidable risk or limitation of damage

P1: avoidable within given conditions

P2: almost unavoidable



PL r(e) provides the greatest contribution to risk reduction, whereas PL r(a) makes the lowest contribution.

Design of the safety related control system and evaluation of the PL

After deciding on the PL r needed, a suitable SRP/CS is designed, calculating the resulting PL and ensuring that it is higher than or equal to PL r.

Fig. 3 shows that, to obtain the PL, the Average probability of dangerous failure/hour of the SRP/CS designed must be calculated. The Average probability of dangerous failure/hour for a safety-related control system may be estimated in various ways.

Using such methods implies that for each components the following are known:

- Failure rate (λ)
- Percent distribution of failure rate for all component failure modes, (e.g. if for a positive action switch the failure modes are: the contact will not open when required = 20% of cases and the contact will not close when required = 80% of cases)
- The effect of each failure on safety-related system performance, (e.g. dangerous failure = λd , or non-dangerous failure = λs)
- Percent of dangerous failures detected (by automatic self-diagnostic techniques implemented) out of total dangerous failures: $\lambda dd = \lambda d \times DC$
- Percent of dangerous failures not detected (by automatic self-diagnostic techniques implemented) out of total dangerous failures: $\lambda du = \lambda d \times (1-DC)$

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ISO 13849-1 simplifies calculation by providing a table based on Markov modelling in which average probability of dangerous failure per hour is pre-calculated for various Category combinations and range values of $MTTF_d$ and DC_{avg} which are in turn obtained using tables.

Denotations of $MTTF_d$	Range in years	Denomination DC_{avg}	Range of values DC_{avg}
Low	$3 \leq MTTF_d < 10$	None	$DC < 60\%$
Medium	$10 \leq MTTF_d < 30$	Low	$60\% \leq DC < 90\%$
High	$30 \leq MTTF_d < 100$	Medium	$90\% \leq DC < 99\%$
		High	$99\% \leq DC$

Category selection

CATEGORY	REQUIREMENTS	BEHAVIOUR	SAFETY PRINCIPLES
B	SRP/CS and/or their protective equipment, as well as their components, shall be designed, constructed, selected, assembled and combined in accordance with relevant standards so that they can withstand the expected influence. Basic safety principles shall be used	The occurrence of a fault can led to the loss of the safety function	Mainly characterized by selection of components
1	Requirements of B shall apply. Well-tried components and well-tried safety principles shall be used	The occurrence of a fault can led to the loss of the safety function but the probability of occurrence is lower than for category B	
2	Requirements of B and the use of well-tried safety principles shall apply. Safety function shall be checked at suitable intervals by the machine	The occurrence of a fault can led to the loss of the safety function between the checks. the loss of safety function is detected	Mainly characterized by structures
3	Requirements of B and the use of well-tried safety principles shall apply. Safety-related parts shall be designed, so that: <ul style="list-style-type: none"> a single fault in any of these parts does not lead to the loss of the safety function, and whenever reasonably practicable, the single fault is detected 	When a single fault occurs, the safety function is always performed. Some, but not all faults will be detected. Accumulation of undetected faults can lead to the loss of the safety function	
4	Requirements of B and the use of well-tried safety principles shall apply. Safety-related parts shall be designed, so that: <ul style="list-style-type: none"> a single fault in any of these parts does not lead to the loss of the safety function, and the single fault is detected at or before the next demand upon the safety function, but that if this detection is not possible, an accumulation of undetected faults shall not lead to the loss of the safety function 	When a single fault occurs, the safety function is always performed. Detection of accumulated faults reduces the probability of the loss of the safety function (high DC). the fault will be detected in time to prevent the loss of the safety function	

For Cat. B and Cat.1 the ability to resist failure is due to robustness of components (avoid failures as far as possible).

For Cat. 2,3,4 the ability to resist failure is due to the system structure (control of the failure). Failure is controlled through cycle monitoring for Cat.2, redundancy for Cat.3, redundancy plus monitoring for Cat.4.

Operational requirements are specified for each Category. The failure modes of the electric components are defined and listed. The relationship among Categories and the safety performance of the control system in case of failure is well defined (deterministic approach).

The problem is thus reduced to: selecting the architecture, calculating DC_{avg} in relation to self-diagnostic techniques implemented, calculating simplified $MTTF_d$ of circuit designed and verifying compliance with requirements for independent channel operation (CCF) for redundant architectures (Cat. 2, 3 and 4).

The combination of Category plus DC_{avg} adopted, is shown in one of the seven columns of fig. 5 of ISO 13849-1. Calculated $MTTF_d$ determines which part of the column is to be considered. Corresponding PL is shown on the left of the table.

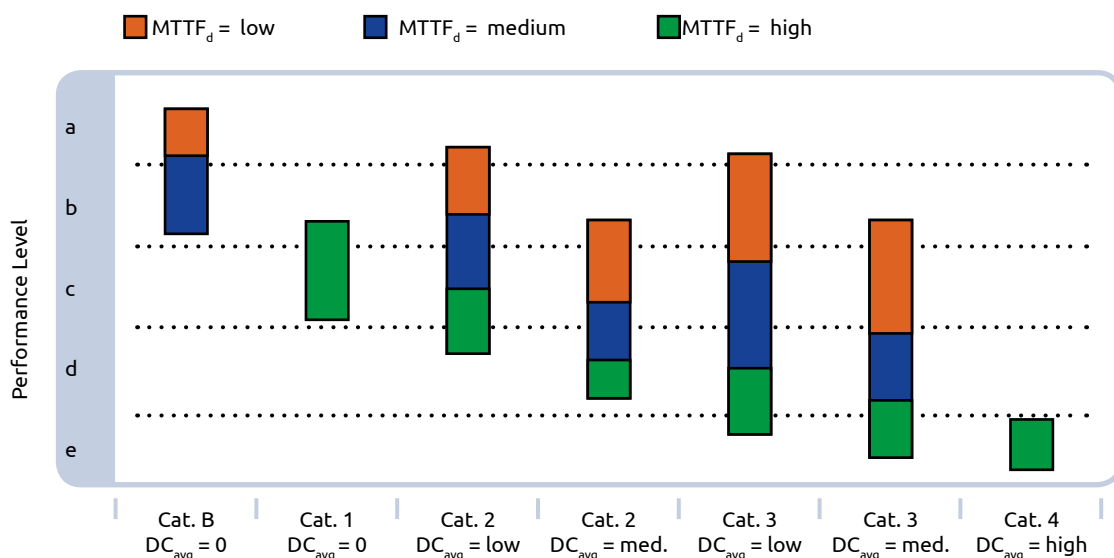


Fig. 5. Figure of ISO 13849-1

The part of column selected may include two or three possible values of PL, e.g. for Cat. 3, DC_{avg} = Medium and $MTTF_d$ = Low, the following three values are possible: PL b, PL c, PL d. In these cases, to obtain the correct PL use is made of Table K.1 of Annex K of the Standard (not shown) providing detailed values of Average probability of dangerous failure per hour and PL in relation to actual value of $MTTF_d$ and the combination Category-plus- DC_{avg} implemented.

As can be seen from Figure 5 for each Performance Level specified are available different choices. An example is given in Table 5 where for a system having PL of "c" the following five alternatives are possible:

Category 3 with $MTTF_d$ = Low and DC_{avg} medium

Category 3 with $MTTF_d$ = Medium and DC_{avg} low

Category 2 with $MTTF_d$ = Medium and DC_{avg} medium

Category 2 with $MTTF_d$ = High and DC_{avg} low

Category 1 with $MTTF_d$ = High

Exception only for the output part of the SRP/CS.

If for mechanical, hydraulic or pneumatic components (or components comprising a mixture of technologies) no application-specific reliability data are available, the machine manufacturer may evaluate the quantifiable aspects of the PL without any $MTTF_d$ calculation.

For such cases, the safety-related performance level (PL) is implemented by the architecture, the diagnostic and the measures against CCF. The next table shows the relationship between achievable PL and categories.

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	PFH _d (1/h)	Cat. B	Cat. 1	Cat. 2	Cat. 3	Cat. 4
PL a	2*10 ⁻⁵	*	0	0	0	0
PL b	5*10 ⁻⁶	*	0	0	0	0
PL c	1,7*10 ⁻⁶	-	*2	*1	0	0
PL d	2,9*10 ⁻⁷	-	-	-	*1	0
PL e	4,7*10 ⁻⁸	-	-	-	-	*1

* Applied category is recommended

0 Applied category is optional

- Category is not allowed

*1 Proven in use or well-tryed (confirmed by the component manufacturer to be suitable for particular application) components and well-tryed safety principles must be used

*2 Well-tryed components and well-tryed safety principles must be used. For safety-related components that are not monitored in the process, the T10d value can be determined based on proven in use data by the machine manufacturer.

Combination of several SRC/PS to achieve the overall PL

The safety-related function may include one or more SRP/CSs, and several safety-related function may use the same SRP/CSs. Individual SRP/CSs could also be obtained using other architectures. Where the safety-related function is obtained by a series connection of several SRP/CSs, e.g. safety light curtains, control logics, power output, and if the PFH_d values of all SRP/CSs are known, than the PHF_d of the combined SRP/CS is the sum of all PFH_d values of the N individual SRP/CSs.

The PL of the combined SRP/CS is limited by:

- the lowest PL of any individual SRP/CSs involved in performing the safety function (because the PL is determined also by non-quantifiable aspects) and
- the PL corresponding to the PFH_d of the combined SRP/CS according to tabel 3 of ISO 13849-1

If the PFH_d values of all individual SRP/CSs are not know:

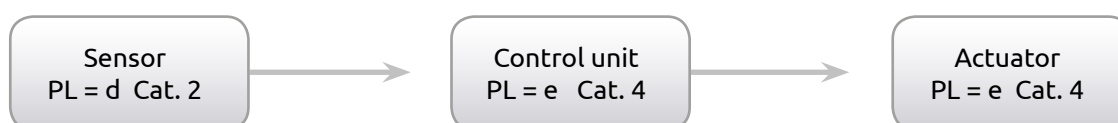
Locate the part with PL = PL low

Find the number of parts having PL = PL low

Enter data in the following table to obtain total PL

PL (low)	n (low)		PL
	>3		-
a	≤ 3	-->	a
	>2		a
b	≤ 2	-->	b
	>2		b
c	≤ 2	-->	c
	>3		c
d	≤ 3	-->	d
	>3		d
e	≤ 3	-->	e

The PL obtained using this table refers to reliability values at mid-position for each of the intervals in Table 3 of ISO 13849-1. Example:



We have: PL low = d N low = 1 (< 3)
Therefore: PL total = d

and average probability of dangerous failure per hour for the entire system will be a number somewhere between 1 x 10⁻⁶ and 1 x 10⁻⁷ (see Table 3 of ISO 13849-1).

IEC 62061 Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control system.

IEC 62061 is derived from IEC 61508 – Functional safety of safety-related electric/electronic/programmable electronic control systems.



IEC 61508 is the international reference standard on functional safety of electric, electronic and programmable electronic systems.

The Standard consists of seven sections. The first three sections specify the safety requirements for hardware and software, the rest are of an informative nature and offer support for the correct application of the former.

IEC 62061 retains the features of IEC 61508, but simplifies safety requirements (of both hardware and software) adapting them to the specific needs of industrial machinery.

Safety requirements are considered only for “high demand mode”, i.e. request of the safety function more than once per year.

The standard is based on two basic concepts:

- Management of Operational Safety
- Safety Integrity Level

Management of Operational Safety

Specifies all design aspects needed to attain the required level of functional safety, from assignment of safety requirements to documentation, design management up to validation.

Each design shall have its own Functional Safety Plan properly written, documented and duly updated as necessary.

The Functional Safety Plan shall identify people, functions and resources needed for design and implementation of the safety system.

Safety Integrity Level (SIL)

Methodology and requirements is given for:

- specifying functional requirements of each safety-related function to be implemented
- assigning the Safety Integrity Level (SIL) for each safety-related function envisaged
- allow the design of a SRECS suitable for the safety-related function to be implemented
- validating the SRECS

SIL assignment

For SIL assignment use the method of Annex A (although the Standard also accepts the techniques of IEC 61508-5).

For each risk identified the following must be assessed:

- Degree of severity (Se) of possible damage
- Frequency and time (Fr) of exposure to danger
- Probability of dangerous event (Pr) linked to machine operating mode
- Avoidability (Av) of danger. The more difficult to avoid danger the higher the number representing avoidability

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The following table, extracted from the form in Figure A.3 of the Standard IEC 62061, will help in obtaining the SIL to be assigned to the safety-related function.

Consequences	Severity Se	Class Cl					Frequency Fr	Probability of hazardous event Pr	Avoidance Av			
		4	5-7	8-10	11-13	14-15						
Death, losing an eye or arm	4	SIL 2	SIL 2	SIL 2	SIL 3	SIL 3	≥ 1 hour	5	Very high	5		
Permanent: losing fingers	3		OM	SIL 1	SIL 2	SIL 3	< 1 hour ≥ 1 day	5	Likely	4		
Reversible: medical attention	2			OM	SIL 1	SIL 2	< 1 day ≥ 1 2 weeks	4	Possible	3	Impossible	5
Reversible: first aid	1				OM	SIL 1	< 1 2 weeks ≥ 1 1 year	3	Rarely	2	Possible	3
							< 1 1 year	2	Negligible	1	Probable	1

OM (Other Measures) = The use of other parameters is recommended.

The sum of marks obtained for attributes of frequency, probability and avoidability provides the probability class of danger:

$$Cl = Fr + Pr + Av$$

To obtain the SIL align actual Cl to level of severity (Se) identified.

This is an iterative process. In fact, depending on the protective action undertaken, some parameters might change, e.g. Fr or Pr, in which case the SIL assignment process will have to be repeated using new values for changed parameters.

Three levels are envisaged: **SIL 1, SIL 2, SIL 3**.

Average probability of serious failure per hour (PFH_d)

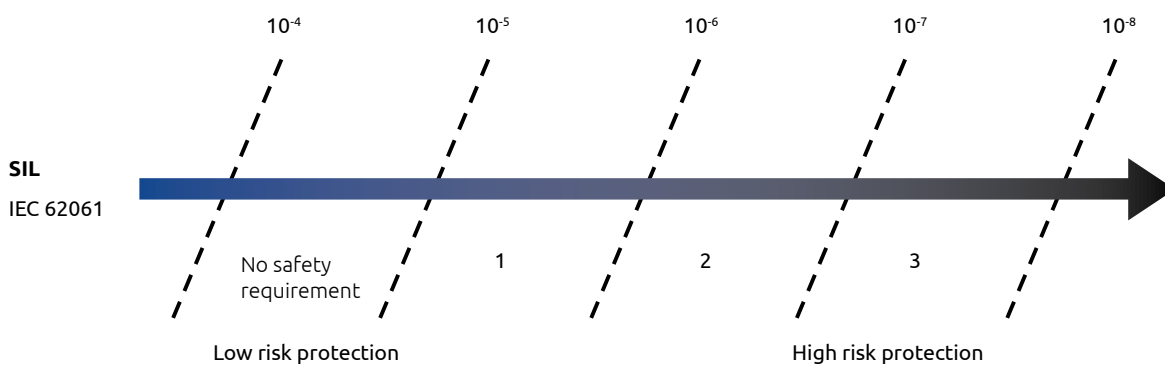


Fig. 6. Table 3 of IEC 62061

Thus, the SIL represents the safety level to be assigned to a SRECS for attainment of its safety integrity in the operating conditions and all the way through the time specified.

The parameter used to define the SIL (Safety Integrity Level) is the probability of dangerous failure/hour (PFH_d).

The higher the SIL, the lower the probability of the SRECS not performing as safely as expected.

The SIL must be defined for each safety-related function resulting from risk analysis.

Development and design process

Each safety-related function identified through risk analysis shall be described in terms of:

- Operational requirements (mode of operation, cycle time, environmental conditions, response time, type of interface with other components or items, EMC level, etc.)
- Safety requirements (SIL).

Each safety-related function shall be broken down into functional blocks, e.g. functional block of input data, functional block of logic data processing, functional block of output data.

A subsystem is associated with each functional block.

In turn, subsystems will consist of electrical components interconnected with one another. Electrical components are known as subsystem elements.

Implementation of the SRECS technique will result in a typical architecture as shown (in this instance access control through photoelectric curtain)

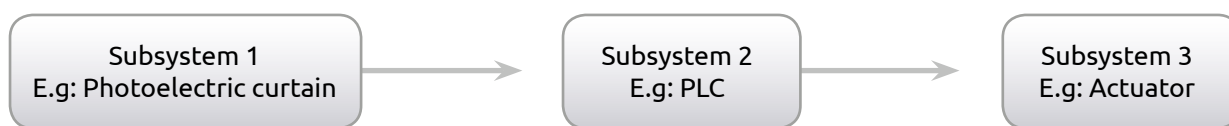
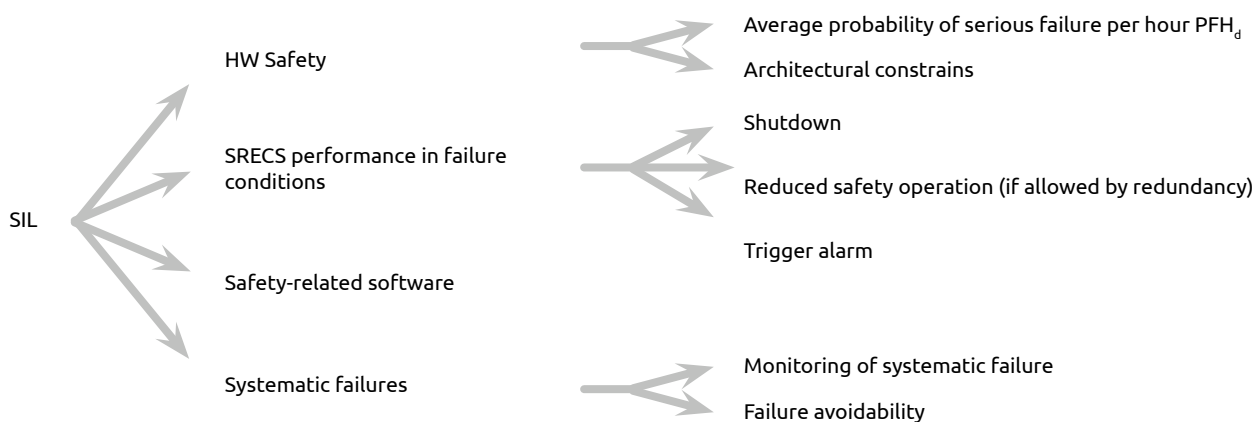


Fig. 7. Typical architecture of the SRECS

For SRECS to comply with identified operational and safety requirements, the following requirements shall be met:



Each subsystem shall consist of electrical circuits suited to attain the required SIL.

