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DESIGN AND SELECTION OF INTERLOCKING DEVICES IN ACCORDANCE WITH EN ISO 14119

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SUMMARY

The new standard EN ISO 14119 "Safety of machinery - Interlocking devices associated with guards - Principles for design and selection" was published at the end of 2013, with a transitional period of 18 months before it replaces EN 1088. The standard classifies various types of interlocking device and outlines the differences between physical operating principles and actuating principles. It also introduces a qualitative assessment for actuator coding and provides guidance for installation to prevent defeating. These improvements and the practical interpretation of the existing content from EN 1088:2008 make EN ISO 14119:2013 a standard that users will find relevant to real-world applications and easy to put into practice. Although there is only a small number of new requirements for machine manufacturers, they will benefit from the advantages brought by the numerous areas in which more specific information has been provided.

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Table of contents

Introduction

The new international standard EN ISO 14119 defines the guidelines that shall, regardless of the type of technology being used, be applied when designing and selecting interlocking devices associated with guards. As a Type B standard according to ISO 12100-1 (generic safety standard), it is essential that it is applied to all machines. This standard, EN ISO 14119:2013, was published at the end of 2013 and will supersede EN 1088 – dating from 1995 – with a transition period of 18 months.

Guards are very common in machinery design. Fixed guards have a straightforward design and can be applied in cases where access to hazardous areas is not required during normal machine operation. This means a machine operation without any malfunctions or interactions. However, it is very rare in practice.

If access through a fixed guard is required, it is very unlikely that the guard will be returned to its proper position afterwards or fastened correctly. As a result, additional measures will be necessary to prevent dangerous machine functions that may occur while the guard is not providing protection. The classic solution in this case is to interlock these functions with the guard status.

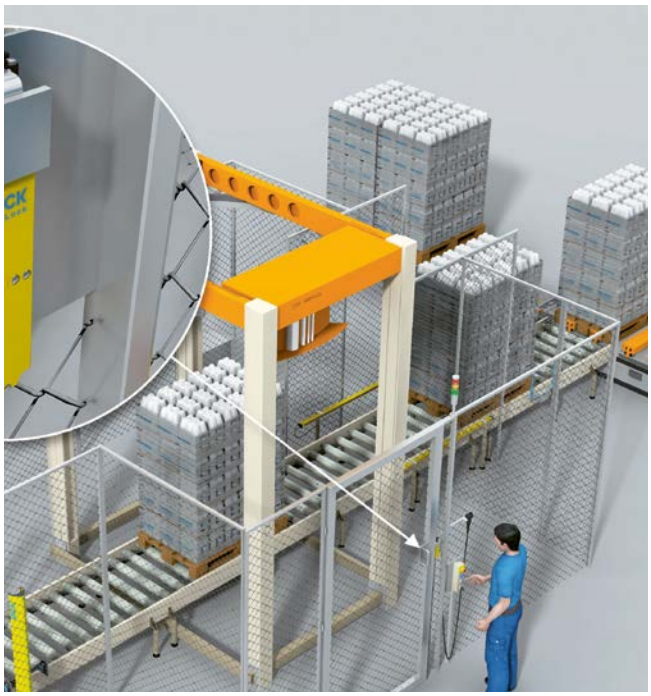

Figure 1: Guard interlocking with time-based access prevention by means of a safety locking device

Specifically, this international safety standard outlines the following points:

- Principles of operation and typical types of interlocking device associated with guards;
- Requirements for the design and installation of interlocking devices;
- The methodology used to select interlocking devices;
- The methodology used to evaluate motivations for defeating;
- Requirements for improving the prevention of defeat;
- Requirements for integration into the control system; and
- Requirements relating to information for operators/users.

As the title of the standard indicates, its scope is not limited to movable guards – it also covers fixed guards that are equipped with interlocking devices. While this seems contradictory at first, it makes sense in applications where guards do not need to be removed during normal operation, but must allow quick access if this becomes necessary – for example, if a fault occurs or a repair needs to be made.

