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Interlocking devices associated with guards - principles for design and selection according to the new standard

A summary of the focal points specified by the ISO 14119 standard which regulates the design and use of interlocking devices and the changes that design engineers in mechanical engineering can expect.

When a machine or plant has to be equipped with a movable guard, the question that arises for the design engineer is: how is the position of this mobile safety device monitored? On the one hand the regulations in standards must be observed here. Of prime relevance here is the Machinery Directive 2006/42/EC, Annex 1 (see Section 1.4 -Required characteristics of guards and protective devices)[1] as well as the A standard ISO 12100 (see Section 6.3.3)[2] and - very important –the standard ISO 14119 "Safety of machinery - Interlocking devices associated with guards - Principles for design and selection". At the same time the selection and design of a protective device and its interlocking device must be considered under technical and economic aspects. The manipulation of protective devices must also be considered, as this forms part of the man/machine interface.

The ISO 14119:2013[3] was released at the end of 2013 and supersedes the previous version, ISO 14119 (1998-05) and the German DIN EN 1088[4]. It is a “B 2” standard in accordance with ISO 12100.

The standard deals with the selection of interlocking devices. But it also provides advice on their design and assessment, and is therefore an aid to mechanical engineers wishing to design their own interlocking device.

"Interlocking" and "guard locking"

Unfortunately, the much used term "interlocking device" is not self-explanatory. The definition can already be found in the Type A standard ISO 12100 (Section 3.28.1), and has now been adopted unchanged in ISO 14119 (Section 3.1). According to this definition, an "interlocking device" or "interlock" is a "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 the guard has not closed).

When this formal definition is translated into everyday language, an interlocking device is therefore a position switch, proximity switch, guard locking etc. on a protective device, which has the effect of enabling the machine controller to react to the position of a guard.

With some interlocking devices which use a position switch with separate actuator, the separate actuator can be restrained so that the associated guard can only be opened under certain conditions, such as when the machine stops. A device which enables such a function is called a guard locking device or guard locking.

In everyday language, one would probably describe this locking of the guard as "interlocking" rather than the link between the position of a guard and the machine controller. In cases of doubt, it is therefore advisable to ask what is precisely meant by the term "interlocking": "interlocking" within the meaning of the EC Machinery Directive and the corresponding European standards or "guard locking" as meant in the sense described above? This confusing terminology of interlocking/guard locking is not only a problem in English, but also in German (Verriegeln/Zuhalten) and in French (verrouillagel interverroui/lage).

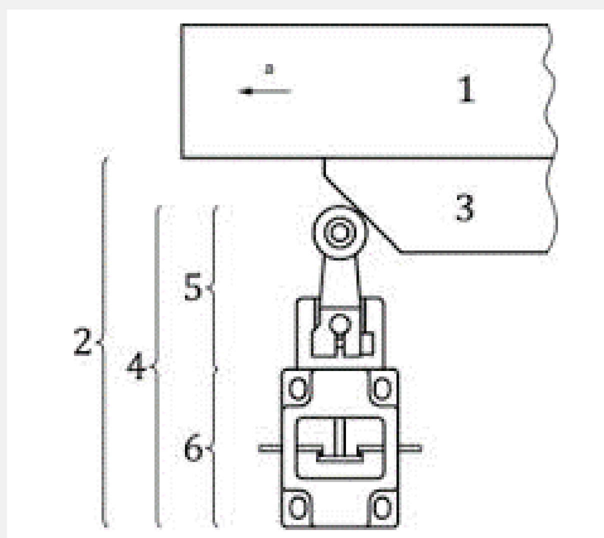


Fig 1: Example of an interlocking device

Key: 1) guard, 2) Interlocking device, 3) Actuator, 4) Position switch, 5) Actuating system, 6) Output system, a) Direction of opening