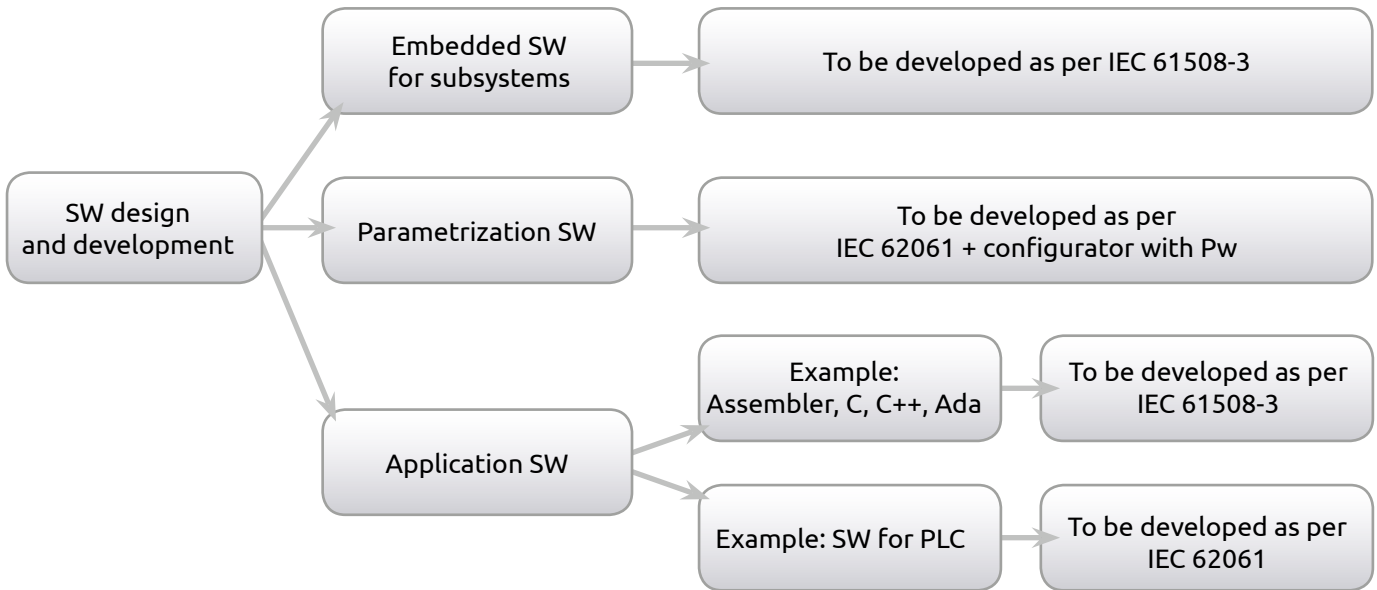
The maximum SIL attainable by a subsystem is identified as SILCL (SIL claim).


Subsystem SILCLs depend on PFH_d , architecture constraints, performance under failure conditions and on the ability to control and avoid systematic failure.

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Safety-related software

For software design, the code must be developed as per reference standards depending on the type of software in question as follows:



 Safety-related PLCs, safety bus, actuators, safety light curtains and in general all complex safety-related devices with integral programmable logics and embedded software, if used to build a SRECS, shall comply with the requirements of the appropriate Product Standards (if applicable) and with IEC 61508 as regards functional safety.

IMPORTANT!

The probability aspect is only one of the elements contributing to assignment of SIL.

To claim a specific SIL applicants must prove and document having:

- adopted adequate management actions and techniques to attain the required level of operational safety
- in place a documented and up-to-date Operational Safety Plan
- avoided systematic failure as far as possible
- evaluated (through inspections and tests) safety system performance in actual environmental conditions
- developed the software after adopting all organisational aspects required.

Calculation of subsystem PFH_d

To calculate subsystem PFH_d, select first the type of architecture (structure). The Standard suggests four pre-defined architectures, providing a different simplified formula for each of them.

This calculation requires the use of the following parameters:

- λ_d** = Dangerous failure rate of each subsystem element.
Obtained from its known failure rate **λ**, percent distribution of failure rate for all failure modes and analysis of subsystem performance after failure (Dangerous Failure = **λ_d** or Non-dangerous Failure = **λ_n**).
- T1** = Proof Test. Proof test interval. For industrial machinery usually coincides with life time (20 years).
- T2** = Test interval of the diagnostic functions. Depending on design or devices used the diagnostic functions can be executed by internal circuitry of the same SRECS or by other SRECSs.
- DC** = Diagnostic Coverage:
Parameter representing the percent of dangerous failures detected out of all possible dangerous failures. DC depends on self-diagnostic techniques implemented.
Assuming that failure is always possible (otherwise there would be no point in defining **λ**), that mechanisms for detecting failures are not necessarily all equally effective and responsive (depending on type of failure some may take longer), that it is impossible to detect all failures, that suitable circuitry architectures and effective testing may permit detection of most dangerous failures, a DC parameter may be defined for estimating the effectiveness of implemented self-diagnostic techniques. IEC 62061 does not provide data for obtaining DC in relation to implemented diagnostic techniques. However, data of IEC 61508-2 Annex A may be used.
- β** = Common cause failure factor. Provides a measure of the degree of independence of operation of redundant channel systems.

Having calculated subsystem PFH_d by means of the formulas from the IEC 62061, it is important to ensure that the associated SILCL obtained from Table 3 of IEC 62061 is compatible with the constraints imposed by the architecture as the maximum SILCL attainable by a given subsystem is restricted by the hardware fault tolerance of the architecture and by SFF as listed in the following table

(Table 5 of IEC 62061)

Safe failure fraction (SFF)	Hardware fault tolerance		
	0	1	2
SFF < 60%	Not allowed	SIL 1	SIL 2
60% ≤ SFF < 90%	SIL 1	SIL 2	SIL 3
90% ≤ SFF < 99%	SIL 2	SIL 3	SIL 3
SFF ≥ 99%	SIL 3	SIL 3	SIL 3

Subsystem safety failure fraction (SFF) is, by definition, the fraction of overall failure rate not involving dangerous failure

$$SFF = (\Sigma\lambda_s + \Sigma\lambda_{dd}) / (\Sigma\lambda_s + \Sigma\lambda_{dd} + \Sigma\lambda_{du})$$

λ_{dd} (failure rate of detectable dangerous failures) and **λ_{du}** (failure rate of undetectable dangerous failures) are obtained from known effectiveness of implemented diagnostic techniques.

If PFH_d and SILCL of each subsystem are known, it will be possible to calculate the overall SIL of SRECS.

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In fact:

The overall probability of dangerous failure/hour of SRECS will equal the sum of the probabilities of dangerous failure/hour of all subsystem involved and shall include, if necessary, also the probability of dangerous failure per hour (PTE) of any safety-related communication lines:

$$PFH_d = PFH_{d1} + \dots + PFH_{dN} + P_{TE}$$

Known the PFH_d , the resulting SIL of the SRECS is obtained from Table 3.

The SIL shall than be compared to the SILCL of each subsystem, as the SIL that can be claimed for the SRECS shall be less or equal to the lowest value of the SILCL of any of the subsystems.

Example:



$$PFH_d(\text{system}) = PFH_d(ss1) + PFH_d(ss2) + PFH_d(ss3) + P_{TE} = 5,56 \times 10^{-7}/h$$

$$SIL = 2$$

Where a subsystem involves two or more safety-related functions requiring different SILs, the highest SIL shall apply.

Conclusions

The procedures specified in EN ISO 13849-1 simplify the estimation of Average Probability of Dangerous Failure per Hour compared to IEC 61508, offering a pragmatic approach more in line with the needs of the machine tool industry.

By retaining Categories and other basic concepts, such as “well tried component”, seamless continuity with EN 954:1996 is assured.

Maintaining a closely linear approach with EN 954-1:1996 however, shows the limits of EN ISO 13849-1. Where the adoption of complex technology is anticipated and different architectures, it will be more appropriate to design to IEC 62061.

Where devices and/or subsystems designed in accordance with EN ISO 13849-1 are used, Std. IEC 62061 shows how to integrate them in SRECS.

A precise bi-univocal equivalence between PL and SIL cannot be identified.

However, the probabilistic side of PL and SIL can be compared as they use the same concept, namely the Average Probability of Dangerous Failure per Hour, to define the extent to failure resistance.

Also, although the probability concept used in the two Standards is the same, the result of the PFH_d may differ as the calculation is not the same.

EN ISO 14119 Safety of machinery - Interlocking devices associated with guards - Principles for design and selection

Main changes introduced by EN ISO 14119

New subdivision of the interlocking devices

Interlocking device interlock (ISO 14119:2013, § 3.1) - Mechanical, electrical or other type of device, the purpose of which is to prevent the operation of hazardous machine functions under specified conditions (generally as long as a guard is not closed).

Type 1 devices - Uncoded

These can be:

- Rotary cam
- Linear cam
- Hinge.

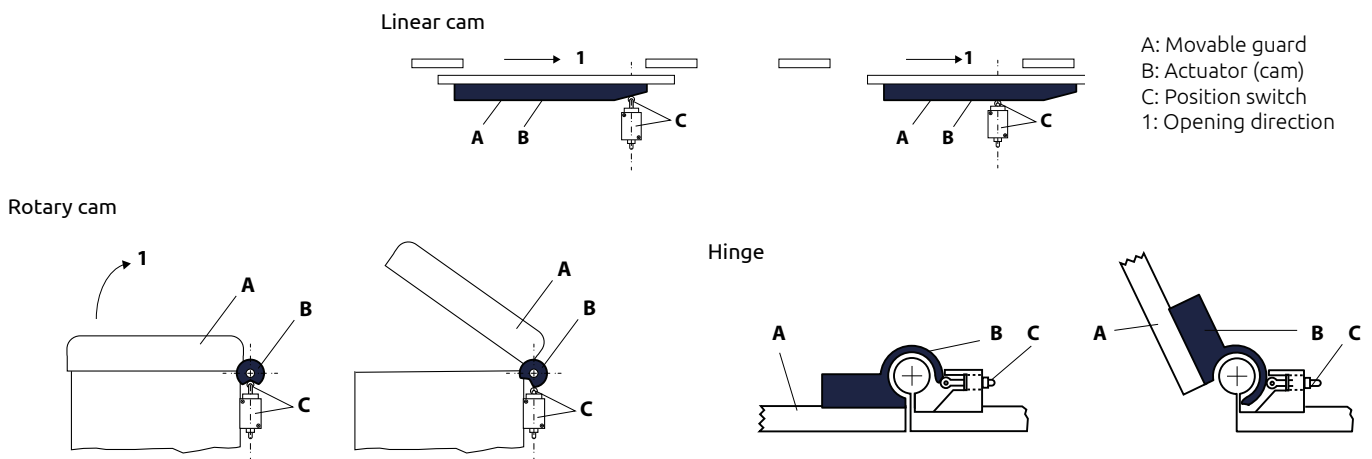


Fig. 8. Type1 interlocking device

Type 2 - Coded

Coded actuator (ISO 14119:2013, § 3.13). Actuator which is specially designed (e.g. by shape) to actuate a certain position switch.

- Low level coded actuator: coded actuator for which 1 to 9 variations in code are available.
- Medium level coded actuator: coded actuator for which 10 to 1000 variations in code are available.
- high level coded actuator: coded actuator for which more than 1000 variations are available.

These can be:

- Position switch with codec tongue actuator
- Trapped key interlocking

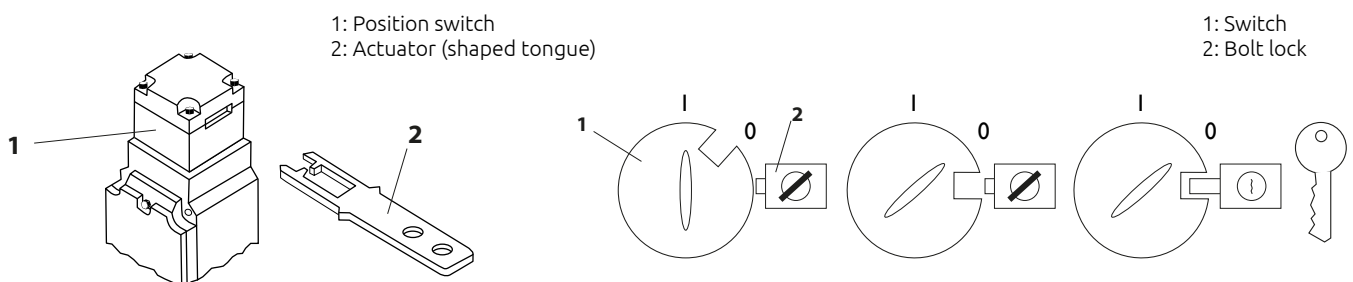


Fig. 9. Type 2 interlocking device - Coded

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Type 3 - Uncoded

These can be:

- Inductive - Actuated by metal of the guard
- Magnetic - Actuated by uncoded magnet
- Capacitive - Ultrasonic or optical

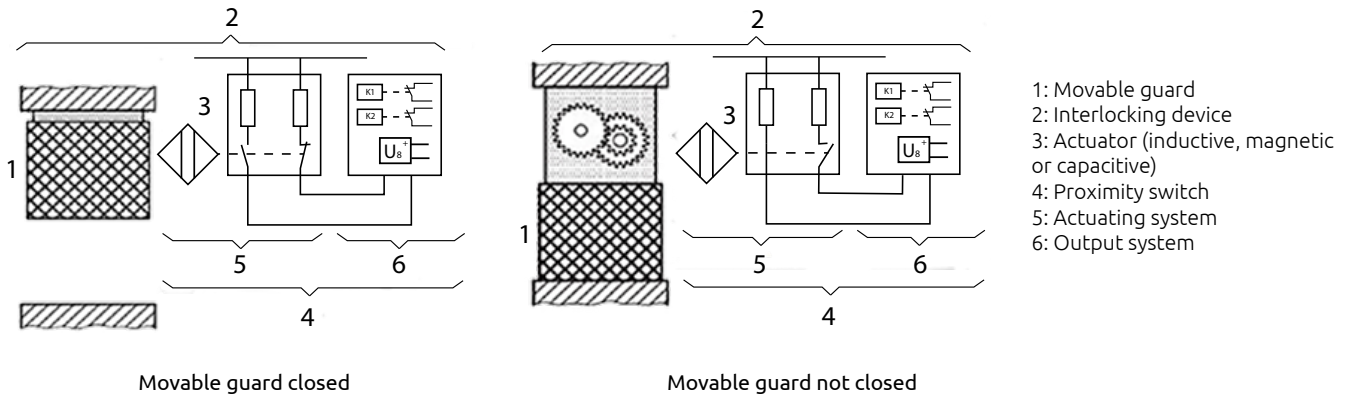


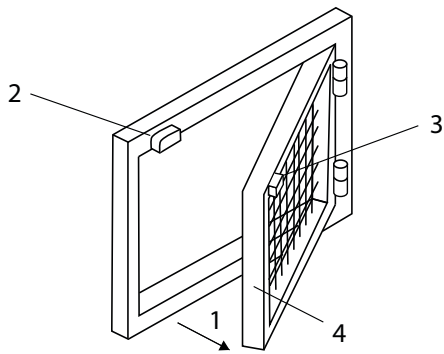
Fig. 10. Type 3 interlocking device with proximity switch actuated by uncoded actuator

Type 4 - Coded

These can be:

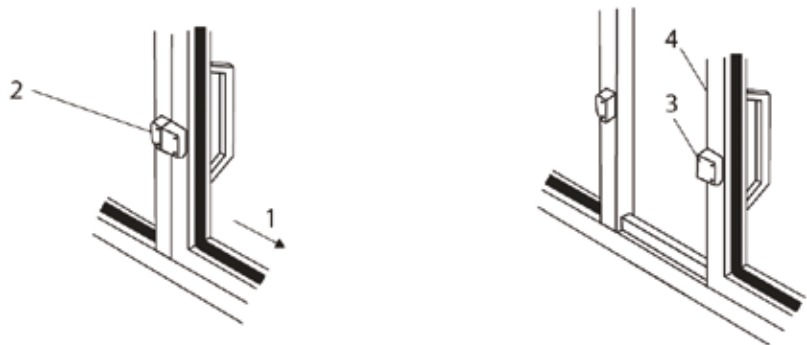
- Magnetic - Actuated by coded magnet
- RFID
- Optical - Actuated by coded optics

Position switch RFID



- 1: Opening direction
- 2: Type 4 interlocking device
- 3: coded magnet actuator
- 4: Movable guard

Type 4 interlocking device with position switch actuated by coded magnetic actuator



- 1: Opening direction
- 2: Type 4 interlocking device
- 3: coded RFID tag actuator
- 4: Movable guard

Fig. 11. Type 4 interlocking device - Coded

Overall system stopping performance and access time (The guards distance)

The access time shall be calculated by using the distance between the hazard zone and the guard together with the approach speed (see ISO 13855:2010 for typical values).

Logical series connection of interlocking devices

Logical series connection of interlocking device means for NC contacts wired in series or for NO contacts wired in parallel.

Up to now, for a logical series of NC contacts, it is considered a DC = 60%, allowing you to get a PL d (not a PL e). The masking of faults, could lead to a lower diagnostic coverage, so nothing.

Based on $DC = \lambda_{dd} / \lambda_d$ (ratio of detected dangerous failures and total) can easily lead to a DC <60%.

Interlocking devices based on "fault exclusion"

The standard specifies that the maximum safety level reached by interlocking devices based on "fault exclusion" is generally PLd. In fact there is the possibility that a single mechanical failure resulting in the loss of the safety function.

For example a mechanical failure relating to the key (actuator), or some part of the mechanical device, can generate false information on the electrical contact output.

In some cases it is still possible reach the safety level PLe. These are cases of "fault exclusion for the guard locking".

The safety level reached in these cases is not necessarily limited by the faults exclusion of the mechanical locking device.

However, specific requirements must be verified: the holding force specified (FZH) of the protection guard locking device must be sufficient to withstand static forces planned on locking bolt, it is also necessary to prevent any effect on the protection locking device determined by the forces dynamic due to movement of the protection guard.

Guard lock and Guard interlock

The standard emphasizes the fact that the interlock function and the lock function are two separate safety functions with PLR that can also be different (PLr Locking < PLr interlock).

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Measures to prevent the defeat of the interlock device

Guards and protection devices of the machines should not be easy to by-pass or render non-operational (Directive 2006/42/EC §1.4.1). Measures required to minimize tampering.

Defeat (ISO 14119:2013, § 3.7 and § 3.8)

Defeat: action that makes interlocking devices inoperative or bypasses them with the result that a machine is used in a manner not intended by the designer or without the necessary safety measures.