The scope of EN ISO 14119 in fact extends to all machines that use interlocking guards (protective doors, for example). The provisions of EN ISO 14119 are relevant for most machines – such as those used in factory and logistics automation systems – unless the previsions of a C-Type Standard for a specific machine type do not deviate from or improve them. On account of this wide scope, the new standard has a significant role.

The changes and additions in the new EN ISO 14119 compared with the old EN 1088 result in certain major implications for users.

What is changing? Differences between EN ISO 14119 and EN 1088

When compared with the European EN 1088:2008, the now international standard EN ISO 14119:2013 has undergone a significant revision of key content (see Figure 2).
The most significant changes are as follows:

- An improved structure as a result of defining and differentiating four interlocking device types;
- A description of interlock technologies, plus the advantages and disadvantages of each (Annexes A to E);
- A definition and consideration of defeating interlocking devices in a reasonably foreseeable way;
- An evaluation of the motivation for manipulating/defeating equipment (Annex H);
- The measures required to reduce the possibility of defeat;
- Consideration of electromagnetic locking devices (Section 5.7.3);
- The introduction of a test for the validation of the locking forces;
- Integration in the control system (Annex G) and series connections (Section 8.6); and
- The introduction of a new symbol for locking device monitoring contacts.

The information that follows in this article sheds light on these improvements that are so important to users (machine manufacturers) and highlights the new implications that result from these.

Scope and terminology

This new standard is also essentially aimed at manufacturers and users of interlocking devices. As compared with EN 1088:2008, there are only two additions to the scope of EN ISO 14119:2013. One is the fact that the standard considers not only conventional

Designation	Actuation		Actuator		SICK product	
	Principle	Example	Principle	Examples	Example	
Type 1	Mechanical	Physical contact, force, pressure	Not coded	Switching cam	i10P	
				Turning lever	i10R	
				Hinge	i10H	
Type 2			Coded	Shaped actuator (switching rod)	i16S	
				Key	–	
Type 3	Electro-sensitive	Inductive	Not coded	Suitable ferromagnetic materials	IN4000	
		Magnetic		Magnets, electromagnets	MM12 [1]	
		Capacitive		All suitable materials	CM18 [1]	
		Ultrasonic		All suitable materials	UM12 [1]	
		Optical		All suitable materials	WT 12 [1]	
Type 4		Magnetic	Coded	Coded magnet	RE11	
		RFID		Coded RFID transponder	TR4 Direct	
		Optical		Coded optical actuator	–	

1) These sensors are not designed for safety applications. If they are used in interlocking devices, the designer must give very careful consideration to systematic and common cause failures and take additional measures accordingly.

Figure 2: Types of interlocking device in accordance with EN ISO 14119:2013

interlocking devices, but also interlocking devices featuring electromagnetic locking devices. While this is not explicitly outlined in the scope, it is included in the new Section 5.7.3. Also new is the addition of the requirements for reducing possibilities for defeating either intentionally, or reasonably forseeable. It should be noted that, while the standard can be applied to trapped key systems, it does not contain all the necessary product requirements. This information will be provided in a separate standardization document.

Where definitions are concerned, a few terms have been added and others have been refined. In particular, this affects definitions relating to interlocking devices themselves and their elements, actuator coding, and the classification into four types that results from this. For actuator coding purposes, EN ISO 14119 also introduces a coding level classification that is applicable independently of the technology used. If the number of different codes of an actuator is between 1 and 9, this is defined as low-level coding. Between 10 to 1,000 different codes are considered by the Standard as a medium coding level, A high coding level applies in cases with more than 1,000 different codes. These coding level limits were defined considering real applications and consulting a range of manufacturers.

The standard does not use the widespread term "safety switch", as it is not possible to define a set of common requirements taking into account the variety of technology options and designs of appropriate sensors for interlocking devices. The following definitions apply regardless of the technology applied (mechanical, electrical, pneumatic, hydraulic):

- An interlocking device consists of an actuator and a position switch as a minimum.
- A position switch consists of an actuating system and an output system as a minimum.
- The new annexes, A to E, describe the various interlocking device types together with their benefits and drawbacks, and show a range of application examples.

