WHITE PAPER

ELECTRO-SENSITIVE PROTECTIVE DEVICES (ESPE) FOR SAFE MACHINES

OPTO-ELECTRONIC PROTECTIVE DEVICES, 2017-08

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ABSTRACT

The measures and products for implementation of machine safety requirements have become more diverse over the years. The goal is ever better integration of the functional safety in machines and systems for safeguarding. Various technologies for implementation of protection measures are now available.

This whitepaper takes a closer look at electro-sensitive protective devices (ESPEs) with a special focus on opto-electronic protective devices. It presents background information on state-of-the-art optical technologies, typical applications, notes on the use of ESPEs, influencing factors to be taken into account and additional functions of ESPEs.

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Introduction

The measures and products for implementation of machine safety requirements have become more diverse over the years. The goal is ever better integration of the functional safety in machines and systems for safeguarding. Various technologies for implementation of protection measures are now available.

With electro-sensitive protective devices (ESPEs) – in contrast to “physical guards” – protection is not based on the physical separation of persons at risk from the risk itself. Protection is achieved through temporal separation. As long as there is somebody in a defined area, no hazardous machine functions are initiated and such functions are stopped if already underway. A certain amount of time, the so-called stopping/run-down time, is required to stop these functions. The ESPE must detect the approach of a person to the hazardous area in a timely manner and depending on the application, the presence of the person in the hazardous area. The safety requirements for ESPEs independent of their technology or principle of operations are stated in the International Standard EN 61496-1.

What benefits do electro-sensitive protective devices provide?

If an operator frequently or regularly has to access a machine and therefore, he is exposed to a hazard, use of an ESPE instead of (mechanical) physical guards (covers, safety fencing, etc.) is advantageous thanks to:

- Reduced access time (operator does not have to wait for the protective device to open)
- Increased productivity (time savings when loading the machine)
- Improved workplace ergonomics (operator does not have to operate a physical guard)

Moreover, not only operators but also other persons are protected.

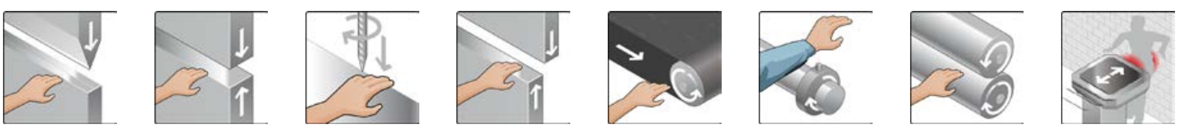


Fig. 1: Typical hazards where electro-sensitive protective device can be used.

Against what hazards do electro-sensitive protective devices not protect?

Since electro-sensitive protective devices do not provide any physical barrier, they are not able to protect persons against emissions, such as ejected machine parts, work pieces or metal shavings, ionizing radiation, heat (thermal radiation), noise, sprayed coolants, cutting oils, lubricants, etc. (Fig. 2). The use of an ESPE is also not possible on machines with lengthy stopping/run-down times, which require unrealizable minimum distances. In such cases, physical guards must be used.

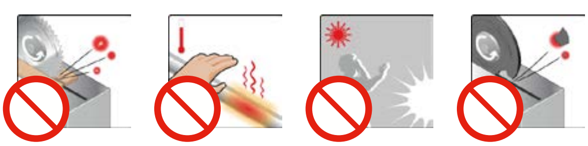


Fig. 2: Typical hazards where electro-sensitive protective cannot be used.

Technologies for electro-sensitive protective equipment

Electro-sensitive protective devices can implement detection of persons through various principles: optical, capacitive, ultrasonic, microwaves and passive infrared detection. Due to inadequate accuracy, capacitive and ultrasonic systems have proven inadequate. Passive infrared detection offers no certainty of distinction and microwave systems have not yet been adequately tested. In practice, opto-electronic protective devices have been proven over many years and in large numbers (Fig. 3).

Opto-electronic protective devices

The most common electro-sensitive protective devices are opto-electronic devices such as:

Safety light curtains and photoelectric switches (AOPD: active opto-electronic protective device)

Safety laser scanners (AOPDDR: active opto-electronic protective device responsive to diffuse reflection)

Camera-based protective devices (VBPD: vision based protective device)

Fig. 3: Examples of opto-electronic protective devices.

Opto-electronic protective devices can be used for numerous safety applications (Fig. 4).

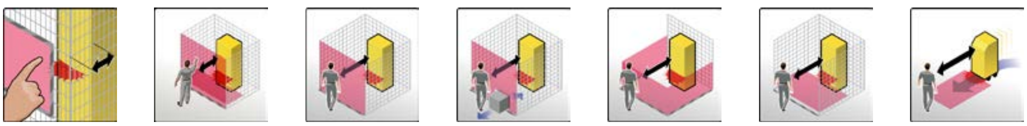


Fig. 4: Typical safety applications for opto-electronic protective devices.

Safety light curtains and photoelectric switches (AOPDs)
AOPDs are protective devices that use opto-electronic emitting and receiving elements to detect persons in a defined two-dimensional area. A series of parallel light beams (normally infrared) transmitted from the sender to the receiver form a protective field that safeguards the hazardous area. Detection occurs when an opaque object fully interrupts one or more beams. The receiver signals the beam interruption by a signal change (OFF state) to its output signal switching devices (OSSDs). The signals of the OSSDs are used to stop the hazardous machine functions. The international standard IEC 61496-2 includes the safety requirements for AOPDs.