Defeat in a reasonably foreseeable manner: defeat of an interlocking device either manually or by using readily available objects. Measures to reduce the defeat of interlocking devices may be adopted:

Prevent access to the elements which constitute the interlock device:

- Mounting out of reach, physical obstruction / shielding, Mounting in hidden position)
- Preventing substitution of the actuators using encoded interlocking devices
- Prevent disassembly or moving of the interlocking devices (welding, gluing, riveting, etc ..)
- Status monitoring or cyclic testing of the interlocking device
- Adding an additional interlock device with a different principle of implementation. In this case, you will be testing the plausibility of the state of both devices

The table 3 of the standard ISO 14119:2013 specifies the additional measures against defeating interlocking devices depending on type.

The anti-tampering measures in case of magnetic sensors low level encoding(MAGNUS)

Mandatory:

- Mounting out of reach places, or mounting recesses and not visible in the machine, or status monitoring
- Mounting the actuator so that it is difficult to remove

Advice:

- Second magnetic sensor
- Plausibility check of both sensors

Safety speed monitoring

The safety speed monitoring using sensors (encoders, proximity switch) for the measurement of speed, must be able to detect possible dangerous failures of the sensors themselves.

Standard EN 61800-5-2 Table D.16 gives the list of dangerous failures for this type of sensors and possible fault exclusion.

- The greater the amount of faults detected by the controller, the higher is the diagnostic coverage and therefore the better the safety level reached by the considered function
- The possibility to apply the fault exclusion removes the need to control and increases the attainable safety performance

Sensors and certificate speed monitoring combinations

Certified Safety Encoder + Certificate safety speed monitoring (example Mosaic MV)	The certificate safety encoder, in combination with a certificate speed monitoring, complies with all the requirements specified in EN 61800-5-2. Easy solution for safety speed monitoring function.	Cat. 4 - SIL 3 - PL e SIL 3 Encoder
Normal Encoder + Proximity + Certificate safety speed monitoring (example Mosaic MV)	The system uses two non safety sensors forming a dual channel system. The controller verifies that the two sensors measure the same speed. Failure of one of the two channels (electrical or mechanical), causes a difference in the measured values. This situation is detected by the controller which generates an alarm signal. Since the two sensors belong to use different technologies, the two channels are not homogeneous. This reduces the possibility of common cause failures by improving the score of the Common Cause Failure (CCF) factor. See Standard ISO EN 13849-1 *. With regards to the reliability values (MTTF _d) of the sensor used it is theoretically possible to achieve a maximum safety level (SIL3 PL e). Such level should be calculated and verified in accordance with EN 13849-1-2.	Cat. 3 - DCavg 90% Safety level up to SIL 3 - PL e
Proximity + Proximity + Certificate safety speed monitoring (example Mosaic MV)	The system uses two proximities forming a dual channel system. The controller verifies that the two sensors measure the same speed. Failure of one of the two channels (electrical or mechanical), causes a difference in the measured values. This situation is detected by the controller which generates an alarm signal. In this case the two sensors use the same technology. The two channels are homogeneous. This may increase the possibility of common cause failures compared to the solution Encoder + Proximity, making it more difficult to achieve the minimum score (65) of the CCF factor. See Standard ISO EN 13849-1 *. DCavg is 90% only if is possible (by means of suitable fastening solutions) to apply the exclusion of mechanical failure (loosening or loss of mechanical coupling with the engine) on the encoder wheel (toothed wheel). With regards to the reliability values (MTTF _d) of the sensor used, it is theoretically possible to achieve a maximum safety level (SIL3 PL e). Such level should be calculated and verified in accordance with EN 13849-1-2.	Cat. 3 - DCavg 90% Safety level up to SIL 3 - PL e
Normal Encoder + Normal Encoder + Certificate safety speed monitoring (example Mosaic MV)	The system uses two non safety encoders forming a dual channel system. The controller verifies that the two sensors measure the same speed. Failure of one of the two channels (electrical or mechanical), causes a difference in the measured values. This situation is detected by the controller which generates an alarm signal. In this case the two sensors use the same technology. The two channels are homogeneous. This may increase the possibility of common cause failures, making it more difficult to achieve the minimum score (65) of the CCF factor. See Standard ISO EN 13849-1 *. With regards to the reliability values (MTTF _d) of the sensor used is theoretically possible to achieve a maximum safety level (SIL3 PL e). Such level should be calculated and verified in accordance with EN 13849-1-2.	Cat. 3 - DCavg 90% Safety level up to SIL 3 - PL e

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<p>Normal Encoder + Certificate safety speed monitoring (example Mosaic MV)</p>	<p>The system uses one non-safety sensor forming a single channel system. The controller cannot make comparisons and verifications. The channel failure (electrical or mechanical) could not be detected.</p> <p>The solution is Cat.B. This category does not include any diagnostic coverage (DC_{avg}).</p> <p>The maximum achievable level of safety is PL b. The solution could be to Cat. 1 only if the used encoder is considered a well-tried component for safety applications (Well Tried Component - ref. ISO 13849-1 Table 10).</p>	<p>Cat. B - Safety level up to PL b</p> <p>or</p> <p>Cat. 1 - Safety level up to SIL 1 - PL c</p>
<p>Proximity + Certificate safety speed monitoring (example Mosaic MV)</p>	<p>The system uses one proximity forming a single channel system. The controller cannot make comparisons and verifications. The channel failure (electrical or mechanical) could not be detected.</p> <p>The solution is Cat.B. This category does not include any diagnostic coverage (DC_{avg}). The maximum achievable level of safety is PL b.</p> <p>The solution could be to Cat. 1 only if the used proximity is considered a well-tried component for safety applications (Well Tried Component - ref. ISO 13849-1 Table 10).</p>	<p>Cat. B - Safety level up to PL b</p> <p>or</p> <p>Cat. 1 - Safety level up to SIL 1 - PL c</p>

* Standard ISO EN 13849-1 Table F.1: Scoring process and quantification of measures against CCF. It's necessary reach minimum score of 65 points Assessment needed for Category 2, 3 and 4.



It is important to verify the possibility, by means of suitable fastening solutions, to apply the mechanical failure exclusion (loosening or loss of mechanical coupling with the engine).

Glossary

Initials	Definition	Standard	Description
β (Beta)	Common cause failure factor	IEC 62061	Degree of operational independence of channels of a multi-channel system. Ranging from 0.1 to 0.01 depending on CCF attained. Random failure frequency. The time-random failure frequency of a component is usually known as Failure Rate, described as number of failures per unit of hour. Its inverse is known as Mean Time Between Failures (MTBF), expressed in hours.
λ (Lambda)	Failure rate	IEC 62061	Random failures are the result of sudden stress accumulation above maximum design strength of a component. May occur at random intervals and entirely unexpectedly. Frequency of failure over sufficiently long periods is virtually constant. PFHd calculation methods given in both Standards refer only to the assessment of random failures. The unit of measure for failure rate is FIT (Failure In Time) equivalent to one failure per billion of operating hours (F=1 means one failure every 10 ⁹ hours).
λ_s	Safe failure rate	IEC 62061	Failure rate for non-dangerous failures. Non-dangerous failures which have no adverse safety-related effect on control system. The control system continues to ensure protection.
λ_d	Dangerous failure rate	IEC 62061	Failure rate of failures which may involve dangerous operation. Dangerous failures prevent the control system from continuing to provide protection.
λ_{dd}	Dangerous detected failure rate	IEC 62061	Failure rate for detectable dangerous failures. Detectable dangerous failures may be detected by automatic self-diagnostic systems.
λ_{du}	Dangerous undetected failure rate	IEC 62061	Failure rate for undetectable dangerous failures. Undetectable dangerous failures cannot be detected by internal automatic self-diagnostic systems. They determine the value of PFHd and, consequently, the value of SIL or PL.
Cat.	Category	ISO 13849-1	The Category is the main parameter to consider to attain a given PL. Describes the SRP/CS performance in relation to its ability to resist failure and resulting performance in failure conditions. Five Categories are envisaged depending on structural positioning of components.
CCF	Common Cause Failure	ISO 13849-1 IEC 62061	Failure resulting from common causes. Failure resulting from one or more events causing simultaneous malfunction of channels of a multi-channel system. Provides a measure of the degree of independence of redundant channel operation. Assessed by assigning marks. Maximum possible score is 100.
DC	Diagnostic Coverage	ISO 13849-1 IEC 62061	Reduced probability of dangerous hardware failure due to automatic self-diagnostic system operation. A measure of system effectiveness in promptly detecting its own possible malfunction. Expressed as 60% to 99%.
MTTF _d	Mean Time to dangerous Failures	ISO 13849-1	Average operating time, expressed in years, to potentially dangerous random failure (not generic failure). May refer to a single component, or to a single channel, or to the entire safety-related system.

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Initials	Definition	Standard	Description
PFH _d	Probability of dangerous Failure /Hour	IEC 62061	Average probability of dangerous failure per hour. Quantitative representation of risk reduction factor provided by the safety-related control system.
PL	Performance Level	ISO 13849-1	Level of performance. In ISO 13849-1, the extent to which failures are controlled is assessed using the Performance Level concept (PL). Represents SRP/CS ability to perform a safety-related function within predictable operating conditions. There are 5 levels, PLa to PL e. PL e represents the highest level of risk reduction, PLa the lowest level.
PL _r	Performance Level required	ISO 13849-1	Level of performance required. Represents the contribution to risk reduction by each safety-related part implemented in SRP/CS. PL _r is obtained using the risk curve.
SIL	Safety Integrity Level	IEC 62061	Level of integrity of a safety-related function. Discrete level (one of three) used to describe the ability of a safety-related control system to resist failure as per IEC 62061, where level 3 assures the highest protection and level 1 the lowest.
SILCL	SIL Claim	IEC 62061	Max. SIL attainable by a subsystem in relation to architecture and ability to detect failure.
SRP/CS	Safety Related Parts of Control Systems	ISO 13849-1	Part of machine control system able to maintain or achieve machine safety status in relation to the status of certain safety-related sensors.
SRECS	Safety Related Electrical, electronic and programmable electronic Control System	IEC 62061	Electrical, electronic and programmable electronic control system the failure of which immediately increases the risk factor associated with machine operation.
T1	Proof test interval	IEC 62061	Interval of proof test. The Proof Test is an external manual inspection for detecting component failure and performance decay, undetectable by internal self-diagnostic systems. The unit of measure is time (months or, more usually, years).
T2	Diagnostic test interval	IEC 62061	Test interval of self-diagnostic functions. Time elapsed between one test for the detection of possible internal failure and the next. Tests are carried out in automatic mode by dedicated circuitry which may be internal to the SRECS in question or may belong to other SRECSs. The unit of measure is time (milliseconds to hours).
SFF	Safe Failure Fraction	IEC 62061	Fraction of overall failure rate which does not involve dangerous failure. Represents the percentage of non-dangerous failures relative to total number of failures of the safety-related control system.



SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

Characteristic elements

Light curtains are protective electro sensitive devices (ESPE) using one or more light beams, emitted by an Emitter and received by a Receiver, to create an intangible controlled area.

When the chosen safety device is a photo-electric barrier (AOPD Active Optoelectronic Protective Device), it shall necessary belong to TYPE 2 or TYPE 4 as established by the International Standard IEC 61496 1-2.



Why “Type” and not “Category”?

The two “Types” differ in their safety related performance and are related to the categories of ISO 13849-1 but do not have the same meaning as here, to define the degree of safety integrity, further parameters in addition to the the architecture of the system and to the types of hardware and software failures are taken into account that are related to the detection technology used (substantially optical); they mainly concern immunity to light interference and the design characteristics of the Optical systems.

New safety parameters for Type 2 light curtains

With the publication of Edition 3 of the harmonized EN 61496-1 standard it is no longer possible to use a Type 2 safety light curtains for safety functions assessed as SIL 2 / PL d. If a safety level of SIL 2 / PL d (or higher) is required and it is nevertheless intended to use a safety light curtain, then it will be necessary to use a Type 4 safety light curtain.

This regulatory requirement derives from the fact that the reduction of risk that can be obtained via a photoelectric safety light curtain is not only a function of the safety level of its electronic parts, but is also determined by its systematic capabilities (for example: environmental influences, EMC, optical performance and detection principle).

The systematic capability of a Type 2 photoelectric light curtain may in fact not be sufficient to ensure adequate risk reduction for SIL 2 / PL d applications. The standard also establishes that the labelling of Type 2 safety light curtains must indicate such limitation to SIL 1 / PL c.

The PFH_d values declared for the electronic control part of the device, on the other hand, are not limited and therefore it is possible to use the PFH_d value provided by the manufacturer of the device in the global assessment of the safety function, even if it exceeds the SIL 1 / PL c range.

Protected height

This is the height controlled by the light curtain. If it is positioned horizontally, this value shows the depth of the protected zone.

Range

This is the maximum working distance that may exist between the emitter and the receiver. When deflection mirrors are used, it is necessary to take into account the attenuation factor introduced by each of them, which it is about 15%.

Response time

This is the time it takes for the light curtain to transmit the alarm signal from the time the protected zone is interrupted.

PHOTOELECTRIC SAFETY LIGHT CURTAINS

Resolution

The resolution, for all ReeR safety light curtains, is the minimum size of an object that, placed into the controlled area, will obscure the controlled zone and hence stop the hazardous movement of the machine.

- Single beam light barriers: their resolution R is the same as the diameter of the lens.
- Multibeam light curtains: their resolution R is the same as the sum of the lens diameter + the distance between two adjacent lenses.

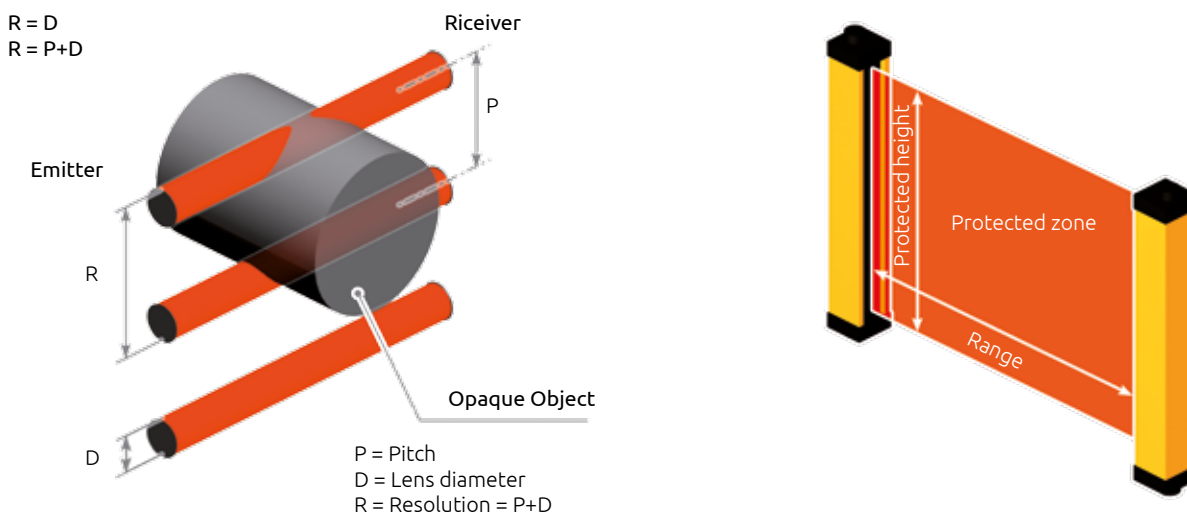
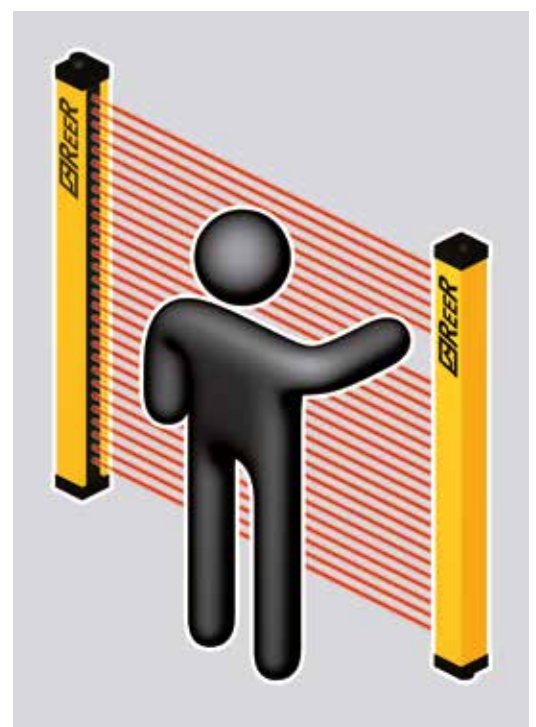


Fig. 12. Resolution

Advantages of light curtains

- Effective protection in the event of fatigue or distraction of the operator.
- Increase in the productive capacity of the machine as the light curtain does not require the manual handling of physical guards or waiting for them to open.
- Faster machine loading/unloading operations.
- Reduced times of approach to the working areas.
- Elimination of the risk of tampering since any irregular intervention on the light curtain stops the machine.
- Simple and quick installation, with greater flexibility of adjustment on the machine, even in the case of subsequent repositioning.
- Possibility to build up large sized protections, either linear or along a perimeter, on several sides, at greatly reduced costs.
- Facilitated and fast maintenance of the machine, as there is no need to remove physical guards, such as grids, gates, etc.
- Improved appearance and ergonomic effectiveness of the machine.



SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

The technical specification IEC 62046: Safety of machinery – Application of protective equipment to detect the presence of persons¹

This technical specification provides recommendations for the installation and use of ESPEs.

It is therefore mainly applied to Safety light curtains and Safety Laser Scanners, Safety Mats

This technical specification meets the needs of the machine manufacturers and of the machine users. Indeed it gives requirements for the selection of the most suitable model, its correct positioning and its correct interfacing to the machine.

Selection process

The purpose of the Selection Process of the Protective Device (ESPE) is to ensure that, through proper choice and application of the device (and if necessary through the integration of other safety measures) the risk of injury to the operator is reduced to the acceptable minimum.

In order to make a correct choice, the following factors must be taken into account which may adversely affect the effectiveness of protection:

- machine characteristics
- environmental characteristics
- human characteristics
- type of use of the protective equipment
- protective equipment characteristics.

Machine characteristics

For optoelectronic safety devices to be effective, it is necessary to verify that they are suitable for the shape and size of the detection zone (e.g. width and height of the access area).

However, some characteristics of particular machines can preclude the use of protective equipment as the sole protective measure.

Examples of these machine characteristics are:

- possibility that the machinery will eject materials, swarf or component parts
- risk of injury from thermal or other radiation
- unacceptable noise levels
- an environment likely to adversely affect the function of the protective equipment
- a material being processed that can influence the effectiveness of the protective measure
- it is impossible to stop the machine immediately when it is started because this could introduce additional risks or because the machine can only be stopped at the end of the processing cycle due to the particular type of operation

Or the ESPE is poorly efficient if:

- The machine stopping time is unknown or is randomly variable due to unquantifiable delays introduced by the control circuit or due to under dimensioned braking systems
- The machine cannot be stopped at any point in its working cycle

¹ Under modification due to a change of the type of document from technical specification to international standard

PHOTOELECTRIC SAFETY LIGHT CURTAINS

SAFETY LASER SCANNER

Environmental characteristics

Care must be taken to assess the environment in which the machine is expected to work. Before choosing the device, all the necessary information about the working environment and the possible variations that are reasonable to expect during the life of the machine should be available.