Depending on the technology used in the position switch and the functional safety requirements, it may be necessary to use either one or multiple interlocking devices for a guard.

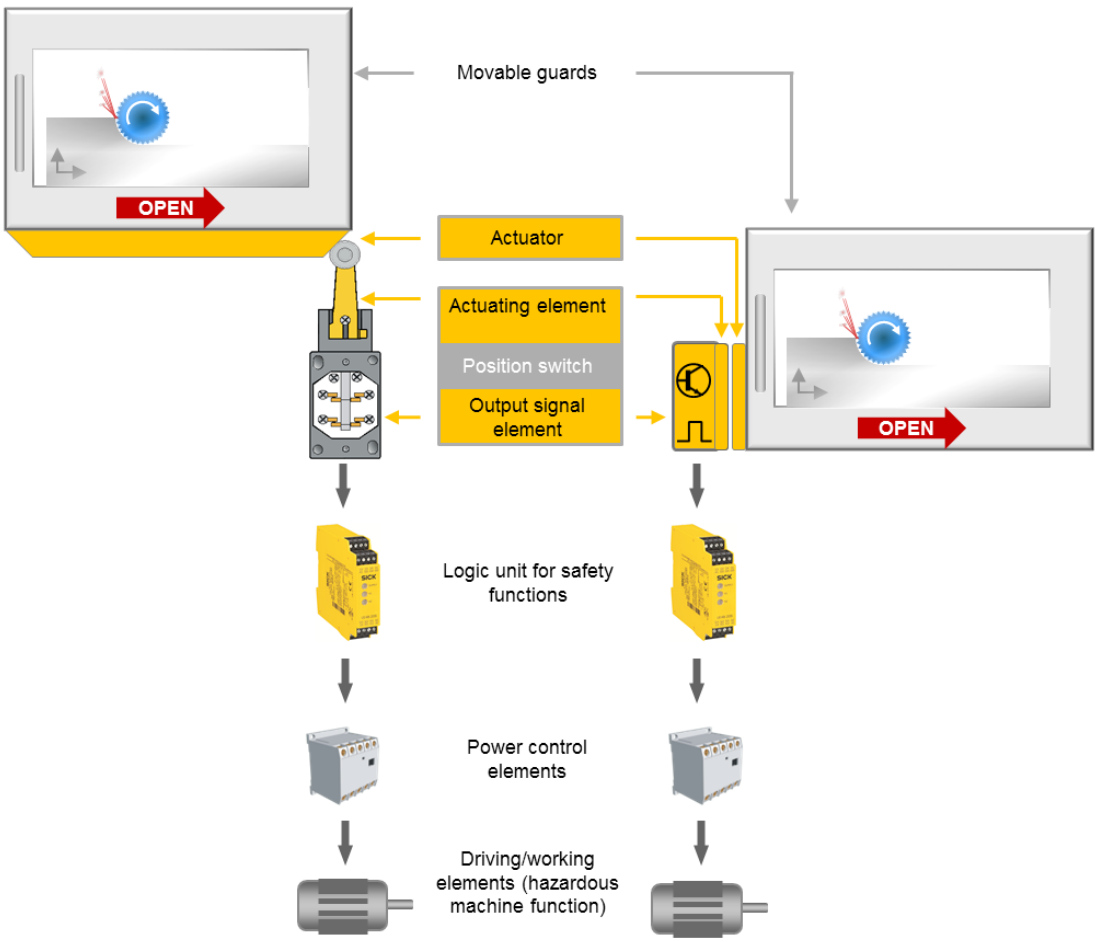

Figure 3: Examples of type 1 (left) and type 3 (right) interlocks

General principles of interlocks

Interlocking devices monitor the position (protective position) of a guard and prevent the operation of a dangerous machine function when the guard is not in the protective position; that is, installed (mounted) and closed. They do this either by preventing the start-up of functions during the time the guard is not in the protective position – closed, in other words – or by triggering a stop command when the guard is opened. If a movable guard is opened and hazardous machine functions are already taking place, these must be stopped in due time before the person reaches the hazardous points. A certain amount of time (known as the "overall stopping time") is required to stop the functions. This has an effect on the minimum distance required between the hazardous point and the movable guard (see EN ISO 13855).