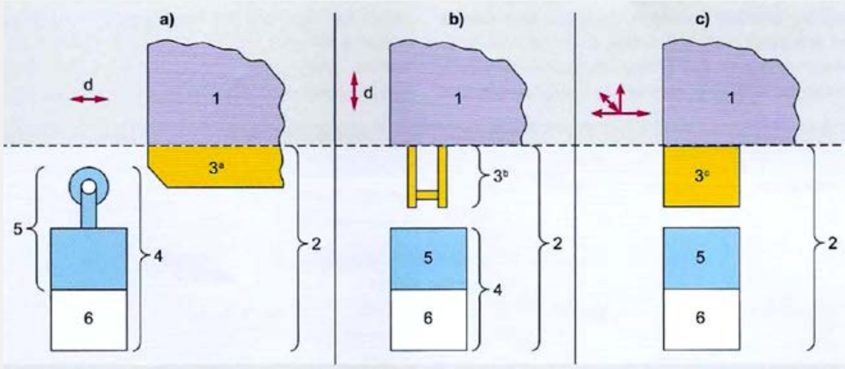


Fig 2: Principles of Type 1, Type 2, Type 3 and Type 4 interlocking devices.

a) Type 1 interlocking device (actuated using uncoded cam, guard closed);

b) Type 2 interlocking device (actuated using encoded tongue, guard not closed);

c) Type 3 or 4 interlocking device (uncoded or encoded, non-contact actuated, guard closed).

Key:
1) movable guard;
2) interlocking device;
3) actuating element: a cam; b tongue; c RFID, reflector, surface;
4) position switch;
5) actuating system;
6) output system.

Four basic designs

For the first time "ISO 14119" (referred to below as standard) provides an illustration specifically according to the definition in Section 3.1, and which makes it easier to understand the definition and the various components of an interlocking device.

The main component of an interlocking device is the position switch, which itself is divided into an actuating system and output system. The actuating element is the part connected to the movable guard. It can be provided by the user or be supplied by the manufacturer of the position switch.

The classification of interlocking devices into various types is primarily made according to the actuation principle and then according to the encoding of the actuating element.

Fig 3: Type 1 switch

Type 1

- Mechanically actuated through physical contact, i.e. using force;
- "Uncoded actuating element".

This design is the classic position switch as shown in Figure 1. Type 1 switches have diverse uses, not least because the actuating element can be configured by the user himself. Due to the many possible designs of the actuating element, this is described as uncoded.

Fig 4: Type 2 switch

Type 2

- Mechanically actuated through physical contact, i.e. using force;
- "Encoded actuating element".

In DIN EN 1088 this model is called "Interlocking device with separate actuator". It has long been known in Germany as a "category 2 switch" and more recently as a "type 2 switch". The latter name has now also found its way into the international standard and has even been extended to include types 3 and 4. Type 2 switches are characterized by very safe actuation whilst also being relatively easy to "circumvent". This fact has already been addressed by A1 (Amendment 1) to DIN EN 1088, and the new standard also devotes an entire section to reducing the circumvention potential.

Fig 5: Type 3 switch

Type 3

- Non-contact actuation, i.e. without physical contact;
- "Uncoded actuating element".

In this design, the actuating element and the actuating system are separated from each other. On approaching (guard closed), they switch the enable to start the machine. A counterpart (actuator) is required, but in the case of proximity switches with safety function, can be a metal flag for example.

Fig 6: Type 4 switch

Type 4

- Non-contact actuation, i.e. without physical contact;
- "Encoded actuating element".

In the case of Type 4 switches, the actuating element and the actuating system are separated from each other. On approaching (guard closed), they switch the enable to tart the machine. The actuating element is encoded; a counterpart to the sensor (actuator) is required.

Table 1 of the standard provides an overview of the design types and refers to the examples in Annexes A to E.

Examples of actuating principle		Examples of actuating elements		Abbreviation	Examples*
Mechanical	Contact, force	Uncoded	Cam profile	Type 1	A.1
			Linear cam		A.2, A.4
			Hinge		A.3
		Encoded	Tongue (actuator key)	Type 2	B.1
			Key transfer system		B.2
Non-Contact	Inductive	Uncoded	Suitable ferrous material	Type 3	C
	Magnetic		Magnet, electromagnet		
	Capacitive		Every suitable object		
	Ultrasound		Every suitable object		
	Optical		Every suitable object		
	Magnetic	Encoded	Encoded magnet	Type 4	D.1
	RFID		Encoded RFID transponder		D.2
	Optical		Optically encoded transponder		-

Table 1: Overview of the interlocking devices. * Examples of devices in Annex A through D of the standard

Encoded actuating elements
The term "uncoded actuating element" (Type 1 and 3) or "encoded actuating element" (Type 2 and 4) are used in conjunction with the design types. Without a precise definition, misunderstandings frequently arise about the meaning of "encoded" in this connection.