A non-exhaustive list of environmental conditions that may adversely affect the operation of an optoelectronic device are as follows.

- electromagnetic interference
 - electrostatic discharge
 - radio frequency interference, for example mobile telephones
 - lightnings
- vibration/shock
- light interference
 - ambient light
 - reflective surfaces
 - infra-red, for example remote controls or other ESPEs that can emit interfering light
- pollution
 - water
 - dust
 - corrosive chemicals
 - smoke
- temperature
- humidity
- weather conditions
- radiation

If there are special operating conditions such as outdoor operation (fog, rain, snow) or operation in potentially explosive or flammable atmospheres (paints, sawdust), then further environmental requirements may be needed that will normally have to be agreed upon with the manufacturer of the device.

Dimensions and characteristics of the human body

Since the main function of the ESPE is to detect the human body or parts of the human body, it should be taken into account its anatomy (fingers, hands, legs), the predictable maximum speed, how it interact with the machine.

The resolution, that is, the detectable minimum object, must be the function of the body part to be protected (eg fingers, hands, legs, arms). Typically, this choice is made by referring to the ESPE manufacturer's catalog or user manual.

Uses of protective equipment

A protective equipment may be used to provide:

- trip function
- presence sensing function
- combination trip function and presence sensing function

SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

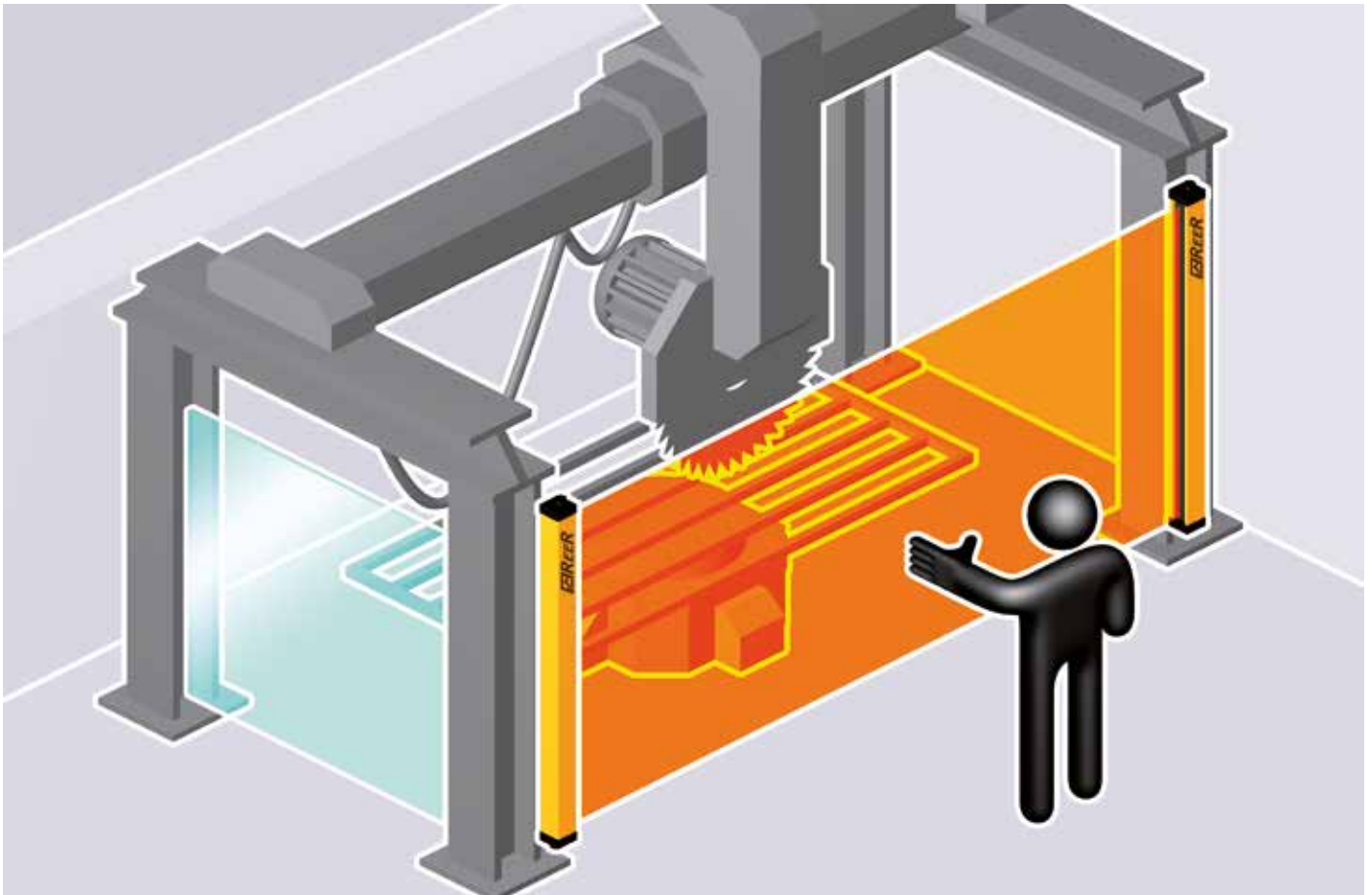
Use of an ESPE for Trip function

Where the protective equipment is used to provide a trip function, it shall be positioned at a sufficient distance from the specific machine hazard(s) to ensure the machine can stop or otherwise reach a safe condition before any part of an approaching person can reach the hazard zone.

This safety distance shall take into account:




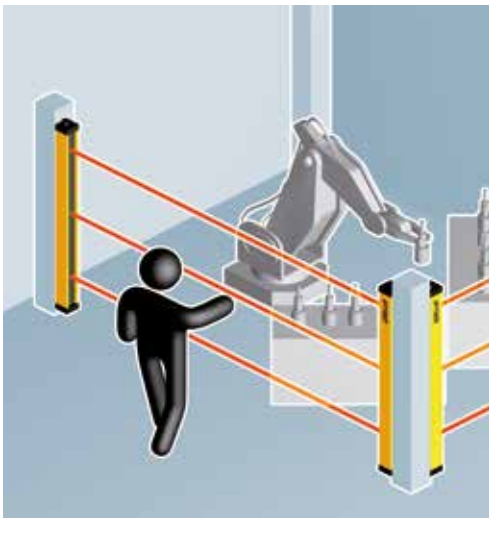

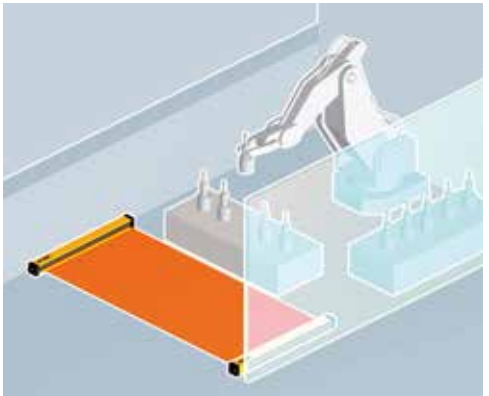

- protective equipment detection capability in relation to human characteristics
- approach speed
- body part penetration/encroachment
- reaching over or under the sensing zone
- possibility of circumvention
- the response time of the ESPE
- the stopping time of the machine measured under the worst operating conditions (maximum load, maximum speed, any factors that may lead to deterioration of the braking performance, low temperatures etc.)
- any reflective surfaces that could, under certain conditions, generate an optical bypass of the beams and consequently prevent the detection of the person

The minimum distance shall be maintained for all foreseeable directions of approach considering also the furthest extension of the moving part towards the direction of approach.



PHOTOELECTRIC SAFETY LIGHT CURTAINS

Definition of type of detection

	DETECTION	CHARACTERISTICS	ADVANTAGES
	<p>Finger or hand</p>  	<p>Detection necessary when the operator must work close to the danger.</p> <p>Barrier resolution must be between 14 mm and 40 mm</p>	<p>Possibility to lower the dimensions by reducing at the top the space between the protection and the dangerous zone.</p> <p>Short time for machine charging and discharging.</p> <p>Less operator fatigue, more productivity.</p>
	<p>Body (use as trip device)</p> 	<p>Ideal detection for access control and protections of several sides, also for long scanning distances.</p> <p>The barrier must be placed at least at 850 mm from the danger.</p> <p>Barrier normally composed by 2, 3, 4 beams.</p>	<p>Protection costs reduced by the restricted number of beams.</p> <p>Possibility to protect zones with big dimensions by using deflection mirrors.</p> <p>See note below</p>
	<p>Presence in a dangerous zone</p> 	<p>Detection realized by positioning the light curtains horizontally to control continuously the presence of an object in a definite zone.</p> <p>The light curtains resolution depends on the height of the detection plane, anyway it cannot be higher than 116 mm.</p>	<p>Possibility to control zones not visible from where the machine's push button controls are located.</p> <p>Possibility of preventing unintended start of the machine while the operator is in the danger zone</p>



Accidental start-up of the machine shall not be possible when anyone crosses the sensitive area and stays undetected in the dangerous area. Suitable ways of eliminating this type of risk include the following:

- Use of start / restart-interlock function positioning the command so that the dangerous area is in full view and so that the command cannot be reached by anyone from inside the dangerous area. The Restart command has to be safe.
- Use of additional presence sensing detectors for the detection of the operator inside dangerous area.
- Use of obstacles preventing the operator from remaining undetected in the space between the sensing zone of the protective device and the dangerous area.

SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

Determination of the safety distance

The effectiveness of the protection depends greatly on the correct positioning of the light curtain with respect to the danger.

The light curtain must be located at a distance greater than or equal to the minimum safety distance S , so that reaching the dangerous point will be possible only when the dangerous action of the machine has been stopped.

The light curtain must be positioned so that:

- It is impossible to reach the dangerous point without going through the zone controlled by the light curtain.
- A person cannot be present in the dangerous zone without his/her presence being detected. To this end, it might be necessary to resort to additional safety devices (i.e.: photoelectric light curtains arranged horizontally).

European Standard EN ISO 13855 provides the elements for the determination of the safety distance.

If the machine in object is governed by a specific C type Standard, it shall be taken into due account.

If the distance S determined in this manner is too big, it is necessary:

- to reduce the total stopping time of the machine,
- to improve the detection capability (resolution) of the light curtain.



Fig. 13. One-side protection



Fig. 14. Three-side protection using deflection mirrors

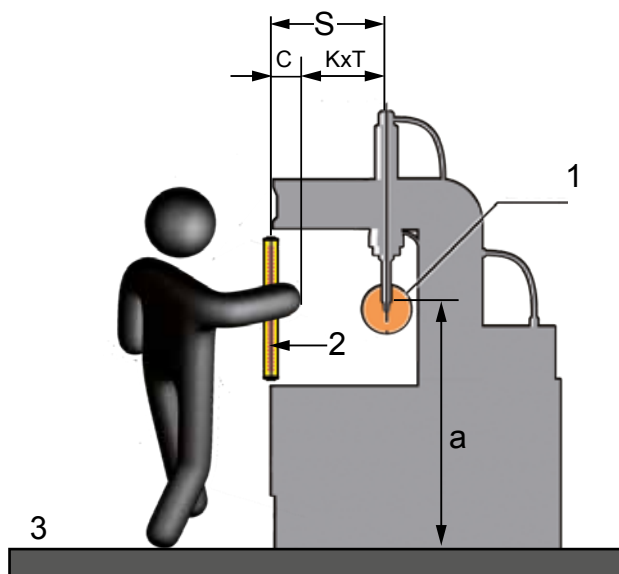
GENERAL FORMULA FOR THE DETERMINATION OF THE MINIMUM SAFETY DISTANCE

$$S = K \times T + C$$

S	minimum safety distance between the protection and hazardous point, expressed in mm.
K	speed of approach of the body or parts of the body, expressed in mm / sec. The K values can be: K = 2000 mm / sec. for safety distance up to 500 mm (forearm movement speed) K = 1600 mm / sec. for safety distance higher than 500 mm (body movement speed).
T	total stopping time of the machine, consisting of: t1 reaction time of the protective device in seconds t2 reaction time of the machine in seconds, until it stops the hazardous action.
C	additional distance in mm.

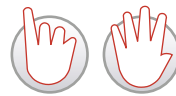
PHOTOELECTRIC SAFETY LIGHT CURTAINS

DIRECTION OF APPROACH PERPENDICULAR TO THE PROTECTED PLANE WITH $A=90^\circ (\pm 5^\circ)$



1. Hazardous point
2. Sensitive area
3. Reference plane
- S. Safety distance
- a. Height of the hazardous point

Fig. 15. Scenario 1 - Possibility to reach the hazardous point only through the sensitive area



Light curtains with resolution for the detection of hands and fingers. Light curtains resolution (d): 14 - 20 - 30 - 40 mm

Determination of the minimum safety distance:

$K = 2000$ or 1600 (see following calculations)

$S = K \times T + C$ $T = t_1 + t_2$ "General formula for the determination of the safety distance" on page 41

$C = 8 \times (d - 14)$

$S = 2000 \times T + 8 \times (d - 14)$

- the distance S must not be lower than 100 mm
- If the distance S is greater than 500 mm it is possible to re-calculate the distance using $K=1600$ but in these circumstances, the distance must in no case be lower than 500 mm

$S = 1600 \times T + 8 \times (d - 14)$



Light curtains with a resolution for detection of arms and legs.

Light curtains resolution (d): 50 - 90 mm

Determination of the minimum safety distance:

$K = 1600$

$T = t_1 + t_2$ "General formula for the determination of the safety distance" on page 41

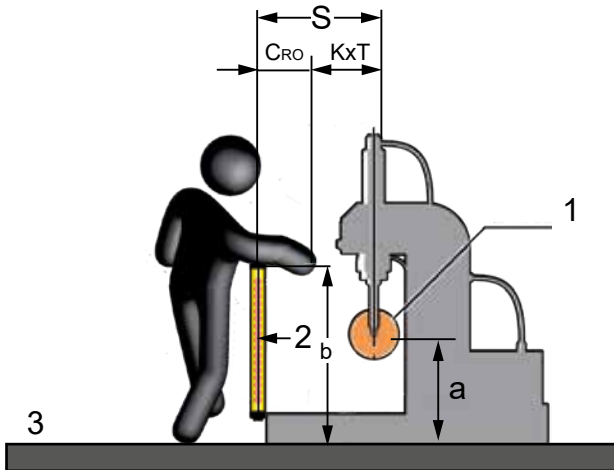
$S = K \times T + C$

$C = 850$

$S = 1600 \times T + 850$

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PHOTOELECTRIC SAFETY LIGHT CURTAINS



1. Hazardous point
2. Sensitive area
3. Reference plane
- a. Height of the hazardous point
- b. Height of the highest beam
- S. Safety distance

Fig. 16. Scenario 2 - Possibility to reach the hazardous point by leaning over the edge of the sensitive area

Possibility to reach the hazardous point by leaning over the edge of the sensitive area

In this case C, called " C_{RO} " is obtained from the following Table 1 of ISO 13855:2010.

Determination of the minimum safety distance:

$$S = K \times T + C_{RO}$$

$K = 2000$ or 1600 (see following calculations)

$T = t_1 + t_2$ "General formula for the determination of the safety distance" on page 41

C_{RO} = see the following Table 1

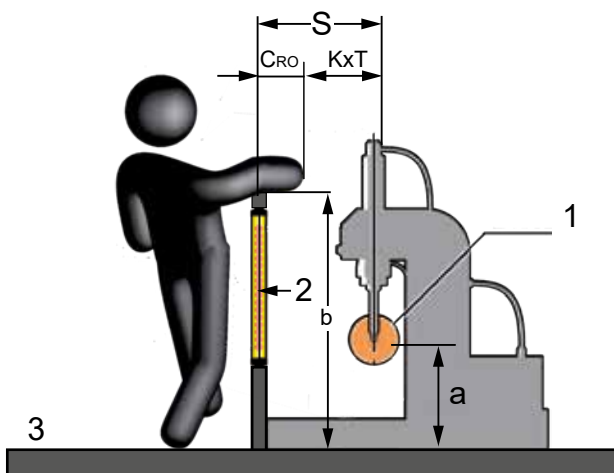
Note:

- Interpolation is not allowed.
- If distances a, b or C_{RO} fall between values listed in the table, use the higher.
- C_{RO} (reaching over) calculated using Table 1 of of ISO 13855:2010 must be compared to C as conventionally calculated (see paragraph 1). Always select the higher value.

Height of Hazard zone "a"	Height "b" of upper edge of area protected by photoelectric light curtain											
	900	1000	1100	1200	1300	1400	1600	1800	2000	2200	2400	2600
	Alternative distance C_{RO}											
2600	0	0	0	0	0	0	0	0	0	0	0	0
2500	400	400	350	300	300	300	300	300	250	150	100	0
2400	550	550	550	500	450	450	400	400	300	250	100	0
2200	800	750	750	700	650	650	600	550	400	250	0	0
2000	950	950	850	850	800	750	700	550	400	0	0	0
1800	1100	1100	950	950	850	800	750	550	0	0	0	0
1600	1150	1150	1100	1000	900	800	750	450	0	0	0	0
1400	1200	1200	1100	1000	900	850	650	0	0	0	0	0
1200	1200	1200	1100	1000	850	800	0	0	0	0	0	0
1000	1200	1150	1050	950	750	700	0	0	0	0	0	0
800	1150	1050	950	800	500	450	0	0	0	0	0	0
600	1050	950	750	550	0	0	0	0	0	0	0	0
400	900	700	0	0	0	0	0	0	0	0	0	0
200	600	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

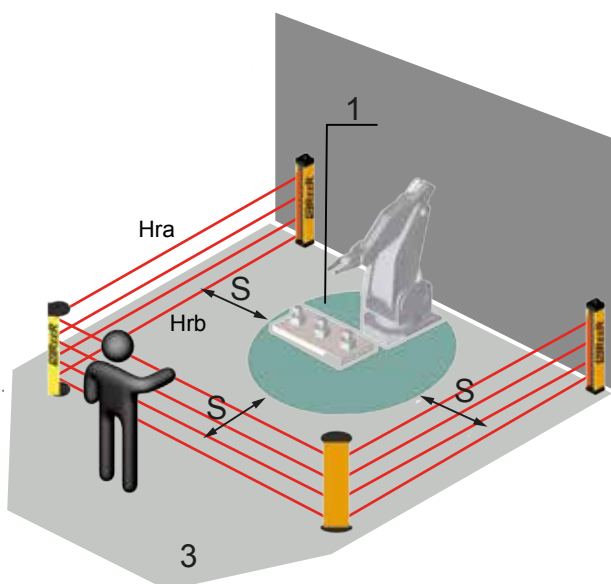
(Table 1 della 13855:2010)

PHOTOELECTRIC SAFETY LIGHT CURTAINS



- 1. Hazardous point
- 2. Sensitive area
- 3. Reference plane
- a. Height of the hazardous point
- b. Height of the upper edge
- S. Safety distance

Fig. 17. Scenario 3 - Possibility to reach the hazardous point by leaning against the mechanical protection and bypass the light curtain



- 1. Hazardous point
- 3. Reference plane
- S. Safety distance
- Hra. Height of the highest beam
- Hrb. Height of the lower beam

Fig. 18. Scenario 1 - Possibility to reach the hazardous point only through the sensitive area. Light curtains with 2, 3, 4 beams

For combined mechanical and electrosensitive protections (as shown), where it would be possible to lean against the mechanical protection and bypass the light curtain

For the calculation of the parameter C should use

- Table 1 (for low risk applications) or
- Table 2 (for high-risk applications)

of ISO 13857:2007 (formerly EN 294) in place of the table on the previous page.