In practice, it is not always possible to implement the minimum distance in machines. In such cases, access to the hazardous points must be prevented until no dangerous machine functions are taking place. This means blocking the opening of guards using locking devices that must be selected in accordance with EN ISO 14119. Locking devices may be integrated components of an interlocking device or separate components.

A locking device that can be released by a person (such as a machine operator) at any time is referred to as a "locking device with unconditional locking". In this case, it is important that this process requires an appropriate amount of time to ensure that the access time is longer than the stopping time. If, on the other hand, it is only possible to release the guard when a certain condition is met (for example, a dangerous movement is brought to a standstill), the standard refers to this as "conditional unlocking".

Blocking and releasing may be performed by either a controlled supply of energy (electrical, pneumatic, hydraulic) or by stored energy (spring force).

Releasing the locking device by applying energy can be performed as follows:
- Time-controlled: In the case that a timer is used, the failure of this device shall not reduce the delay;
- Automatic: Only if there is no dangerous machine state prevailing (e.g., due to standstill monitoring devices);
- Manual: The time between release and the opening of the guard shall be greater than the time it takes for the dangerous machine function to stop.

Selecting the appropriate interlocking device
Whether a guard needs to have an interlock with or without a locking device depends on whether the minimum distance according to EN ISO 13855 can be implemented. The possible mechanical loads shall be carefully considered. According to EN ISO 14119, both conventional static loads and dynamic loads must be taken into account when selecting an interlocking device. Dynamic loads include, for instance, vibrations affecting interlocking devices with design 2 on closed guards, and mechanical bouncing in the case of high actuation speeds.
Where sources of environmental stress are concerned (abrasive dust, chips or other particles, for example), the new standard also requires that the potential failure of mechanically actuated interlocking devices is taken into account, along with appropriate countermeasures such as hidden installation, for example.
Another option is to use electromagnetic locking devices, whose locking force is generated with electromagnets. Electromagnetic locking devices are a new addition to EN ISO 14119:2013 and additional requirements apply for them.

Positive mechanical actuation and positive opening
An important requirement of mechanical interlocking devices is that they can be actuated reliably. Positive mechanical actuation is the forced movement of the mechanical components of the interlocking device forced by the mechanical components of the guard (e.g., fence door) either by means of direct contact or by rigid parts. Positive mechanical actuation in an interlocking device ensures that the position switch is actuated when the guard is opened and reduces possibilities for defeating.
A contact element is positive-opening if the switching contacts are isolated directly by a defined movement of the actuating element by non-elastic parts (e.g., springs). The use of positive-opening (normally closed contacts) in position switches with

Figure 4: Symbol for positive-opening normally closed contacts in accordance with EN 60947-5-1, Annex K

mechanical actuation ensures that the electrical circuit will be interrupted even if the contacts are welded or other electrical faults have occurred.
According to EN ISO 14119, when using mechanically actuated interlocking devices (type 1 or type 2) at least one device shall meet both requirements of positive mechanical actuation and positive opening. If a interlocking device type 3 or 4 is the only interlocking device on a guard, then it shall meet the requirements of IEC 60947-5-3. Using two redundant electronic outputs with non-contact position switches is considered equivalent to positive opening if those outputs are monitored accordingly.

Installation: Fastening and types of actuators
Appropriate fastening is a fundamental requirement for interlocking devices. Therefore, the fastening requirements to be met in the new standard are exactly the same as those in the earlier standard. The standard does, however, draw a distinction between cams or turning levers and other types of actuator (mechanical or non-contact), as these elements are provided by machine manufacturers rather than position sensor manufacturers. While EN 1088 prohibits the use of position sensors as mechanical stops, this is allowed in EN ISO 14119 – but only under the condition that the manufacturer expressly specifies this and the position sensors are used in accordance with the information supplied by the manufacturer.
Requirements for the appropriate distances to hazardous areas are not in the scope of the standard, nevertheless those distances can only be achieved by the correct design of interlocking devices. EN ISO 14119 includes the requirement that at any position of the guard which does not cause a change of status of the position sensor the protective effect provided by the guard shall be maintained. The safety distances as specified in EN ISO 13857 and minimum distances as specified in EN ISO 13855 shall be met.