Sometimes a Type 2 position switch is described as "encoded" if its interlocking device can only be actuated using the (always identical) supplied actuating element. However, there are also ranges of actuating elements which have several thousand variations. The probability that an identically encoded actuating element is available and that the interlocking device can be circumvented with it is extremely small.

Fig 7: Type 4 switch with high level encoded actuator

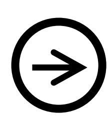
The standard creates clarity here too by defining three encoding levels: low, medium and high. Thus a "low level encoded actuator" is one which has between 1 and 9 encoding possibilities. The number of possibilities for a medium encoding level is between 10 and 1,000; more than 1,000 possibilities correspond to a high encoding level.

A mechanical actuating element which, while having a specific shape, is always manufactured in its thousands in the identical shape, is classified as being a low level encoded actuator. Similarly, a magnetic actuator element is classed as encoded (at a low level) as soon as a specific rather than a standard commercial magnet or simple metal flag is required for actuation. Reference is made to a high encoding level for non-contact acting RFID-based interlocking devices, for which an almost infinite number of encoding variations are available.

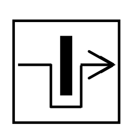
Interlocking devices with guard locking function
As can be seen from the heading, this product is an interlocking device which has been supplemented by a guard locking mechanism so as to keep a movable guard closed during a hazardous machine function (e.g. where dangerous stopping movements take longer). A separate status detection, which detects the position of the guard locking device, and generates a corresponding output signal which is used for control purposes, is a component of a guard locking device.

The guard locking device can be an integral part of the interlocking device or a separate unit. The link to enable the machine (guard "closed" and "locked") must be guaranteed. As with electromechanical interlocking devices with guard locking function, one way of achieving this is by means of series connection or using the design measure of an integrated fail-safe locking mechanism. The design here ensures that an enable to start the machine can only be given when the protective device is closed and the guard locking is safely meshed.

Since there are now several interlocking devices with guard locking functions on the market which contain a large number of potential-free contacts, the question for design engineers is, what are the right contacts to integrate in the safety circuit. The familiar symbol for positively driven contacts from IEC 60947-5-1[5], Annex K is available here:



The standard has a new symbol for monitoring the guard locking of guard locking elements:



This symbol identifies the contacts that the design engineer must integrate in the safety circuit of the controller in order to receive the message "protective device is closed". This does not apply in the case of interlocking devices with guard locking and electronic evaluation. The safe enabling outputs are realized by monitored outputs, usually transistor outputs (AOPD) here.

Fig 8: Solenoid locking interlock device

Modes of operation and functions of guard locking

An interlocking device with guard locking function, such as that shown in Figure 8, can be designed in a number of manifestations. For example, it can be released or actuated using different types of actuation:

- Power-released
- Released by spring force
- Power-released, power-actuated
- Power-actuated.

However, the standard points out explicitly that when using guard locking that operates according to the principle of spring force release or energy actuation, the guard locking will be released during a power failure and that longer stopping times of machinery can arise and represent a hazard. Access to a danger zone, e.g. before a movement stops, would then be possible. This should be taken into account during the risk assessment, and additional measures may be required.

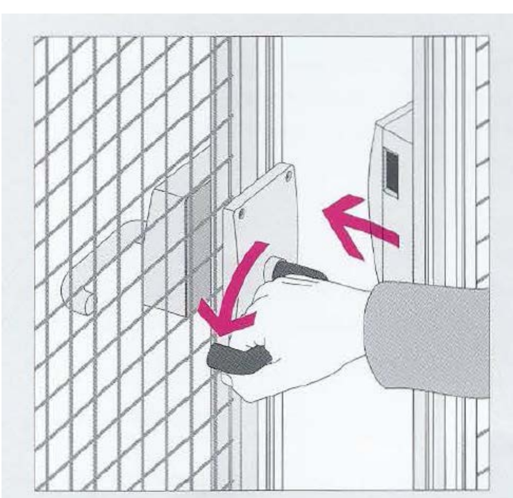


Fig 10: Actuation of a panic handle to leave a protected area

Fig 9: Electromagnetic locking interlock device

New in the standard: interlocking devices with electromagnetic guard locking

The interlocking device with electromagnetic guard locking has been newly adopted in ISO 14119. In this case an electromagnet keeps the protective device closed. Mechanical locking mechanisms are not present.