In this catalog the two tables of ISO 13857:2007 (formerly EN 294) - Safety distances to prevent danger zones being reached by upper and lower limbs - are not mentioned.



Light curtains for the detection of the presence of the body in a dangerous area. Light curtains with 2 - 3- 4 beams

Determination of the minimum safety distance:

$$K = 1600$$

$$S = K \times T + C$$

$T = t_1 + t_2$ "General formula for the determination of the safety distance" on page 41

$$C = 850$$

$$S = 1600 \times T + 850$$

Note for 2 beams light curtains:

- H lower beam = 400 mm (can be used if allowed by risks analysis).
- H higher beam = 900 mm

Note for 3 beams light curtains:

- H lower beam = 300 mm
- H middle beam = 700 mm
- H higher beam = 1100 mm

Note for 4 beams light curtains:

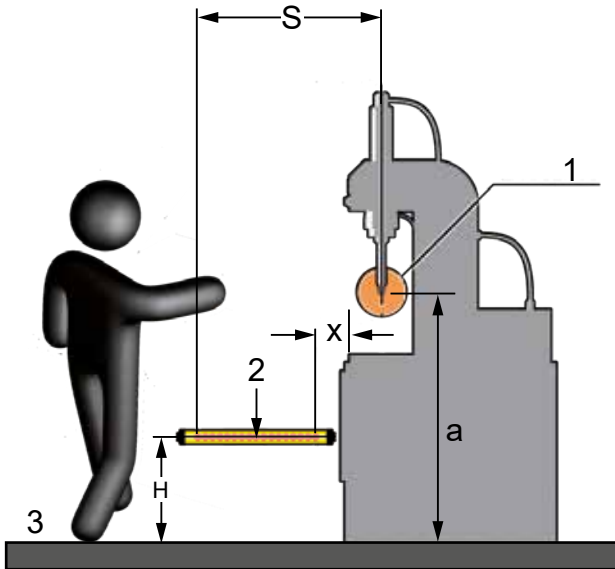
- H lower beam = 300 mm
- H middle beam 1 = 600 mm
- H middle beam 2 = 900 mm
- H higher beam = 1200 mm

Height of the beams from the reference plane (eg. floor).

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PHOTOELECTRIC SAFETY LIGHT CURTAINS

DIRECTION OF APPROACH PARALLEL TO THE PROTECTED PLANE WITH $A=0^\circ (\pm 5^\circ)$



- 1. Hazardous point
- 2. Sensitive area
- 3. Reference plane
- a. Height of the hazardous point
- x. Distance between end of the detection zone and machine edge
- S. Safety distance
- H. Height of the sensitive area

Fig. 19. Horizontal light curtains for presence control in a dangerous area



Horizontal light curtains for presence control in a dangerous area

Determination of the minimum safety distance:

$$K = 1600$$

$T = t_1 + t_2$ "General formula for the determination of the safety distance" on page 41

$$C = 1200 - (0,4 \times H)$$

$$S = K \times T + C$$

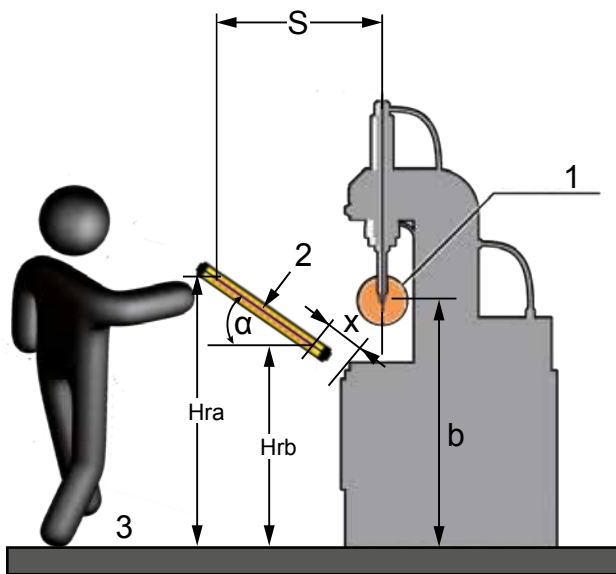
$$S = 1600 \times T + (1200 - 0,4 \times H)$$

Note:

- $C = 1200 - (0,4 \times H)$ must be equal to or greater than 850 mm
- The maximum height allowed is: $H_{max} = 1000$ mm
- The height H depends on the resolution d of the light curtains and is determined through the following formula:
 $H = 15 \times (d - 50)$
- This formula can also be used to determine the maximum resolution that can be used at the different heights
 $d = H / 15 + 50$
- For example, the maximum resolution limits will be:
for $H = 1000$ mm $d = 116$ mm
for $H = 0$ mm $d = 50$ mm
- If H is greater than 300 mm, at the stage of risk assessment it becomes necessary to take into consideration the possibility of access from beneath the beams
- When using the light curtain as a combination of trip and presence sensing device, the distance x must be less than or equal to the detection capability

PHOTOELECTRIC SAFETY LIGHT CURTAINS

DIRECTION OF APPROACH ANGLED TO THE PROTECTED PLANE WITH $5^\circ < \alpha < 85^\circ$



- 1. Hazardous point
- 2. Sensitive area
- 3. Reference plane
- a. Height of the hazardous point
- S. Safety distance
- x. Distance between end of the detection zone and machine edge
- Hra. Height of the highest beam
- Hrb. Height of the lower beam

Fig. 20. Possibility to reach the hazardous point only through the sensitive area



When calculating the safety distance, also consider installation tolerances, accuracy of the measured response time and possible decay of the brake system performance of the machine.

It is advisable to increase the calculated value by at least 10% in order to take into account installation tolerances, accuracy in response time and possible degradation of brake system performance.

As can be seen from the formulas, the total stopping time plays an important role in calculating the safety distance; When a deterioration in braking time is expected, a Stopping Time monitoring device (SPM) is required. Checking of the stopping time is not necessary when:

- The system is very reliable and not subject to deterioration
- The machine is only rarely stopped
- Effective preventive control of the braking systems of the machine is implemented.



Slanted light curtains to detect hands and arms and for presence control in the dangerous area

With angle $\alpha > 30^\circ$ refer to the case of "Approach perpendicular to the protected plane". (Previous case page 42).

Note:

- The distance S refers to the beam farthest away from the hazardous point
- The height of the beam farthest away from the hazardous point must not be greater than 1000 mm

With angle $\alpha < 30^\circ$ refer to the case of "Approach parallel to the protected plane". (Previous case page 45).

Note:

- For the determination of height H or resolution d apply the following formulas to the lowermost beam:

$$H = 15 \times (d - 50)$$

$$d = H / 15 + 50$$
- When using the light curtain as a combination of trip and presence sensing device, the distance x must be less than or equal to the detection capability.

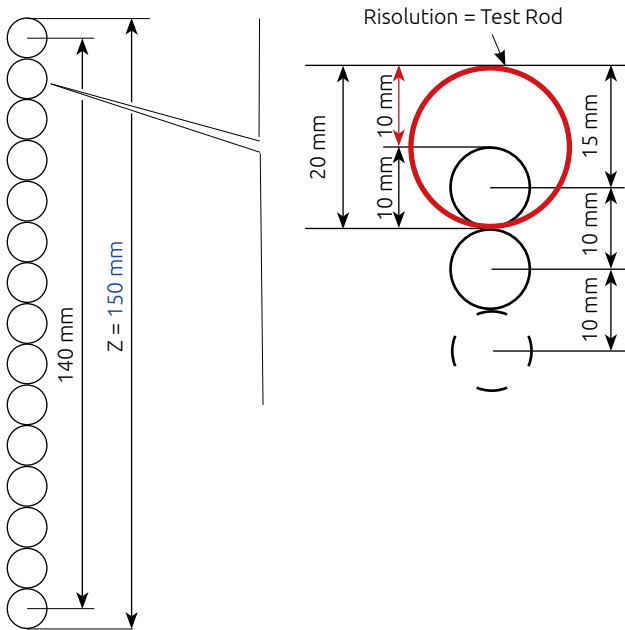
SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

Light curtains protected height - Determination criteria

The following calculation, for the correct definition of the light curtains protected height are related to these models of light curtains:

- model: EOS 152 A
- Nominal protected height: 160 mm
- Resolution: 20 mm
- Numbers of beams: 15
- Lens diameter: 10 mm



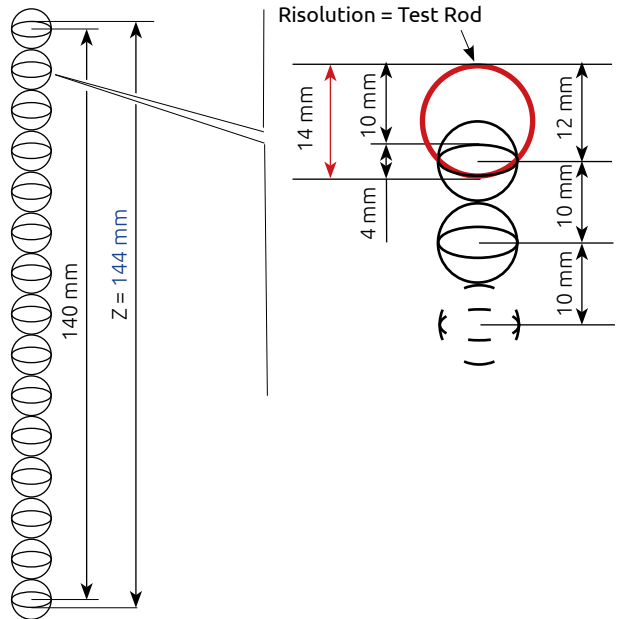
In order to keep in account the dimension of the "Test Rod" (resolution), it is necessary to add 10 mm for each side to the Z dimension.

Protected height = $150 + 10 + 10 = 170$ mm.

This value is conventionally rounded to 160 mm (Nominal protected height).

We can use the same nominal protected height value (160 mm) for all other resolutions.

- model: EOS 151 A
- Nominal protected height: 160 mm
- Resolution: 14 mm
- Numbers of beams: 15
- Lens dimensions: 10 x 4 mm



In order to keep in account the dimension of the "Test Rod" (resolution), it is necessary to add 10 mm for each side to the Z dimension.

Protected height = $144 + 10 + 10 = 164$ mm.

This value is conventionally rounded to 160 mm (Nominal protected height).

You can see that we can use the same nominal protected height value (160 mm) also for the 14 mm resolution.

Using the ESPE as a presence sensing device

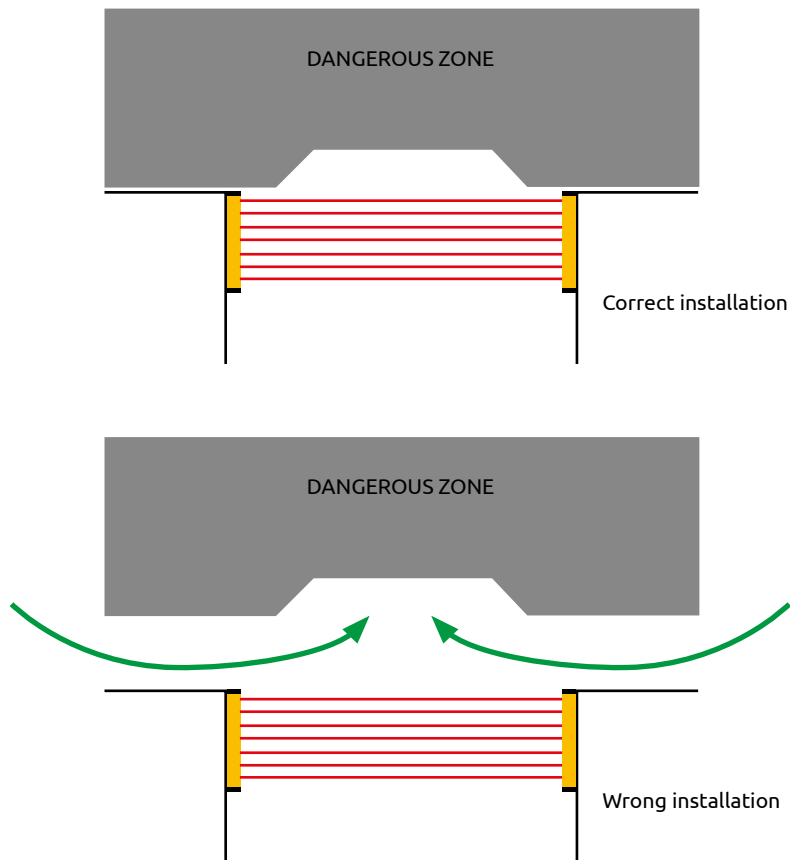
The main function of a protective device used for presence sensing is to keep the machine in a safe state as long as a person or part of it is within its sensing area.

The sensing area must therefore be configured so as not to allow for a person to remain within the hazardous area or to a distance below the stated safety distance without being detected.

If the ESPE only performs the presence sensor function, it must be used in combination with other safety measures (eg interlocked shield or crossover sensor) to ensure that the machine is in a safe state before it is possible access it.

PHOTOELECTRIC SAFETY LIGHT CURTAINS

In dimensioning the protected area, additional protective measures shall be implemented in addition to computing the safety distance, to prevent that a person can circumvent the protected area.



It shall not be possible to reach the dangerous area by climbing on the machine or crawling below the sensitive area or leaning over the edge of the sensitive area.

The parts of the machine not guarded by the ESPE, shall be protected by means of solid repairs (e.g. interlocked guards if can be removed to allow access for maintenance).

Unexpected start-up of the machine shall be prevented after a person has passed through the detection zone of the trip device to the hazardous zone of the machine.

Suitable methods are:

- barriers to ensure that a person cannot approach the machine hazard from directions not protected by the protective equipment
- provision of a restart interlock
- provision of a presence sensing device
- measures to prevent a person being present between the protective equipment and the hazardous zone.

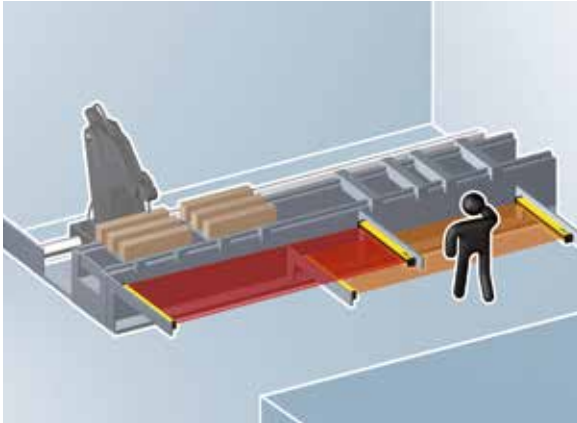
SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

MUTING FUNCTION

The Muting function is the provisional and automatic cut-out of the light curtain protective function in relation to the machine cycle. Muting can only occur in a safety condition. Two types of applications are envisaged:

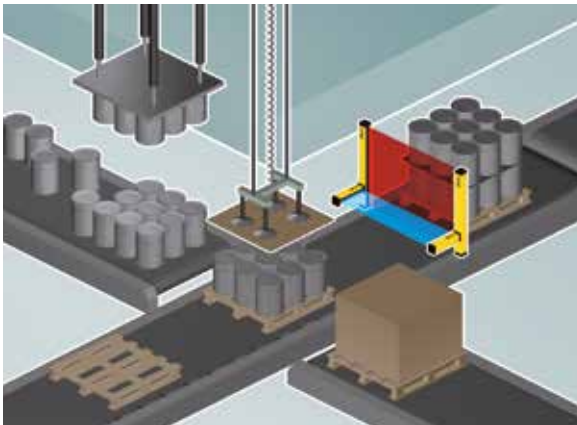
1. Enabling personnel access inside dangerous area during the non-dangerous part of machine cycle.



Example: Positioning or removal of workpiece

Depending on the position of the tool, which is the most dangerous part, one of the two curtains (the one facing the tool working area) is active whereas the other is in Muting mode to enable the operator to load/unload the workpiece. Muting mode of the light curtains is subsequently reversed when the tool works on the opposite side of the machine.

2. Enabling access to material and preventing access to personnel.



Example: Pallet exit from dangerous area

The safety light curtain incorporates Muting sensors able to discriminate between personnel and materials. Only the material is authorized to pass through the monitored area.

The essential requirements regarding the Muting Function are described by the followings Standards:

IEC TS 62046 "Application of the protective equipment to detect the presence of persons"

EN 415-10 "Safety of the Machinery - automatic palletizing systems"

IEC 61496-1 "Electro-Sensitive Protective Equipment"

General Requirements:

- Muting is a temporary suspension of the safety-related function and it must be activated and de-activated automatically.
- The safety integrity level of the circuit implementing the Muting function shall be equal to that of the safety function temporarily suspended, so that the protection performance of the entire system is not adversely affected.
- Muting should be activated and de-activated only by means of two or more separate and independent hardwired signals triggered by a correct time or space sequence. Such that a signal fault cannot be considered a muting condition.
- It shall not be possible to trigger Muting while the ESPE outputs are in the off state.
- It shall not be possible to initiate Muting by turning the device off and then on again.
- Muting shall be only activated in an appropriate point of the machine cycle, i.e. only when there is no risk for the operator.
- Muting sensors shall be mechanically protected to prevent mismatch in case of impact.

