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Safety of machinery — Interlocking devices associated with guards — Principles for design and selection

Sécurité des machines — Dispositifs de verrouillage associés à des protecteurs — Principes de conception et de choix

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 199, *Safety of machinery*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 114, *Safety of machinery*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 14119:2013), which has been technically revised.

The main changes are as follows:

— ISO/TS 19837 has been integrated as new Annex K with specific requirements for Type 5 interlocking devices – “trapped key interlocking devices” (see definition 3.18.1);

— trapped key interlocking systems and Type 5 interlocking devices have been defined;

— Table 5 has been improved and renamed;

— test procedures are described in new Annex I;

— ISO/TR 24119 has been integrated into new Annex J.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The structure of safety standards in the field of machinery is as follows:

a) type-A standards (basic safety standards) giving basic concepts, principles for design, and general aspects that can be applied to all machinery;

b) type-B standards (generic safety standards) dealing with one safety aspect or one type of safeguard that can be used across a wide range of machinery:

   — type-B1 standards on particular safety aspects (e.g. safety distances, surface temperature, noise);

   — type-B2 standards on safeguards (e.g. two-hand controls, interlocking devices, pressure-sensitive devices, guards);

c) type-C standards (machine safety standards) dealing with detailed safety requirements for a particular machine or group of machines.

This document is a type-B2 standard as stated in ISO 12100.

This document is of relevance, in particular for the following stakeholder groups representing the market players with regard to machinery safety:

— machine manufacturers (small, medium and large enterprises);

— health and safety bodies (regulators, accident prevention organizations, market surveillance).

Others can be affected by the level of machinery safety achieved with the means of the document by the above-mentioned stakeholder groups:

— machine users/employers (small, medium and large enterprises);

— machine users/employees (e.g. trade unions, organizations for people with special needs);

— service providers, e.g. for maintenance (small, medium and large enterprises);

— consumers (in case of machinery intended for use by consumers).

The above-mentioned stakeholder groups have been given the possibility to participate in the drafting process of this document.

In addition, this document is intended for standardization bodies elaborating type-C standards.

The requirements of this document can be supplemented or modified by a type-C standard.

For machines which are covered by the scope of a type-C standard and which have been designed and built according to the requirements of that standard, the requirements of that type-C standard take precedence.

This document has been prepared to give guidance to machinery designers and writers of product safety standards on how to design and select interlocking devices associated with guards.

Relevant clauses of this document, used alone or in conjunction with provisions from other standards, may be used as a basis for verification procedures for the suitability of a device for interlocking duties.

Annexes A to E describe the technology and the typical characteristics of the defined interlocking devices types 1 to 4. Other solutions may be adopted, provided that they are in conformity with the principles of this document.

Annexes F to H give information on particular aspects such as interlocking devices used within safety functions, risk assessment considering the motivation to defeat and static action forces.

Annex I describes a locking force test and an impact resistance test for guard-locking devices.

Annex J provides information on the masking of faults in series connection of interlocking devices with potential free contacts.

Annex K provides requirements for trapped key interlocking systems and describes their technology.

Safety of machinery — Interlocking devices associated with guards — Principles for design and selection

1 Scope

This document specifies principles for the design and selection (independent of the nature of the energy source) of interlocking devices associated with guards and provides guidance on measures to minimize the possibility of defeat of interlocking devices in a reasonably foreseeable manner.

This document covers principles for the design, selection and application of the following:

— parts of the guards which actuate interlocking devices;

— trapped key interlocking devices and systems for machinery applications.

NOTE ISO 14120 specifies general requirements for the design and construction of guards provided primarily to protect persons from mechanical hazards. The processing of the signal from the interlocking device to stop the machine and prevent unexpected start up is covered in ISO 14118, ISO 13849-1 and IEC 62061.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 13849-1:2023, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*

ISO 13849-2:2012, *Safety of machinery — Safety-related parts of control systems — Part 2: Validation*

ISO 13855:—[1)], *Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of the human body*

ISO 14118:2017, *Safety of machinery — Prevention of unexpected start-up*

IEC 60204-1:2016+AMD1:2021, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*

IEC 60947-1:2020, *Low-voltage switchgear and controlgear — Part 1: General rules*

IEC 60947-3, *Low-voltage switchgear and controlgear — Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units*

IEC 60947-5-1:2016+COR:2016, *Low voltage switchgear and controlgear — Part 5-1: Control circuit devices and switching elements — Electromechanical control circuit devices*

IEC 60947-5-3, *Low-voltage switchgear and controlgear — Part 5-3: Control circuit devices and switching elements — Requirements for proximity devices with defined behaviour under fault conditions (PDDB)*

IEC 62061:2021, *Safety of machinery — Functional safety of safety-related control systems*

1) Under preparation. Stage at the time of publication: ISO/FDIS 13855.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100:2010, ISO 13849-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

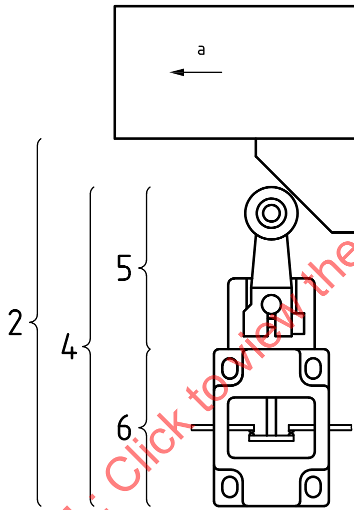
— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
interlocking device
interlock
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)

Note 1 to entry: See Figure 1 and Table 2.

[SOURCE: ISO 12100:2010, 3.28.1, modified — Note 1 to entry and Figure 1 were added.]



Key

1 guard
2 interlocking device
3 actuator
4 position switch
5 actuating system
6 output system
a Direction of opening.

Figure 1 — Example of an interlocking device

3.2
interlocking guard
guard associated with an interlocking device such that, together with the control system of the machine, prevents the:

— operation of the hazardous machine functions associated with the guard until the guard is closed;

— if the guard is opened while hazardous machine functions are operating, a command to bring the machine to a safe state (a stop command) is given

Note 1 to entry: An interlocking guard can contain/be equipped with one or more interlocking devices. These interlocking devices can also be of different types.

Note 2 to entry: The generation of the (stop) command to bring the machine to a safe state when the guard is open does not apply to guards locked with a trapped key interlocking system.

3.3
guard-locking device
device intended to lock a guard in the closed position and to be linked to the control system

Note 1 to entry: A guard-locking device may be a separate device or integrated in an interlocking device.

Note 2 to entry: See Annex E for detailed examples.

3.4
interlocking guard with guard-locking function
guard associated with an interlocking device and a guard-locking device so that, together with the control system of the machine, the following functions are performed:

— the hazardous machine functions associated with the guard cannot operate until the guard is closed and locked;

— the guard remains closed and locked until the risk due to the hazardous machine functions associated with the guard has ceased; and

— when the guard is closed and locked, the hazardous machine functions associated with the guard can operate (the closure and locking of the guard do not by themselves start the hazardous machine functions)

[SOURCE: ISO 12100:2010, 3.27.5, modified — Note 1 to entry was deleted and in the first and second list item, "associated" replaces "covered", in the second list item "ceased" replaces "disappeared".]

3.5
defeat
defeat in a reasonably foreseeable manner
reasonably foreseeable action, either manually or by using readily available objects, 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 protective measures

Note 1 to entry: This definition includes the removal of position switches or actuators using tools that are needed for the intended use of the machine or that are readily available (screwdrivers, wrenches, hexagon keys, pliers).

Note 2 to entry: Readily available objects for substitute actuation include:

— screws, needles and sheet-metal pieces;

— objects in daily use, e.g. keys, coins, adhesive tape, string and wire.

Note 3 to entry: Uncontrolled spare and master keys for Type 5 interlocking devices (see also 8.4.3) and spare actuators (for all types) are also considered as readily available objects.

3.6
automatic monitoring
diagnostic function, which initiates a fault reaction function if the ability of a component or an element to perform its function is diminished, or if the process conditions are changed in such a way that hazards are generated

3.7
direct mechanical action
positive mechanical action
movement of a mechanical component, which arises inevitably from the movement of another mechanical component either by direct contact or via rigid elements

3.8
direct opening action
direct opening action of a contact element
achievement of contact separation as a direct result of a specified movement of the switch actuator through non-resilient members (for example not dependent upon springs)

[SOURCE: IEC 60947-5-1:2016 + COR1:2016, K 2.2.]

3.9
position switch
part of interlocking device comprising the actuating system and the output system

3.10
actuator
separate part of an interlocking device, which transmits the state of the guard (closed or not closed) to the actuating system

EXAMPLE Guard-mounted cam, shaped tongue, reflector, magnet, RFID tag.

Note 1 to entry: See also Annexes A to E and Annex K.

Note 2 to entry: For type 1 and Type 3 interlocking devices the actuator can be a part of the guard itself.

Note 3 to entry: Examples of actuators are shown in Figure 2.

Note 4 to entry: A key as used in a trapped key system is not covered by this definition.

3.11
coded actuator
actuator which is specially designed (e.g. by shape) to actuate a certain position switch

3.11.1
low-level coded actuator
coded actuator for which 1 to 9 variations in code are available and the different codes are evaluated by the interlocking device

3.11.2
medium-level coded actuator
coded actuator for which 10 to 1 000 variations in code are available and the different codes are evaluated by the interlocking device

3.11.3
high-level coded actuator
coded actuator for which more than 1 000 variations in code are available and the different codes are evaluated by the interlocking device

3.12
actuating system
part of the interlocking device which transmits the position of the actuator or the key and changes the state of the output system

EXAMPLE Roller plunger, cam mechanism, and optical, inductive or capacitive sensor.

Note 1 to entry: Examples of actuating systems are shown in Figure 2.

3.13
output system
part of the interlocking device that signals the state of the actuator or the key to the control system

EXAMPLE Contact element (electromechanical), semiconductor output, valve.

3.14
Type 1 interlocking device
interlocking device with mechanically actuated position switch with uncoded actuator

EXAMPLE Hinged interlocking devices.

Note 1 to entry: See Annex A for detailed examples.

3.15
Type 2 interlocking device
interlocking device with mechanically actuated position switch with coded actuator

EXAMPLE Tongue-actuated position switches.

Note 1 to entry: See Annex B for detailed examples.

3.16
Type 3 interlocking device
interlocking device with non-contact actuated position switch with uncoded actuator

EXAMPLE Proximity switches.

Note 1 to entry: See Annex C for a detailed example.

3.17
Type 4 interlocking device
interlocking device with non-contact actuated position switch with coded actuator

EXAMPLE RFID tag actuated position switches.

Note 1 to entry: See Annex D for detailed examples.

3.18
trapped key interlocking system
system fulfilling safety function(s) or part of safety function(s) and comprising at least two different Type 5 interlocking devices which work together through the transfer of a key

Note 1 to entry: See Figure 2 d) and Annex K for detailed examples.

3.18.1
Type 5 interlocking device
trapped key interlocking device
device, which fulfils a function by trapping or releasing one or more keys in a given trapped key interlocking system

EXAMPLE Door locks, key-operated switches, key exchange units.

3.18.2
personnel key
key which is released from a trapped key interlocking device and retained by a person to prevent a hazardous situation (e.g. unexpected start-up)

3.18.3
key trapped
situation in which a key in a Type 5 interlocking device is locked and cannot be removed.

EXAMPLE A solenoid or the insertion of an actuator releases the trapped key.

3.18.4
key releasable
situation in which a key is not locked and so can be (turned and) removed causing a change of state of the device

EXAMPLE Change of state of the device releases or traps another key or changes contact state.

3.18.5
master key
key which can operate multiple locks of different coding

3.18.6
key transfer plan
drawing, scheme or diagram depicting the trapped key interlocking system with its individual Type 5 interlocking devices and the sequence(s) in which they are to be operated

3.18.7
bolt lock
trapped key interlocking device that extends a bolt to lock an object

EXAMPLE Bolt locks can be used to lock disconnector switches, valves or sliding doors.

3.18.8
access lock
trapped key interlocking device intended to lock a guard in the closed position for trapped key interlocking systems, and linked to the control system via the key transfer

Note 1 to entry: Access locks can also be used for locking in position objects other than guards, e.g. isolators, valves or barriers.

3.18.9
time delayed key release
trapped key interlocking device that releases a key after a pre-determined period of time has elapsed

3.18.10
key exchange device
trapped key interlocking device in which the insertion of one or more keys releases one or more keys with a different coding, trapping the inserted key(s)

3.18.11
key-operated switch
key-operated switch as part of trapped key systems
trapped key interlocking device comprising a switch which can only be operated by means of a key

3.18.12
key-operated solenoid-controlled switch
key-operated solenoid-controlled switch as part of trapped key systems
trapped key interlocking device comprising a key-operated switch which can be mechanically locked by the operation of a solenoid

3.18.13
trapped key valve lock
trapped key interlocking device used to lock a valve in the open position [locked open (LO)], in the closed position [locked closed (LC)] or in both positions by different keys

3.18.14
energy control
sub-function of a trapped key interlocking system to achieve and maintain a safe state to prevent hazardous machine functions

3.18.15
intermediate transfer
sub function of a trapped key interlocking system that allows the transfer of keys between two Type 5 interlocking devices

3.18.16
access control
subfunction of a trapped key interlocking system that controls the access to safeguarded spaces or access to machine operating modes and functions

3.18.17
switch-disconnector
switch, which, in the open position, satisfies the isolating requirements specified for a disconnector

[SOURCE: IEC 60947-1:2020, 2.2.10]

3.19
whole body access
situation where a person can be completely inside a safeguarded space

Note 1 to entry: The term whole body access is used in other standards to specify the opening size for safe access.

3.20
safeguarded space
volume enclosing a hazard zone(s) where guards or protective devices, or both, are intended to protect persons

3.21
stop command
signal generated by the interlocking device that initiates the intended risk reduction

3.22
overall system response time
time interval between the stop command given by opening the guard and achieving the intended risk reduction

3.23
access time
time taken by a person to reach the hazard zone after initiation of the stop command by the interlocking device, as calculated on the basis of an approach speed of the body or part of the body

Note 1 to entry: For the selection of the approach speed and the calculation, see ISO 13855.

3.24
locking force
force that a guard-locking device can withstand without being damaged so that its further use will not be impaired and the guard will not leave the closed position

3.25
prevention of inadvertent locking position
feature of a guard-locking device, which ensures that the locking elements (e.g. a locking bolt) cannot achieve the locking position when the guard is not closed

3.26
emergency release of guard-locking
manual release without auxiliary means of the guard locking from outside the safeguarded space in case of an emergency

Note 1 to entry: The guard locking with emergency release can be necessary for releasing trapped persons or fire-fighting, for example.

3.27
auxiliary release of guard locking
manual release by use of a tool or a key of the guard locking from outside the safeguarded space in case of its failure or absence of power supply

Note 1 to entry: The guard locking with auxiliary release is not suitable for emergency or escape release of guard locking.

3.28
escape release of guard locking
manual release without auxiliary means of the guard locking from inside the safeguarded space to leave the area

3.29
tool
implement intended by the manufacturer for the purposes of tightening or loosening a fastener

Note 1 to entry: An improvised implement, such as a coin or a nail file, cannot be considered as a tool.

3.30
power interlocking
function which directly interrupts the energy supply to the hazard sources

Note 1 to entry: Resumption of the energy supply is only possible with the guard in the safeguarded position. "Directly" means that, unlike control interlocking, the control system does not play any intermediate role in the interlocking function.

3.31
control interlocking
function which interrupts the energy supply to the hazard using indirect means

Note 1 to entry: Examples of indirect means can include a combination of relay modules, standstill monitoring devices, PLCs or other control devices/systems.

3.32
safety function
function of a machine whose failure can result in an immediate increase of the risk(s)

Note 1 to entry: See Figures 3 and 4.

[SOURCE: ISO 12100:2010, 3.30, modified — Note 1 to entry added.]

3.33
fault masking
unintended resetting of faults or preventing the detection of faults in the safety-related parts in the control system (SRP/CS) by operation of parts of the SRP/CS which do not have faults

3.34
potential free contact
electrical switch contact in which electrical power is not directly provided by the device

Note 1 to entry: Potential free contact is also referred to as "dry contact" or "voltage free contact".

3.35
series-connected devices
interlocking devices with potential free contacts that are connected in series to one logic unit which performs the diagnostics

3.36
interlock blocking device
mechanical means, capable of either being locked (e.g. by a padlock or other lockable device) or otherwise secured in a position, used to physically block or hold the actuator of an interlocking device to prevent actuating or engaging the interlocking device

3.37
direct guard monitoring
monitoring of the position of the guard, characterized by the detection of the position of the guard provided by a position switch directly

3.38
indirect guard monitoring
indirect guard monitoring of the position of the guard
monitoring of the position of the guard, characterized by the signaling of the closed position of the guard provided by an actuated key-operated switch

Note 1 to entry: The key required for the operation of the switch is only available after the closing and locking of the guard. This can include intermediate steps (transfers).

3.39
category 3 behaviour
behaviour of mechanical parts of trapped key interlocking systems where no single fault results in a loss of the safety function

Note 1 to entry: Category 3 behaviour is characterized by (see ISO 13849-1:2023, 6.1.3.2.5):

— continued performance of the safety function in the presence of a single fault;

— detection of some, but not all, faults;

— possible loss of the safety function due to accumulation of undetected faults.

3.40
category 4 behaviour
behaviour of mechanical parts of trapped key interlocking systems where no accumulation of faults results in a loss of the safety function

Note 1 to entry: Category 4 behaviour is characterized by (see ISO 13849-1:2023, 6.1.3.2.6):

— continued performance of the safety function in the presence of a single fault;

— detection of faults in time to prevent the loss of the safety function;

— the accumulation of undetected faults is taken into account;

— the consideration of an accumulation of two faults may be sufficient.

4 Symbols

Table 1 — Symbols

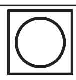
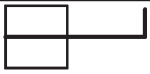
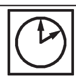
	Symbol	Function
1		key
2	-----	key path
3		key trapped (see 3.19.3)
4		key releasable (see 3.19.4)
5		key inserted and removable
6		key removed
7		actuator locked

Table 1 *(continued)*

	Symbol	Function
8		actuator unlocked
9		actuator removed
10		time delayed function (see 3.18.9, see Figure K.21)

5 Operating principles and types of interlocking devices associated with guards

5.1 General

Interlocking techniques involve a broad spectrum of technological aspects. Interlocking devices can be classified using a great variety of criteria, e.g. the nature of the link between guard and interlock device (types 1 to 5 interlocking devices, see Figure 2), or the technological type (electromechanical, pneumatic, electronic) of the interlock device's output system. For more information regarding trapped key interlocking systems see Annex K.

Interlocking devices have a guard position monitoring function that senses whether the guard is closed or not and produces a stop command when the guard is not in the closed position. An interlocking device can also be used in the control of other functions, e.g. application of a brake to stop hazardous machine functions before access is possible. Some interlocking devices also have a guard-locking function to keep the guard locked while hazardous machine function is present. A guard-locking device status monitoring function monitors whether the guard-locking device is engaged or released and produces an appropriate output signal [see 5.3.1 a) and b)].

NOTE 1 The guard-locking device can be an integral part of an interlocking device, or a separate unit.

NOTE 2 See also ISO 12100:2010, 6.3.3.1 for additional information on guards.

Table 2 shows the actuation principles and actuators for the defined interlocking device types.

NOTE 3 The five types of interlocking device are not presented in a hierarchical order. The correct application of each type of interlocking device will be dependent on the risk assessment that is made for the specific machine.

NOTE 4 A hybrid device consisting of two or more types of interlock technology can be used, depending on the application requirements.

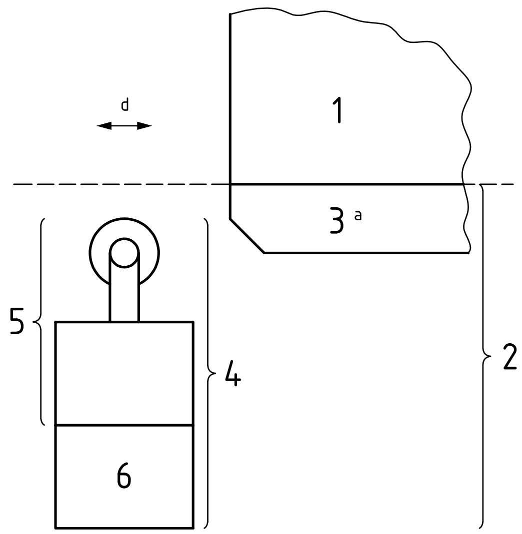
In addition, under specific conditions, an interlocking guard can be designed such that once it has reached its closed position, it gives a command to initiate the hazardous machine function(s) without the use of a separate start control (control guards).