Typical AOPDs include single-beam photoelectric safety switches, multiple light beam safety devices and safety light curtains. Multiple light beam safety devices are the AOPDs with a detection capability of more than 40 mm. They are used to protect access to hazardous areas (Fig. 5). AOPDs with a detection capability of 40 mm or less are called safety light grids or safety light curtains and are used to protect hazardous points directly (Fig. 6).

Fig. 5: Access protection using a multiple light beam safety device.

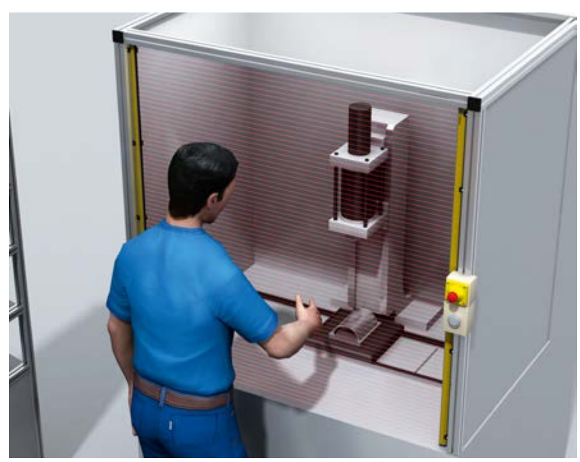


Fig. 6: Hazardous point protection using a safety light curtain.

On multiple light beam safety devices and safety light curtains, not all light beams are generally activated at the same time, but switched ON and OFF one after the other in rapid succession. This improves resistance to interference from other sources of light and increases the reliability accordingly. For state-of-the-art AOPDs, sender and receiver automatically synchronize through an optical link (Fig. 7).

By using microprocessors, the beams can be evaluated individually. This ensures beside the pure protective function also additional functionalities (see "Additional functions of ESPEs" on page 13).

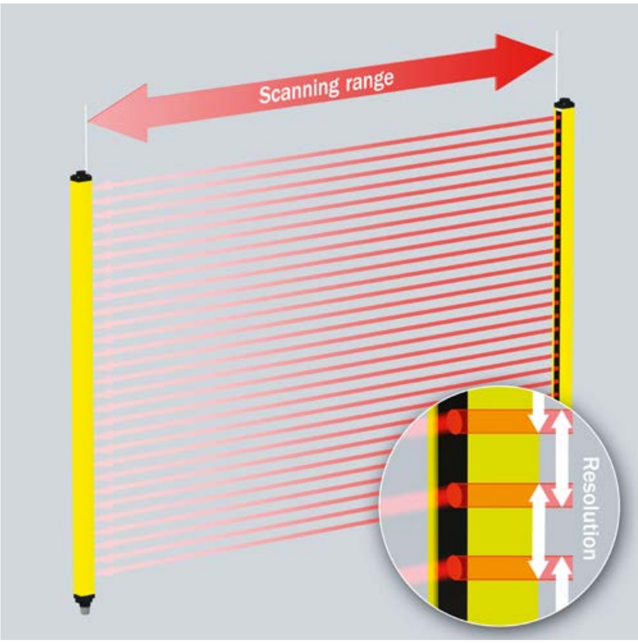


Fig. 7: Typical structure of a safety light curtain with sender and receiver.

Safety laser scanners (AOPDDRs)
AOPDDRs are protective devices that use opto-electronic transmission and reception elements to detect the reflection of the optical radiation generated by the protective device. The reflection is generated by an object in a defined two-dimensional area. Detection is signaled by a signal change (OFF state) to its output signal switching devices (OSSDs). These signals of the OSSDs are used to stop the hazardous machine functions.

Safety laser scanners are mainly used for stationary and mobile hazardous area protection.

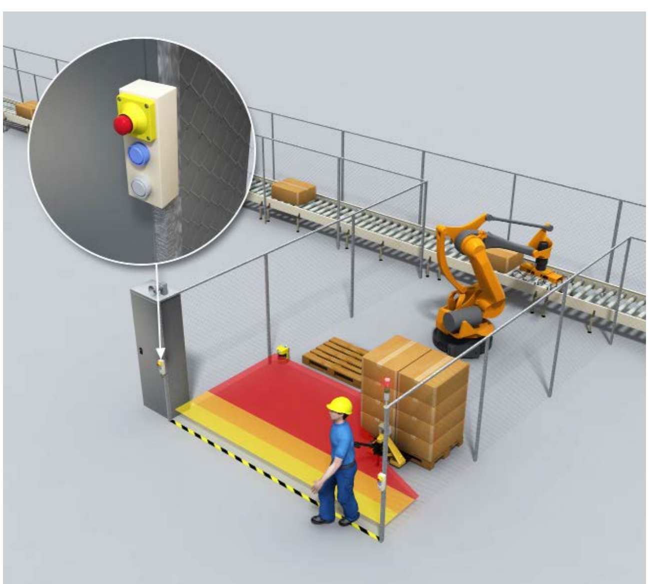


Fig. 8: Stationary hazardous area protection with a safety laser scanner.