Special features of locking devices
Locking devices for safety-related applications shall always be released by a controlled supply of energy. According to EN ISO 14119, a release mechanism that uses spring force may only be used if the risk assessment indicates that it is not possible to apply this type of locking device. However, the release mechanism shall have the same safety level.
According to the new standard, if locking devices are used to protect persons as well as machines, workpieces or processes, then the requirements relating to the protection of persons take priority.
The output system used for guard position monitoring, and the one used for locking device monitoring, shall be compatible with control systems designed n accordance with EN ISO 13849-1 or EN 62061 (IEC 62061). This means that it is absolutely essential for manufacturers to specify the necessary safety-related parameters such as B10d or MTTFd.
Whereas EN 1088 required that locking devices with release by means of controlled energy shall provide a manual release by using a tool, the new standard no longer imposes this requirement. However, in the event that manual unlocking becomes necessary in an emergency, the locking device being used shall provide this function. It is important to note that only in a very small number of cases will the risk assessment deem this feature necessary. EN ISO 14119 now also includes requirements relating to auxiliary and emergency release.

As outlined previously, electromagnetic locking devices have been incorporated into the scope. The new standard includes specific requirements in this regard: the locking force shall be monitored to ensure it reaches the level necessary for the application.
The table in Annex I can be used as a guide to determine the necessary locking force: It shows examples of maximum actuating forces expected during typical actuations of movable guards. Dangerous machine functions may only be allowed by an electromagnetic locking device if the guard is in the protective position and the required locking force is reached.
Contrary to mechanical locking devices, electromechanical locking devices can be circumvented without being damaged or destroyed it if sufficient force is applied. The force applied simply has to be greater than the locking force. This can be achieved via simple means and introduces the risk of defeating. In a case such as this, EN ISO 14119 requires that there is a delay before the dangerous machine functions are resumed. This requirement is intended to ensure that resuming dangerous machine functions after such a defeat shall require the same amount of time as repairing a damaged mechanical guard locking device.

According to EN ISO 14119, this requirement may be met applying any of the following measures:
- Activating an integrated reset inhibit function with a 10-minute delay;
- Generating a fault status that can only be reset by repairing or replacing the guard locking device;
- Measures in the machine control system that cause a similar delay.

Another new addition to EN ISO 14119 is the requirement to monitor the locking force; this applies irrespective of the type of technology being used. In addition, the new standard states a safety coefficient for this requirement, according to which the locking force of the locking device being used should be at least 1.3 times the locking force required for the application.

Reducing possibilities for defeat

The EN 1088 requirements relating to reducing possibilities for defeating interlocks on guards have been separated into general and additional design measures in EN ISO 14119.

The new standard also provides a methodology for evaluating the motivation to defeat interlocks, and for the selection of any necessary additional measures. However, the user shall first apply the basic design measures intended to reduce possibilities for defeating interlocks. The measures specified in EN 1088 for various interlock types are compiled in the new standard. In the next step, the user of the standard shall evaluate the strength of the motivation for defeating the interlocking device. For this purpose, the informative Annex H of EN ISO 14119 includes the methodology developed by the Institute for Occupational Safety and Health of the German Social Accident Insurance (DGUV/IFA), and also shows an example of the evaluation process (http://www.dguv.de/ifa/Praxishilfen/Bewertungsschema-für-Manipulationsanreize/index.jsp).

Where the evaluation of the motivation for defeat reveals that the risk of defeat requires the application of additional measures, the new standard describes these measures in Section 7.2 and states the relevant minimum requirements in Table 3.