NOTE 5 See ISO 12100:2010, 3.27.6 and 6.3.3.2.5, for additional information on control guards.

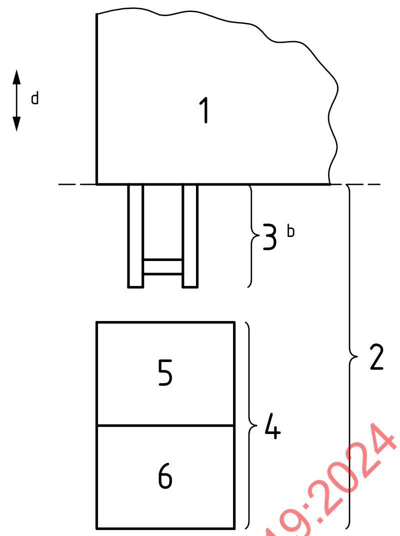
Table 2 — Overview of interlocking devices

Type	Actuation principles	Actuator	Guard monitoring	Example		
				Actuation principles	Actuator	Annex Clause
Type 1	Mechanical	Uncoded	direct	Physical contact / force	Rotary cam	A.1
					Linear cam	A.2, A.4
					Hinge	A.3
Type 2	Mechanical	Coded	direct	Physical contact / force	Tongue (shaped actuator)	B.1
Type 3	Non- contact	Uncoded	direct	Magnetic	Magnet, solenoid	C.1
				Inductive	Suitable ferric metal	
				Capacitive	Any suitable object	
				Ultrasonic	Any suitable object	
				Optic	Any suitable object	
Type 4	Non- contact	Coded	direct	Magnetic	Coded magnet	D.1
				RFID	Coded RFID tag	D.2
				Optic	Optically coded tag	—
Type 5	Mechanical (Trapped key)	Coded	indirect or direct		shaped	Annex K

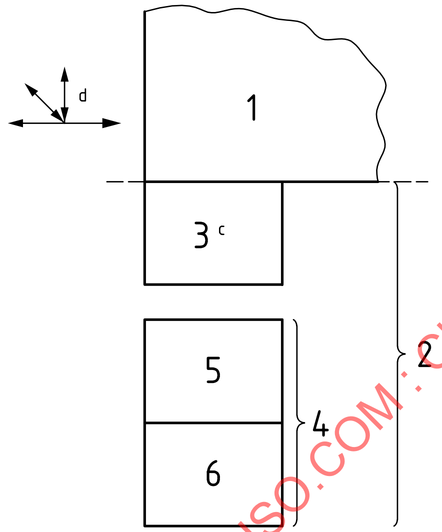
The interlocking function shall have precedence over the guard-locking function as selection criteria for the type of interlocking device (see Table 2) and actuation principle.



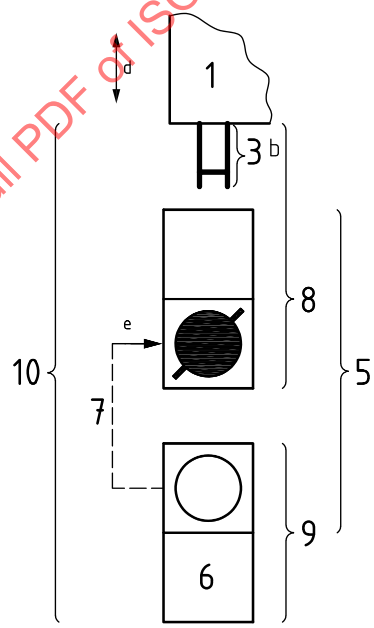
a) Type 1 interlocking device (uncoded cam-operated, guard closed)



b) Type 2 interlocking device (coded tongue-operated, guard not closed)



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



d) Trapped key interlocking system comprising two trapped key interlocking devices respectively. Type 5 interlocking devices (guard not closed)

Key

1 movable guard
2 interlocking device
3 actuator
4 position switch
5 actuating system
6 output system
7 intermediate key transfer
8 Type 5 interlocking device (access lock)
9 Type 5 interlocking device (key operated switch)
10 trapped key interlocking system

[a] Cam.
[b] Tongue.
[c] E.g. RFID, reflector, suitable surface.
[d] Movement direction.
[e] Key trapped.

NOTE In some exceptional cases, the position switch can be installed on the movable guard and the actuator on the stationary part of the machine. In these cases, "1" is the stationary part of the machine.

Figure 2 — Principle of Types 1, 2, 3, 4 and 5 interlocking devices

5.2 Principles of guard interlocking without guard locking

When guard interlocking function without guard locking is used, the guard can be opened at any time regardless of the function of the machine.

If the guard is not closed, the interlocking device shall initiate a stop command.

The access time shall be longer than the overall system response time (see ISO 13855:—, 5.4).

NOTE 1 For interlocking with the machine control system, see Clause 9.

NOTE 2 Examples of interlocking devices without guard locking are shown in Annexes A, B, C and D.

NOTE 3 A functional diagram of interlocking devices without guard locking is shown in Figure 3.

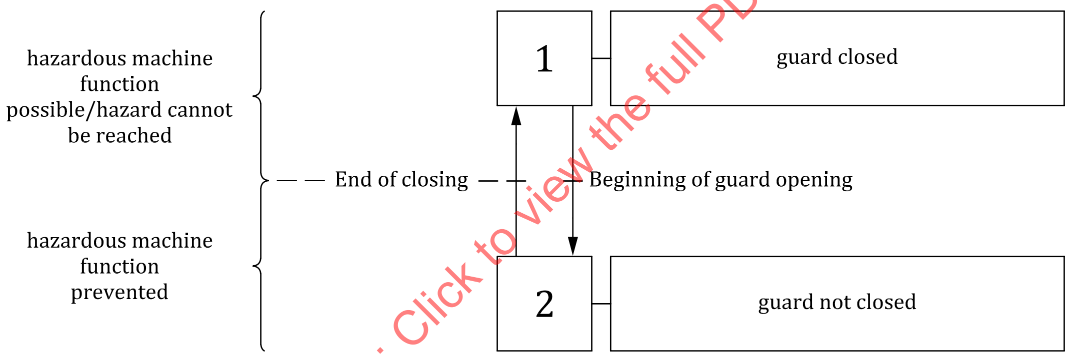


Figure 3 — Functional diagram of interlocking devices without guard locking

5.3 Principles of guard interlocking with guard locking

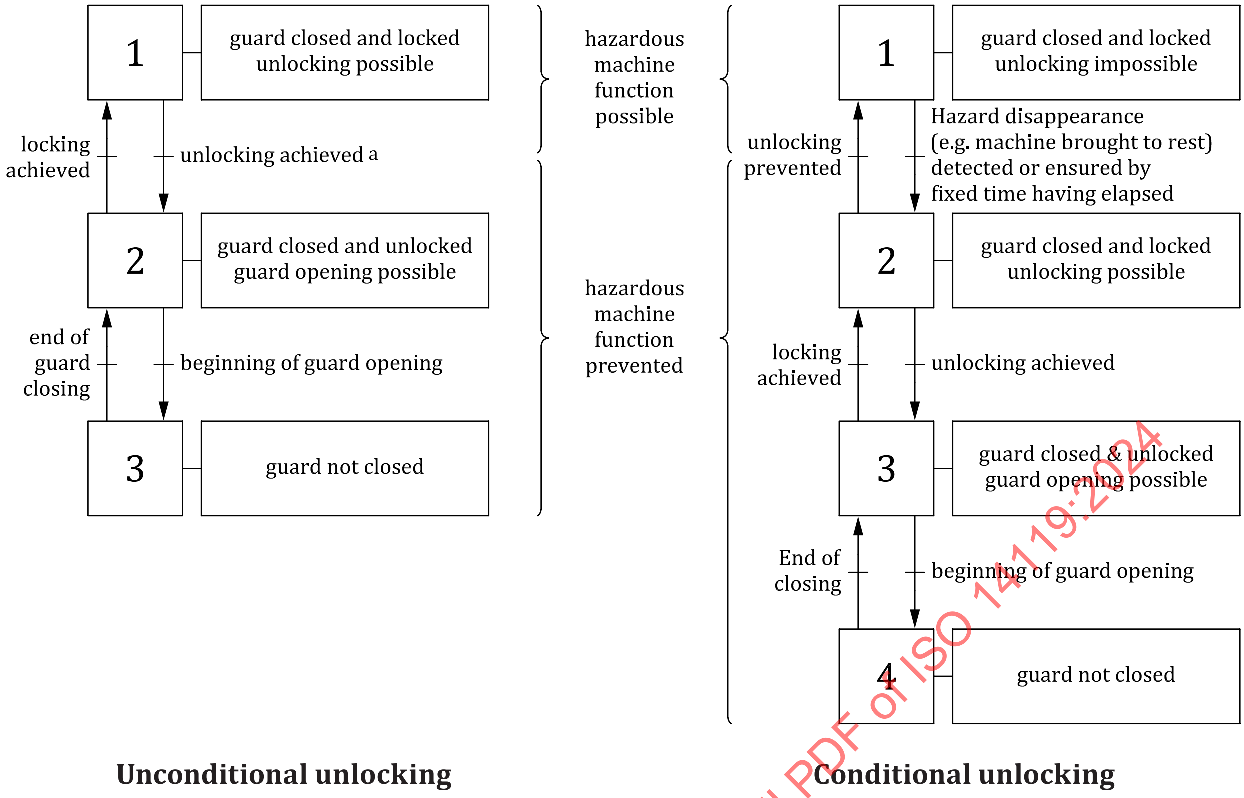
5.3.1 General

When interlocking with guard locking is applied, opening of the guard shall be prevented by a guard-locking device unless all hazardous machine functions associated with this guard have reached a safe state.

There are two alternatives for the design of the guard-locking function (see Figure 4).

a) Unlocking of the guard can be initiated at any time by the operator. When unlocking is started, the guard-locking device generates a stop command. This is called unconditional unlocking. The time necessary for the guard to be unlocked shall be greater than the time necessary for the hazardous machine function to cease.

b) Unlocking of the guard is possible only when the hazardous machine functions have ceased or hazardous situation has ceased. This is called conditional unlocking.



Key

a "unlocking achieved" implies that:

— a stop command has been initiated simultaneously with and as a consequence of, the beginning of the actuation of unlocking device;

— the time necessary for the guard to be unlocked is greater than the time necessary for the hazard to cease.

NOTE In conditional locking, the change from state 2 to state 3 or from state 3 to state 2 can happen without time delayed.

Figure 4 — Functional diagrams of interlocking devices with guard locking

Examples of guard-locking devices are given in Annex E.

5.3.2 Interlocking device with guard locking

5.3.2.1 Interlocking device with guard locking by form

The mechanical part (e.g. bolt) which locks the interlocking guard can be:

— manually applied and manually released (see E.5);

— spring (or similar) applied and power-ON released [see a) in Table 3];

— power-ON applied and spring (or similar) released [see b) in Table 3];

— power-ON applied and power-ON released [see c) in Table 3].

Mechanically operated guard locking shall use the principle of direct mechanical blocking due to form. Friction and force alone shall not be relied upon.

5.3.2.2 Interlocking device with power-operated guard locking by electromagnetic force

The guard is kept closed (locked) without any mechanical locking elements by an electromagnetic force [see d) in Table 3]. The electromagnetic guard locking operates on the principle of power-ON applied and power-OFF released.

Table 3 — Operating modes of guard-locking device in power-operated guard-locking devices

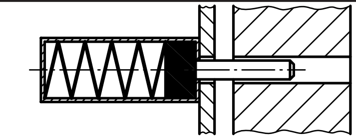
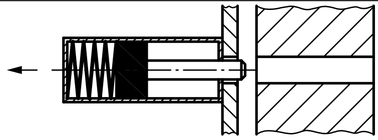
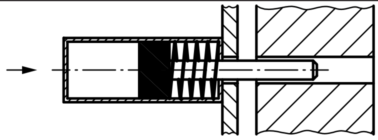
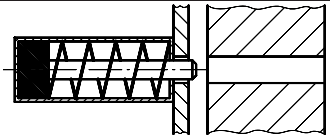
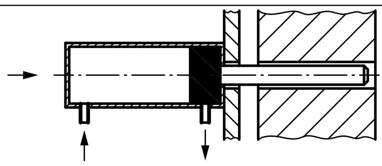
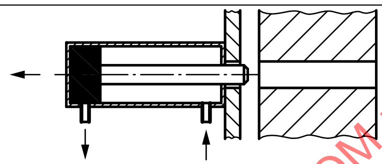
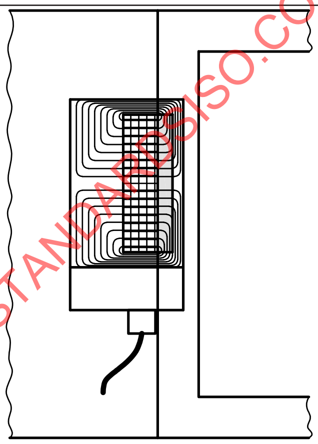
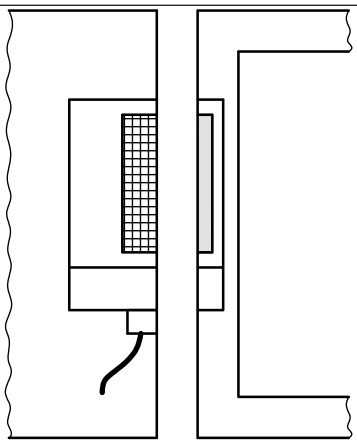
a)		Spring applied	Engaged
		Power-ON released	Released
b)		Power-ON applied	Engaged
		Spring released	Released
c)		Power-ON applied	Engaged
		Power-ON released	Released
d)		Power-ON applied	Engaged

Table 3 *(continued)*

		Power-OFF released	Released

6 Requirements for the design and the arrangements of interlocking devices with and without guard locking

6.1 General

Interlocking devices shall be installed in accordance with the instructions provided by the manufacturer (see Clause 10).

6.2 Arrangement and fastening of position switches, bolt locks and access locks

Position switches, bolt locks and access locks shall be arranged so that they are protected against a change of their position. In order to achieve this, the following requirements shall be met:

a) fasteners of the position switches, bolt locks and access locks shall be reliable and loosening them shall require a tool;

b) position switches of Type 1 interlocking devices and bolt locks shall have provisions for permanently fixing the location after adjustment (e.g. by means of drill holes in combination with non-removable fasteners, pins or dowels);

c) for bolt locks and access locks, oblong holes shall not be used as the sole means of fastening;

d) necessary means of access to position switches, bolt locks and access locks for maintenance and checking for correct operation shall be ensured. Prevention of defeat in a reasonably foreseeable manner shall also be considered when designing the access means;

e) self-loosening shall be prevented;

f) the position switch, bolt lock or access lock shall be located and, if necessary, protected so that a failure due to foreseeable external causes is avoided;

g) the movement produced by mechanical actuation or the gap of the proximity device actuating system shall remain within the specified operating range of the position switch or actuating system specified by the manufacturer of the interlocking device to ensure correct operation and/or prevent overtravel resulting in damage;

h) a position switch, bolt lock or access lock shall not be used as a mechanical stop, unless this is the intended use of the position switch, bolt lock or access lock as declared by the device manufacturer;

i) misalignment of the guard that creates a gap before the position switch, bolt lock or access lock changes its state, shall not impair the protective effect of the guard (for access to hazard zones, see ISO 13855 and ISO 13857);

j) the support and fastening for the position switches, bolt locks and access locks shall be sufficiently rigid to maintain correct operation of the position switch, bolt lock or access lock.

6.3 Arrangement and fastening of actuators

6.3.1 General

Actuators (see Figure 2) shall be so fastened to minimize the possibility that they come loose or change their intended position relative to the actuation system during the intended lifetime.

NOTE A regular check can be necessary (see 10.2.2).

The following requirements shall be met:

a) fasteners of the actuators shall be reliable and loosening them shall require a tool;

b) self-loosening shall be prevented;

c) the actuator shall be located and, if necessary, protected so that failure due to foreseeable external causes is avoided;

d) an actuator shall not be used as a mechanical stop, unless this is the intended use of the actuator as declared by the manufacturer;

e) the support and fastening for the actuators shall be sufficiently rigid to maintain correct operation of the actuator.

6.3.2 Cams

Rotary and linear cams (actuator, see Annex A) for Type 1 interlocking devices shall meet the following requirements:

a) they shall be fixed by fasteners requiring a tool for loosening them;

b) final fixing shall be achieved by form (e.g. spline or pin) or other methods that provide equivalent integrity of fixing;

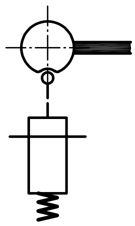
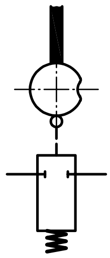
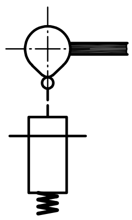
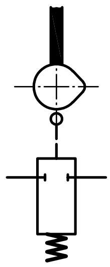
c) they shall not damage the position switch or impair its durability.

6.4 Actuation modes of interlocking devices

When a single Type 1 or Type 2 interlocking device is used to initiate a stop command, it shall be actuated by direct mechanical action between guard, actuator and actuating system and the contact element shall have direct opening action (see 3.7, 3.8 and Table 4).

Non-direct mechanical action for a Type 1 interlocking device shall be used only in conjunction with a Type 1 or Type 2 interlocking device with direct mechanical action between guard, actuator and output system. Combining one interlocking device with direct mechanical action with a second interlocking device with non-direct mechanical action avoids common cause failures (CCFs) (see 9.2).

Table 4 — Direct and non-direct mechanical action of Type 1 interlocking devices

Mechanical action	Guard closed	Guard not closed	Working mode	Example of behaviour in case of failure (see 9.2.4)
Direct			The plunger is held depressed by a cam as long as the guard is not closed. When the guard is closed, the output system changes its state as the result of action of the return spring.	The output system remains in a safe state when the guard is not closed even if the spring breaks.
Non-direct			The plunger is held depressed by a cam as long as the guard is closed. When the guard is not closed, the output system changes state as the result of action of the return spring.	If the spring breaks, the output system can go to an unsafe state even if the guard is not closed.

Interlocking devices shall be actuated appropriately to the actuation principle of the applied position switch.

If a Type 3 or Type 4 electronic position switch is the only interlocking device, it shall meet the requirements of IEC 60947-5-3.

6.5 Mechanical stop

Where an interlocking device or guard-locking device is used as a mechanical stop of the interlocking guard, it shall be ensured that the device is not subjected to impact (s) in excess of the maximum impact energy withstand value stated by the manufacturer.

NOTE Additional mechanical stops can be installed to ensure the device is not subjected to such impact(s).

If an interlocking device is declared by its manufacturer to be suitable for use as a mechanical stop, the maximum impact energy withstand value shall be evaluated according to I.2 and its value shall be stated in the instructions for use [see 10.2.2 q)].

6.6 Additional requirements on guard-locking devices

6.6.1 General

In addition to the requirements stated in 6.1 to 6.5, the following requirements apply to guard-locking devices.

If the application of the guard-locking function creates hazards, e.g. a person exposed to a hazard whilst trapped within a safeguarded space, additional measures shall be taken (according to 7.2.3 and ISO 12100:2010, 6.3.5.3).

The locking element (e.g. bolt) intended to lock the guard shall be "spring applied — power-ON released" [see Table 3 a)] or “power-ON applied – power-ON released” [see Table 3 c)] unless this is not appropriate based on the risk assessment. If, in a specific application, operating modes of the guard-locking device according to Table 3 b) or Table 3 d) are used, measures shall be taken to reduce risks generated by power failures. For a selection see, e.g. 7.2.3.

Electromagnetic coils used for the locking and unlocking function shall meet the construction and performance requirements of IEC 60947-1:2020, 8.2.2.7.