The prerequisite for using such systems, however, is that the electromagnetic force is safely monitored in order to ensure that the defined guard locking force of the magnet is always achieved. If this is not the case, the interlocking device must not enable the machine start. As such a simple electromagnet is not suitable for such tasks.

The advantage of these systems is that their smooth surfaces can be cleaned more easily. Compared to conventional systems, there are no openings to support the locking bolt, and no components or modules protrude on the moving part of the protective device. One disadvantage of the electromagnetic guard locking is that high locking forces with correspondingly high continuous current must be purchased.

Release of interlocking devices with guard locking

There may be a number of different reasons why an interlocking device which is currently kept closed should be released contrary to the command given by the machine controller. The standard defines three new terms on this subject for the first time:

Emergency release

This is the manual release of the guard locking without tools from outside the protected area. It is intended for freeing trapped persons or for fire-fighting, in other words in situations requiring fast action and where other risks are present in addition to those risks presented by the machine.

Auxiliary release

As with the emergency re lease, the manual release is effected from outside the protected area, but with the help of a tool or key. It is intended for interventions where speed is not of the essence, such as for a repair, when the guard locking cannot be released by the controller as a result of a fault.

Escape release
This is the manual release of the guard locking without tools from inside the protected area. Frequently, a kind of "escape route actuator/panic handle" is used here for simple actuation in the case of an escape.

Selection of interlocking devices
The new standard bears the title "Principles for the design and selection of interlocking devices". It is therefore directed at two, sometimes very different, target groups, namely the manufacturer of interlocking devices and the design engineer who is deploying them on his products. This ambivalence does not make the standard any easier to read. However, it does ensure that the specifications for manufacturer and user are to some extent consistent.

Section 6 of the standard offers help in the selection of a suitable interlocking device. "The following criteria must be taken into consideration when selecting or designing an interlocking device:

- The conditions and the intended use of the machinery (see ISO 12100)
- The dangers arising on the machinery (see ISO 12100)
- The severity of the possible injury (see ISO 12100)
- The stopping time of the entire system and the access time
- The probability of a failure of the interlocking device
- The required Performance Level PL (see ISO 13 849-1[6]) or Safety Integrity Level SIL (see IEC 62061 [7]) of the safety function
- Consideration of dynamic forces such as "bouncing back", especially to be considered for guard locking

However, other criteria may also play a role depending on the application. One of the most important factors for selection is the question of whether the stopping time of the overall system is greater than the time required to reach the danger zone. If this question is answered in the affirmative, an interlocking device with guard locking must be selected.

The flow diagram in the standard (see Figure 11) is designed to help come to a quick decision about which type of interlocking device is needed. Irrespective of the technology, a sufficiently high locking force on the guard locking device must be selected relative to the application. The informative Annex I in the standard is helpful here.

The selection and specification of a suitable interlocking device with guard locking are the task of a Type C standard or a mechanical engineer.

As a rule, the selection is made by a mechanical engineer. The device must, however, be selected in such a way that it can resist the anticipated forces in the application. Dynamic effects, such as "bouncing back", when a protective device is closed quickly and can rebound, must also be taken into consideration.

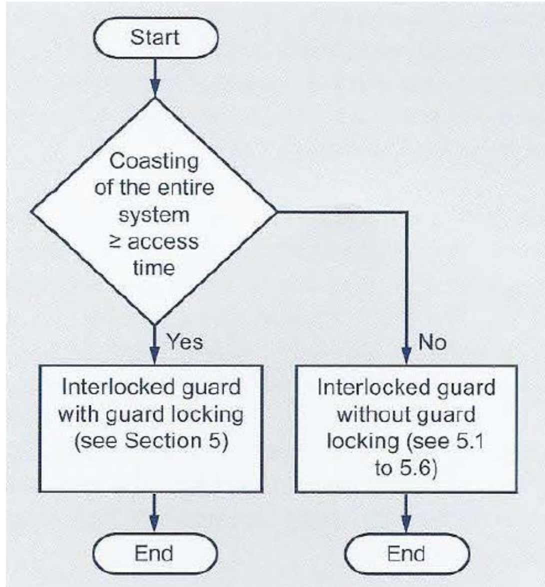


Fig 11: Determination of the need for a locking interlock device

If the anticipated impact forces are greater than the forces that can be withstood by the selected device, measures must be taken to reduce or prevent these forces. Attenuators such as shock absorbers represent a solution here.