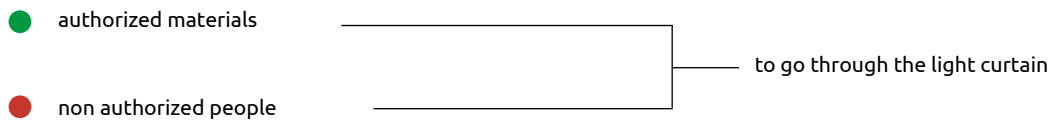
PHOTOELECTRIC SAFETY LIGHT CURTAINS

MUTING: palletizers and materials handling systems

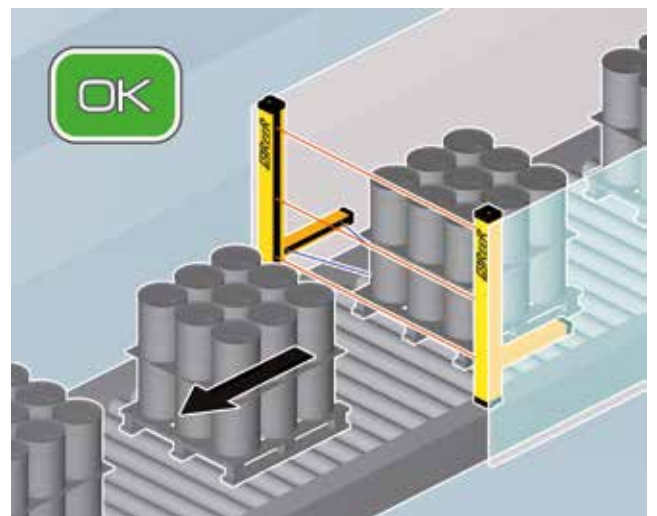
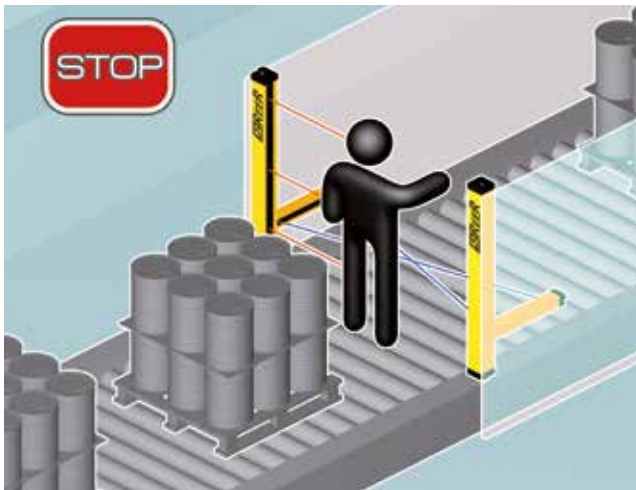
Requirements for the monitoring of the openings:

- Monitor the load, not the pallet, otherwise the operator might go into the hazardous zone being dragged by the pallet.
- Muting time must be restricted to the actual time taken by the material to pass through the opening.
- Muting must be time-restricted.
- Sensor mismatch with effect similar to their actuation shall not allow a condition of permanent Muting.
- The configuration and positioning of the Muting sensors shall ensure reliable differentiation between personnel and material.
- The layout of the opening, the positioning of the Muting sensors and the additional side protections shall prevent personnel access to the dangerous area for all the time the Muting function is activated and throughout the time the pallet crosses the opening.

Therefore it is necessary to realise a safety system able to distinguish between:



The Muting function can be present on both type 2 and type 4 safety light curtains.



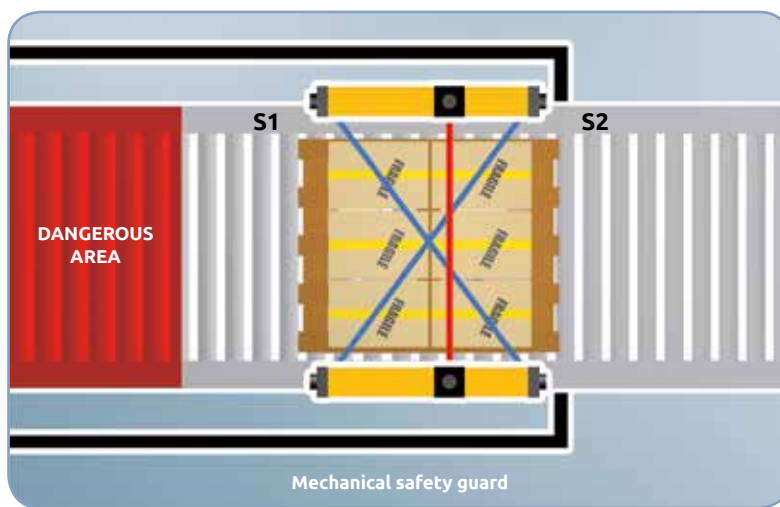
SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

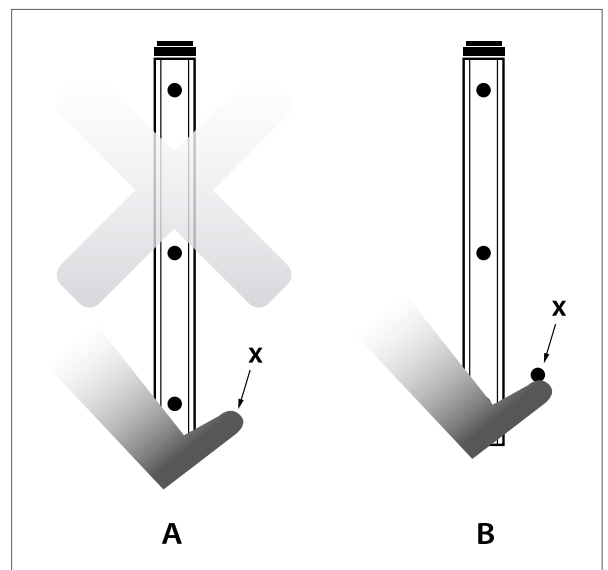
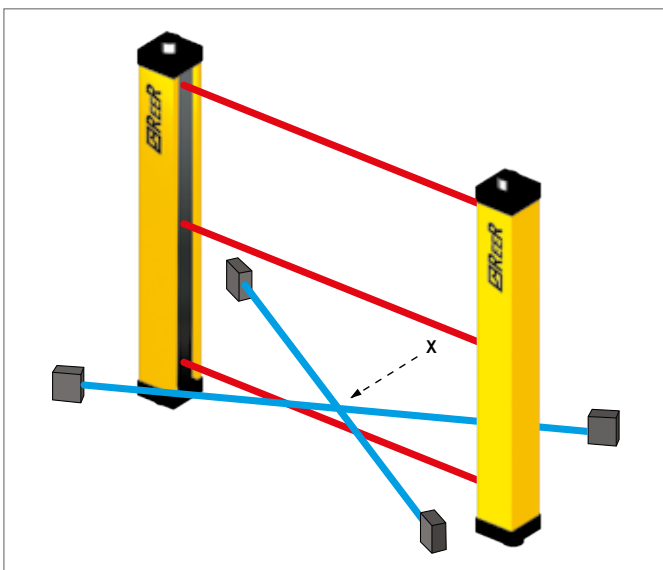
Common solutions for Muting sensor positioning

Muting with 2 crossed-beam sensors – Configuration type T with timing monitoring and two-way pallet operation:

- The point of intersection of the two beams shall lie in the segregated dangerous area beyond the light curtain.
- A fail safe timer shall be provided to restrict Muting to the time needed for the material to cross the opening.
- The Muting function shall be activated only if the Muting sensors are contemporaneously intercepted: ($t_2(S_2) - t_1(S_1) = 4$ seconds max.).
- The two beams shall be continuously interrupted by the pallet throughout the transit through the sensors.
- A matt cylindrical object $D=500$ mm (simulating the size of a human body) shall not trigger the Muting function.



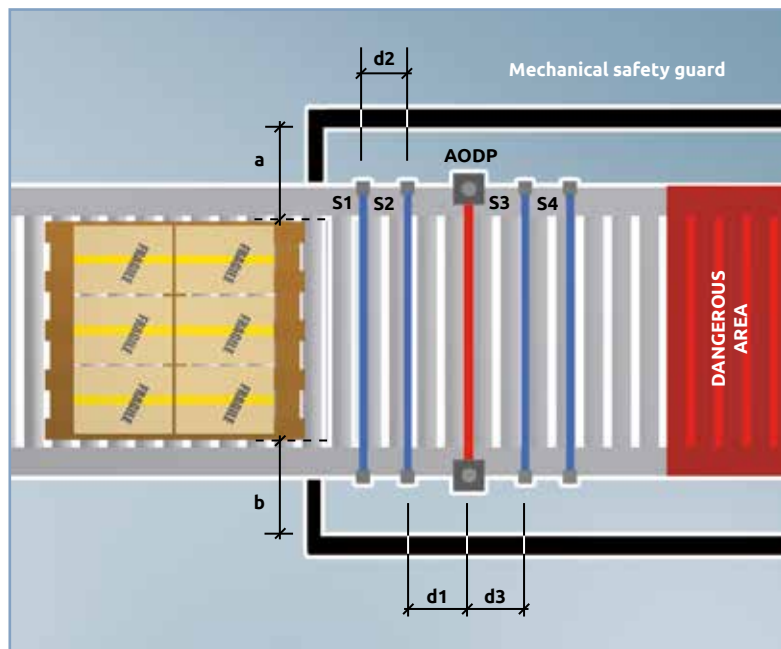
Muting sensor beam intersection shall be positioned the higher up or equal than level of the lower light curtain beam to avoid possible tampering or accidental triggering of Muting.



PHOTOELECTRIC SAFETY LIGHT CURTAINS

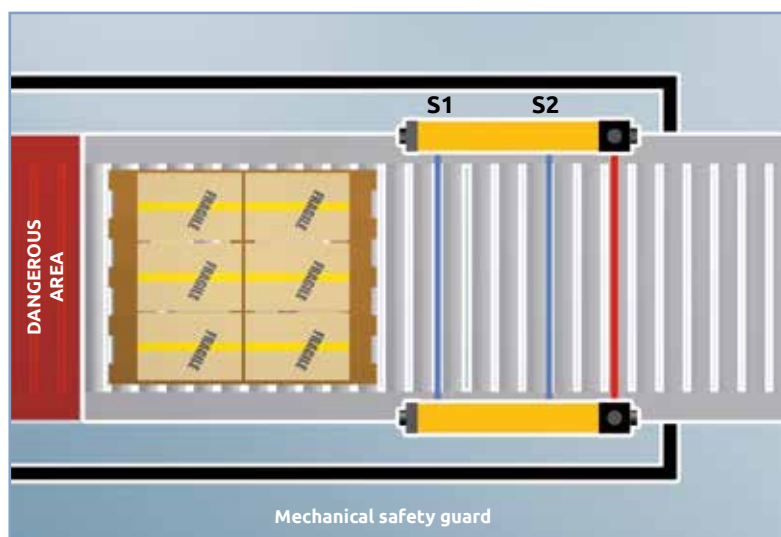
Muting with 4 parallel-beam sensors – Configuration type T with timing and/or sequence monitoring - Two-way pallet operation:

- The 4 Muting sensors shall be all actuated together for a brief moment (sequential actuation and de-activation of the 4 sensors).
- The distance between sensors and the sensing field of the light curtain shall be:
 - $d1$ and $d3 < 200$ mm to prevent undetected personnel access by preceding or following immediately after the pallet during Muting.
 - $d2 > 250$ mm to prevent personnel limb, garment, etc. from enabling Muting by triggering two sensors simultaneously.



Muting with 2 crossed-beam or parallel-beam sensors – Configuration type L with timing monitoring and one-way only(exit from dangerous area) pallet operation:

- Muting sensors shall be positioned beyond the light curtain in the dangerous area.
- Muting shall be disabled as soon as the light curtain is cleared and not later than 4 seconds max. from the instant the first of the two Muting sensor is cleared. The timer monitoring the 4 seconds shall be a safety-related item.



SENSORS

PHOTOELECTRIC SAFETY LIGHT CURTAINS

Blanking function

Blanking is an auxiliary function of safety light curtains for which the introduction of an opaque object inside parts of the light curtain's protection field is allowed without causing the stoppage of the machine. Blanking is only possible in the presence of determined safety conditions.

The blanking function is therefore particularly useful when the light curtain's protection field must be inevitably intercepted by the material being worked or by a fixed or mobile part of the machine.

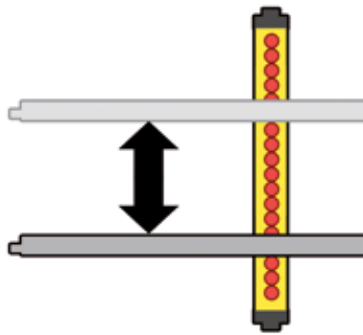
In practice, it is possible to keep the light curtain's safety outputs in an ON condition, and the machine working, even if a pre-determined number of beams within the protection fields are being intercepted.

Fixed Blanking allows a fixed portion of the protection field (i. e. a fixed set of beams) to be occupied, while all the other beams operate normally.

Floating Blanking allows the object to move freely inside the light curtain's protection field occupying a given number of beams, at the condition that the occupied beams are adjacent and that their number is not higher than the configured one.

Floating Blanking with compulsory object presence makes the light curtain work in a reverse way within the blanked portion of the protection field. That is, the blanked beams must be occupied during blanking and therefore the object has to be inside the protection field for the light curtain to remain in the ON state. In this case too the object can move freely within the protection field if the above conditions are respected.

Requirements for the blanking function can be found in the Technical Specification IEC/TS 62046 describing additional means required to prevent a person from reaching into the hazard through the blanked areas of the detection zone.



WARNING!

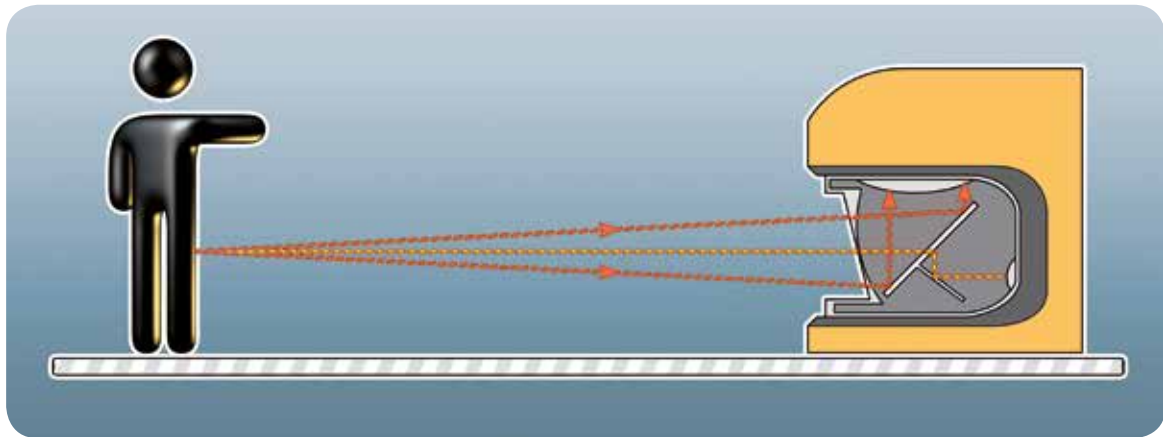
The use of the blanking function can be allowed depending on the characteristics of the application to be protected. Based on the risk analysis of your application, check whether the use of the blanking function is allowed for that particular application and with what features.

The use of the blanking function may need a recalculation of the safety distance due to the modified detection capability.

Characteristic elements

The Laser scanner (Active Opto-electronic Protective Device responsive to Diffuse Reflection) measures the distance between the objects that fall into its sensing field by means of the small fraction of energy that is re-diffused by the objects themselves in axis with the direction of emission.

AOPDDRs do not need a cooperating target for their operation, especially where the protected area is mobile, as is the case with AGVs, or where it is necessary to vary the position and size of the protected area during the production process .



For [EN 61496-3](#), Laser Scanners must be classified in accordance to type 3 or lower safety sensors.

For [IEC 61508](#), [IEC 62061](#), [ISO 13849-1](#), they must be used to realize safety functions up to SIL 2 - PL d or lower.

Using the Safety Laser Sensor, precise programmable horizontal protected areas of variable shape can be created (i. e. semi-circular, rectangular or segmented), suitable for all applications with no need of a separate reflective or receiving element.

It is also possible to use the Laser Scanner in a vertical position for the access protection to a dangerous area, in that case detection of the edge of the gate is mandatory ([IEC TS 62046](#)).

Any person or object entering or remaining in the safety zone during survey causes, through the self-monitored static safety outputs of the device, an emergency stop command to the control system of the protected machine. The machine's hazardous movement will thus be interrupted.

If the warning zone is instead occupied, thanks to a non-safety dedicated solid state output, a signal is sent to the machine control system, which can be used to activate a light or a sound signal in order to prevent operators to break into the safety zone and stop the machine. Or, on an AGV application, the warning signal can be used to slow the vehicle down, so that a possible further break of the safety zone will not force it to stop abruptly, thus reducing the mechanical wear of the AGV.

The profiles of the controlled areas, as well as all the other configurable parameters, are programmable through a dedicated user interface software, installed on a laptop or PC and connected with the scanner via a serial interface.

The Laser Scanner is also able to automatically detect the controlled area by means the teach-in function.

SENSORS

SAFETY LASER SCANNER

Controlled areas

Safety zone

This is the effective protection zone, in which the laser scanner assures the detection of any obstacle having a minimum reflectivity to infrared light of 1.8%. This means any human body in any possible clothing.

The occupation of this zone causes the switching of the two safety outputs that control the emergency stopping of the machine.

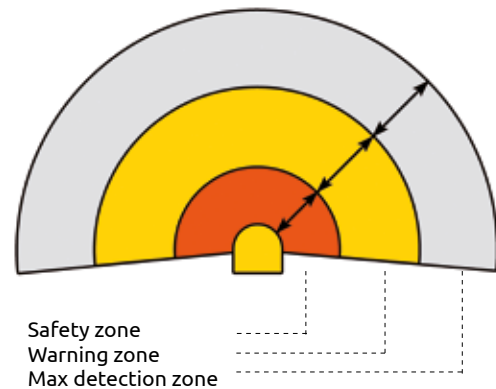
The shape of the zone can be programmed according to the application requirements.

Warning zone

This is the zone in which the laser scanner is able to detect the presence of an obstacle approaching the safety zone.

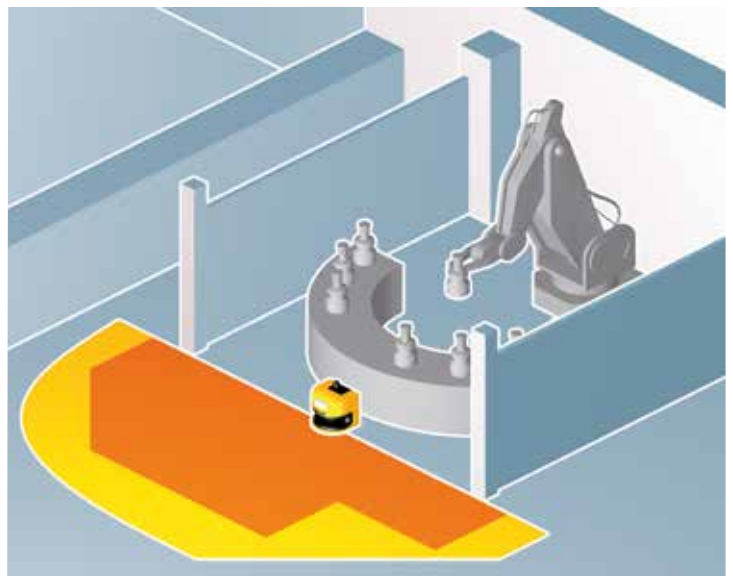
The occupation of this zone causes the switching of the auxiliary output that can be used to activate light or sound signals or in order to slow down the hazardous movement.