The requirements of 6.6 apply when guard-locking function is used for the protection of persons. The requirements do not apply when guard-locking function is used solely for the protection of a process. Nevertheless, if guard-locking function and guard interlocking function are part of the same device, the functional safety performance of the guard interlocking shall not be negatively affected by the guard-locking function (i.e. where the guard-locking function is used solely for the protection of the process).

The requirements of 6.6 apply to both guard-locking devices composed of separate components as well as to guard-locking devices which form an integral part of an interlocking device with guard locking. They apply to all technologies.

The guard-locking device shall allow the engaged position to be monitored by providing an output system compatible with a control system designed in accordance with ISO 13849-1 or IEC 62061.

The guard-locking device shall only allow hazardous functions of the machine when the guard is closed and locked.

6.6.2 Locking force

The manufacturer of the guard-locking device shall specify the maximum locking force F_{ZH} the guard-locking device withstands in the engaged position. This force, F_{ZH}, shall be determined according to Annex I.

When applied, a guard-locking device shall be selected such that the maximum expected force exerted on the guard F_{MAX} in the application (see Annex H) does not exceed the maximum locking force, F_{ZH}.

6.6.3 Electromechanical guard-locking device

6.6.3.1 General

Electromecanically operating guard locking shall result from the engagement of two rigid parts [form closure, see Table 3 a) to Table 3 c)].

Figure 5 shows the functionality of such a device.

6.6.3.2 Guard-locking monitoring

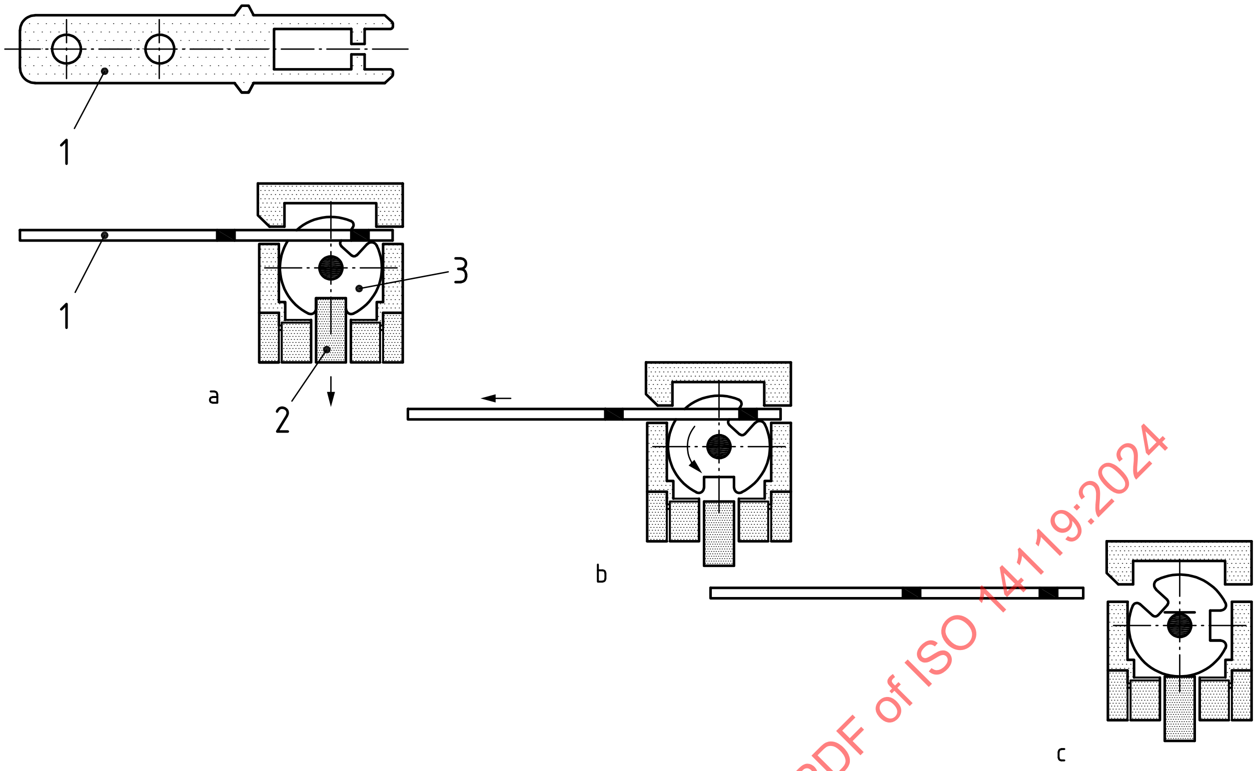
The engaged position of the locking element shall be monitored in accordance with the requirements of Clause 9.

The hazardous function of the machine shall only be possible when the monitoring detects the closed position of the guard and the engaged position of the locking element (see Annex E).

Monitoring of the guard-locking device requires one of the following methods to be applied:

a) if the locking element can only be engaged when the movable guard is in the closed position (see Figure 5), by monitoring of the locking element (prevention of inadvertent locking position);

b) monitoring of the locking element and additionally monitoring the guard position.



Key

a Guard closed and locked.
b Guard closed and not locked.
c Guard not closed and not locked.

1 actuator (tongue)
2 locking element (bolt)
3 actuating system (internal rotating cam)

NOTE In this kind of position switch the actuator has two functions: to operate the contacts (not shown in the figure) and together with the internal rotating cam and the bolt to provide the guard-locking function. The bolt can be operated by external means, e.g. a solenoid or pneumatic cylinder.

Figure 5 — Example of locking element that can only be engaged when the movable guard is in the closed position

6.6.4 Electromagnetic guard-locking device

6.6.4.1 General

The force required for the locking of the guard is applied by the generation of an electromagnetic field [see Table 3 d)].

6.6.4.2 Guard-locking monitoring

When an electromagnetic guard-locking device is used for safeguarding, its effective locking force shall be monitored to determine that it is equal or exceeds the specified locking force F_{ZH}.

The hazardous function of the machine shall only be possible when the monitoring detects the closed position of the guard and the achievement of the specified locking force F_{ZH}.

NOTE Depending on the design of the electromagnetic guard-locking device, this function can be achieved by different means, e.g. measuring the solenoid current, by measuring the electromagnetic field strength.

When the lock force monitoring function is not provided by the electromagnetic guard-locking device itself, it shall be provided by external safety-related parts of the control system of the machine.

6.6.4.3 Basic measures for minimizing defeat possibilities

If an electromagnetic guard-locking device is opened by force, it shall be ensured that the process cannot be immediately continued.

This can be implemented by:

a) means of measures within the guard-locking device, such as, for example:

   1) a reset after an interruption of the hazardous machine function is only possible after a minimum of 10 min; or

   2) the generation of a malfunction of the guard locking, which requires replacement or repair; or

b) means of equivalent time-consuming measures in the machine control system, such as, for example, the following sequence:

   1) warning message at the machine;

   2) cycle stop;

   3) switching-off the production mode;

   4) testing of the guard-locking function;

   5) switching-on the production mode;

   6) restarting the next machine cycle (after a fixed time period of a minimum of 10 min).

NOTE 1 In contrast to an electromechanical guard-locking device, an electromagnetic guard-locking device shows no damage after an opening by force.

NOTE 2 The objective of the measure is that an opening by force results in a time expenditure which is similar to that of repair works (time delay) and comparable with the repair of a damage to an electromechanical guard-locking device.

6.7 Additional requirements on access locks

6.7.1 General

In addition to the requirements stated in 6.1, 6.2, 6.3.1 and 6.5, the following requirements apply to access locks.

If the application of the guard-locking function creates hazards, e.g. a person exposed to a hazard whilst trapped within a safeguarded space, additional measures shall be taken (according to 7.2.3 and ISO 12100:2010, 6.3.5.3).

The access lock shall only allow hazardous functions of the machine when the guard is closed and locked.

Parts designed with intentionally weak points may also be used to create safe failures in order that other critical parts are not exposed to high loading and, therefore, cannot fail dangerously, e.g. a key designed to break at a low force (safe failure) prevents damage to the lock if an attempt is made to force the key to override the locking mechanism.

6.7.2 Locking force

The manufacturer of the access lock shall specify the maximum locking force F_{ZH} the access lock withstands in the engaged position. This force, F_{ZH}, shall be determined according to Annex I.

When applied, an access lock device shall be selected such that the maximum expected force exerted on the guard F_{MAX} in the application (see Annex H) does not exceed the specified locking force, F_{ZH}.

6.8 Whole body access

For applications where there is a risk that person(s) can be trapped inside a safeguarded space, measures to reduce or eliminate risks arising from the situation shall be implemented.

These measures can include:

— application of personnel keys according to K.4.3;

— escape release according to 6.9.1;

— use of interlock blocking devices according to 6.10.

If there is a risk of unexpected startup of a machine when a person is inside a safeguarded area of the machine, means in accordance with ISO 14118 shall be applied. These measures can include:

— a manual reset function according to ISO 13849-1:2023, 5.2.2.3;

— presence sensing devices according to IEC 62046.

Depending on the application, supplementary methods of release of guard locking can be necessary (see ISO 12100:2010, 6.3.5.3). For their selection, see 7.2.3.

NOTE Escape and emergency releases can be separate devices or provided with the guard-locking device.

Where applied, separate devices for escape or emergency release and guard-locking devices, with provided escape or emergency releases, shall withstand the following:

— expected operating stresses, e.g. force and frequency of operation;

— environmental influence, e.g. influence of abrasive materials, e.g. cement dust in a cement production line;

— other relevant external influences, e.g. mechanical vibration.

6.9 Supplementary releases

6.9.1 Escape release of guard locking

When the guard-locking device is provided with an escape release, the following requirements shall be met:

— deliberate unlocking of the guard locking from inside of the safeguarded space shall be easily possible without auxiliary means and regardless of the operating condition;

— the unlocking means shall be manually operated and act directly on the principle of the locking mechanism;

— the unlocking shall generate a stop command which is maintained;

— the unlocking means for the escape release shall only be accessible from inside the safeguarded space.

6.9.2 Auxiliary release of guard locking

When the guard-locking device is provided with an auxiliary release the following requirements shall be met.

— Deliberate unlocking of the guard locking from outside the safeguarded space shall be possible only by the use of a tool or key(s) and regardless of the operating condition. The instructions for use shall state that the restoring of the function of the guard-locking device is necessary before normal operation is resumed.

— The unlocking of the auxiliary release shall generate a stop command which is maintained.

— The resetting of the auxiliary release shall be possible only by means of a tool, key(s) or similar objects or by other equivalent methods (e.g. change of a component). This requirement can be fulfilled on a control system level. If the requirements are intended to be fulfilled on a safety control system level (not in the guard-locking device), clear instructions that this needs to be achieved shall be provided in the instructions for use of the guard-locking device [see 10.2.2 m)].

6.9.3 Emergency release of guard locking

If it is foreseeable that access is necessary in case of emergency, for "spring applied – power-ON released" or “power-ON applied – power-ON released” systems [see Table 3 a) and Table 3 c)], a guard-locking device with emergency release shall be provided. When the guard-locking device is provided with an emergency release the following requirements shall be met:

— deliberate unlocking of the guard locking from outside the safeguarded space shall be possible and be easily actuated without auxiliary means, regardless of the operating condition;

— the unlocking means shall be manually operated and act directly on the principle of the locking mechanism;

— the unlocking shall generate a stop command which is maintained;

— the unlocking results in a blocking of the locking means in the released condition;

— the emergency guard locking release shall be clearly marked to be used only in emergency situations and shall be positioned and/or shielded to prevent accidental opening of the lock;

— the resetting of the emergency release shall be possible only by means of a tool or by other methods (e.g. change of a component). This requirement can be fulfilled on a control system level. If the requirements are intended to be fulfilled on a control system level (not in the guard-locking device), clear instructions that this needs to be achieved shall be provided in the instructions for use of the guard-locking device [see 10.2.2 m)].

6.10 Interlock blocking

For the prevention of an unexpected startup according to ISO 14118:2017, 6.3.3, interlock blocking devices can be provided.

Where an interlock blocking device is provided, it shall not negatively affect either the interlocking or guard-locking function.

The interlock blocking device shall not be used as an insulator means as described in ISO 14118.

The interlock blocking device itself is neither considered as a part of the interlocking device nor of a safety function.

7 Selection of an interlocking device

7.1 General

When selecting an interlocking device for a machine, it is necessary to consider all phases of the machine life cycle.

Selection shall take into account, but not be limited to, the following criteria:

— the conditions of use and the intended use of the machine (according to ISO 12100:2010, 5.3);

— the hazards present at the machine (according to ISO 12100:2010, 5.4);

— the severity of the possible injury (according to ISO 12100:2010, 5.5);

— the probability of failure of the interlocking device (see Clause 9);

— overall system response time and access time (see 7.2.1);

— the required performance level (PLr, see ISO 13849-1) or the required safety integrity level (SIL, according to IEC 62061) for the safety functions (see 9.1);

— information for use according to 10.2.2 provided for the interlocking device(s);

— for Type 4 interlocking devices, the means to avoid that a single actuator can be taught in an unlimited manner by the operator without special knowledge and special tools;

— environmental conditions (see 7.3).

7.2 Selection of a guard-locking device

7.2.1 Overall system response time and access time

An interlocking device with guard-locking function according to 6.6.1 shall be applied to an interlocking guard when the overall system response time is greater than or equal to the access time taken by a person to reach the hazard zone (see Figure 6).

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 for typical values).

In case of loss of power, the stopping time of a machine is often considerably lengthened. Where this leads to significant hazard the lengthened stopping time shall be considered as the overall response time.

NOTE For the determination of overall systems response time, the speed of moving equipment does not need to be considered under fault conditions.

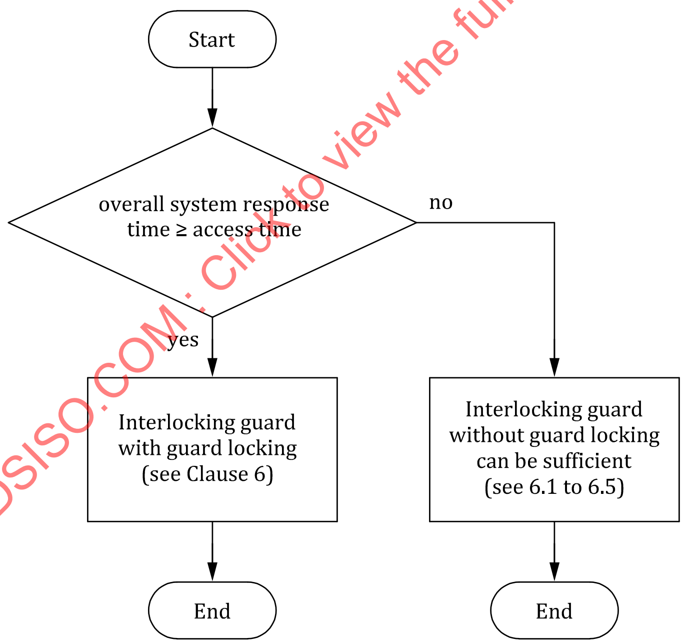


Figure 6 — Determination of the need for guard-locking devices

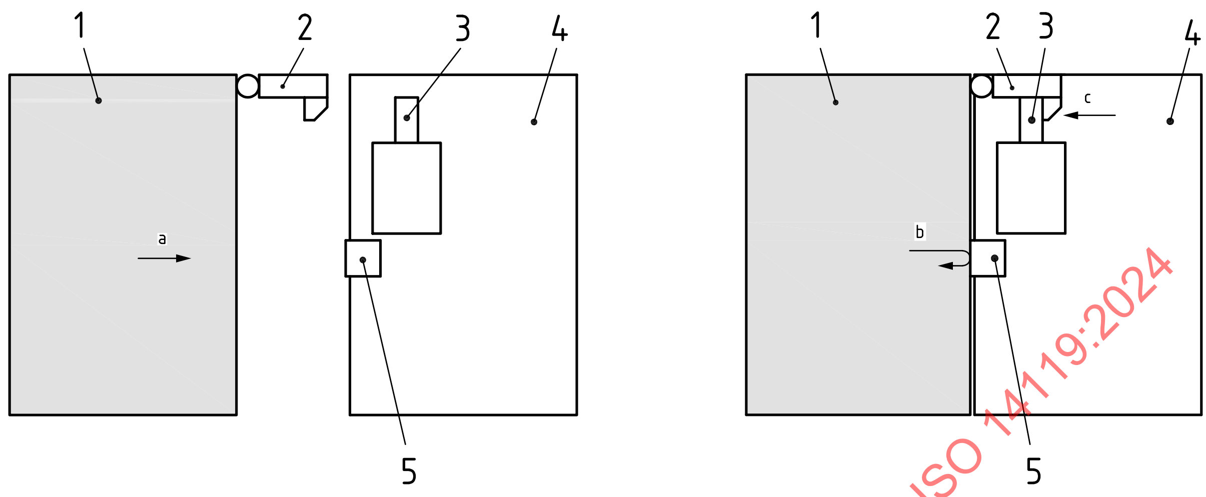
7.2.2 Specific requirements for selection of guard-locking devices

The guard-locking device shall be selected such that the maximum expected force exerted on the guard F_{MAX} in the application (see Annex H) does not exceed the specified locking force, F_{ZH}. Dynamic effects such as bouncing or chattering shall be considered as well.

NOTE 1 A dynamic force occurs when the door is closed and the locking mechanism is already activated (see Figure 7).

If the expected impact reaction forces are higher than the forces the selected device can withstand, then design measures shall be applied to reduce or avoid the impact reaction forces.

When the guard-locking device is intended to be activated automatically when the guard reaches the closed position, the selected guard-locking device shall withstand the resulting mechanical forces.



Key

1 movable guard

2 actuator

3 guard-locking mechanism (lock)

4 fixed part of the guard

5 mechanical stop

a Direction of closing.

b Rebound at mechanical stop.

c Dynamic force expended on locking mechanism.

Figure 7 — Example of a guard-locking device affected by dynamic forces

NOTE 2 It is assumed that the construction of the guard is sufficiently rigid so that it does not impair the guard-locking function (see ISO 14120).

Depending on the design, geometry and orientation of the movable guard, the exerted maximum static forces can result in a higher value on the guard-locking device. Therefore, the integration shall consider the design, geometry and orientation (see Annex H).

NOTE 3 Annex H gives orientation for the maximum static action forces which can be exerted on movable guards.

7.2.3 Selection of supplementary guard-locking releases

Depending on the application, supplementary methods of release can be necessary. These measures can include, but are not limited to:

— an escape release of guard locking according to 6.9.1;

— an emergency release of guard locking according to 6.9.3;

— special design of the guard to allow escape;

— auxiliary release of guard locking according to 6.9.2 can be necessary when it is foreseen that it is necessary to get to the safeguarded space in special situations, e.g. when the locking is power ON released and the power is lost and the guard locking does not have emergency release function.

NOTE An escape release can be used in combination with an emergency or auxiliary release.

7.3 Environmental conditions considerations

7.3.1 General

The technology and type of an interlocking device shall be suitable for the conditions of use (e.g. environmental, hygiene) and for the intended use of the machine. Environmental conditions shall be considered for the selection of the appropriate interlocking device. Criteria are for example:

— temperature;

— dust;

— moisture;

— vibration and shocks;

— substances used in the process (e.g. processed materials, cleaning agents);

— electromagnetic influences.

The interlocking device shall withstand all foreseeable influences during its intended lifetime.

Failure and the possibility of such effects, particularly over time (e.g. induced by corrosion from salts, acids or alkalis like seawater), shall be taken into account. The particular design of the interlock and type of technology used can cause it to be susceptible to the ingress of chemicals or particles. In areas where significant pollution is present, manufacturer's guidance should be sought.

When combining Type 3 or Type 4 interlocking devices using reed contacts together with monitoring logic units, it shall be verified that possible current spikes caused by the monitoring logic unit are not exceeding the admissible limits of the reed contacts.

7.3.2 Influence of dust on Type 2 and Type 5 interlocking devices

If Type 2 or Type 5 interlocking devices are applied, the possible pollution at the mounting location shall be considered. Type 2 or Type 5 interlocking devices can be unsuitable in applications where the ingress of particles, chips or dusts cannot be prevented unless suitable measures (e.g. dust protection cover) are applied.