Non-contact interlocking devices
In addition to the familiar and proven electromechanical interlocking devices with positively driven contacts, ever more non-contact interlocking devices are available and in use.

The advantages of such systems are clear to see. They are as follows:

- Specially suitable for removable protective devices
- Compact and have no external moving parts
- Little vulnerability to dust and liquids
- Easy to keep clean
- Encoded
- Tolerant to misalignment of the guard
- Free of wear and tear.

The new standard ISO 14119 has described these products and incorporated them in the informative Annexes C and D (see Figure 6, Type 3 and Type 4). The requirements of a non-contact interlocking device are described in the product standard IEC 60947-5-3[8]. This standard deals with proximity switches under fault conditions, but does not deal with the subject of manipulation in detail. For this reason, the issue is dealt with thoroughly in ISO 14119 (see below).

NB: In the past, an interlocking device was also implemented using commercially available proximity switches, and this is possible under ISO 14119. The EMC requirements are being made more stringent with the revision of product standard IEC 60947-5-3, however. With the introduction of IEC 61326-3-1[9] to IEC 60947-5-3, it will become difficult to comply with the requirements of this product standard, which is also required under ISO 14119, using common inductive proximity switches.

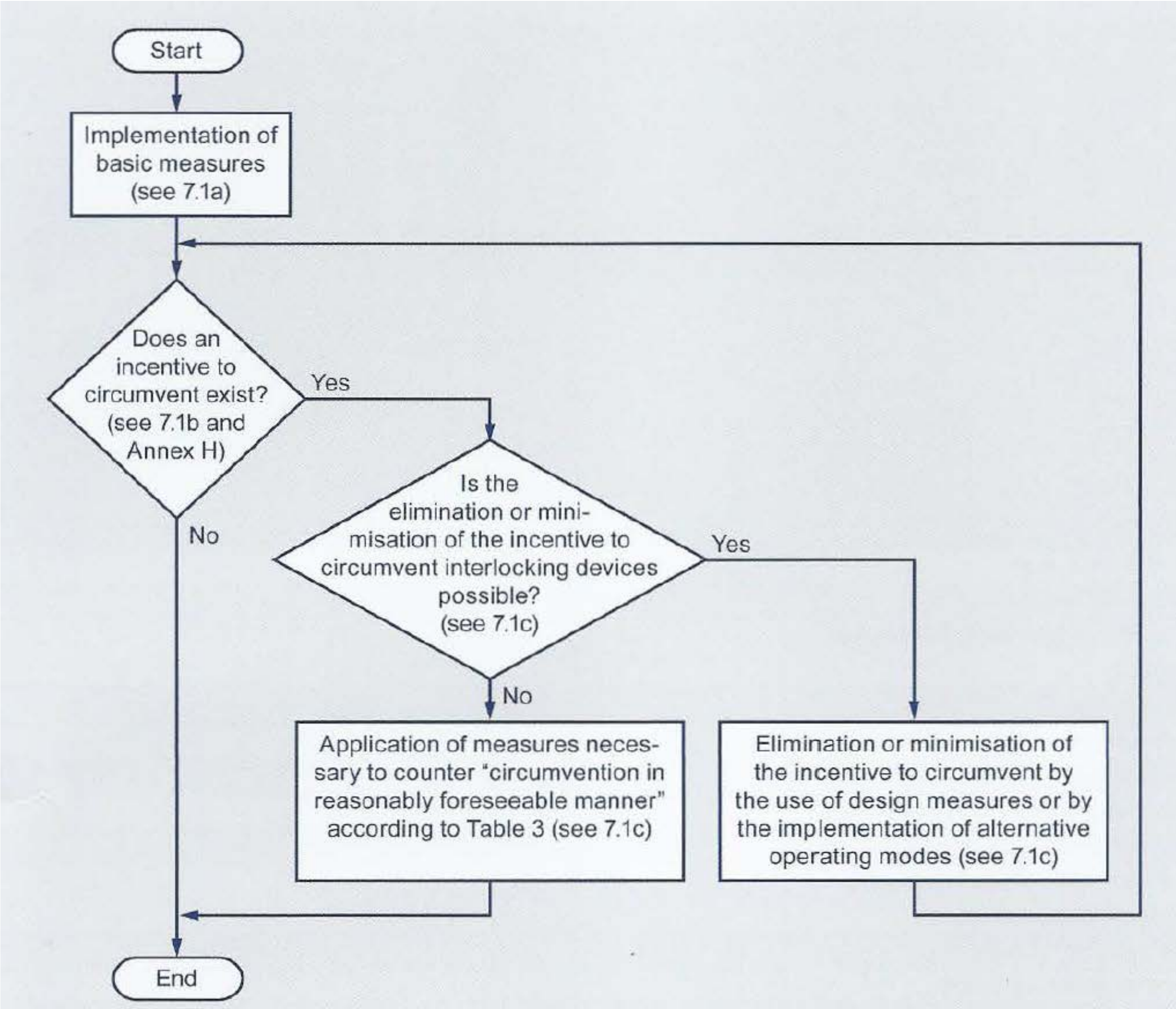


Fig 12: Method to determine the possible incentive to tamper with interlocking devices and the requisite measures to be taken by the manufacturer

Type 3 or Type 4 interlocking devices can be used to compensate for problems which can arise during the use of Type 1 or Type 2 interlocking devices. When considering possible manipulation and the resultant required measures, interlocking devices equipped with RFID technology are suitable, for example.

Manipulation of interlocking devices

In addition to selecting interlocking devices that comply with standards, it is also necessary to consider their design and/or integration in processes in terms of possible manipulation. There is a chapter in the standard for this. It is entitled "The use of design to minimize the opportunities for circumvention of interlocking devices". The background to this includes the BGIA manipulation study[10] from 2006, which established a strong accumulation of manipulation on machine tools.