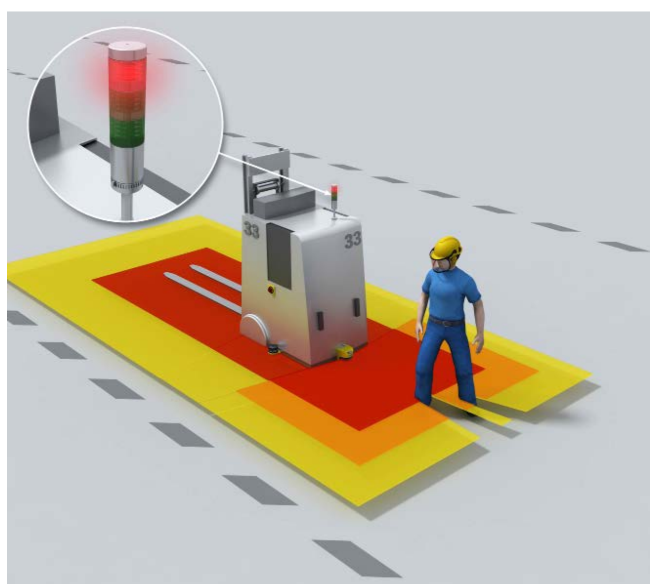


Fig. 9: Mobile hazardous area protection with a safety laser scanner.

The safety laser scanner is an optical sensor that scans the surroundings with infrared laser beams in two dimensions and monitors a hazardous area near a machine or vehicle. It operates on the principle of time-of-flight measurement (Fig. 10 and 11). The scanner transmits very short light pulses (S) while an "electronic stopwatch" runs simultaneously. If the light strikes an object, it is reflected and received by the scanner (R). The scanner calculates the distance to the object based on the time difference between the sender and receiver (Δt). A uniformly rotating mirror (M) in the scanner deflects the light pulses so that a section of a circle is covered. The scanner determines the exact position of the object from the measured distance and the angle of rotation of the mirror. The user can program the area in which object detection trips the ESPE (protective field). State-of-the-art devices allow simultaneous monitoring of several areas or switching of these areas during operation. E.g., this can be used for adjustment of the monitored area to the speed of the vehicle or a graduated response (warning field – protective field) to prevent unnecessary interruptions in operations.

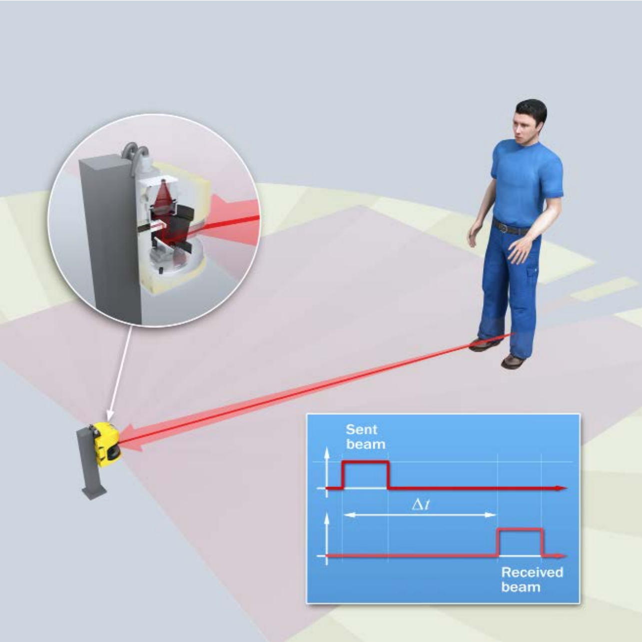


Fig. 10: The safety laser scanner forms a protective field. The object is detected by reflection and time-of-flight measurement of the transmitted laser beam.

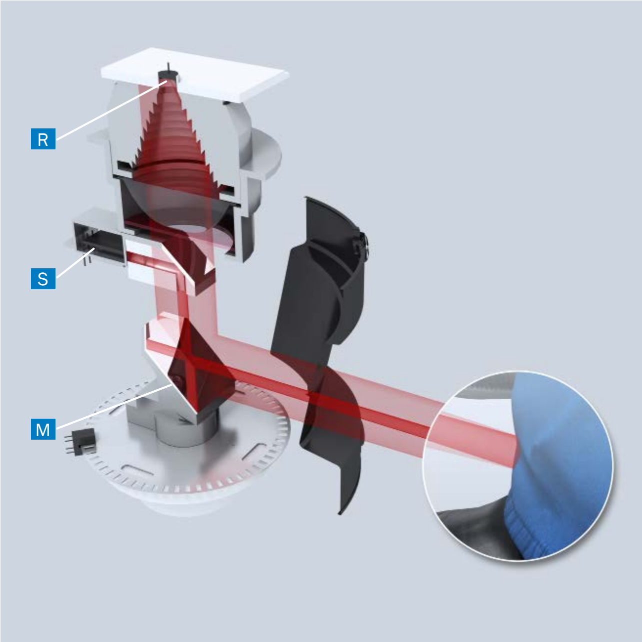


Fig. 11: Basic structure of a laser scanner.

Safety laser scanners use individual pulses of light in precise directions and do not continuously cover the area to be monitored. Resolutions (detection capabilities) between 30 mm and 150 mm are achieved through this operating principle. With the active scanning principle, safety laser scanners do not need external receivers or reflectors. Safety laser scanners have to be able to reliably detect objects with extremely low reflectivity (e.g., black work clothing). The international standard IEC 61496-3 states the safety requirements for AOPDDRs.