NOTE The actuator is inserted into the position switch, therefore the position switch has an opening which allows the ingress of dust. The indicated degree of protection IPXX according to IEC 60529 relates exclusively to the electrical enclosure. The pollution of the mechanical parts can result in the degradation of the mechanism and in a dangerous failure of the interlocking device.

7.4 Considerations for the application of trapped key interlocking systems

A key transfer plan shall be designed for each trapped key interlocking system. This transfer plan shall detail the key path. Key coding shall be established based on the safety related specifications.

A Type 5 interlocking device may be operated by two or more differently coded keys or a key may operate two or more differently coded Type 5 interlocking devices. Selection of Type 5 interlocking devices shall be in accordance with Annex K.

8 Design to minimize the motivation to defeat

8.1 System design

Interlocking functions shall be designed such that they cannot be easily defeated (see ISO 12100:2010, 5.5.3.6).

The defeating of interlocking devices makes the protective measure of protective devices inoperative and therefore can increase significantly the risk of harm. As far as practicable, protective measures shall take such foreseeable misuse into account.

The interlocking device shall provide the minimum possible interference with activities during operation and other phases of machine life, in order to reduce any incentive to defeat it:

— easy operation of the machine, in particular during maintenance and service operations;

— failure-free operation of functionality of a machine.

8.2 Methodology procedure

The following procedure shall be followed:

a) Implement the basic measures described in 6.2, 6.3, 6.5, 6.6.4.3 and 7.2.

Type 3 interlocking devices shall not be used unless the device cannot be defeated in a reasonably foreseeable manner.

b) Check whether the motivation to defeat the interlocking devices in a reasonably foreseeable manner exists.

NOTE 1 Considering experience of use of similar machines is helpful, see ISO 12100:2010, 5.2 c).

NOTE 2 Table G.1 can be used for guidance to evaluate or eliminate, or both, the motivation to defeat interlocking devices.

c) Check whether the motivation to defeat the interlocking device can be eliminated or minimized by either:

— design measures; or

— appropriate operating modes, or both.

The implementation of appropriate operating modes shall have precedence.

NOTE 3 The implementation of appropriate operating modes can avoid the motivation to defeat. Appropriate operation modes can be, for example, special modes for setting, tool changing, fault finding, maintenance or process observation. They depend highly on the type of machine and its application and cannot be covered comprehensively in this document. A type-C standard describing operating modes can also be used instead of Annex G to find out about appropriate modes of operation.

NOTE 4 See ISO 12100:2010, 6.8.

d) If foreseeable motivation for defeat continues to exist, additional measures are required (see 8.3).

Figure 8 provides a schematic representation of the methodology for determining the possible incentive and the required measures done by the machine manufacturer.

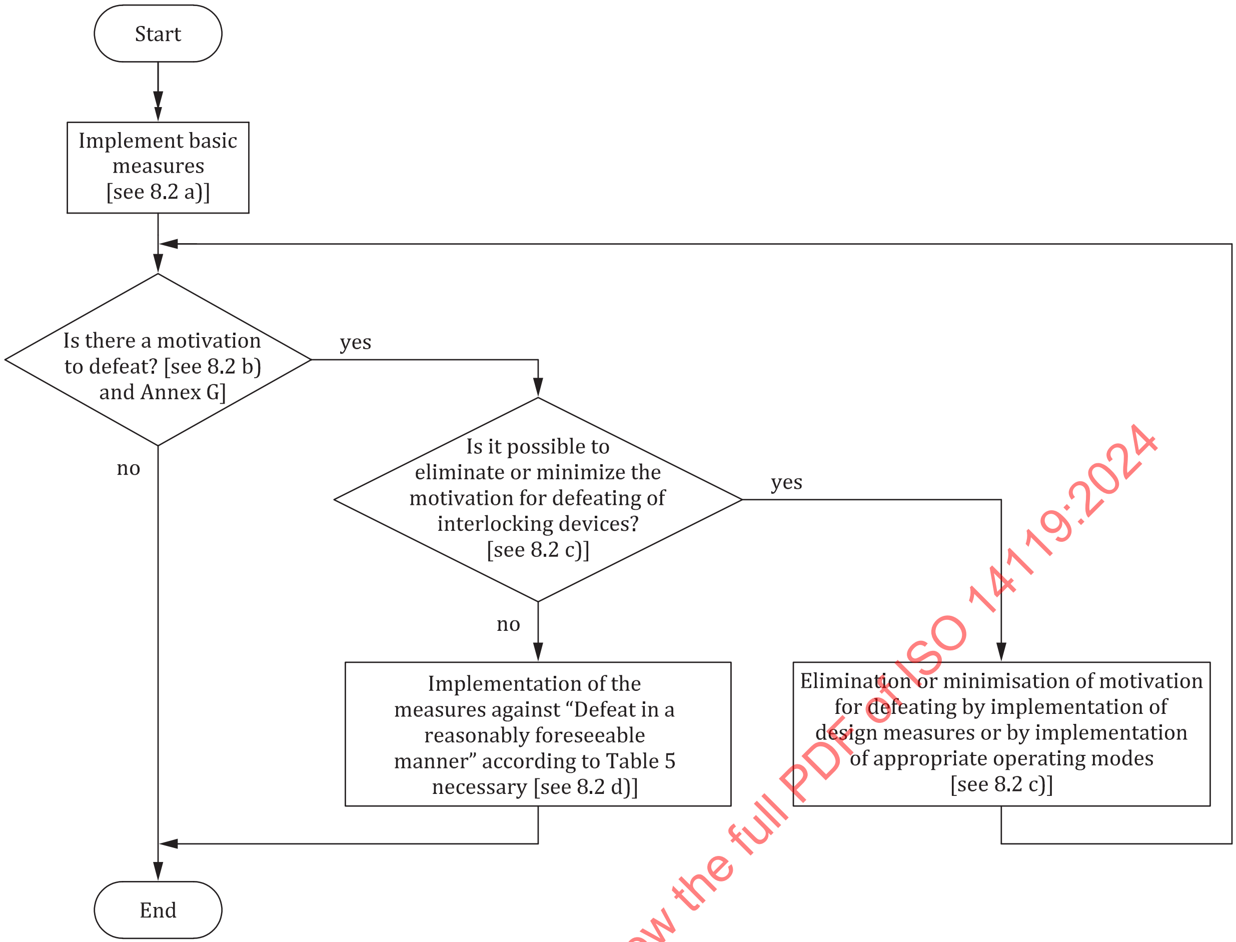


Figure 8 — Methodology for determining the possible incentive to defeat interlocking devices and the required measures to be applied by the integrator

8.3 Additional measures to minimize possibility of defeat

This subclause presents possible measures against defeat in a reasonably foreseeable manner. For requirements and applicability, see Table 5.

a) Restrict access to the elements of the interlocking device:

NOTE 1 The term restrict is used to express a certain physical hindrance but not to restrict the access to a certain group of persons.

1) mounting out of reach (see Figure 10);

2) physical obstruction or shielding (see Figure 9);

3) mounting in hidden position, under consideration of 6.2 d);

b) Limit substitute actuation of the interlocking device by readily available objects by use of:

1) low-level coded actuators;

2) medium-level coded actuators;

3) high-level coded actuators;

c) Prevention of dismantling or de-positioning of the elements of the interlocking device by use of non-detachable fixing;

EXAMPLE Considered as non-detachable fixing in this context are:

— welding;

— gluing (strong enough that requires at least heat or chemical agent to be removed) of the thread;

— one-way screws;

— riveting;

— wear out the slots of the head of screws to prevent their removal;

— filling (with plastic, resin, coverages or caps removable only by destruction or a metal ball) the opening of bolts and screws.

Not considered as non-detachable in this context are:

— screws and bolts with hexalobular socket or similar and a pin in the opening, because tools for these screws are readily available, except when the pin has been bent after installation;

— use of easily detachable blocking substances, e.g. caps, wax, tamper proof labels;

NOTE 2 Use of non-detachable fixing can be an inappropriate solution in cases where a failure (or e.g. replacement due to wear) of the interlocking device during lifetime of the machinery can be expected and a fast change is necessary. In this case other measures, e.g. a), b) and d), are more appropriate.

d) Minimize possibility of defeat:

1) integration of defeat monitoring in the control system by means of:

i) status monitoring;

ii) cyclic testing;

NOTE 3 In i) the control system for instance expects the opening of a door in a defined machine cycle. The absence of the control signal indicates a defeat.

NOTE 4 In ii), cyclic testing, the operator is requested by the control system to actuate the safeguard. The absence of the expected control signal indicates a defeat.

2) checking for plausibility using different actuation principles which require an additional action for defeating.

NOTE 5 Different actuation principles means than one position switch is actuated by direct mechanical action while the other is not.

NOTE 6 In this context, checking for plausibility means checking that both interlocking devices are reacting in a predefined manner.

Table 5 — Additional measures in case forseeable motivation for defeat continues to exist depending on type of interlocking devices

Principles and measures	Reference	Type 1 Not hinged	Type 1 Hinged	Type 2 Low/ medium coded	Type 2 High coded	Type 3	Type 4 Low/ medium coded	Type 4 High coded	Type 5 Low/ medium coded	Type 5 High coded
Additional interlocking device and plausibility check	8.3 d) 2)	R		R		R	R		X	
Mounting out of reach (see Figure 10)	8.3 a) 1)	X		X		X	X			
Physical obstruction/ shielding	8.3 a) 2)								X	
Mounting in hidden position	8.3 a) 3)									
Status monitoring or cyclic testing	8.3 d) 1)								X	
Non-detachable fixing of the actuator	8.3 c)			M	M		M	M	M	M
Non-detachable fixing of the interlocking device	8.3 c)			R	R		R	R	R	R
Non-detachable fixing of the interlocking device and the actuator	8.3 c)	X	M							

NOTE

– The medium coded actuator from Type 5 can be treated as high coded provided duplicate coded actuators are not readily available.

– If duplicate medium-level coded actuators are available on one site, they are treated as low-level coded actuators for this table.

– For trapped key interlocking systems, this table applies to access locks and bolt locks only.

– For switching devices with an electrical connection providing a safe state upon dismounting or disconnection, the non/detachable fixing is not required.

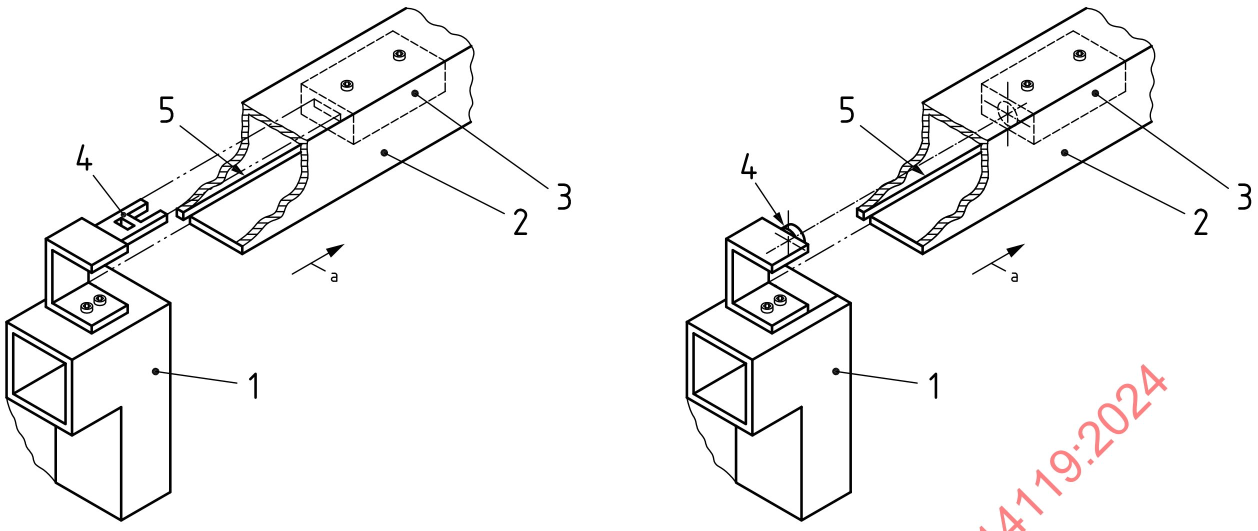
– This table is intended to be used for the selection of appropriate measures against defeating of interlocking devices. According to the risk assessment the application of more than one of the indicated measures can be necessary.

Key

X at least one of the measures

M mandatory measure

R recommended measure based on an assessment on the motivation for defeat (see Annex G)



a) Type 2 interlocking device

b) Type 3 or Type 4 interlocking device

Key

1 sliding guard (not closed)

2 cover (fixed part)

3 position switch

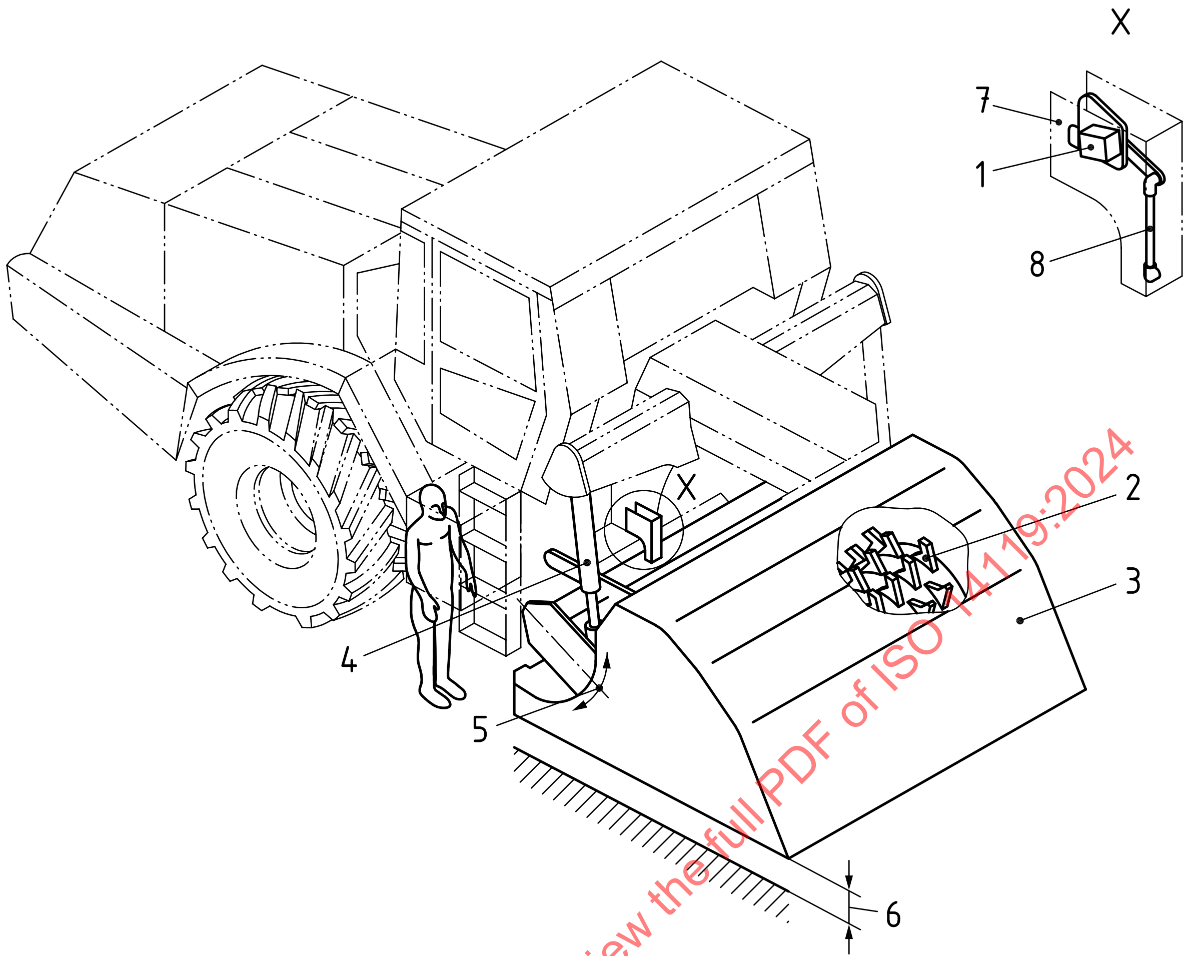
4 actuator

5 slot

[a] Direction of closing.

NOTE Defeating of the interlocking device is made difficult by the cover (2), or by the presence of the guard in front of it.

Figure 9 — Examples of protection against defeating by physical obstruction or shielding



Key

1 hinge position switch
2 rotor (hazardous tool)
3 guard
4 lifting gear of the guard
5 moving direction of the guard
6 process dependent height over ground
7 cover attached to frame
8 actuation coupling

Figure 10 — Example of protection against defeating of a torsion angle operated interlocking device by mounting out of reach at a machine for road construction

8.4 Additional measures to minimize possibility of defeat for Type 5 devices

8.4.1 General

The following specifics apply to trapped key interlocking devices. It is important to note that none of these issues affect the performance level (PL or SIL) and are only of consideration in cases where motivation to defeat the interlock exist.

NOTE There is a clear distinction between the coding of keys and the coding of actuators in a trapped key system (see K.1.1.2 and 8.3).

8.4.2 Key retention

In order to prevent the key from being easily removed from the Type 5 interlocking device in the trapped position it shall not be possible to remove the key out of the Type 5 interlocking device with a force less than 250 N.

All of the parts that are intended for blocking the key, including the key itself, shall be able to withstand a torque of at least 5 Nm applied to the key.

Furthermore, at torque values greater than 5 Nm, it shall be ensured that the key does not shear out of the device resulting in a loss of the safety function (e.g. through design features such as predetermined breaking points).

8.4.3 Reproduction of keys

Keys for Type 5 interlocking devices shall be designed in a way that they are not easily reproducible (for example with hand tools or a locksmith), other than by the original device manufacturer.

Consideration shall be given with regards to the processes that allow the ordering of spare keys.

9 Requirements for the control system

9.1 General

Interlocking devices with or without guard locking are safety-related parts of the control system (SRP/CS) of a machine (see ISO 13849-1) or a subsystem or a subsystem element of a safety-related electrical control system (SCS) (see IEC 62061) with the purpose to prevent hazardous situations.

An interlocking guard is able to fulfil several independent safety functions:

— stop function when opening the guard;

— prevention of unintended start-up while the guard is not closed (see ISO 14118:2017, Clause 6).

Interlocking guards with guard-locking function are able to fulfil several independent safety functions:

— release of the guard-locking device according to 9.3;

— stop function when releasing the guard-locking device;

— prevention of unintended start-up while the guard is not closed and locked (see ISO 14118:2017, Clause 6).

According to ISO 13849-1:2023, 5.1 and IEC 62061:2021, 5.2.5, a risk estimation shall determine the required PL or SIL for each safety function that shall be carried out.

Where an interlocking system requires PL e in accordance with ISO 13849-1, a designated architecture of category 3 or 4 is required. Where SIL 3 in accordance with IEC 62061 is required, a minimum hardware fault tolerance (HFT) of 1 is required. These requirements can be achieved, e.g. by implementing two Type 1 interlocking devices, or by using a single PL e device that displays the relevant category behaviour.

NOTE 2 Examples of interlocking devices realised in several architectures are given in Annex F.

9.2 Assessment of faults and fault exclusions

9.2.1 Assessment of faults

For applications using interlocking devices with automatic monitoring to achieve the necessary diagnostic coverage (DC) for the required safety performance, a functional test (see ISO 13849-1 and IEC 62061) can be carried out every time the device changes its state, e.g. at every access. If, in such a case, there is only infrequent access, the interlocking device shall be used with additional measures because, between consecutive functional tests, the probability of occurrence of an undetected fault is increased. If, for detecting of a fault, a manual test (e.g. opening of a guard) is necessary, but frequency of access to the safeguarded area is seldom, the following intervals shall be chosen:

— at least every 12 months for PL d with Category 3 or 2 (according to ISO 13849-1) or SIL 2 with HFT = 1 (according to IEC 62061).

— at least every 1 month for PL e (according to ISO 13849-1) or SIL 3 (according to IEC 62061).

The control system of the machine should demand these tests at the required intervals, e.g. by visual display unit or signal lamp. If implemented, the control system shall monitor the tests and stop the machine if the test is omitted or fails.