Amendment 1/2007 of DIN EN 1088 described design requirements aimed at circumvention opportunities; these have been incorporated in the latest ISO 14119. Section 7 of the standard deals with this subject. The background is the requirement from the A standard ISO 12100, Section 1.4. "Requirements on protective devices", and in particular Section 1.4.1.2 "General requirements".

Guards and protective devices other than a guard

- must be built strongly
- must not be capable of being easily circumvented or rendered ineffective

The basis for considerations to prevent opportunities for circumvention is a tiered concept based on the tiered concept in ISO 12100:

- Basic measures, such as securely affixing the interlocking device, protection from external influences and loosening of the fastening, compliance with tolerances etc., encoding of actuators on interlocking devices (Type 2 and Type

4 devices), use of electromechanical switchgear with positively driven contacts etc.

- Establishing whether a manipulation incentive exists. The informative annex in the standard offers a procedure in the form of a tabular evaluation as suggestion, together with a further, completed table as example. This enables the possible incentive to manipulate every protective device, depending on the operating mode, to be checked and documented and for corresponding countermeasures to be specified where applicable. This systematic approach is also suitable as a component of the technical file.

Application of additional measures to minimize the opportunities for circumventing interlocking devices (design check)

Additional measures must be taken if the risk of circumvention in a reasonably foreseeable manner still exists after implementing the above mentioned measures. For such cases, the standard contains a diagrammatic representation of the method to determine possible incentives and the measures that machine manufacturers are required to take. It furthermore indicates additional measures which are designed to at least make the circumvention of interlocking devices more difficult.

Additional measures

Essentially measures of a design nature are addressed here:

- Accessibility to the interlocking device
  - Attaching out of reach
  - Cordons or screening
  - Attaching in a concealed position
- Avoidance of alternative actuation using available objects
  - encoded actuators with low encoding level
  - encoded actuators with high encoding level
- Avoidance of removal or changing the position
  - Use of non-detachable fastenings. This primarily refers to Type 2 switch actuators.
- Integration of a circumvention monitoring in the Controller
  - Status monitoring
  - Periodic inspections
  - Use of an additional position sensing and plausibility check.