Camera-based protective devices (VBPD)
VBPDs are camera-based protective devices and use image capturing and processing technologies for safety detection of persons (Fig. 12). Special light senders are currently used as light sources. VBPDs that use the ambient light are also possible.

Various principles can be used to detect persons, including:

- Interruption of the light reflected back from a retro reflector
- Time-of-flight measurement of the light reflected by an object
- Size and distance measurement of an object
- Monitoring of changes from background patterns
- Detection of persons based on human characteristics

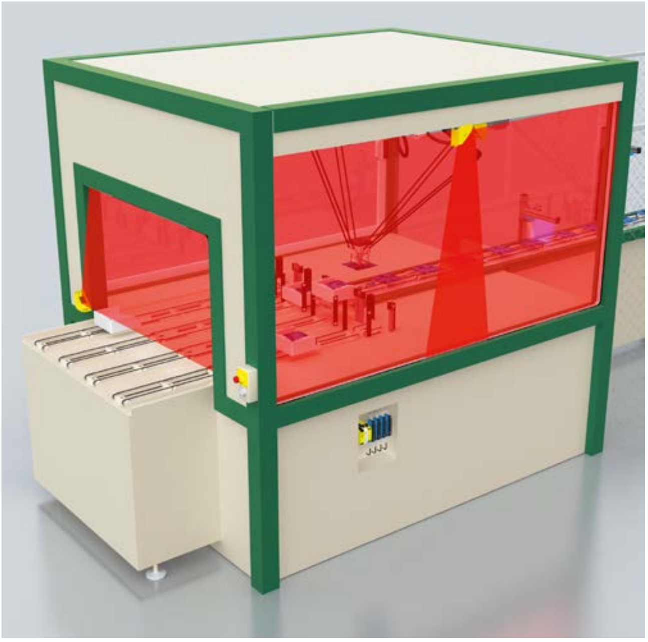


Fig. 12: Hazardous point protection using a safety camera system on a handling robot in solar cell production.

The upcoming international standard series IEC 61496-4-x includes the safety requirements for VBPDs.

Detection capability (resolution) of opto-electronic protective devices

The detection capability is defined as the limit for the sensor parameter that causes the electro-sensitive protective device (ESPE) to trigger. In practice, this is the size of the smallest object detected by the ESPE within the defined monitored area (protective field). The detection capability is specified by the manufacturer. In general, the detection capability is determined by the sum of the beam separation and effective beam diameter. This ensures that an object of this size always interrupts a light beam and is therefore detected regardless of its position in the protective field. For safety laser scanners, the detection capability is dependent of the distance to the object, the angle between the individual beams of light (pulses) and the shape and size of the transmitted beam.

The reliability of the detection capability is determined by the type classification in the standard series EN 61496. For AOPDDR the Type 3 is defined. For AODP are defined Type 2 and Type 4 (Fig. 13). Requirements regarding optical sources of interference (sunlight, different lamp types, devices of the same design, etc.), reflective surfaces, misalignment during normal operation and the diffuse reflection of safety laser scanners play an important role.

	Type 2	Type 4	Advantage Type 4
Functional safety	Between the test intervals, the protective function may be lost during a failure.	The protective function is retained even during several failures.	Higher risk reduction
EMC (electromagnetic compatibility)	Basic requirements	Increased requirements	Higher reliability of the detection capability Higher system availability in difficult ambient conditions.
Maximum field of view of the optics	10°	5°	
Minimum distance a to reflective surfaces over a distance D of < 3 m	262 mm	131 mm	
Minimum distance a to reflective surfaces over a distance D of > 3 m	= distance × tan (10°/2)	= distance × tan (5°/2)	
Several senders of the same design in a system (workplace)	No special requirements (Beam coding is recommended)	No effect; however, if affected, OSSDs switch off	

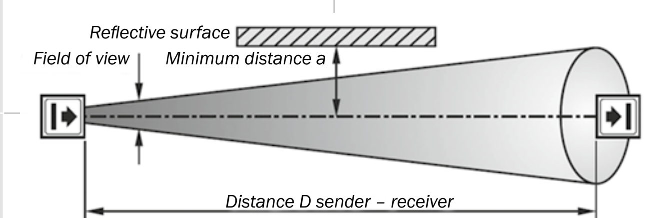


Fig. 13: Main difference between AOPDs of Type 2 and Type 4 acc. to IEC 61496. The requirements for Type 4 devices are higher than those for Type 2.

Important factors that influence reliable ESPE protection

Minimum distance and stopping/run-down time
There is always a stopping/run-down time after the signal is given to cease the hazardous machine functions. The time of the entire system (the entire control chain) is contained in this so called overall stopping time. This time determines the required minimum distance of the protective device to the hazardous area. The required minimum distance is calculated according to the standard EN ISO 13855.

The consideration of the minimum distance applies to ESPEs with two-dimensional protective fields, e.g., light curtains (AOPD), laser scanners (AOPDDR) or two-dimensional camera systems.

The general formula for calculating the minimum distance (safety distance) is:

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

where

- S is the minimum distance in millimeters, measured at the next hazardous point to the detection point and or detection line or detection plane of the protective device.
- K is a parameter in millimeters per second, derived from the data for the approach speeds of the body or parts of the body.
- T is the overall stopping time of the system.
- C is an additional distance in millimeters.