9.2.2 Fault exclusion

9.2.2.1 General

Possible fault exclusions shall be evaluated separately for mechanical, hydraulic, pneumatic and electrical systems, taking into account the environmental conditions and external influences to be expected.

Fault exclusions shall only be applied where devices are used within the limits specified by the manufacturer (see 10.2).

Fault exclusions shall be in accordance with ISO 13849-1:2023, 10.1.4 or IEC 62061:2021, 7.3.3.3.

The requirements for fault exclusion shall be maintained during the lifetime (mission time of a device), taking into account influences, e.g. wear, sub-surface defects and fatigue of mechanical parts, which degrade the properties of a device.

NOTE 1 Sub surface defects of parts are, e.g. cavities, inclusions and porosity.

Fault exclusion on mechanical parts shall be based on the technical improbability of occurrence of such faults. The improbability of these faults shall be justified based on FMEA and according to 9.2.2.2 to 9.2.2.6.

To reach PL e or SIL 3, an interlocking function shall not rely entirely on fault exclusions. In case of a fault exclusion for interlocking functions intended to reach PL e or SIL 3, the interlocking device shall exhibit a dual channel structure or a category 4 behaviour to the majority of its architecture. Individual parts in the architecture of an interlocking device may be of single channel structure. If it can be proven that the single channel part cannot fail before other dual channel parts, e.g. through over dimensioning, a fault exclusion is permissible and will not limit the PL or SIL.

NOTE 2 For more information, see 6.4.

9.2.2.2 Mechanical fault exclusions for Type 1 interlocking devices

For Type 1 interlocking devices, fault exclusion for their mechanical parts shall not be applied.

An interlocking system applying Type 1 interlocking devices and requiring PL e in accordance with ISO 13849-1 or SIL 3 in accordance with IEC 62061, shall be implemented by the integration of an additional interlocking device of any of the Types 1 to 4.

9.2.2.3 Mechanical fault exclusions for Type 2 interlocking devices without guard locking

For Type 2 interlocking devices, the following faults of their mechanical parts can be excluded: damage (breaking) and wearing of the actuator and the actuating system due to misalignment, only if additional mechanical alignment elements prevent the actuation of the position switch outside the limits of misalignment specified by the manufacturer.

The additional mechanical alignment elements shall be designed and constructed as to be effective when subjected to a load equal to two times the maximum force expected during the operation of the guard for the intended lifetime (mission time) of the interlocking device.

NOTE For additional information on maximum forces see Annex H.

Where not all mechanical faults can be excluded, an interlocking system applying Type 2 interlocking devices and requiring at least PL d in accordance with ISO 13849-1 or SIL 2 in accordance with IEC 62061 shall be implemented by the integration of an additional interlocking device of any of the Types 1 to 4. Application of diversity is recommended.

9.2.2.4 Mechanical fault exclusions for Type 3 and Type 4 interlocking devices without guard locking

For Type 3 and Type 4 interlocking devices, fault exclusion for their mechanical parts is only applicable for the fastening of the position switches and the actuators. The fastening shall be in accordance with 6.2 and 6.3 and with the manufacturer's specification.

NOTE At certain mounting positions of the actuator, the failure of the fastening can lead to the immediate actuation of the interlocking device.

9.2.2.5 Mechanical fault exclusions for guard locking

It shall be ensured that the specified locking force, F_{ZH}, (see 6.6.2) of the guard-locking device is sufficient to withstand static forces on the locking element (bolt) and that shearing forces on the locking element by bouncing of the movable guard are prevented.

NOTE 1 A means to mitigate such effects due to bouncing is a locking element that does not move into the engaged position before the movable guard is closed and stationary, e.g. by time delay between closing the door and switching-off the voltage to the locking solenoid.

For guard locking, the following faults of their mechanical parts can be excluded.

Damage (breaking) and wearing of the actuator and the locking element (bolt) due to misalignment or excessive forces, only if additional mechanical alignment elements prevent that forces exerted on these elements exceed the limits of misalignement specified by the manufacturer. The additional mechanical alignment elements shall be designed and constructed as to be effective when subjected to a load equal to two times the force limits for the guard-locking mechanism specified by the manufacturer during the intended lifetime (mission time) of the guard-locking device.

NOTE 2 Intended lifetime means influence from, e.g. environment, aging, but not a specific number of cycles to withstand the load.

Alternatively, this mechanical fault exclusion is not required if the following is achieved:

Breakage of locking means shall be detected at the next opening of the guard when the locking function is activated. This shall lead to an immediate stop command and the restart is not possible until the locking means are restored. The subsystem detecting the breaking of the locking means shall be in conformity at least with the requirements of PL c or SIL 1.

NOTE 3 The proper resetting of the fault can be achieved by disabling the reset of the interlocking function in the SRP/CS until a proper signal sequence from the guard and the locking element monitoring according to 6.6.3.2 is detected.

9.2.2.6 Fault exclusions for Type 5 interlocking devices

In ISO 13849-1, the concept of redundancy is used, particularly in electrical/electronic systems whereby SRP/CS in two channels are monitored by the control system. Monitoring is used to determine when a channel has failed and initiated the control system to bring the machine to a stop. This designated dual channel architecture is used in category 3 and 4 systems.

In Type 5 interlocking devices, a single channel architecture in accordance with ISO 13849-1 is typically used for the mechanical parts, and the detection of their faults by the control system is not always possible. All possible faults shall be evaluated and any dangerous failure modes shall either be eliminated or proven to be technically improbable (highly unlikely). This can be achieved by over-dimensioning of critical parts. Over-dimensioning shall be validated (e.g. by calculation or by proof testing).

Parts designed with intentionally weak points may be used to create safe failures in order that other critical parts are not exposed to high loading and, therefore, cannot fail dangerously, e.g. a key designed to break at a low force (safe failure) prevents damage to the lock if an attempt is made to force the key to override the locking mechanism.

For Type 5 interlocking devices, systems according to category 3 and 4 of ISO 13849-1 or HFT1 according to IEC 62061 shall be achieved by one of the following:

a) by implementing two interlocking devices;

b) by single channel interlocking devices providing they achieve the relevant category behaviour. Non-mechanical aspects of trapped key interlocking system shall be in accordance with the category requirements as specified in ISO 13849-1:2023;

NOTE 1 The behaviour of a category does not necessarily include the designated architecture, but the definition of the category.

NOTE 2 Where all dangerous faults are proven to be technically improbable, detection is not applicable.

NOTE 3 Where faults are proven to be technically improbable, “continued performance of the safety function in the presence of a single fault” is assumed.

c) by single channel interlocking devices providing that all possible faults are evaluated and that any dangerous failure modes are either eliminated or proven to be technically improbable (highly unlikely) as follows:

If all single faults that cause a loss of the safety function are excluded, category 3 behaviour may be assumed and a DC is not necessary. Because there is no occurrence of faults that can lead to loss of the safety function, a maximum performance level (PL) = d may be assumed for the entire system. Non-mechanical aspects of trapped key interlocking system shall be in accordance with the category requirements as specified in ISO 13849-1:2023.

For systematic failures, ISO 13849-1:2023, Annex G, is applicable and requirements to avoid systematic failures relating to key coding (see K.1.1.2 and 8.4.3) shall be followed.

In addition to the permissible fault exclusions according to ISO 13849-2:2012, Annexes A, B, C and D, the presumption of breakage and deformation faults for safety relevant mechanical components (except for springs) can be excluded if:

— a safety factor of 4 compared to the expected forces is verified by calculation or suitable testing; or

— a safety factor of 2 compared to the expected forces is verified by calculation or suitable testing and if the quality of safety-relevant mechanical components is verified by means of continuous quality assurance measures.

In order to achieve performance level e (PL e), category 4 behaviour is required. In particular, an accumulation of faults does not lead to the loss of the safety function and the consideration of a fault combination of two faults is sufficient (unless three or more faults are reasonably foreseeable).

NOTE 4 Typically, this is achieved by ensuring that, if a fault occurs, the device or the system is rendered inoperable and, therefore, prevents access to a hazardous zone or the restart of a machine.

In cases where a single fault cannot be excluded, which in itself does not cause a failure to danger, the tests for no failure to danger shall be continued with the fault applied first and all other faults added and removed in turn. Tests shall be carried out for all non-excluded single faults. Testing for the accumulation of faults may be limited to two faults in combination, when:

— the fault rates are low;

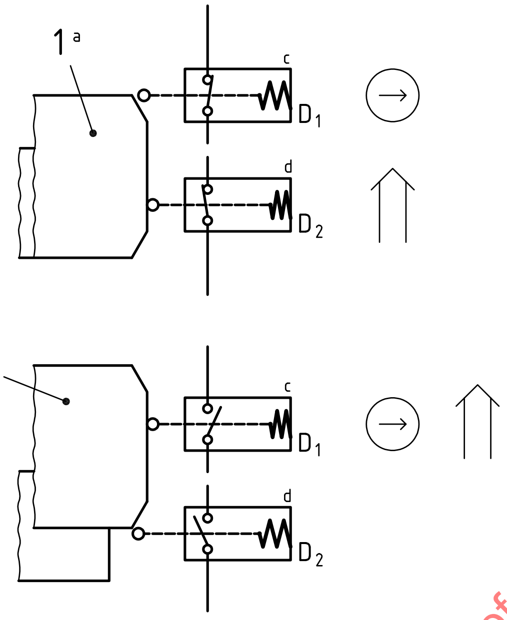
— the faults in combination are independent of each other;

— the loss of the safety function occurs only when the faults appear in a certain order.

9.2.3 Examples for measures to prevent common cause failures through direct and non-direct mechanical action of the position switches of Type 1 interlocking devices

The use of direct and non-direct mechanical action of the position switches of Type 1 interlocking devices is commonly used to prevent CCFs.

Figure 12 shows the combination of direct and non-direct mechanical action of the position switches of Type 1 interlocking devices.



Key

1	guard	a	Closed.
D_1	position switch (NC)	b	Not closed.
D_2	position switch (NO)	c	Direct mechanical action.
		d	Non-direct mechanical action.

⇑ switch actuated

(→) direct opening action

Figure 12 — Avoiding common cause failure (CCF) of two mechanically actuated position switches by using associated direct and non-direct mechanical action

Typical causes for failure Type 1 interlocking devices are:

a) excessive wear of the actuating system (e.g. plunger or roller) or of the actuator attached to the guard;

b) misalignment between actuator and position switch;

c) jamming of the actuating system (plunger) making actuation by the spring impossible.

In case of a failure of D_1 or D_2, breaking of the circuit is ensured by the other position switch. Position switches with direct mechanical action, as D_1, fail to danger in case a), but not in case c). It can fail to danger in case b) depending on the misalignment. Position switches with non-direct mechanical action, as D_2, fail to danger in case c), but not in case a). It can fail to danger in case b) depending on the misalignment.

If two position switches of Type 1 interlocking devices using associated direct and non-direct mechanical action, are applied, diversity may be claimed for the quantification of common cause failure (CCF) according to ISO 13849-1 for this subsystem.

NOTE This can also be achieved by one mechanically actuated position switch and one non-mechanical actuated position switch.

9.2.4 Energy source diversity

In order to minimize the probability of CCF, two independent interlocking devices, each of which interrupts the supply from a different energy source, may be associated with a guard (see example given by Figure A.6).

EXAMPLE A machine uses hydraulic components to apply the necessary forces to run the production process while the machine control is electrically/electronically driven. The opening of an interlocked movable guard initiates two independent position switches. The first position switch directly operates a hydraulic valve which interrupts the hydraulic pressure. The second position switch interrupts the control voltage which operates another valve. Either valve causes the hazardous motion to cease. Due to different technologies applied, there is no CCF possible that would cause both position switches to fail dangerously.

9.3 Release of guard-locking device

For the release of a guard-locking device, all of the following devices are part of the SRP/CS:

— devices applied to detect the release conditions (e.g. speed or position monitoring, time delay);

— devices applied to process the logic signals;

— devices applied to unlock the guard.

NOTE 1 For an explanation, see Figure F.2.

NOTE 2 The PL or SIL is dependent on the application-specific risk assessment. In most cases, the PL or SIL of the guard-locking function is lower than the PL or SIL of the interlocking function. The probability of the malfunction of the guard-locking function at the same time as the access of a person usually is very low. For the guard-locking function, even in case PL e fault exclusions for the mechanical parts are possible (see 9.2.2 and ISO 13849-2:2012, Annex A), ISO 13849-2:2012, Table D.8, does not apply to the guard-locking elements (e.g. locking bolt), since it is only relevant for position switches.

If elapsed time between detection of an unintended unlocking of the guard-locking device and reaching a safe condition of the machine can result in a hazardous situation and risk reduction by a safety function for guard locking is necessary, then all devices providing the unlocking and locking signal shall be considered part of the SRP/CS.

9.4 Series connection of electro-mechanical interlocking devices

When interlocking devices with redundant contacts are connected in series, the detection of a single fault can be masked by the actuation of any interlocking device connected in series with the defective interlocking device to the safety-related control system.

It is foreseeable that one of the guards whose interlocking devices are connected in series with a defective interlocking device is actuated. In that case, the fault is masked and the effect on the DC value shall be considered in accordance with Annex J.

For a series connection, the maximum DC (see ISO 13849-1 or IEC 62061) shall be considered.

9.5 Electrical and environmental conditions

9.5.1 General

Electrical interlocking devices shall be in accordance with IEC 60204-1:2016+AMD1:2021.

When the devices are foreseen to be used outside the environmental limits stated in IEC 60204-1:2016+AMD1:2021, the interlocking devices shall be selected such that they meet the foreseeable environmental conditions.

9.5.2 Performance considerations

Power interlocking devices to isolate electric power shall have suitable current breaking capacity, taking into account all foreseeable situations (e.g. overload).

9.5.3 Immunity from disturbance

Proximity switches and magnetic switches shall be selected and used so that foreseeable external electrical, magnetic or electromagnetic fields do not impair their function.

9.5.4 Electrical operating conditions

When electronic components are used in interlocking devices, necessary precautions shall be taken to prevent malfunction caused by, e.g. voltage fluctuations, transient overvoltage.

9.5.5 Clearances and creepage distances

Clearances and creepage distances between adjacent electrical components of interlocking devices shall be in accordance with IEC 60947-1:2020, 8.1.4.

10 Information for use

10.1 General

An interlocking device can be:

a) manufactured and placed on the market as a complete device or system ready for use; or

b) designed and manufactured by the machine manufacturer using available separate components.

Therefore, there are different requirements for the information for use that apply to the manufacturer of the machine or the manufacturer of interlocking devices.

10.2 Information for use given by the manufacturer of interlocking devices

10.2.1 Marking

The marking shall be in accordance with ISO 12100:2010, 6.4. Where this is not practicable due to space restrictions, the full address of the manufacturer and the designation of the device type shall be stated in the instruction for use and the device shall be clearly marked with the manufacturers name or logotype.

Furthermore, interlocking devices designed and constructed for use in a potentially explosive atmosphere shall be marked accordingly.

The marking for locking monitoring in accordance with 6.6.1, 6.6.3.2 and 6.6.4.2 shall be with the symbol according to Figure 13.

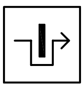


Figure 13 — Symbol for locking monitoring of locking elements

The marking shall be sufficient to identify the document containing the information for use according to 10.2.2 or 10.3, as appropriate.

NOTE The aim of the marking is to identify the manufacturer and to show the intended functionality of the component (e.g. type or symbol for direct opening action), see IEC 60947-5-1:2016+COR1:2016, K 2.2, and for the explanation of the symbols, see Figure 13.

10.2.2 Instructions

The manufacturer of the interlocking device shall indicate the following in the instructions:

a) the business name and full address of the manufacturer and, where applicable, the authorized representative;

b) designation of the interlocking device;

c) designation of series or type;

d) a general description of the interlocking device;

e) the drawings, diagrams, descriptions and explanations necessary for the use, maintenance and repair of the interlocking device and for checking its correct functioning;

f) a description of the intended use of the interlocking device;

g) assembly, installation and connection instructions, including drawings, diagrams and the means of attachment of the interlocking device;

h) instructions for putting into service and use of the interlocking device and, if necessary, instructions for the training of operators;

i) description of adjustment and maintenance operations that should be carried out by the user and the preventive maintenance measures that should be observed;

j) instructions designed to enable adjustment and maintenance to be carried out safely, including the protective measures that should be taken during these operations;

k) any data necessary for the manufacturer of the machine to determine PL or SIL for the intended safety function(s);

and, where relevant:

l) warnings relating to reasonably foreseeable misuse;

m) warning that the device itself does not contain reset facilities for emergency and auxiliary release of guard locking and that additional measures are required to achieve it (see 6.9.2 and 6.9.3);

n) specified locking force, F_{ZH}, according to I.1;

o) range of actuation movement;

p) specifications of the spare parts to be used, when these affect the health and safety of operators;

q) the maximum impact energy withstand value in Annex I, if the device can be used as a mechanical stop;

r) the maximum peak current and voltage of the output system of the position switch;

s) information that it should not be possible to reach the manual actuator of the escape release from outside the safeguarded space or that additional measures should be taken to reduce the risk of improper activation;

t) where interlocking systems rely on actuators, advice shall be given in the instruction handbook concerning risks associated with the availability of spare actuators and that any spare actuators should be securely controlled. This also includes reset keys for emergency and escape release;

u) the level of coding (low, medium, high) for coded interlocking devices (Type 2, Type 4 or Type 5);

v) all fault exclusions shall be listed (see 9.2);

w) warning if a locking force monitoring function is not provided by the electromagnetic guard-locking device itself.

In addition, the following shall be provided for Type 5 devices:

x) the information for use shall contain information to prevent unintentional duplication of key codes;

Use of a register, database or other means of recording key codes is highly recommended. The register or database can be controlled by the trapped key manufacturer, the machine builder or the user. Where the manufacturer or machine builder controls the register, special care is important when selling through third parties (such as distributors) to ensure the final location of the lock and key is known. A key coding register per location and organization is recommended.

y) the information for use shall give advice that special consideration shall be given to the application of trapped key systems to mobile machinery and secondhand equipment to prevent unintended key duplication.

NOTE This can be achieved by checking the new codes against the key code register and adding them to the register.

10.3 Information for use given by the manufacturer of the machine

The manufacturer of the machine shall include the relevant information of 10.2.2 regarding the interlocking devices. For trapped key interlocking systems, information for use of the machine shall include the key transfer plan. When spare keys or master keys are provided, information for management and use shall be provided in the operating manual.

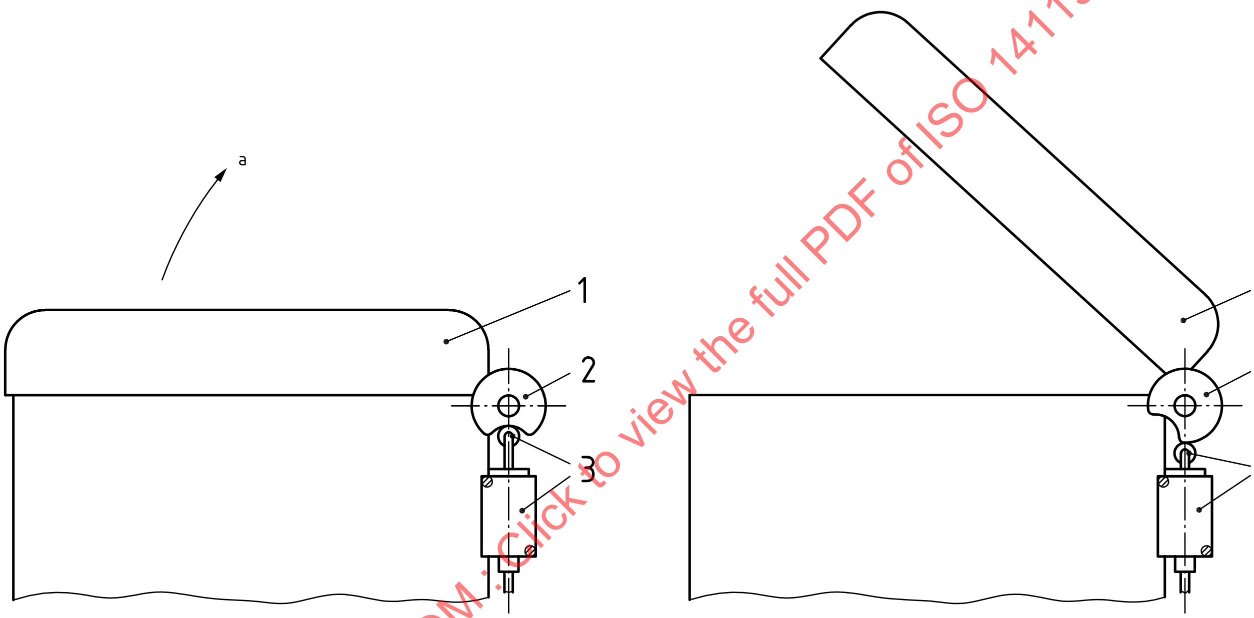
Annex A
(informative)

Type 1 interlocking device — Examples

A.1 Rotary cam

A.1.1 Description

One single Type 1 interlocking device, with position switch actuated in direct mechanical action, monitors the position of the movable guard (see 6.4 and Figure A.1).



a) Movable guard closed **b) Movable guard not closed**

Key

1 movable guard
2 actuator (cam)
3 position switch
a Opening direction.