This zone is generally larger than the safety zone. In this case also the shape of the zone can be programmed according to the application requirements.



Advantages of the laser scanner

- No receiving and reflecting elements
- Simple programming of differently-shaped controlled areas
- Monitoring and protection of large areas
- Horizontal mount for the detection of the body in a dangerous area
- Vertical mount for the detection of hands and arms or for the detection of the body in access control
- Use on moving vehicles (AGVs)
- Measurement of object size, shape and position
- Fast and reliable installation

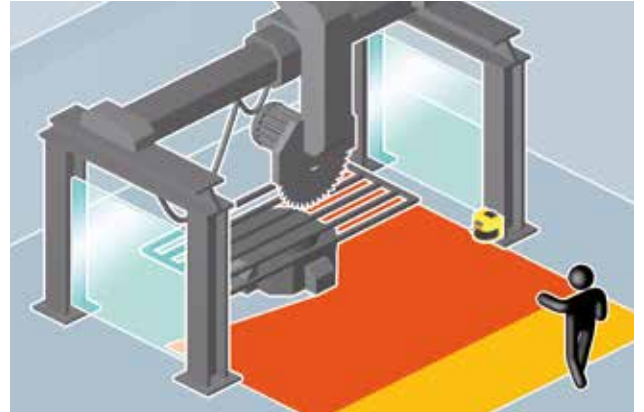


SAFETY LASER SCANNER

Applications

Area control

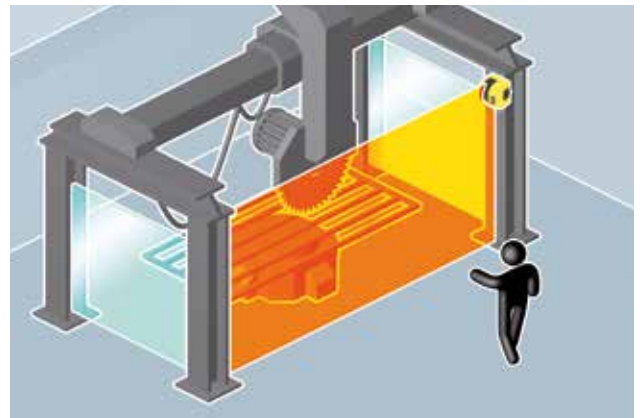
Example of an horizontally mounted protective field permanently monitored by Pharo. In this way a larger area can be monitored through the detection of the lower limbs of the body.



Access control

If the controlled plane is installed in a vertical position, even very large accesses can be protected. Hands, arms or the whole body can be detected, depending on the chosen resolution.

Note: the contour detection is mandatory for the vertical mount / access control applications.



Protection of Automatic Guided Vehicles (AGV)

The vast size of the controlled area allows the AGV to travel at higher speeds with respect to bumper protection.

The warning area permits speed reduction in the presence of obstacles.

The data measured by the sensor can be sent to the vehicle on the serial interface and used as navigation aid.



Dimensional measurement

The sensor is first of all a measurement device. Therefore, the measurement data of the surrounding environment, which are always available during operation, can also be used for object profile, position and dimensions measurement in industrial automation.

SENSORS

SAFETY SENSORS

RFID safety sensors

The RFID technology enables Magnus RFID sensors to be individually coded in three different ways to allow the appropriate tampering protection in all applications. The highest configurations allow each sensor to be paired with one only assigned actuator.

The RFID technology used allows to reach safety levels up to PL e / SIL 3 (EN ISO 13849-1 directive) also when connecting the sensors in series.



Magnetic safety sensors

Magnus series safety switches can be connected to Mosaic safety configurable controller (PL e) or to the dedicated safety control unit MG d1 (PL d).

MG switches connected to Mosaic safety controller form a certified PL e safety system.



Safety switch with guard locking

Safelock is a safety switch utilised in the protection of personnel when opening doors leading to dangerous areas. It acts by monitoring and interrupting the safety circuit during dangerous scenarios.

The solenoid locks and unlocks access to the dangerous area, guaranteeing safety until the danger has stopped. Two available models:

- Retention mechanism actuated by a spring and unlocked by ON current. Guard locking by spring force, release by applying voltage to the guard locking solenoid.
- Retention mechanism actuated by ON current and unlocked by spring. Guard locking by applying voltage to the guard locking solenoid, release by spring force



3 different safety functions according to the standard EN ISO 13849-1

Category / Safety Level	Safety device
Cat. 1 / PL c	1 Safelock + 1 safety relay AD SRE3C or 1 input of the Mosaic safety controller
Cat. 3 / PL d	1 Safelock + 1 safety relay AD SRE3C or 2 inputs of the Mosaic safety controller + fault exclusion according to the standard (EN ISO 13849-2)
	1 Safelock + 2 Magnus RFID + safety relay AD SR1 or 2 inputs of the Mosaic safety controller
	2 Safelock + 1 safety relay AD SRE3C or 2 inputs of the Mosaic safety controller
Cat. 4 / PL e	2 Safelock + 2 safety relay AD SRE4C or 4 inputs of the Mosaic safety controller



Finger detection

Detection of the presence
of the body in a dangerous
area

Hand detection

Detection of the body
in access control

In this document, for each of the applications listed above, the appropriate solutions realized with the devices in the ReeR range are presented.

Depending on the functions to be performed by the safety system, on the resolution required or on the maximum scanning distance, it is possible to select, among the different families of ReeR's safety protective devices, the right tool for the safeguarding of dangerous machines.

GLOSSARY

Start/Restart interlock: Interlock function (manual restart required) at machine start or restart.

EDM: External Device Monitoring: controls the switching of external contactors via feedback input.

Master, Slave: Two or three light curtains can be connected in cascade; all the outputs are managed by only one of these (Master).

Blanking: The light curtain can be programmed to ignore a single object of defined dimensions that may also be greater than the resolution (see page 52).

Muting: The protective function of the light curtain can be inhibited under certain safety conditions (see page 48).

I Models: Models with connections for external Muting sensors.

L, T Models: Models with built-in Muting sensors in pre-assembled kits for pallet outfeed only (L) or infeed/outfeed (T).

SENSORS

SELECTION GUIDE



	EOS 4 A	EOS 4 X	ADMIRAL AD	ADMIRAL AX	ADMIRAL AX BK
Sensor	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain
Safety level	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e
Resolution (mm)	14	14	14	14	14
Controlled area heights (mm)	160 ...1960	160 ...1960	160 ...1810	160 ...1810	160 ...1810
Max. range (m)	6	6	5	5	5
Start/Restart interlock integrato	-	yes	-	yes	-
EDM integrato	-	yes	-	yes	-
Blanking	-	-	-	-	yes, floating
Versioni Master/Slave	-	yes (1/2 slave)	-	yes (1 slave)	yes, master



	EOS 4 A	EOS 4 X	SAFEGATE SM - SMO	SAFEGATE SMPO	ADMIRAL AD	ADMIRAL AX	ADMIRAL AX BK	JANUS M
Sensor	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain
Safety level	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e	Type 4 SIL 3 – PL e
Resolution(m)	20, 30, 40	20, 30, 40	30, 40	30, 40	20, 30, 40	20, 30, 40	20, 40	30, 40
Controlled area heights(mm)	160 ... 2260	160 ... 2260	310 ... 2260	310 ... 2260	160 ... 2260**	160 ... 2260**	160 ... 2260**	310 ... 1810
Max. range (m)	12 or 20	12 or 20	4 or 12	4 or 12	18	18	18	16 or 60
Start/Restart Interlock	-	yes	yes	yes	-	yes	-	yes
EDM	-	yes	yes	yes	-	yes	-	yes
Blanking	-	-	-	-	-	-	yes, floating	-
Muting	-	-	yes	yes	-	-	-	yes
Master, Slave	-	yes (1/2 slave)	-	-	-	yes (1 slave)	yes master	-
Integrated Muting lamp	-	-	SMO model	yes	-	-	-	-
Programmable	-	-	-	yes	-	-	-	-
TRX version with passive element	-	-	yes	yes	-	-	-	yes
Long Range	-	-	-	-	-	-	-	yes (up to 60 m)



** Are available, on request, ADMIRAL series safety light curtains (AX, AD and AX BK models) with protected height up to 2260 mm. Resolutions (30 mm, 40 mm, 50 mm and 90 mm).

In detail the new protected heights are: 1960 mm, 2110 mm and 2260 mm.

Master and Slave models are not available for these new heights.

* VISION VXL and VISION MXL 30 mm resolution models: maximum controlled area height 1210 mm.

SENSORS

SELECTION GUIDE



JANUS J	LASER SCANNER PHARO	EOS 2 A	EOS 2 X	VISION V	VISION VX	VISION VXL	VISION MXL
Light curtain	Laser scanner	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain
Type 4 SIL 3 – PL e	Type 3 SIL 2 – PL d	Type 2 SIL 1 – PL c	Type 2 SIL 1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c
40	30, 40 selectable	30, 40	30, 40	20, 30, 40	20, 30, 40	30, 40	30, 40
610 ... 1210	--	160 ... 2260	160 ... 2260	160 ... 1810	160 ... 1810	160 ... 1810*	160 ... 1810*
16 or 60	2,6 (radius)	12	12	16	18	8	8
yes	yes	-	yes	-	yes	yes	yes
yes	yes	-	yes	-	yes	yes	yes
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	yes
-	-	-	yes (1/2 slave)	-	yes (1 slave)	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
yes	-	-	-	-	-	-	-
yes (up to 60 m)	-	-	-	-	-	-	-

SENSORS

SELECTION GUIDE



	EOS 4 A	EOS 4 X	ADMIRAL AD	ADMIRAL AX	ADMIRAL AX BK	JANUS M	JANUS J
Sensor	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain
Safety level	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e
Resolution (mm)	50, 90	50, 90	50, 90	50, 90	40,90	40, 90	40
Controlled area heights(mm)	160 ... 2260	160 ... 2260	310 ... 2250**	310 ...2250**	310 ... 2250**	310 ... 1810	610 ... 1210
Max. range (m)	12 or 20	12 or 20	18	18	18	16 or 60	16 or 60
Start/Restart interlock	-	yes	-	yes	-	yes	yes
EDM	-	yes	-	yes	-	yes	yes
Blanking	-	-	-	-	yes, floating	-	-
Muting	-	-	-	-	-	yes	-
Master/Slave	-	yes (1/2 slave)	-	yes (1 slave)	yes (master)	-	-
Long Range	-	-	-	-	-	yes (up tp 60 m)	yes (up to 60 m)



	EOS 4 A	EOS 4 X	SAFEGATE SM - SMO	SAFEGATE SMPO	ADMIRAL AD	ADMIRAL AX	JANUS M	JANUS J
Sensor	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain
Safety level	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e	Type 4 SILCL3 – PL e	Type 4 SILCL3 – PL e	Type 4 SIL 3 – PL e	Type 4 SIL 3 – PL e
Number of beams	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4
Resolution (mm)	-	-	-	-	-	-	-	-
Controlled area heights(mm)	510 ... 910	510 ... 910	510 ... 910	510 ... 910	510 ... 910	510 ... 910	510 ... 910	510 ... 910
Max. range (m)	12 or 20	12 or 20	4 or 12	4 or 12	18	18 or 60	16 or 60	16 or 60
Start/Restart interlock	-	yes	yes	yes	-	yes	yes	yes
EDM	-	yes	yes	yes	-	yes	yes	yes
Muting	-	-	yes	yes	-	-	yes, I, L and T models	-
Master/Slave	-	yes (1/2 slave)	-	-	-	yes	-	-
Integrated Muting lamp	-	-	SMO Model	yes	-	-	-	-
Programmable	-	-	-	yes	-	-	-	-
TRX versions with passive retroreflector elements	-	-	yes	yes	-	-	yes	yes
Long Range	-	-	-	-	-	yes (fino a 80 m)	yes (up to 60 m)	yes (up tp 80 m)

SENSORS

SELECTION GUIDE

LASER SCANNER PHARO	EOS 2 A	EOS 2 X	VISION V	VISION VX
Laser scanner	Light curtain	Light curtain	Light curtain	Light curtain
Type 3 SIL 2 – PL d	Type 2 SIL 1 – PL c	Type 2 SIL 1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c
50, 70 selectable	50, 90	50, 90	50, 90	50, 90
-	160 ... 2260	160 ... 2260	310 ... 1810	310 ... 1810
4 (radius)	12	12	16	18
yes	-	yes	-	yes
yes	-	yes	-	yes
-	-	-	-	-
-	-	-	-	-
-	-	yes (1/2 slave)	-	yes (1 slave)
-	-	-	-	-

LASER SCANNER PHARO	EOS 2 A	EOS 2 X	VISION V	VISION VX	VISION VXL	VISION MXL	ILION	ULISSE
Laser scanner	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Light curtain	Single beam	Single beam
Type 3 SIL 2 – PL d	Type 2 SIL 1 – PL c	Type 2 SIL 1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c	Type 2 SILCL1 – PL c
-	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	2, 3, 4	1, 2, 3, 4	1, 2, 3, 4
-	-	-	-	-	-	-	-	-
-	510 ... 910	510 ... 910	510 ... 910	510 ... 910	510 ... 910	510 ... 910	-	-
4 (radius)	12	12	16	18 or 60	8	8	8 or 20	6
yes	-	yes	-	yes	yes	yes	yes with AU SX or AU SXM	yes with AU SX or AU SXM
yes	-	yes	-	yes	yes	yes	yes with AU SX or AU SXM	yes with AU SX or AU SXM
-	-	-	-	-	-	yes	yes with AU SXM	yes with AU SXM
-	-	yes (1/2 slave)	-	yes (1 slave)	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	yes (up to 60 m)	-	-	-	-

SENSORS

SELECTION GUIDE

As the ESPE will be integrated in the machine safety-related control system, the choice of its safety level will depend on the result of risk analysis and, consequently, on parameters such as PL, SIL or Category resulting from the related safety function.

Product Standards (Type C) usually recommend the most suitable ESPE type for each safety-related function involved. If type C Standards are not available, adopt the recommendations of ISO 13849-1 and IEC 62061. Also consider that the overall safety integrity of the serial connection: input – control unit – actuators, shall necessarily be equal to or lower than that of the weaker device.

Rules for correct interconnection of protection devices to machine control system

The interconnections between safety outputs of ESPE (OSSD) and the machine primary control elements, the positioning and selection of reset push buttons shall not reduce or eliminate the extent of safety integrity assigned to the safety-related machine control system.

Next figure shows the most common example, i.e. where the machine control and monitoring system (e.g. the PLC) has no safety-related function. In this case, the safety-related control system monitoring the protective devices connected to it must operate autonomously and must be inserted between the machine control system and the machine primary control elements.

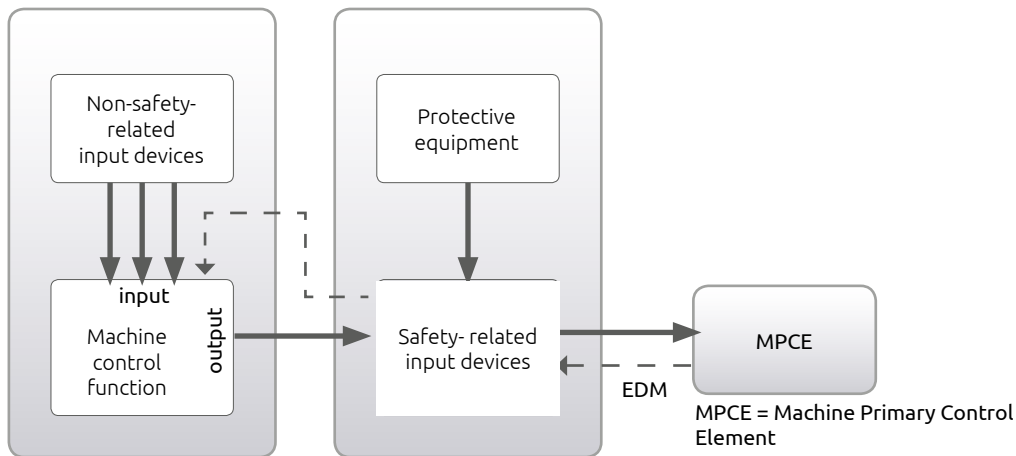


Fig. 21. Machine control and monitoring system (e.g. the PLC) has no safety-related function

If the machine is equipped with an integrated safety-related control and management system (safety-related PLC), see figure 15, machine operational functions and safety-related functions should be governed through the centralized safety-related system.

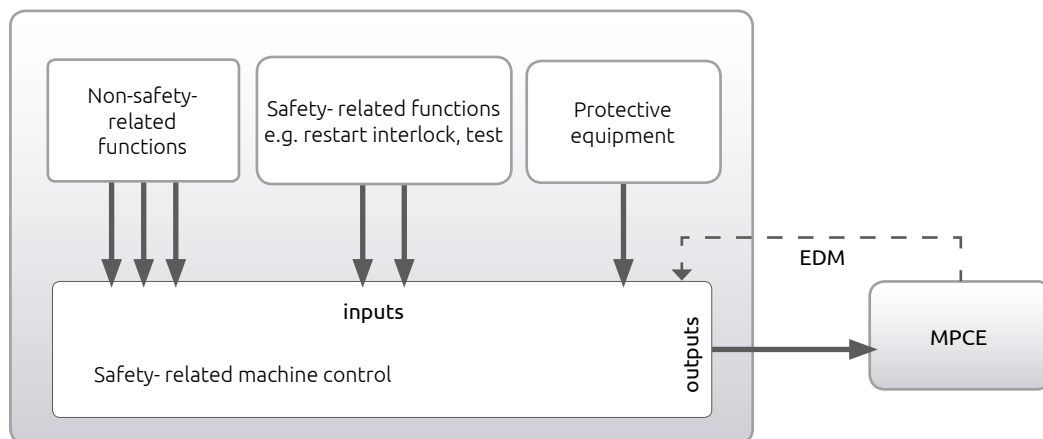


Fig. 22. Integrated safety-related control and management system (safety-related PLC)



Placement of the access control light curtains in the palletizer plant

This standard study tries to answer these two questions:

- how high, compared with to reference plane, it must be the first beam of the light curtains?
- What is the selection criterion to determine the number of the beams of the light curtains?