The additional distance C is dependent on the detection capability (Fig. 14) for an ESPE when approaching at a right-angle, and dependent on the height of the protective field above the reference level for a parallel approach.

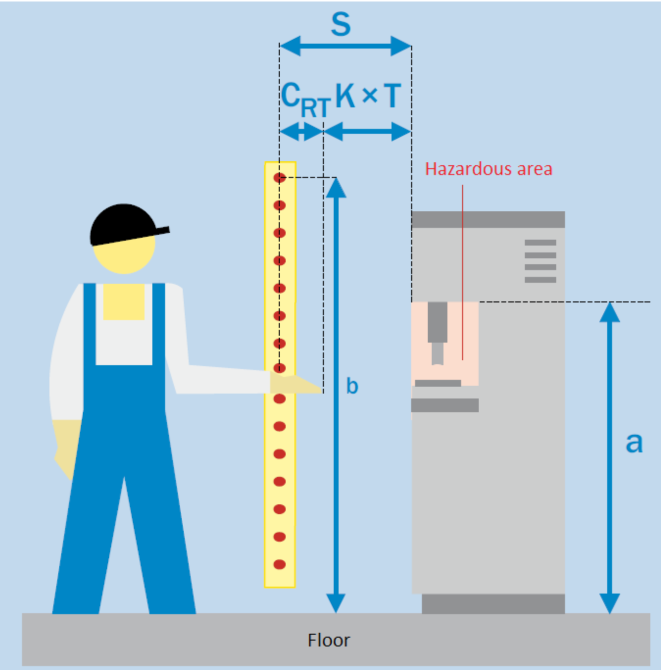


Fig. 14: Parameters for determining the required minimum distance or protective field height when approaching at a right-angle.

For the overall stopping time T the following parameters must be taken into account:

- Stopping time of the machine
- Response time of the safety-related control
- Response time of the protective device (ESPE)
- Additions according to the detection capability of the ESPE, the protective field height and/or the type of approach

Preventing reflections from AOPDs

For AOPDs, the light beam is focused from the sender. The aperture angle of the lens is reduced as far as possible such that an operation free of false trips can be ensured even in the event of small alignment errors. The same applies to the aperture angle of the receiver (effective aperture angle acc. IEC 61496-2). Nevertheless, also for smaller aperture angles, there is the possibility for light beams from the sender to be deflected and thus, a failure to detect an object (Fig. 15 and 16). Therefore, all reflective surfaces and objects (e.g., material containers, reflective floors) have to maintain a minimum distance to the protective field of the system (see Fig. 13). This minimum distance depends on the distance D between sender and receiver (protective field width). It must be maintained on all sides of the protective field.

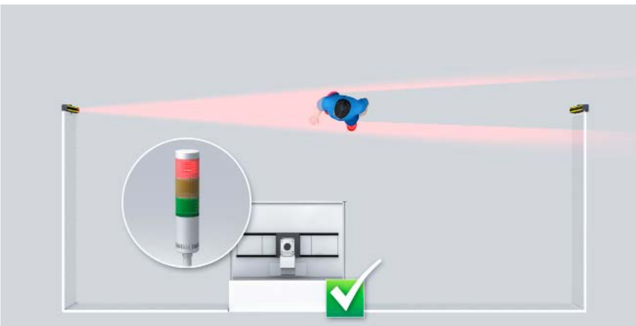


Fig. 15: The person is detected reliably and the hazardous movement stopped.

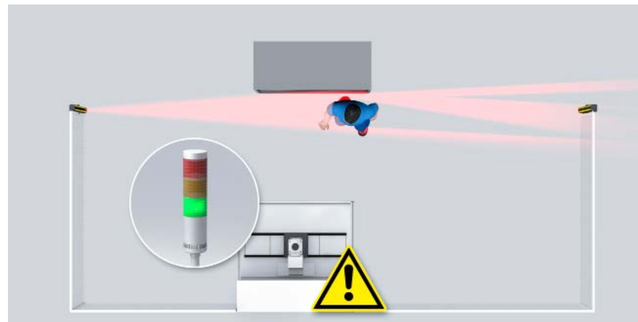


Fig. 16: Reflection hinders the protective effect of the ESPE is nullified.

Prevention of mutual interferences between AOPDs

If several AOPDs are operated in close proximity to each other, the sender beams from one system (S1) can affect the receiver of the other system (R2). This is the risk that the affected AOPD provides no protection (Fig. 19). Installation situations of this kind must be avoided or suitable measures must be taken, e.g., mounting of opaque partitions or reversing the direction of transmission of a system. Type 4 AOPDs either have to have suitable extraneous sender detection and change to a safe state (outputs in OFF state) when affected or have technical means to prevent the interference. Beam coding is normally used, so that the receiver only responds to light beams from the assigned sender (coded the same) (Fig. 17 and 18).