Figure A.1 — Type 1 interlocking device with rotary cam actuated position switch

A.1.2 Typical characteristics

— Direct mechanical action of the actuator (rotary cam) (2) on the actuation system of the position switch (3);

— possibility for direct opening action of the NC contact of the position switch due to direct mechanical action;

— impossible to defeat by manually operating the actuation system without removing rotary cam or position switch.

Fails to danger in case of:

— failure of the mechanical link between guard and position switch (wear or breaking of the actuator);

— misalignment between the position switch and the rotary cam.

A.1.3 Remarks

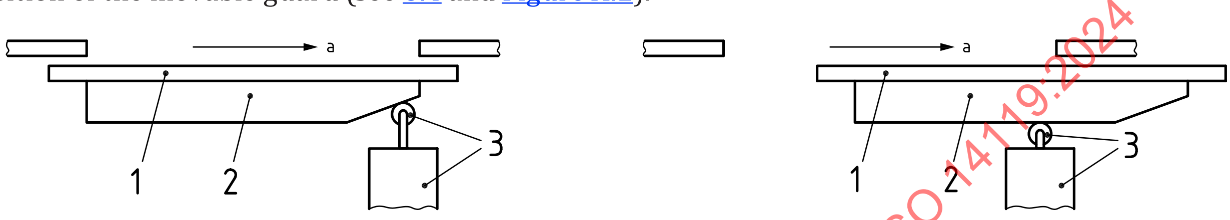
As the absence of the movable guard is not detected, it is essential that the guard cannot be dismantled without tools (see also 6.2 and 6.3).

NOTE For assessment of faults and fault exclusion, see 9.2.

A.2 Linear cam

A.2.1 Description

One single Type 1 interlocking device, with position switch actuated in direct mechanical action, monitors the position of the movable guard (see 6.4 and Figure A.2).



a) Movable guard closed

b) Movable guard not closed

Key

1 movable guard

2 actuator (cam)

3 position switch

a Opening direction.

Figure A.2 — Type 1 interlocking device with linear cam actuated position switch

A.2.2 Typical characteristics

— Direct mechanical action of the actuator (linear cam) (2) on the actuation system of the position switch (3);

— possibility for direct opening action of the NC contact of the position switch due to direct mechanical action (see 3.7);

— impossible to defeat by manually operating the actuation system without removing linear cam or position switch.

Fails to danger in case of:

— failure of the mechanical link between guard and position switch (wear or breaking of the actuator);

— misalignment between the position switch and the linear cam.

A.2.3 Remarks

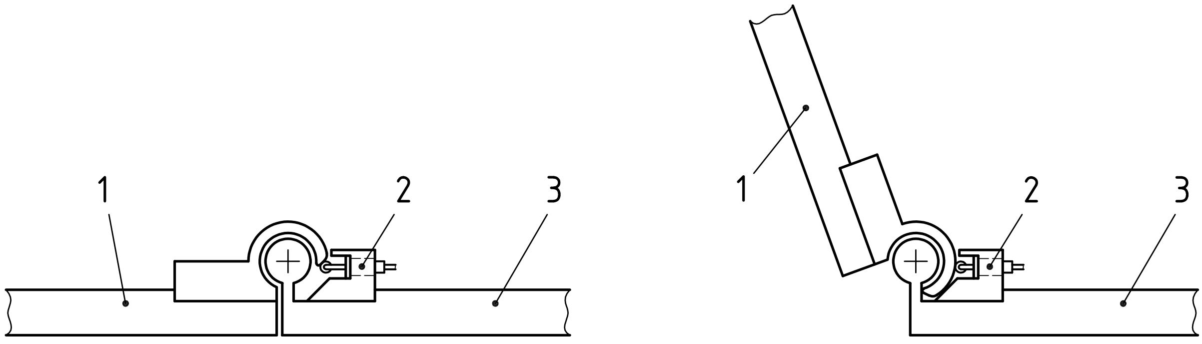
As the absence of either the movable guard or actuator, or both, is not detected, it is essential that either the guard or actuator, or both, cannot be dismantled without tools (see also 6.2 and 6.3).

NOTE For fault exclusion, see 9.2.2.

A.3 Hinge

A.3.1 Description

One position switch is mounted into a hinge (see Figure A.3).



a) Movable guard closed

b) Movable guard not closed

Key

1 movable guard

2 hinged interlocking device

3 fixed part of guard

Figure A.3 — Hinged interlocking device

A.3.2 Typical characteristics

— Direct mechanical action of built-in position switch;

— impossible to defeat without dismounting;

— works as hinge for a movable part of a guard;

— adjustment of switching point has to be accurate and therefore can be unsuitable for wide movable guards;

— only usable for hinged movable guards.

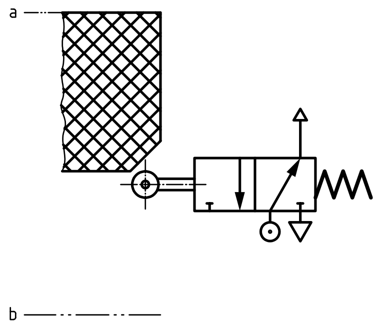
A.3.3 Remarks

As the absence of the movable guard is not detected it is essential that the movable guard and the hinged position switch cannot be dismounted without tools.

A.4 Pneumatic/hydraulic interlocking devices

A.4.1 Examples

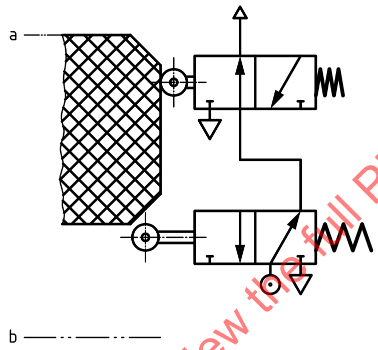
Examples of pneumatic/hydraulic interlocking devices are shown in Figures A.4 to A.6.



a Closed.

b Not closed.

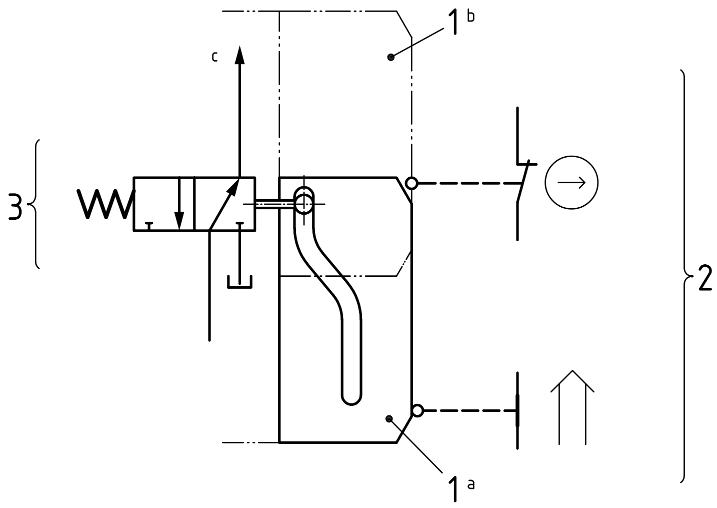
Figure A.4 — Single valve (output system) with direct-mechanical action of single valve by movable guard



a Closed.

b Not closed.

Figure A.5 — Two valves (output system)



Key

1ᵃ movable guard closed

1ᵇ movable guard not closed

2 independent interlocking device that acts on electrical control circuit (with automatic monitoring)

3 independent interlocking device that acts on hydraulic circuit (power interlocking, see 9.5.2) when direct interruption of power circuit possible

[c] To machine actuators.

Figure A.6 — Hybrid (electrical and hydraulic) interlocking device

A.4.2 Remarks

A hybrid interlocking device is particularly interesting in very severe environmental conditions which can induce CCFs (i.e. simultaneous failures having the same cause) of components with the same technology, e.g. melting of the insulating layer of conductors on a machine working under hot conditions, or simultaneous failure of two proximity detectors under the effect of electric or electromagnetic interference.

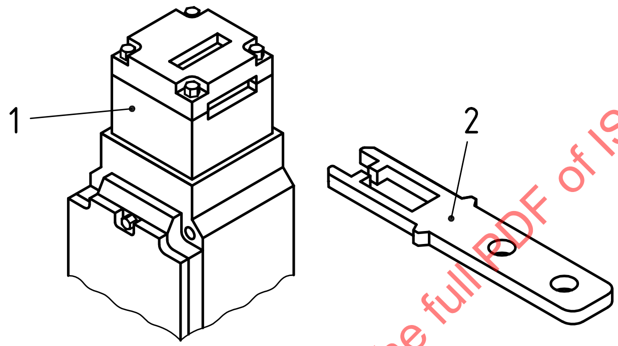
Annex B
(informative)

Type 2 interlocking device — Examples

B.1 Tongue-actuated position switch

B.1.1 Description

A single Type 2 interlocking device, with position switch actuated by direct mechanical action, monitors the position of the movable guard (see Figure B.1 and Figure B.2).



Key

1 position switch

2 actuator (shaped tongue)

Figure B.1 — Position switch with coded tongue actuator

B.1.2 Typical characteristics

— Easy principle for integrated guard-locking devices;

— especially suitable for use on the opening edge of a movable guard;

— direct mechanical action between guard, actuator and actuating system;

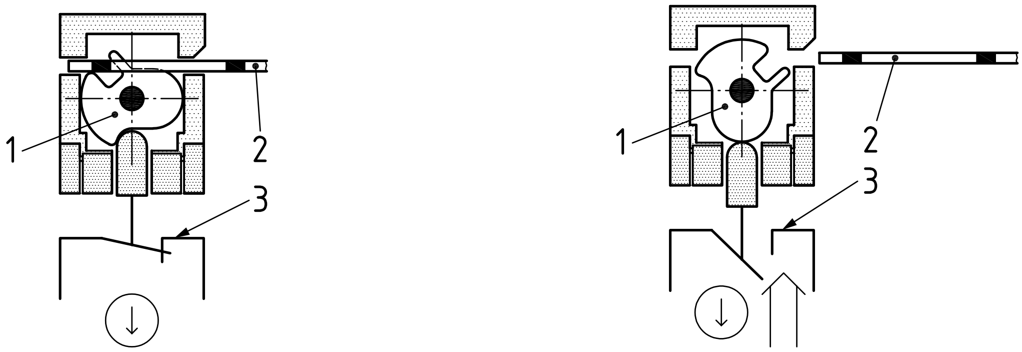
— possibility for direct opening action of the NC contact of the position switch due to direct mechanical action;

— depending on the level of coding, additional measures against defeating can be required;

— can be damaged due to misalignment during the machine life cycle;

— can be degraded by pollution;

— impact from actuator can cause harm to persons.



a) Movable guard closed

b) Movable guard not closed

Key

1 internal rotating cam position

2 tongue inserted

3 switching element

Figure B.2 — Working principle of the tongue-actuated position switch

B.1.3 Remarks

For measures to minimize defeating, see Clause 8.

Annex C
(informative)

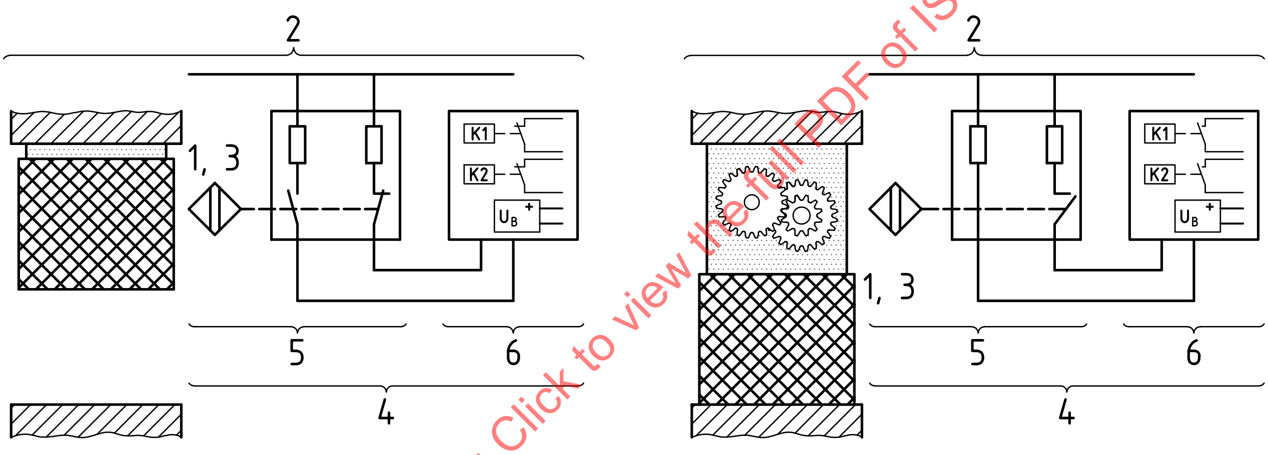
Type 3 interlocking device — Example

C.1 Proximity position switch

C.1.1 Description

A Type 3 interlocking device consisting of one or more non-mechanically actuated position switch(es) (inductive, magnetic, capacitive, ultrasonic or optic proximity switch) actuated by an uncoded actuator linked to a movable guard (see Figure C.1).

To fulfil requirements for safety integrity, two single position switches with monitoring are required in most cases, unless the single position switch is designed to meet the requirements according to IEC 60947-5-3.



a) Movable guard closed

b) Movable guard not closed

Key

1 movable guard
2 interlocking device
3 actuator
4 proximity switch
5 actuating system
6 output system

Figure C.1 — Type 3 interlocking device with proximity switch actuated by an uncoded actuator

C.1.2 Typical characteristics

— No moving parts;

— high resistance to dust, liquids;

— easily kept clean;

— due to the lack of coding, additional measures against defeating are required;

— limited application possibilities.

C.1.3 Remarks

For measures to minimize defeating, see Clause 8.

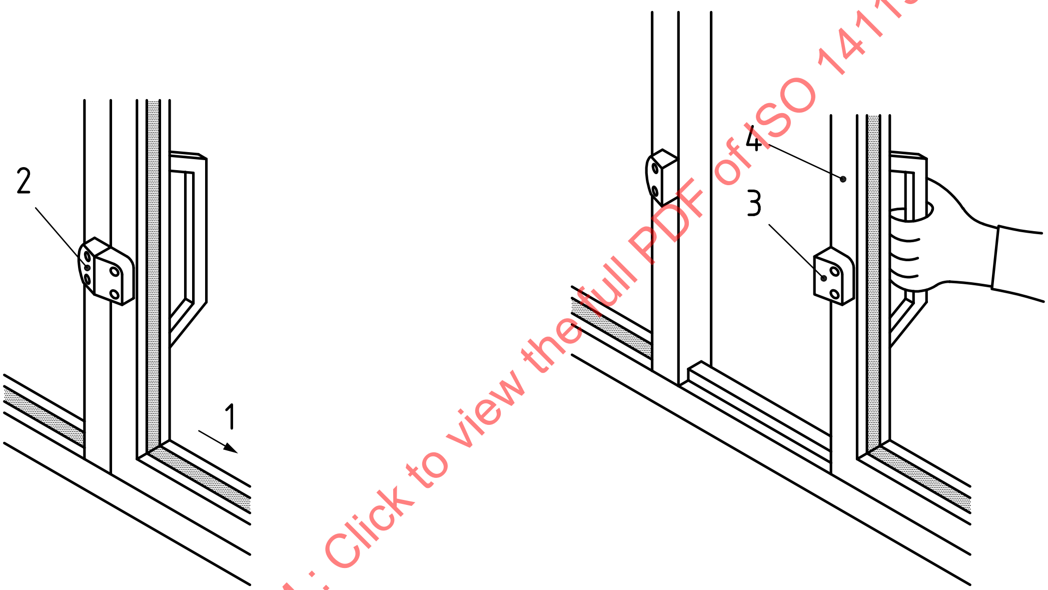
Annex D
(informative)

Type 4 interlocking devices — Examples

D.1 Coded magnetic operated interlocking device

D.1.1 Description

A Type 4 interlocking device with a position switch actuated by coded magnetic actuator associated with the movable guard opens its contacts when the guard is not closed (see Figure D.1).



a) Movable guard closed **b) Movable guard not closed**

Key

1 opening direction
2 Type 4 interlocking device
3 coded magnet actuator
4 movable guard

Figure D.1 — Example of Type 4 interlocking device with position switch actuated by coded magnetic actuator

D.1.2 Typical characteristics

— Compact, no external moving parts;

— high resistance to dust, liquids;

— easily kept clean;

— coded;

— tolerance to guard misalignment;

— sensitive to electromagnetic interference;

— if reed contacts are used, they are susceptible to vibrations and shocks and transient electrical effects (e.g. current spikes);

— medium- or high-level coding not available.

D.1.3 Remarks

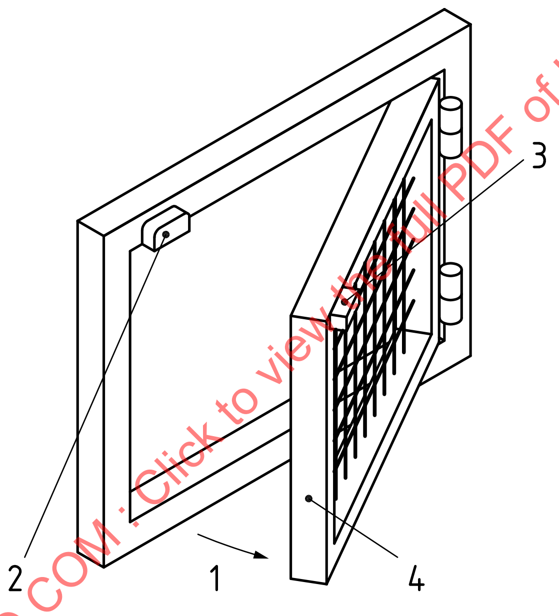
For measures to minimize defeating, see Clause 8.

If reed contacts are used, defeating can be possible by using a simple strong magnet which is a readily available object.

D.2 Coded RFID-operated interlocking device

D.2.1 Description

A Type 4 interlocking device with a position switch actuated by coded RFID tag actuator associated with the movable guard opens its contacts when the guard is not closed (see Figure D.2).



Key

1 opening direction

2 Type 4 position switch

3 coded RFID tag actuator

4 movable guard

Figure D.2 — Example of Type 4 interlocking device with position switch actuated by coded RFID tag actuator

D.2.2 Typical characteristics

— Compact, no external moving parts;

— high resistance to dust, liquids;

— easily kept clean;

— medium- and high-level coding possible;

— tolerance to guard misalignment;

— possible sensitivity to electromagnetic interference.

D.2.3 Remarks

For measures to minimize defeating, see Clause 8.