Principles and measures	Type 1* and Type 3	Type 1**	Types 2 and Type 4 interlocking devices			Trapped key systems	
			low	medium	high	medium	high
Mounting out of reach	X		X	X			
Physical obstruction/Shielding							
Mounting in hidden position							
Status monitoring or cyclic testing							
Non-detachable fixing of position switch and actuator							
Non-detachable fixing of position switch		M				M	M
Non-detachable fixing of actuator		M	M	M	M	M	M
Additional interlocking device and checking for plausibility	R		R	R			

X = mandatory to apply at least one of the measures

M = mandatory measure

R = recommended measure (additionally)

* except hinged

** hinged switches only

NOTE 1: Table 3 is intended to be used for the selection of appropriate measures against defeating of interlocking devices. According to the risk assessment the application of more than one of the indicated measures can be necessary.

NOTE 2: If the number of trapped key devices used within one site is known, coded actuators can be used as a sufficient measure against reasonably foreseeable defeating under the following conditions:
- if the coding is marked on the device each interlocking device should have a different coding and
- the actuator should be medium or high level coded

NOTE 3: There is a clear distinction between the coding level of actuator keys and the coding of "locking bolt or catch mechanisms" in a trapped key system. This table refers solely to the coding level of actuator keys.

NOTE 4: Measures in accordance with Table 3 provide minimum requirements.

Figure 5: Table 3 of EN ISO 14119, mod. Additional measures designed to reduce possibilities for defeating interlocking devices

Requirements for control systems

One of the major improvements of EN ISO 14119 is that it provides further clarification of the requirements related to the control system which evaluates or processes the outputs of the interlocking devices. The standard states that interlocking devices on guards and locking devices act as safety-related parts of control systems in accordance with EN ISO 13849-1 or as sub-systems of a safety-related electrical control system in accordance with EN IEC 62061. Thus, misinterpretations can be avoided.

Clarification on fault exclusion

As far as possible, the new standard provides more precise information on the much discussed subject of fault exclusion. The standard user shall also consider that a B-type standard can only affect general requirements and statements that are applicable to the majority of machines. If the required reliability level of a control system should reach PL e or SIL 3, the safety function shall not fail when an individual fault occurs. According to the new standard, excluding certain faults – such as a broken actuator – is not normally justifiable. However, fault exclusions in accordance with ISO 13849-2 are permitted. The same requirements shall be observed for PL d or SIL 2; in practice, this generally means that two interlocking devices are necessary in order to meet the requirements of PL e or SIL 3. In the case of PL d and SIL 2, a single interlocking device may be sufficient if a fault analysis in accordance with EN ISO 13849-1 or EN IEC 62061 allows the relevant fault exclusions.

Reliability when actuation occurs rarely

More new additions to the EN ISO 14119 standard are requirements for checking the reliability of interlocks on guards that are actuated only on rare occasions. With such guards, there is a risk that fault accumulation during the time between two actuations may result in the failure of the safety function. If manual function tests are required (to prevent fault accumulation), these tests shall be performed within the following intervals:

- 1 x per month in the case of applications with PL e (in accordance with EN ISO 13849-1) or SIL 3 (in accordance with EN 62061);
- 1 x per year in the case of applications with PL d and Category 3 (in accordance with EN ISO 13849-1) or SIL 2 with HFT=1 (hardware fault tolerance in accordance with EN 62061).

It is recommended that the triggering of the required tests is indicated by the machine control system, and that the tests are designed in such a way that the machine operation can only be resumed after a successful test.

Common cause failures

To avoid common cause failures, EN ISO 14119 describes the conventional solution applying the diverse actuation of redundant mechanical interlocking devices, as previously featured in EN 1088. The new standard is also consistent while pointing out how different types of operating energy are applied; for example, the application of a redundant locking device with one channel acting directly on an hydraulic power transmission while the second channel controls an hydraulic valve by means of an electronic position transmitter.

Reliability of the release function

A note in the new standard outlines the reliability level required for the release of guard locking devices. At first sight this may seem to be a scarce information. Users of the standard should consider the fact that the normative text in a standard shall mainly contain requirements. For this reason, any useful information for the user that the standard contains can only be provided in the form of notes. The following points are highly important:

- In most cases (but not all!), the required PL or SIL of the guard locking function is lower than the interlock function.
- The probability of a failure of the locking device at the same time as the access is intended can be considered as very low.
- Fault exclusion can normally be accepted for the locking device function, including in cases where PL e is required.
- Table D.8 of EN ISO 13849-2:2013 does not apply to guard locking devices, as it is only intended for interlocking devices.