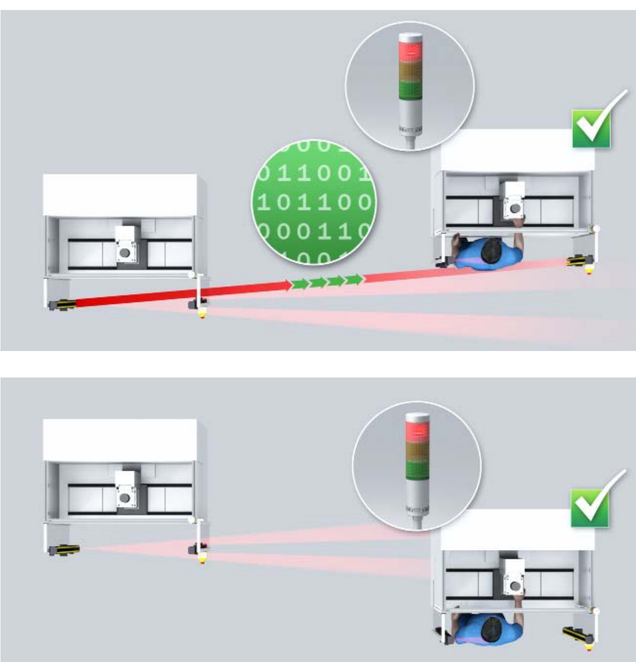


Fig. 17 and 18: There is no mutual interference between protective devices. The person is detected reliably by encoding the beams or by arranging the protective adequately.

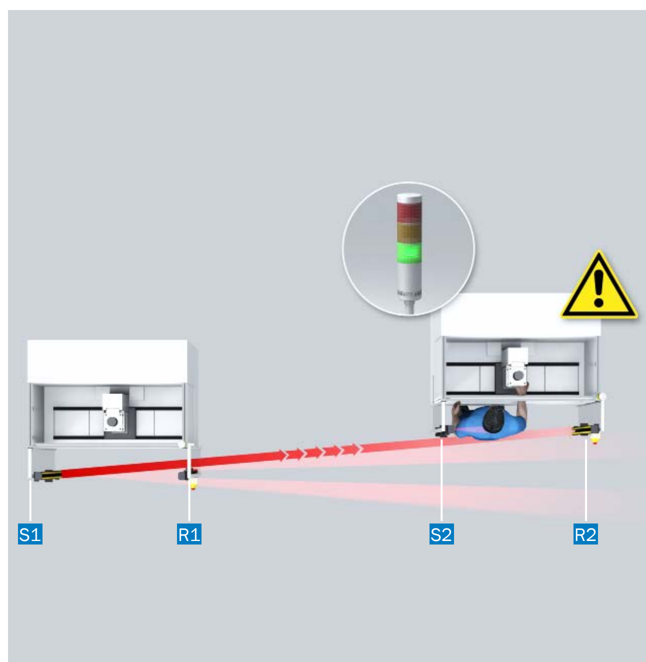


Fig. 19: By mutual interference the ESPE protection is rendered inoperative.

Automatically ignoring material passing through ESPEs

The following safety functions can be supported through the logic unit or directly through a suitable ESPE.

Temporary deactivation of the protective function (Muting)
The muting function allows temporary deactivation of the protective function of a protective device. This is necessary when material must be moved through the protective field of the protective device without stopping the machine operation routine (hazardous state of the machine). It can also be used effectively to optimize the machine operation routine (e.g. muting a safety light curtain during the safe run-up of the die in a power press, making it easier for the operator to remove work pieces).

Muting is only allowed when access to the hazardous point is blocked by the material passing through (Fig. 20) or – in case if it is not possible to trespass the protective device – when no hazardous machine functions are present. This condition is assessed by muting sensors and muting signals.

For the muting function, great care is necessary when selecting and positioning the muting sensor and controller signals used.

The following conditions are to be met to implement a safe, standardized muting function:

- During muting, a safe state must be ensured by other means, i.e. the hazardous area must be inaccessible.
- Muting must be automatic, i.e., not manual.
- Muting may not depend on a single electrical signal.
- Muting may not entirely depend on software signals.
- An invalid combination or sequence of muting signals shall not allow any muting state.
- The muting state must be ceased immediately after the material passes.

To improve the quality of differentiation, additional limits, or signals can be used including:

- Direction of movement of the material (sequence of the muting signals)
- Limiting of the muting duration
- Material demand by the machine controller
- Operational status of the material handling elements (e.g., conveyor belt, roller conveyor)
- Material identification by additional properties (e.g., bar code label)

Fig. 20: Muting function with safety light curtain and muting sensors on a wrapping machine.

Safety light curtains with entry/exit function

Another possibility to transport material in a protected area is through active differentiation between man and material (entry/exit-function) using AOPDs. For this application, horizontally arranged safety light curtains (AOPDs) are used. The possibility of evaluating each light beam is used to differentiate the interruption pattern of the material or material carrier (e.g., pallet) from a person. By using self-teaching dynamic blanking, as well as other differentiation criteria such as direction of movement, speed, entry and exit position in the protective field, etc., a safety-relevant distinction can be made. That way, undetected entry into the hazardous area by persons can be reliably prevented (Fig. 21 and 22).