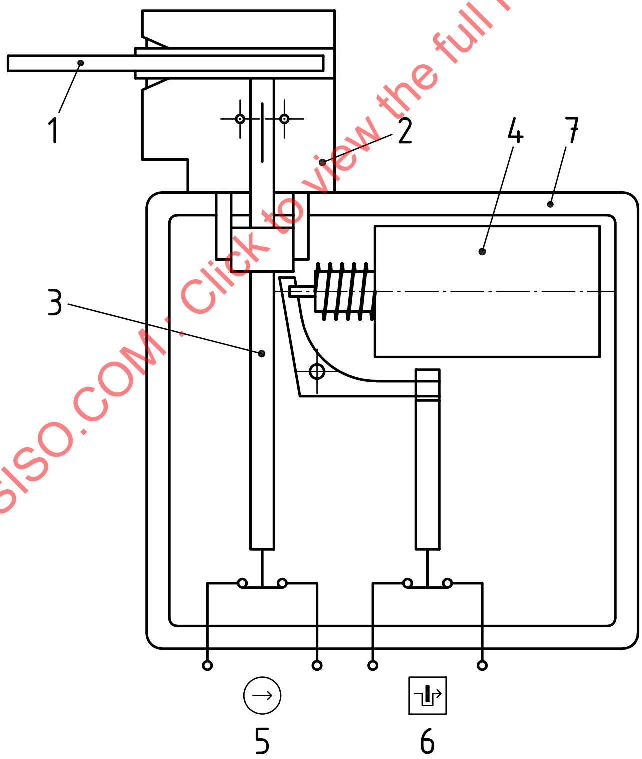
Annex E
(informative)

Example of guard-locking devices

E.1 Example of interlocking device with separate detection of guard position and position of the locking elements

E.1.1 Description

Figure E.1 shows a Type 2 interlocking device with integrated guard locking and guard-locking monitoring. The actuator is shown in the closed position of the movable guard which is linked to the actuator. The guard-locking solenoid is in the locking position held by the spring. If the solenoid is powered, the plunger of the solenoid is moved to the right, thus compressing the spring. The guard-locking monitoring contact is opened via the lever linked to the solenoid plunger. Now the interlocking plunger can be moved downwards by an opening movement of the guard and the attached actuator. In the un-closed position of the guard, the wide part of the interlocking plunger prevents the locking mechanism from moving into the locking position (prevention of inadvertent locking). By linking the interlocking plunger to a contact, both interlocking and guard-locking position can be monitored within one device.



Key

1 actuator
2 actuating head
3 interlocking plunger
4 guard-locking solenoid
5 interlocking monitoring contact
6 guard-locking monitoring contact
7 housing

Figure E.1 — Interlocking device with spring applied/power released guard-locking device

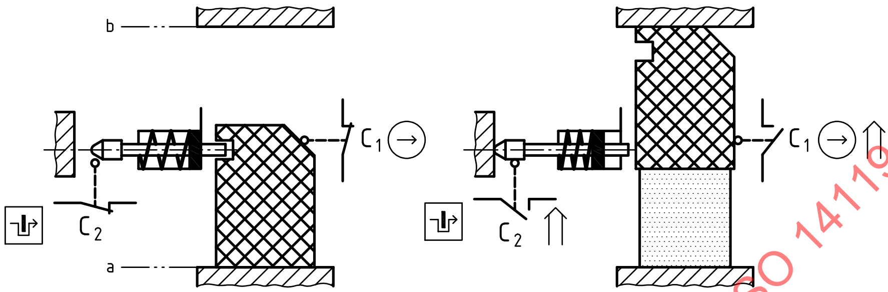
E.1.2 Typical characteristic

Separate indication of the movable guard status is provided.

E.2 Interlocking function ensured by detecting separately guard position and position of the guard-locking device

E.2.1 Description

In Figure E.2, C_1 detects the position of the movable guard and C_2 detects the position of the locking device.



Key

C_1 detects the position of the movable guard

C_2 detects position of locking device

a Closed.

b Not closed.

NOTE C_1 and C_2 can be detectors of any technological type (see 5.1).

Figure E.2 — Separate detection of positions of movable guard and guard-locking device

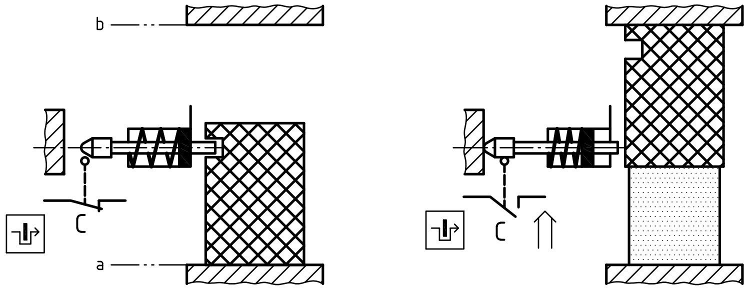
E.2.2 Typical characteristics

Indication of the movable guard status is provided by comparing the seperate status indications of the movable guard and the locked position. Through the use of a plausibility check, the mechanical failure of the locking function can be detected.

E.3 Interlocking function ensured by detecting lock position only by detecting the position of the locking device

E.3.1 Description

By detecting the position of the locking device, the single detector (C) can also be used to monitor the position of the movable guard, provided that the closed position of the guard is rigorously and reliably detected due to good design and construction of the guard-locking-device-contact and movable guard assembly (see Figure E.3).



Key

C detects position of locking device

a Closed.

b Not closed.

NOTE C can be a detector of any technological type (see 5.1).

Figure E.3 — Combined detection of positions of movable guard and locking device

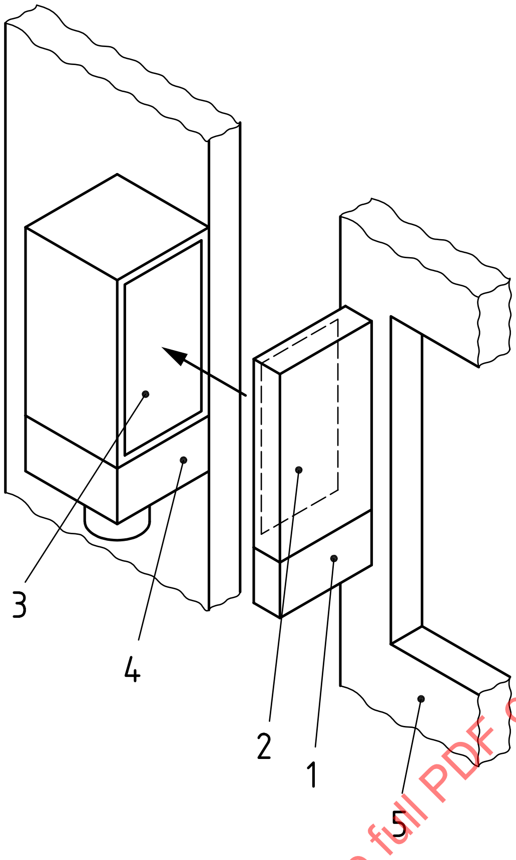
E.3.2 Typical characteristic

No separate indication of the movable guard status is provided.

E.4 Interlocking device with electromagnetic guard-locking device

E.4.1 Description

The guard-locking of the closed movable guard is done electromagnetically (electromagnetic principle of action, see Figure E.4). The interlocking function is provided by detection of the guard position. The locking function includes monitoring of the electromagnetic force. Forced opening results in a reaction function, e.g. 10 min delay until a reset is possible (see 6.6.4.3).



Key

1 coded actuator
2 magnetic keeper plate
3 guard-locking electromagnet
4 non-contact actuated position switch
5 movable guard

Figure E.4 — Interlocking device with electromagnetic guard-locking device

E.4.2 Typical characteristics

— Easy to clean due to sealing;

— high resistance against dusts and fluids;

— decreasing of locking force possible by environmental influence;

— compact, no moving parts;

— unlocking in case of power failure, depending on the design;

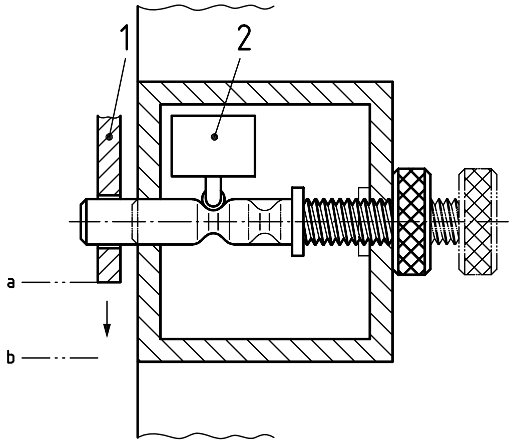
— very high locking force not available.

E.5 Interlocking device with guard locking, with manually operated delay device

E.5.1 Description

The threaded pin is turned by hand (unconditional unlocking, according to Figure 4, see Figure E.5). The time elapsing between the switch opening and guard release is determined so that it is longer than the time taken to stop the hazardous functions.

When not closed, the movable guard prevents the pin from being screwed in again, thus closing the switch contacts.



Key

1 movable guard

2 position switch

a Closed.

b Not closed.

Figure E.5 — Interlocking device with guard-locking, with manually operated delay device

E.5.2 Typical characteristics

— Reliability through simplicity;

— can be unlocked quickly with additional means, e.g. by power driven screw drivers.

E.5.3 Remarks

Only appropriate for applications with low-frequency operations.

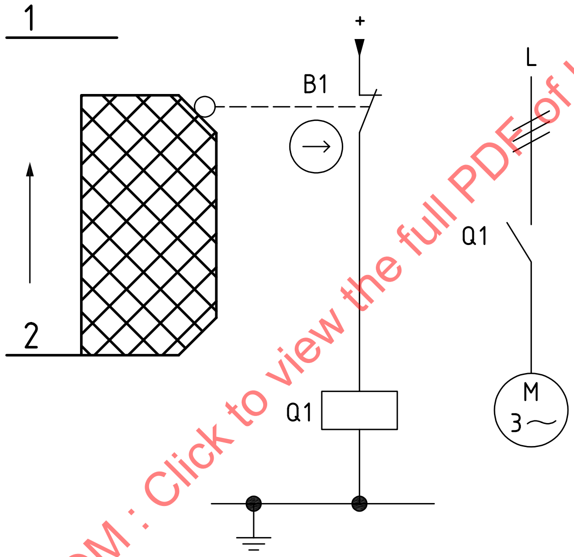
Annex F
(informative)

Application examples of interlocking devices used within a safety function

F.1 General

The descriptions in this annex are limited to the appropriate categories according to ISO 13849-1 with regard to their behaviour in case of fault occurrence (architecture). To achieve the required safety related performance, additional requirements (e.g. DC) need to be considered.

Annex F provides different examples. Not every example is applicable in each situation.



Key

1	not closed	2	closed
B1	position switch monitoring guard position	Q1	contactor
(→)	direct opening action		

Figure F.1 — Position monitoring of movable guards for the prevention of hazardous movements

F.2 Example 1 — Category 1

F.2.1 Safety function

Safety-related stopping function, initiated by a protective device: opening of the movable guard initiates the safety function STO – safe torque off according to IEC 61800-5-2 or stop category 0 according to IEC 60204-1.

F.2.2 Functional description

— Opening of the movable guard is detected by a position switch B1 with direct opening action. B1 de-energizes a contactor Q1 which stops the hazardous movement (see Figure F.1).

— The safety function can be lost at the occurrence of single faults and is dependent upon the reliability of the components.

— No measures for fault detection are implemented.

— Removal of the protective device is not detected.

F.2.3 Design features

To achieve category 1 the following shall be fulfilled:

— Basic and well-tried safety principles are implemented and the requirements of category B are met. Protective circuits (e.g. contact protection) are implemented. The de-energization principle is used as a basic safety principle. Earthing of the control circuit is regarded as a well-tried safety principle.

— Position switch B1 has direct opening action in accordance with ISO 13849-2:2012, Table D.2, and is regarded as a well-tried component. The break contact interrupts the circuit with direct mechanical action when the movable guard is not closed.

— Contactor Q1 is a well-tried component provided that the additional conditions in accordance with ISO 13849-2:2012, Table D.3 are observed.

— The movable guard has a stable arrangement for actuation of the position switch B1. The actuating elements of the position switch B1 are protected against displacement. Only mechanical parts (no spring elements) having sufficient rigidity are employed.

— The actuating stroke for the position switch is in conformity with the manufacturer's specification.

NOTE A detailed description including the estimation of the probability of dangerous failure per hour is available in section 8.2.5 of Reference [11].

F.3 Example 2 — Category 3

F.3.1 Safety functions

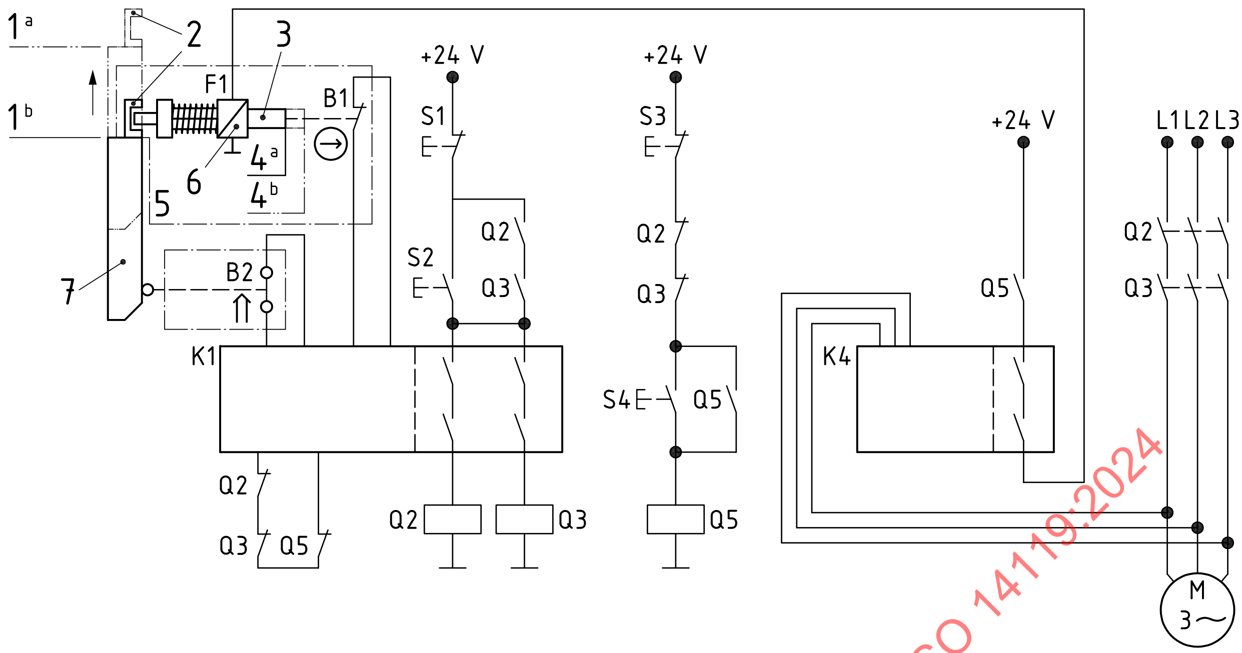
— No unlocking of the movable guard as long as the drive motor speed is greater than zero;

— generating of a stop command when the movable guard is unlocked or not closed;

— prevention of unexpected start up while the movable guard is unlocked or not closed.

F.3.2 Functional description

— Access to the hazardous movement is prevented by a movable guard which is closed and locked while the motor is powered or coasting to a standstill (see Figure F.2). The movable guard is unlocked and can be opened when the locking element (bolt) is withdrawn by energizing the unlocking solenoid. The unlocking solenoid can only be energized when the motor is at a standstill. This is achieved by the standstill monitor K4.



Key

1[a]	movable guard not closed	S1	stop
1[b]	movable guard closed	S2	start
2	notch for inserting the bolt	S3	lock
3	locking element (bolt)	S4	unlock
4[a]	bolt in engaged position	K1	monitoring logic unit
4[b]	bolt in released position	Q2	contactor
5	guard-locking device	Q3	contactor
6	unlocking solenoid	K4	safety standstill monitor
7	movable guard	Q5	contactor
⇑	actuated position, door closed	F1	spring
→	direct opening action	B1	position switch monitoring locking element
		B2	position switch monitoring guard position

Figure F.2 — Guard-locking device with safety relay and standstill monitor — Category 3

— Starting the motor by pressing the start button S2 is only possible when the movable guard is closed (B2 is closed) and locked (B1 is closed); Q2, Q3 and Q5 are de-energized, so the feedback loop of K1 is closed. When S2 is momentarily closed, Q2 and Q3 are energized and remain latched. Power supply to the motor is turned on.

— By pressing the stop button S1, Q2 and Q3 are de-energized and the motor stops.

— Opening of the movable guard during movement of the motor is prevented by a locking element (bolt). Opening is only possible if the bolt is released. The following procedure is required to release the bolt:

  — push stop switch S1; Q2 and Q3 are de-energized and their contacts change state;

  — push unlock switch S4 to request unlocking (Q5 becomes energized and latched);

  — when the motor stops, the output of standstill monitor K4 closes;

  — the unlocking solenoid is energized, the locking element (bolt) moves to the unlocked position.

The unlocking request is cancelled by pushing the lock switch S3; Q5 de-energizes.

— When the movable guard is closed, the spring applied locking element (bolt) engages in the intended notch. The movable guard becomes locked and B1 and B2 are closed.

— The outputs of K1 open if one of the input circuits, B1 (monitoring locking element) or B2 (monitoring guard) is open.

F.3.3 Design features

To achieve category 3 the following shall be fulfilled.

— Basic and well-tried safety principles are observed and the requirements of category B are met. Protective circuits (e.g. contact protection) are implemented.

— Faults in the wiring are considered (see ISO 13849-2:2012, Table D.4). Short circuits are detected and a safe condition is initiated or the cables are routed so that fault exclusions are possible.

— The contactor relays Q2, Q3 and Q5 have mechanically linked contact elements in accordance with IEC 60947-5-1:2016+COR1:2016, Annex L.

— To fulfil the single fault safety needed for a category 3 system, the position switch B2 is a separate position switch (mechanically independent from actuation of B1).

— The position switch B1 has direct opening action in accordance with IEC 60947-5-1:2016 + COR1:2016, Annex K, therefore fault exclusion for non-opening due to welding of the contact is permitted.

— The guard-locking device with the spring applied locking element (bolt), the unlocking solenoid and the locking element monitoring position switch B1 are contained in one single enclosure. The notch for inserting the bolt is part of the movable guard.

— The spring of the guard-locking device is a well-tried spring according to ISO 13849-2:2012, Table A.3. The unlocking solenoid does not energize without electrical input.

— Fault exclusion for "breakage of the locking element (bolt)" due to:

  — proper selection of the devices ensuring that the specified locking force (F_{ZH}) of the guard-locking device is sufficient to withstand the static force F_{MAX} on the locking bolt;

  — dynamic forces on the locking bolt due to rebound or bouncing of the movable guard are prevented. The design of the control system ensures that the spring applied locking element (bolt) does not move into the locked position, before the movable guard is closed and stationary, e.g. by time delay between closing the door and de-energising the solenoid (not shown in Figure F.2).

  The use of fault exclusion for breakage of the locking bolt does not necessarily limit the PL or SIL for the safety function.

— Due to the design arrangement, the locking element (bolt) cannot reach the locked position (guard-locking position) when the movable guard is not closed (prevention of inadvertent locking position).

— K1 is a monitoring logic unit that meets at least the requirements of category 3 in accordance with ISO 13849-1. The input circuits are monitored for shorts to earth and supply voltage. The safe state is initiated at detection of a fault. The safety relevant output can be activated only when the input circuits and the feedback loop are closed. Errors such as contact welding of Q2, Q3 or Q5 are detected by the feedback circuit of K1.

— Standstill monitor K4 meets at least the requirements of category 3 in accordance with ISO 13849-1. It monitors the input circuits for short circuits across contacts, open wires to the motor and short circuits to the supply voltage. The safe state is initiated at detection of a fault.

— Switches B1 and B2 are also tested by the process, because the safety relevant outputs of K1 are only switched on again when B1 and B2 have been operated. This is done by opening and closing the guard.