Below there are three examples of palletizers where the safety light curtains are positioned:

- Example 1
at the ground floor,



- Example 2
on a conveyor placed near the ground,



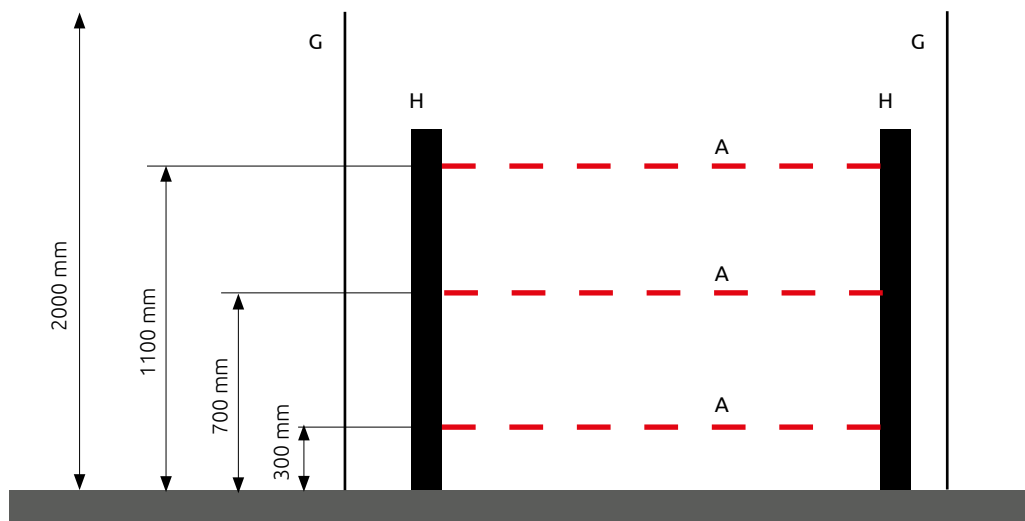
- Example 3
on a conveyor in the case of a raised conveyor if its surface is flat and, moreover, easily accessible by stairs.



For each of these conditions the EN 415-19 defines:

3. how high must be positioned the first beam of the light curtain
4. the number of beams of the same light curtain.

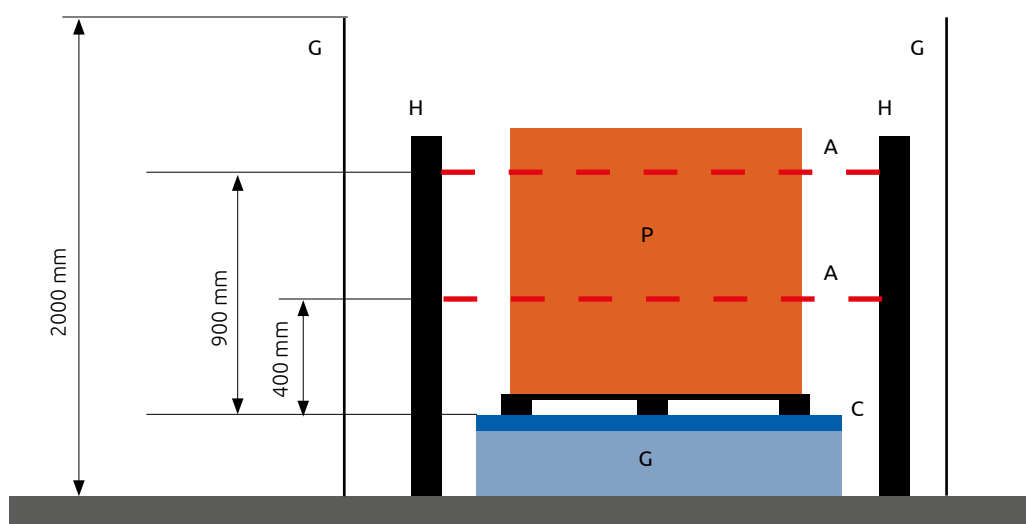
When the opening includes the floor or an easily accessible platform as in follow example, the AOPDs must have at least 3 beams positioned at 300mm, 700mm and 1100mm from the access plane.



- A. AOPD with 3 beams
- G. Fixed guard
- H. Column of the AOPD

Fig. 23. Positioning of the AOPD - General

When the opening is on a conveyor, the AOPDs must have at least 2 beams positioned at 400mm and 900mm from the conveyor plane.



- A. AOPD with 2 beams
- C. Conveyor
- G. Fixed guard
- H. Column of the AOPD
- P. Pallet

Fig. 24. Positioning of the AOPD - Above the roller conveyor

INSIGHTS

The safety distance must be calculated using the formula:

$$S = 1600 \times T + 850 \text{ (see ISO 13855: 2010)}$$

If it is possible to reach the dangerous point by leaning over the edge of the higher beam then the following formula must be used

$$S = 1600 \times T + C_{ro}$$

Where C_{ro} comes from Table 1 of ISO 13855: 2010

Or an ESPE with a larger number of beams must be selected.

Using mechanical obstacles

To prevent a person from crawling below the lower beam and reaching the dangerous area without being intercepted by the AOPD, mechanical obstacles can be used.



Industrial thermal processes

Control of all applications where burners are used or, in general, in industrial thermal processes. Example: ovens, dryers for ceramic or cereals, shrink-sleeve wrappers & spreading lines, etc..

The most common requests for this kind of applications are the following:

- Flame monitoring, according to ISO 13849-1 standard, must reach PL e safety level.
- Gas and burning oil pressure control (PL d).
- Post-purge monitoring of gas presence in pipes (PL d).
- Combustive-air ventilation turn-off control (PL d).



With regards to these type of applications, a key factor should be highlighted: there should be no confusion between the actual “burner” and the plant or thermal process in which the burner is used.

Burners must comply with specific standards requiring analogic reading functions of air-gas mixture and many other relating logic functions.

Instead, standard EN 746-2 regulates burner’s applications defining the thermal process required safety levels and regulations applicable.

Sensors required by the EN 746-2 standard

- Flame extinction monitoring: flame-presence detector sensors are normally used (often optical, non-safety) instead of the required SIL3-type or 2x SIL2-type flame detectors. More commonly, certified integrated burner monitoring systems (BMS), including flame control, are used. The SIL3-type or the 2x SIL2-type digital signal generated by the BMS can be used as input.
- Gas pressure monitoring: pressure switches (SIL2-type, SIL3 not available).
- Pilot-flame temperature control: temperature detectors (SIL3).
- Gas pipes purging control: gas detector (SIL3 or SIL2).
- Air-vent fans monitoring: flow sensors (SIL2).
- Air/fuel ratio monitoring: pressure switches (SIL2).



The block diagram shown below indicates the relationships between system's components.

The diagram clearly shows where Mosaic safety controller can take action. Based on the input received from sensors and safety systems, Mosaic OSSDs acts on the combustion-gas and combusive-air nozzles, controlling and adjusting the combustion process.

Process control (a)

1. Control and instrumentation system / Operator control level
 - Process control level
 - Control level (local)
 - Control (non-fail-safe)
 - Tuning and adjustments
 - Monitoring
2. Protective systems
 - E-stop
 - Safety interlock
 - Purge and pipe monitoring
 - Tightness control
 - Automatic burner control unit
 - Flue gas venting
 - Air/fuel ratio
 - Flow and pressure detectors
 - High temperature limits

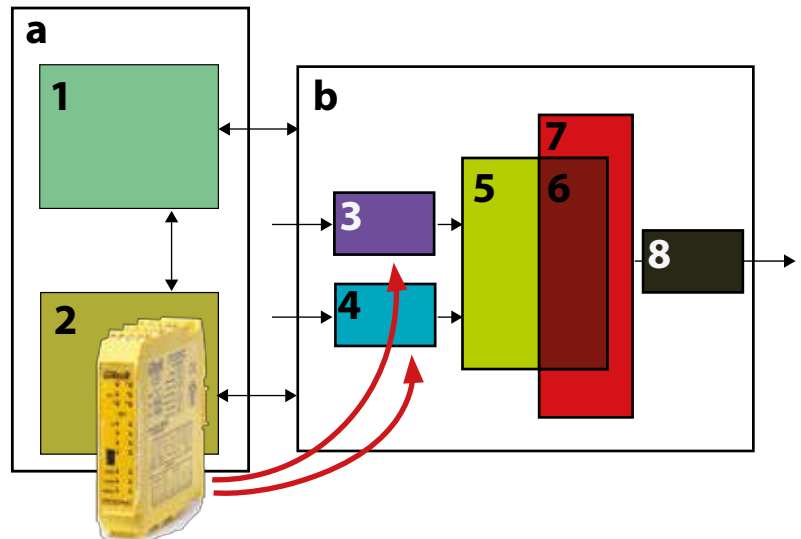


Fig. 25. Block diagram showing equipment for industrial thermal process


Heated system (b)

3. Fuel supply (gas)
4. Combustion air supply
5. Burner system and ignition device
6. Combustion chamber
7. Processing chamber
8. Flue gas system.

Standard

These types of systems are regulated by European Standard EN 746-2 - "Industrial thermoprocessing equipment safety requirements for combustion and fuel handling systems" May 2010.

This Type C standard and is part of the 8 standards forming the EN 746 safety standards "Industrial Thermoprocessing Equipment".

 The EN 746-2 assumes that all equipments are not creating any potential explosive atmosphere and are located in a normally ventilated area.

EN 746-2 defines the requirements for the protective-and-safety systems of these devices:

- The protective-and-safety system is a group of devices, control units and safety circuits whose main purpose is the protection of the personnel, the plant and the environment.
- The protective-and-safety system includes all components required to carry out the safety function:
 - Sensors for monitoring safety-related parameters (e.g. flame temperature, air pressure, etc..)
 - Combustion-gas and combusive-air blocking devices (valves)
 - Combustion-chamber ventilation control and burner protection devices (e.g. temperature level monitoring).

A protective-and-safety system is typically made up of sensors, control logics, actuator devices and a multi-channel system allowing communication between all elements. The required safety monitoring of the whole system can be performed by Mosaic.

The standard also defines the conditions that the protective-and-safety system should fulfill, indicating 4 possible scenarios as shown in the following table:

Condition	Device	Standard
Hardwired system in which all components comply with the relevant product standards as specified in 5.2 to 5.6	Automatic burner control systems	EN 298
	Valve testing systems	EN 1643
	Pressure sensing devices	EN 1854
	Automatic shut-off valves	EN 161
	Gas/Air ratio controls	EN 12067-2
Hardwired system with a combination of: components complying with the relevant product standards as specified in 5.2 to 5.6 components complying with defined SIL/PL level in accordance respectively with EN 62061 and EN ISO 13849-1	Automatic burner control systems	EN 298
	Valve testing systems	EN 1643
	Pressure sensing devices	EN 1854
	Automatic shut-off valves	EN 161
	Gas/Air ratio controls	EN 12067-2
PLC based system with a combination of: components complying with the relevant product standards as specified in 5.2 to 5.6 components complying with defined SIL/PL level in accordance respectively with EN 62061 and EN ISO 13849-1	Guarding functions (e.g. gas pressure, temperature) performed by components for which no relevant product standards are existing shall comply with at least: SIL 2 / PLd	IEC 62061 (SIL)
	Functions which will lead to immediate hazard in case of failure (e.g. flame detector device, ratio monitoring) performed by components for which no relevant product standards are existing shall comply with at least: SIL 3 / PLe	EN ISO 13849 (PL)
	Automatic burner control systems	EN 298
	Valve testing systems	EN 1543
	Pressure sensing devices	EN 1854
PLC based system in which all components comply with defined SIL 3 / PL e and with a defined SIL 3/PL e of hard and software.	Automatic shut-off valves	EN 161
	Gas/Air ratio controls	EN 12067-2
	Guarding functions (e.g. gas pressure, temperature) performed by components for which no relevant product standards are existing shall comply with at least: SIL 2 / PLd	IEC 62061 (SIL)
	Functions which will lead to immediate hazard in case of failure (e.g. flame detector device, ratio monitoring) performed by components for which no relevant product standards are existing shall comply with at least: SIL 3 / PLe	EN ISO 13849 (PL)
	Software for safety functions should be separate from other functions (e.g. control functions) the software for safety functions shall be designed in accordance with the requirements of EN ISO 13849 and EN 62061. A PLC used for safety functions shall comply with EN ISO 13849-1 and EN 62061.	
	In this case EN ISO 13849-1 and EN 62061 shall be applied for the protective system in general	IEC 62061 (SIL) EN ISO 13849 (PL)

Perimeter protection

Combined application of safety light curtains and deflector mirrors

For perimeter protections up to 4 sides, floor support columns with deflection mirrors can be used in combination with safety light curtains. An example of application is illustrated in the following figure.



Fig. 26. Machine for laser cutting perimeter protection

Columns with deflection mirrors range offer from ReeR is the following:

Models	FMC-S2	FMC-SB2	FMC-S3	FMC-SB3	FMC-S4	FMC-SB4	FMC-S1700	FMC-S2000
Ordering codes	1200620	1200645	1200621	1200646	1200622	1200647	1200625	1200623
Description	single mirror for 2 beams light curtains	2 mirrors for 2 beams light curtains	single mirror for 3 beams light curtains	3 mirrors for 3 beams light curtains	single mirror for 4 beams light curtains	four mirrors for 4 beams light curtains	controlled height up to 1360 mm	controlled height up to 1660 mm
Overall height with base (mm)	1055		1255		1385		1725	2025

The SP deflection mirrors make it possible to create perimeter protection of areas with access point on multiple sides with large distances between the protection elements.

Normally the light curtains used in this type of applications are those with 2, 3 and 4 beams for detecting the presence of the body in a hazardous area. However, You can also use light curtains with different resolutions. In this case, do not apply the measures listed in the table of the next page. For these applications it is necessary to assess the safety distances depending on the type of plant.

The layout of safety light curtains and columns with the deflection mirrors clearly depend on the type and the specific requirements of the protection system we intend to create.

There are three factors to take into account in calculating the distances between safety barriers and columns:

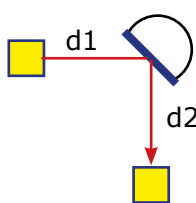
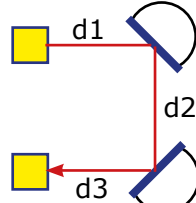
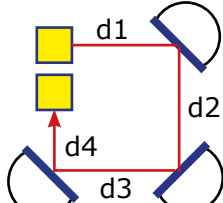
- Divergence between the beams - Should be taken into account that the beams emitted from the light curtain emitter present a certain degree of divergence, so there are never perfectly parallel.
- Any problems of flatness of the mirror - This factor, as the previous increases its influence with increasing distances.
- Absorption coefficient of mirrors - For each mirror used is necessary to take into account the reduction in power of the optical beam emitted from the light curtain emitter. Refer to the following diagram:
 - FMC (S2 - S3 - S4)
 - 15% for light curtains with range up to 20 m
 - 20% for light curtains with range higher than 20 m.
 - FMC (SB2 - SB3 - SB4)
 - 10% for light curtains with range up to 20 m
 - 15% for light curtains with range higher than 20 m.

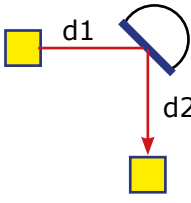
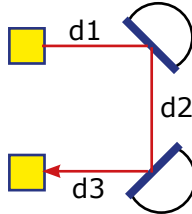
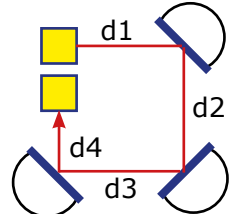
This reduction is due to the specific characteristics of the mirror and takes account of the dirt and dust that settles on the same, especially in industrial environments. This reduces the range of the system mirror/light curtains.

These three factors determine the choice of the barrier model and the minimum distances for the positioning of the elements of the protection system.

The following table is intended to provide a guide for:

- choice of the type of column and light curtain to be used;
- define the maximum distance allowed for the correct placement of the devices taking into account the factors mentioned above and the maximum range of the light curtain used.

		INSTALLATION TYPE			
COLUMN WITH DEFLECTION MIRROR TYPE	LIGHT CURTAINS MODEL	LIGHT CURTAINS RANGE			
			Max. Distance	Max. Distance	Max. Distance
FMC S2 FMC S3 FMC S4	EOS SAFEGATE	4 - 12 m	$(d1+d2) < 10 \text{ m}$	$(d1+d2+d3) < 8,5 \text{ m}$	$(d1+d2+d3+d4) < 6,5 \text{ m}$
	EOS H	10 - 20 m	$(d1+d2) < 17 \text{ m}$	$(d1+d2+d3) < 14,5 \text{ m}$	$(d1+d2+d3+d4) < 12 \text{ m}$
	ADMIRAL	6 - 18 m	$(d1+d2) < 15 \text{ m}$	$(d1+d2+d3) < 13 \text{ m}$	$(d1+d2+d3+d4) < 11 \text{ m}$
	VISION	6 - 16 m	$(d1+d2) < 13,5 \text{ m}$	$(d1+d2+d3) < 11,5 \text{ m}$	$(d1+d2+d3+d4) < 9,5 \text{ m}$
	JANUS LR	30 - 60 m			
	ADMIRAL LR	22 - 60 m	$(d1+d2) < 48 \text{ m}$	$(d1+d2+d3) < 38 \text{ m}$	$(d1+d2+d3+d4) < 30 \text{ m}$
	VISION LR	22 - 60 m			
	JANUS LR ILP	40 - 80 m	$(d1+d2) < 64 \text{ m}$	$(d1+d2+d3) < 51 \text{ m}$	$(d1+d2+d3+d4) < 41 \text{ m}$

COLUM WITH DEFLECTION MIRROR TYPE	LIGHT CURTAINS MODEL	LIGHT CURTAINS RANGE	INSTALLATION TYPE					
			Max. Distance	Max. Distance	Max. Distance			
FMC SB2 FMC SB3 FMC SB4	EOS SAFEGATE	4 - 12 m				$(d1+d2) < 11 \text{ m}$	$(d1+d2+d3) < 10 \text{ m}$	$(d1+d2+d3+d4) < 9 \text{ m}$
			$(d1+d2) < 18 \text{ m}$	$(d1+d2+d3) < 16 \text{ m}$	$(d1+d2+d3+d4) < 14,5 \text{ m}$			
			$(d1+d2) < 16 \text{ m}$	$(d1+d2+d3) < 14,5 \text{ m}$	$(d1+d2+d3+d4) < 13 \text{ m}$			
			$(d1+d2) < 14,5 \text{ m}$	$(d1+d2+d3) < 13 \text{ m}$	$(d1+d2+d3+d4) < 11,5 \text{ m}$			
			$(d1+d2) < 51 \text{ m}$	$(d1+d2+d3) < 43 \text{ m}$	$(d1+d2+d3+d4) < 36,5 \text{ m}$			
			$(d1+d2) < 68 \text{ m}$	$(d1+d2+d3) < 58 \text{ m}$	$(d1+d2+d3+d4) < 49 \text{ m}$			



For small distances the column with single mirror is enough; for longer distances, which amplify all the factors mentioned above, are required multiple mirrors that let you retrieve the divergence of beams parallelism.



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