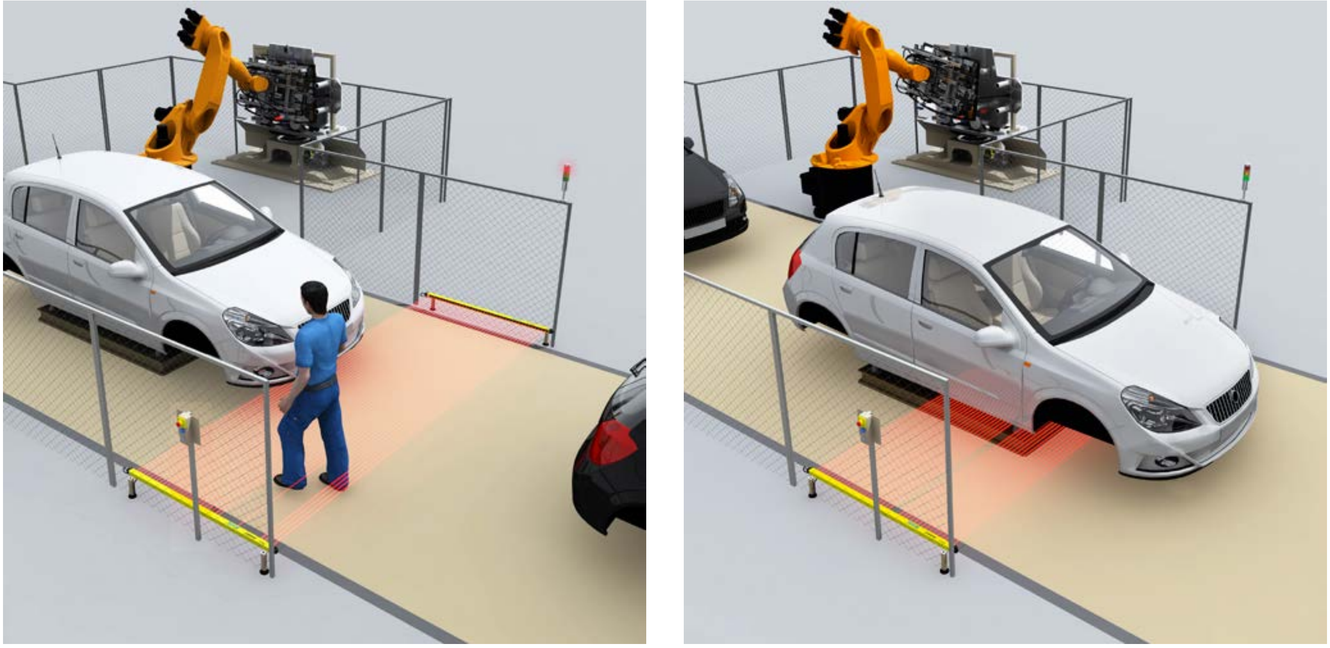


Fig. 21 and 22: Entry/exit function with horizontally arranged safety light curtain in a processing station of an automobile assembly line.

Safety laser scanners with protective field switching

An additional possibility to transport material through a protected area is via switching the protective fields. For this application, safety laser scanners are normally used with vertical (and slightly angled) protective fields. The appropriate protective field is activated from a series of preprogrammed protective fields, by adequately positioned sensors and appropriate signals from the machine controller. The contour of the protective field is preprogrammed so that passage of the material does not cause the protective device to activate, but unmonitored areas are small enough to prevent undetected entry into the hazardous area by anyone (Fig. 23).

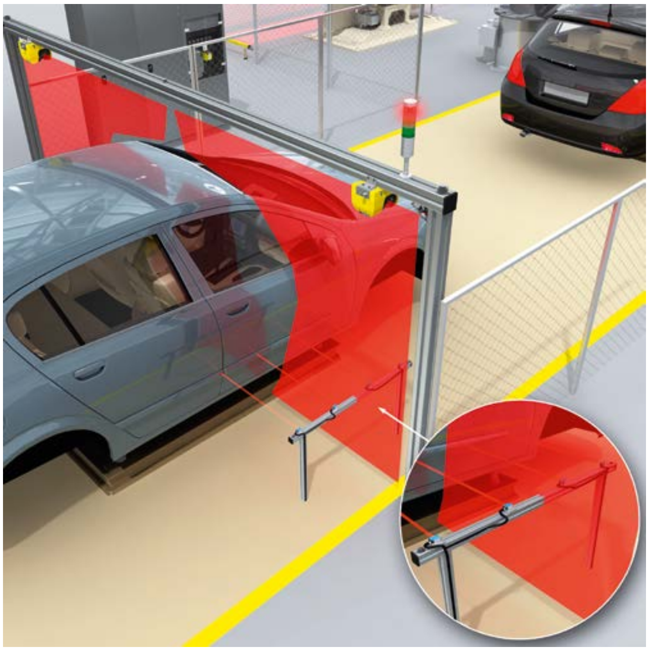


Fig. 23: Passing of material with safety laser scanners, horizontal protective fields and adequately positioned sensors

Additional functions of ESPEs

Blanking

For many AOPDs, configuration of the detection capability and/or protective field can be set so that the presence of one or more objects within a defined section of the projective field does not trigger the safety function (OFF state). Blanking can be used to allow specific objects pass through the protective field (e.g., hose for cooling lubricant, slide or carrier for work pieces, Fig. 24).

For fixed blanking, the blanked area is precisely defined in size and position. For floating blanking, only the size of the blanked area is defined, but not the position in the protective field (Fig. 25).