Table 3 in the normative part of the standard lists the measures to be carried out when the measures described in Figure 12 fail to produce the desired result. In some cases alternative measures are proposed; in others extremely restrictive measures are demanded or recommended.

It is not always possible to implement the measures described above effectively or in a cost-neutral manner. Therefore in many cases it makes sense to deploy products directly that have been produced with a high encoding level.

These are now supplied as electromechanical interlocking devices (Type 2 switches - see Figure 7), as interlocking device with guard locking (see Figure 8) or as electronic safety sensors with integrated RFID technology.

Interface to the controller

Interlocking devices are safety-related parts of the control system of a machine (SRP/CS in accordance with ISO 13849-1) or a subsystem of a safety-related part of an electrical control system (SRECS in accordance with IEC 62061) and must correspond to the requirements of the above standards.

In their technical data and depending on the characteristics of their product, the manufacturers of interlocking devices generally specify the requisite safety-related parameters (B_{10d}, PFH etc.).

An interlocking device with a required PL_r = e under ISO 13849-1 or SIL 3 under IEC 62061 demands a minimum fault tolerance of 1 (e.g. two Type 1 interlocking devices), because faults cannot normally be ruled out.

Fault exclusions are possible, however. ISO 13849-2[11] provides information on this in the informative annexes (see article "Validation of control systems in accordance with ISO 13849-2" on Page 169). For example, the following is supplemented in Annex D of ISO 13849-2 (Safety-related parts of control systems: Validation) under Table D8 (Faults and fault exclusions – Switches - Electromechanical Position Switches): "For PL_e, no fault exclusion is permissible for mechanical (e.g. the mechanical connection between switch and contact elements) and electrical aspects. In this case redundancy is necessary." The conclusion from this is that a position switch or guard locking can be sufficient for applications in PL_r = d.

Monitoring the locked position

A further aspect which has been described in detail for the first time in the standard is the monitoring of the locked position of guard locking. This additional safety function guarantees that a machine can only be set in motion if:

- the safety device is closed; and
- the guard locking device keeps the protective device closed.

This safety function must be executed according to the risk analysis. All parts of the devices used to unlock/lock the signal are counted as safety-related parts of the control system. The question here is: does the guard locking also need to be performed redundantly in the case of a required PL, = e or PL, = d? The standard answers this question in its final version: a fault exclusion in PL e and in PL d is possible on the mechanical components of the guard locking, with the prerequisite that the requirements of guard locking which are similarly described in the standard are complied with. It means it is sufficient for applications in accordance with PL e to have just one guard locking and a further redundantly arranged position switch.

Conclusion

ISO 14119 does not only result in an adjustment to technical progress through the consideration of new principles of operation for interlocking devices, it also provides practical hints on the design of protective devices and addresses the fact that protective devices are being repeatedly manipulated in practice. As such, probability is also being increasingly incorporated in the world of machine safety standards in this application area too.

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Pages: 121 - 132

Footnotes/Bibliography

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Images (credits):

Fig 1: Example of an interlocking device - Source: ISO 14119
Fig 2: Principles of interlocking devices - Source: ISO 14119
Fig 3: ZR335 Position Switch - Source: KA Schmersal GmbH & Co KG
Fig 4: AZ16 interlock switch - Source: KA Schmersal GmbH & Co KG
Fig 5: IFL Proximity Switch - Source: KA Schmersal GmbH & Co KG
Fig 6: RSS36 Safety Sensor - Source: KA Schmersal GmbH & Co KG
Fig 7: AZ16ZI with individually coded actuator - Source: KA Schmersal GmbH & Co KG
Fig 8: AZM300 in application - Source: KA Schmersal GmbH & Co KG
Fig 9: MZM100 in application - Source: KA Schmersal GmbH & Co KG
Fig 10: Drawing of emergency release handle actuation - Source: KA Schmersal GmbH & Co KG
Fig 11: Flowchart - Source: ISO 14119
Fig 12: Flowchart - Source: ISO 14119

Table 1: Overview of interlocking devices - Source: ISO 14119