Logical series connection of interlocking devices and fault masking
If position sensors with redundant contacts are connected in series, fault detection can be reset by actuating any switch between the fault and the following safety-related parts of the control system. This phenomenon is called fault masking. If it is foreseeable that a protective door, maintenance hatch, or other movable guard whose interlocks are connected between the fault and the following safety-related control system may be actuated during fault finding, then the fault will be masked. As a result, the resulting reduction of the diagnostic coverage that applies in this case must be taken into account. If the interlock function is required to be highly reliable, additional measures for preventing or detecting faults shall be applied

The Technical Report TR 24119 has been recently published. This report supports the users of standards in the evaluation of the DC value resulting from a logical series connection of interlocking devices. It contains additional information on this subject as well as two methods for evaluating the effect that series connections of this kind have on the diagnostic coverage of the overall interlocking function.

Figure 6: Machine with multiple doors for wafer production in an electronics manufacturing factory

Information for users

The new EN ISO 14119:2013 standard applies to interlocking devices and locking devices that are produced by machine manufacturers using available components and to interlocking devices and locking devices that are independently placed on the market. Therefore, the standard includes the different requirements which are applicable in these cases. Generally, the marking and labeling requirements of EN ISO 12100 apply; however, if they cannot be met for reasons of space, then the product label (showing the name, manufacturer's logo, and type) shall refer to the operating instructions, which shall contain the relevant information.

A new, internationally valid symbol has been developed to make it easier to identify the outputs (contacts, etc.) that signal the position of the locking device (locking device monitoring):

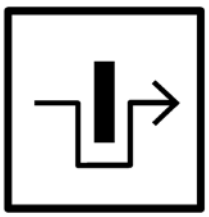

Figure 7: Symbol for guard locking monitoring in accordance with EN ISO 14119

EN ISO 14119 adds more information and specifications to the content of the operating instructions (in accordance with the Machinery Directive 2006/42/EC and EN ISO 12100). The most important are listed below:

- All data that the user requires to determine the PL (in accordance with EN ISO 13849-1) or SIL (in accordance with EN 62061);
- Warnings if a locking device does not feature emergency or auxiliary unlocking and additional measures are required for this;
- Locking force FZh in accordance with Section 5.7.4;
- Permissible actuating travel;
- Maximum permissible impact energy in J if the interlocking device can be used as a stop;
- Maximum switching current (peak value) and switching voltage;
- Coding level (high/medium/low)

Conclusion

This structural and editorial revision, the clarification of terminology, the practical approach that has been taken to setting out the existing content from EN 1088, and the improvements make EN ISO 14119 a standard that users will find relevant for real applications and easy to put into practice. The new requirements for machine manufacturers are clear, and the benefits resulting from the numerous areas where more specific information has been provided are particularly evident, especially with respect to functional safety and new technologies.

8017393/2016-01-19/MK-2M

REFERENCES

EN ISO 14119:2013 “Safety of machinery - Interlocking devices associated with guards - Principles for design and selection”
EN 1088 “Safety of machinery - Interlocking devices associated with guards - Principles for design and selection”
EN ISO 13855 “Safety of machinery - Positioning of safeguards with respect to the approach speeds of parts of the human body”
EN 60947-5-2 (IEC 60947-5-3) “Low-voltage switchgear and controlgear - Control circuit devices and switching elements - Requirements for proximity devices with defined behavior under fault conditions (PDDB)”
EN ISO 13857 “Safety of machinery - Safety distances to prevent hazard zones being reached by upper and lower limbs”
EN 62061 (IEC 62016) “Safety of machinery - Functional safety of safety-related electrical, electronic and programmable electronic control systems”
EN ISO 13849-1 “Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design”
EN ISO 13849-2 “Safety of machinery - Safety-related parts of control systems - Part 2: Validation”
EN ISO 12100 “Safety of machinery - General principles for design - Risk assessment and risk reduction”
Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006, “Machinery Directive”

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