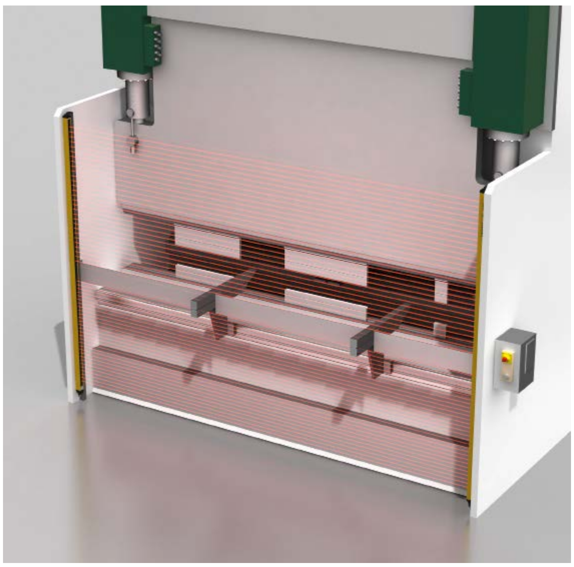


Fig. 24: Fixed blanking of light curtain beams on a trimming press.

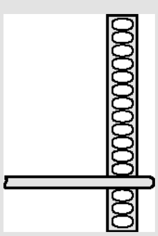
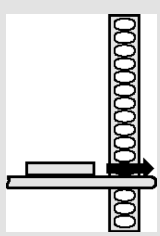
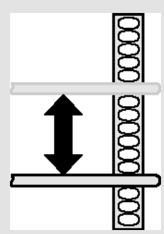
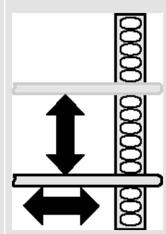
Fixed blanking		**Floating blanking**	
Fixed blanking	Fixed blanking with increased size tolerance	Floating blanking with complete object monitoring	Floating blanking with partial object monitoring
An object of *fixed* size *must* be at a specific point in the protective field.	From the operator’s side an object of *limited* size *is allowed* to move through the protective field.	An object of *fixed* size *must* be within a specific area of the protective field. The object is allowed to move.	An object of *limited* size *is allowed* in a specific area of the protective field. The object is allowed to move.
			

Fig. 25: Criteria for fixed and floating blanking.

To prevent gaps in the protective field, the presence (or in some cases, a change in the size or position) of an object can be used to trigger the safety function (OFF state).

Presence Sensing Device Initiation (PSDI) mode

Use of the protective device to trigger the machine function (cycle re-initiation) is described as PSDI mode. This mode has its advantages when work pieces are manually loaded or unloaded at each machine cycle. Conforming to standards, PSDI mode can only be executed with type 4 AOPDs and an effective resolution d ≤ 30 mm. In PSDI mode, the machine waits at a defined position for a specified number of interactions by the operator. The AOPD releases the dangerous movement automatically after this specific number of interruptions.

The ESPE has to be reset under the following conditions:

- When the machine starts
- On restart when the AOPD is interrupted within a dangerous movement
- If no cycle initiation was triggered within the specified time

It is necessary to check that no danger to the operator can arise during the work process. This limits the use of this mode on machines in which the hazardous area is only accessible through the protection field of the AOPD or through interlocked guards and it is not possible for the operator to remain undetected between the protective field and the machine (presence detection).

Single break PSDI mode means that the AOPD triggers the machine function (next cycle) after the operator has completed one intervention (interruption) (Fig. 26).

Double break PSDI mode means the AOPD locks the machine function after the operator's first intervention (e.g., removal of a work piece). Only after the operator has completed the second intervention (interruption) will the AOPD release the machine function (e.g., feeding of a billet).

PSDI mode is often used on presses and stamps, but can also be used on other machines (e.g., rotary tables, automatic assembly systems). When using PSDI mode, it shall not be possible to trespass the safety light curtain. For presses, special conditions apply for PSDI mode.

Fig. 26: Single break PSDI mode on a press with safety light curtain. During the work piece loading, the press die (ram) is at the top point. After release of the protective field by the operator, the die automatically moves downward.

Conclusion

Due to their mode of action, their functional flexibility and the various application possibilities to safeguard machines, electro-sensitive protective devices have many advantages. Special opto-electronic protective devices have been established in the automation world for many years. While their design requirements are defined in product standards, their application is stated in different machinery-specific, C-Type standards. Due to the optical principle, the design engineer has to take special care when planning application of AOPDs to a machine. The support of unhindered workflow and their positive impact on productivity are important arguments for using opto-electronic protective devices.

Because a slowdown in the work process is virtually non-existent, the manipulation of protective devices by the machine operator is not very common. Therefore, the creation of a potential risk of injury due to such manipulations – the manipulating person being aware of the risk or not – is hardly relevant for electro-sensitive protective devices. In addition to the required safeguarding of operators, the achievable productivity improvement is an important advantage of electro-sensitive protective devices.

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REFERENCES

EN 61496-1:2004: Safety of machinery – Electro-sensitive protective equipment – Part 1: General requirements and tests

IEC 61496-2:2013: Safety of machinery – Electro-sensitive protective equipment – Part 2: Particular requirements for equipment using active opto-electronic protective devices (AOPDs)

IEC 61496-3:2008: Safety of machinery – Electro-sensitive protective equipment – Part 3: Particular requirements for active opto-electronic protective devices responsive to diffuse reflection (AOPDDR)

EN ISO 13855:2010: Safety of machinery – Positioning of safeguards with respect to the approach speeds of parts of the human body