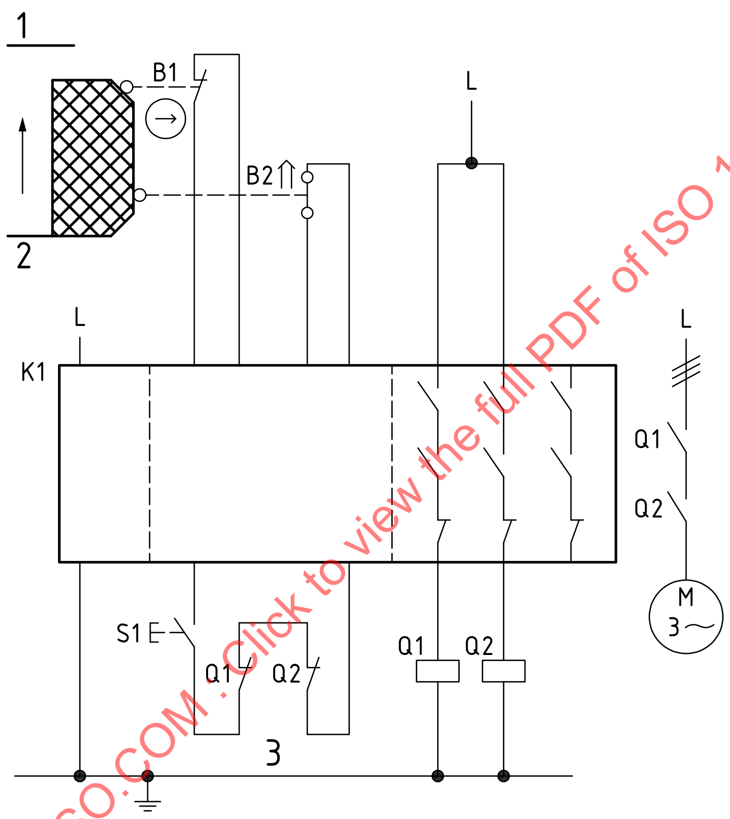
F.4 Example 3 — Category 4

F.4.1 Safety function

Safety-related stop function, initiated by a protective device: opening of the movable guard initiates the safety function (STO, safe torque off, according to IEC 61800-5-2 or stop category 0 according to IEC 60204-1).

F.4.2 Functional description

— Hazardous movement is safeguarded by a movable guard (see Figure F.3). Opening of the movable guard is detected by two position switches B1/B2, using a NC/NO contact combination, and evaluated by a monitoring logic unit K1. K1 de-energizes two contactors, Q1 and Q2, which stop the hazardous movement.



Key

1	not closed	S1	start (reset)
2	closed	Q1	contactor
3	feedback circuit	Q2	contactor
B1	position switch monitoring guard position	K1	monitoring logic unit
B2	position switch monitoring guard position		
⥣	shown in actuated position	(→)	direct opening action

Figure F.3 — Position monitoring of movable guards by means of a safety module

— The position switches are monitored for plausibility in K1 for the purpose of fault detection. Faults in Q1 and Q2 are detected by external device monitoring by K1. A start command is successful only if the main contacts at Q1 and Q2 had previously opened.

— The safety function remains intact in the event of a component fault. Faults are detected during operation or at actuation (opening and closing) of the movable guard resulting in de-energization of Q1 and Q2. Energization of Q1 and Q2 is prevented until fault has been corrected.

F.4.3 Design features

To achieve category 4, the following shall be fulfilled.

— Basic and well-tried safety principles are observed and the requirements of category B are met.

— A stable arrangement of the protective devices is assured for actuation of the position switches.

— Switch B1 is a position switch with direct opening action in accordance with IEC 60947-5-1:2016+COR1:2016, Annex K.

— The supply conductors to position switches B1 and B2 are laid separately or with protection.

— The monitoring logic unit K1 satisfies all requirements for category 4.

— The contactors Q1 and Q2 possess mechanically linked contact elements according to IEC 60947-5-1:2016+COR1:2016, Annex L.

NOTE 1 Category 4 is observed only if several mechanical position switches for different protective devices are not connected in a series arrangements (i.e. no cascading), since otherwise faults in the switches cannot be detected.

NOTE 2 A detailed description, including the estimation of the probability of dangerous failure per hour, is available in 8.2.34 of Reference [11].

Annex G
(informative)

Motivation to defeat interlocking devices (defeating of protective devices)

Personnel often attempt to intervene whilst machinery remains operational in order to maintain production and to prevent the compound effect of a particular problem.

The operator in these circumstances tends to concentrate on the immediate problem, rather than on potential hazards and consequences following the intervention.

This annex is an example for automatic machine tools. When the principles and tables presented in this annex are used for other types of machines, it is recommended that Table G.1 is modified to suit the specific characteristics of the machines and the production.

The motivation for defeating interlocking devices of guards comprises several aspects, one of which is how hindering the safeguards are when a certain machining task has to be performed. Another aspect is that the operator might need to monitor closely and fine tune the machining in order to avoid scrap of workpieces, which is not possible when the protective device is operative

The following method supports the machine designer in identifying possible incentives for defeating interlocking devices. Use of this method requires that all intended modes of operation and protective devices shall be considered. Each individual protective device is regarded separately, and for each relevant task, a person familiar with operating the machine is asked the following question:

> "What would be the benefits of defeating the protective device for work on the machine?".

Table G.1 supports the execution of the procedure. The most common operator tasks are listed versus the respective benefits, when defeating the interlocking devices. Table G.1 offers some basic entries, but additional entries can be supplemented, if necessary.

To follow the procedure, these four steps are performed.

a) All modes of operation provided with the machine shall be identified, e.g. mode 1 = automatic, mode 2 = manual.

b) All individual tasks applied on the machine should be collected in the table rows and marked with an "x" at the column for the corresponding mode of operation.

c) The next two columns shall be marked with "Yes" or "No", whether the intended task is permissible in that mode and whether it is possible in that mode without defeating. One "No" in these two columns identifies an unsafe machine. Improvement of the machine design is mandatory.

d) Several further columns are filled with potential benefits of "working without protective devices" such as "Higher precision". These should be checked and marked with "0" (none), "+" (minor) and "++" (substantial). The entries "++" and "+" identify operating conditions where safeguards hinder the working process. The designer should check whether improved practice-orientated safeguards are possible.

NOTE Practice-oriented modes of operation are an important means of making defeating of the interlocking device unnecessary or unattractive. Restricted operating conditions (e.g. reduced speed, hold to run control in combination with an enabling device, restricted functionality) provide both reduced residual risk and a kind of "switchback motivation" to automatic mode (lowest residual risk).

Table G.2 gives an example of applying Table G.1. As a result, from Table G.2 for this specific machine a setup mode would overcome the problem of incentive for defeating in the line "Setup / adjustment conversion / tooling". This operating mode can also help for troubleshooting.

Table G.1 — Evaluation of motivation to defeat interlocking devices

Task	Mode 1[a]	Mode 2[a]	Mode 3[a]	Mode 4[a]	Mode 5[a]	Task permissible in these modes of operation?	Task possible without defeating?	Easier/more convenient[b]	Faster, increased productivity[b]	Flexibility, e.g. for larger workpieces[b]	Higher precision[b]	Better visibility[b]	Better audibility[b]	Less physical effort[b]	Reduced travel[b]	Greater freedom of movement[b]	Improved flow of movement[b]	Avoidance of interruption[b]
Initial operation																		
Program test/Test run																		
Setup/adjustment conversion/tooling																		
Machining																		
Manual change of workpiece																		
Manual intervention for trouble shooting																		
Checking/random sampling																		
Manual intervention for measuring/fine tuning																		
Manual change of tools																		
Maintenance servicing																		
Rectification of machine faults																		
Cleaning, e.g. removal of swarf																		

[a] Modes of operation.

[b] Benefits without protective device: 0 = None; + = Minor; ++ = Substantial.

Table G.2 — Example of an evaluation of motivation to defeat interlocking devices on a machine

Task	Automatic[a]	Manual[a]	Task permissible in these modes of operation?	Task possible without defeating?	Easier, more convenient[b]	Faster, increased productivity[b]	Flexibility, e.g. for larger workpieces[b]	Higher precision[b]	Better visibility[b]	Better audibility[b]	Less physical effort[b]	Reduced travel[b]	Greater freedom of movement[b]	Improved flow of movement[b]	Avoidance of interruption[b]	
Initial operation		X	Yes	Yes	0	0	0	0	0	0	0	0	0	0	0	
Program test/test run		X	Yes	Yes	0	0	0	0	0	0	0	0	0	0	0	
Setup/ adjustment conversion/ tooling/	X		No	No	++	0	0	0	++	++	0	0	0	0	0	Appropriate mode of operation missing
Machining	X		Yes	Yes	0	0	0	0	0	0	0	0	0	0	0	
Manual change of workpiece																
Manual intervention for trouble shooting		X	Yes	Yes	++	0	0	0	0	0	0	0	0	0	0	Improvement necessary
Checking/ random sampling																
Manual intervention for measuring/																
Manual change of tools		X	Yes	Yes	0	0	0	0	0	0	0	0	0	0	0	

[a] Modes of operation.

[b] Benefits without protective device: 0 = None; + = Minor; ++ = Substantial.

Table G.2 *(continued)*

Task	Automatic[a]	Manual[a]	Task permissible in these modes of operation?	Task possible without defeating?	Easier, more convenient[b]	Faster, increased productivity[b]	Flexibility, e.g. for larger workpieces[b]	Higher precision[b]	Better visibility[b]	Better audibility[b]	Less physical effort[b]	Reduced travel[b]	Greater freedom of movement[b]	Improved flow of movement[b]	Avoidance of interruption[b]	
Maintenance/ servicing																
Rectification of faults machine																
Cleaning, e.g. removal of swarf																

a Modes of operation.

b Benefits without protective device: 0 = None; + = Minor; ++ = Substantial.

Annex H
(informative)

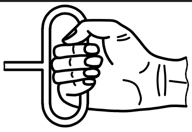
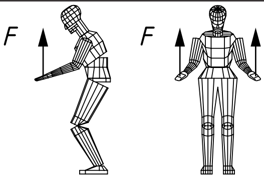
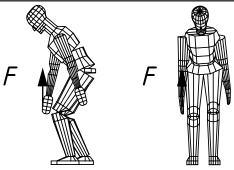
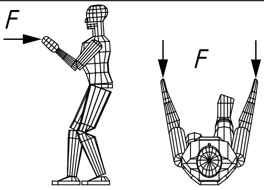
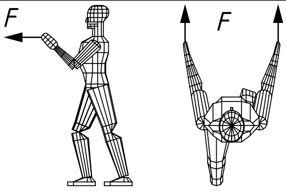
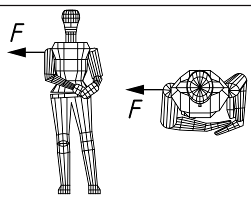
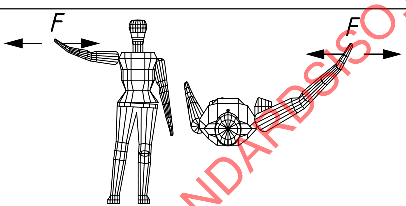
Examples for maximum static action forces

The examples in Table H.1 can give orientation for the maximum static action forces.

The maximum static action forces depend on the grip a person has, e.g. a large handle that can be operated with two hands most likely results in the maximum values given, while a small handle that can be operated by one hand only, significantly reduces the static action forces.

Table H.1 shows examples for static forces [13]. For some applications, dynamic forces also need to be taken into account.

Table H.1 — Examples for maximum static action forces

Direction of force		Posture	Force application	Force value [N]
	Horizontal pulling (dragging)	Sitting	Single-handed	600
	Vertical upward	Standing, torso and legs bent, feet parallel	Bi-manual, horizontal grips	1 400
	Vertical upward	Standing, free	Single-handed, horizontal grips	1 200
	Horizontal, parallel to body symmetry plane backward, Pull	Standing upright, feet parallel or in step posture	Bi-manual, vertical grips	1 100
	Horizontal, parallel to body symmetry plane forward, Push	Standing, feet parallel, or in step posture	Bi-manual, vertical grips	1 300
	Horizontal, normal to body symmetry plane body off	Standing, torso bent sideward	Shoulder pushing on metal plate on the side	1 300
	Horizontal, normal to body symmetry plane	Standing, feet parallel	Single-handed, vertical grip	700

Annex I
(normative)

Test procedures

I.1 Locking force test

I.1.1 General

The guard-locking device is fastened onto a base as intended by the manufacturer. The guard-locking device is then loaded up to the point of failure of the guard-locking function, by moving the locking element at its maximum operating angle at a constant speed in the direction "open guard". During this loading, the maximum applied force, F, is measured during the course of deformation. The test shall be carried out on five unused as-new samples. The lowest value of F within these measurements is the maximum locking force F_{TEST}.

I.1.2 Evaluation

I.1.2.1 General

Based on the maximum locking force, F_{TEST}, measured during the test, taking into consideration the safety factor S, the maximum locking force F_{ZH} is ascertained using Formula (I.1):

$$F_{ZH} = \frac{F_{TEST}}{S} \tag{I.1}$$

where $S = 1,3$.

I.1.2.2 Requirements on the test device

Traction speed: constant (10 ± 0,25) mm/min.

I.1.2.3 Requirements on the force measurement device

Sampling rate: ≥10 Hz.

Measurement accuracy of maximum force: ±2,5 %.

NOTE For test details, see Reference [14].

I.2 Impact resistance test

I.2.1 General

The test is only required when interlocking devices or guard-locking devices are suitable for use as a mechanical stop according to manufacturer specifications.

I.2.2 Test procedure

The number of switching cycles that shall be tested is determined by manufacturer specifications.

If the switching cycle count specified by the manufacturer for use as a mechanical stop is identical with the switching cycle count specified for the mechanical service life, then it is permissible to verify both requirements with one combined test.

I.2.3 Test requirements

Testing shall be performed on complete devices in as-new condition with a mass and speed corresponding to the maximum impact energy specified by the manufacturer.

If the manufacturer specifies a maximum mass and maximum speed, then testing shall be performed using these values. The test method is based on IEC 60947-5-1:2016+COR:2016, C.1.2 and C.1.3.

One switching cycle comprises the following steps:

a) actuator approaches the device up to the stop;

b) actuator withdraws from the device.

The actuator shall be approached at the maximum possible actuation angle for this purpose. Actuation shall be carried out from the least favourable approach direction.

Following loading, proper functioning of the device shall be warranted and guard-locking devices shall be able to withstand at least the locking force F_{ZH}, in the locked position, as specified by the manufacturer.

The guard-locking device shall be properly attached to a base. The guard-locking device is subsequently loaded by movement of the locking element actuator at the maximum actuating angle at a constant speed in the direction "open safeguard" until failure of the locking function. During loading, the maximum applied force, F_{TEST}, is measured along the deformation pattern. This force shall be $\geq F_{ZH}$.

Annex J
(normative)

Evaluation of fault masking in series connections of interlocking devices with potential free contacts

J.1 General

This annex illustrates and explains principles of fault masking in applications where multiple interlocking devices with potential free contacts are connected in series to a single monitoring logic unit which does the diagnostics (see Figure J.1 to Figure J.7). It further provides a guide to estimate the probability of fault masking and the maximum DC for the involved interlocking devices. This annex only covers interlocking devices in which both channels are physical series connections.

This annex provides:

— guidance for users for estimation of the maximum DC values and PL;

— design guidance for SRP/CS.

NOTE 1 Interlocking devices with integrated self-monitoring are not covered by this annex.

NOTE 2 Limitation is also given by the diagnostic means implemented in the monitoring logic unit.

NOTE 3 This annex is not restricted to mechanical actuated position switches.

J.2 Fault masking

J.2.1 Principle

Where multiple interlocking devices are connected to a single monitoring logic unit, which performs the diagnostics for the overall safety function, the possible masking of a fault and the subsequent possible accumulation of undetected faults shall be considered. This consideration is required for interlocking functions with category 2, 3 or 4 according to ISO 13849-1 or HFT1 according to IEC 62061.

NOTE A common approach in the design of safety related circuits is to series connect devices with potential free contacts, e.g. multiple interlocking devices connected to a single safety logic controller which performs the diagnostics for the overall safety function. Although in such applications a single fault, in most cases, does not lead to the loss of the safety function and is detected, problems sometimes occur in practice. It is foreseeable that more than one movable guard will be open at the same time or in a sequence, e.g. due to subsequent fault-finding procedure or as part of the regular operation of the machine. Due to the serial connection of the contacts, faults in the wiring or contacts detected by the logic unit can be masked by the operation of one of the other (non-faulty) in series-connected devices. As a result, the operation of the machine is possible while a single fault is present in the SRP/CS. Consequently, this can enable the accumulation of faults leading to an unsafe system. Figure J.7 to Figure J.9 show examples for fault masking in situations with movable guards with series-connected interlocking devices.

The likelihood of specific faults and their possible effects depends on installation of the electrical equipment and the way the interlocking devices are cabled. The following cabling structures are considered in this annex:

— star cabling, where every interlocking device is wired with a single cable to the electric cabinet or enclosure of the monitoring logic unit. Figure J.1 shows a star cabling.

— branch or trunk cabling, where a single cable from the electric cabinet or enclosure of the monitoring logic unit, is wired to the first interlocking device and from this interlocking device to the next, and so on, until the last interlocking devices and the resulting signals are wired the same way back to the electric cabinet or enclosure. Figure J.2 shows a branch (trunk) cabling.

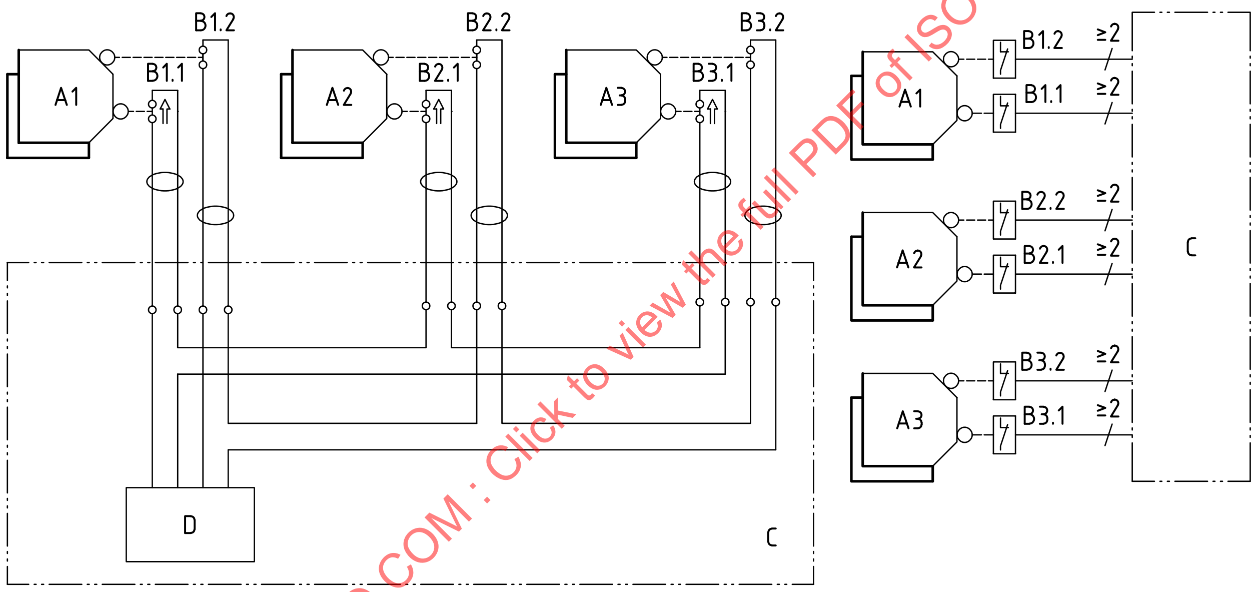
— loop cabling, where a single cable from the electric cabinet or enclosure of the monitoring logic unit, is wired to the first interlocking device and from this interlocking device to the next, and so on, until the last interlocking device while the signals return to the electric cabinet or enclosure in a separate cable. Figure J.3 shows a loop cabling.

Fault exclusions for cables are possible for cables permanently connected (fixed) and protected against external damage, e.g. by cable ducting, armoring, or within an electrical enclosure according to IEC 60204-1 (see ISO 13849-2:2012, Annex D, Table D.4). This annex considers such fault exclusions.

In addition, the way in which different contacts of a single interlocking device are applied to the interlocking circuit for a single guard interlocking, also affects the likelihood of specific faults and their possible effects. The following arrangements are considered in this annex:

— redundant arrangement where the single contacts of two (redundant) interlocking devices in the redundant channels of an interlocking circuit are applied for a single guard interlocking. Figures J.1 to J.3 show examples of redundant arrangements;

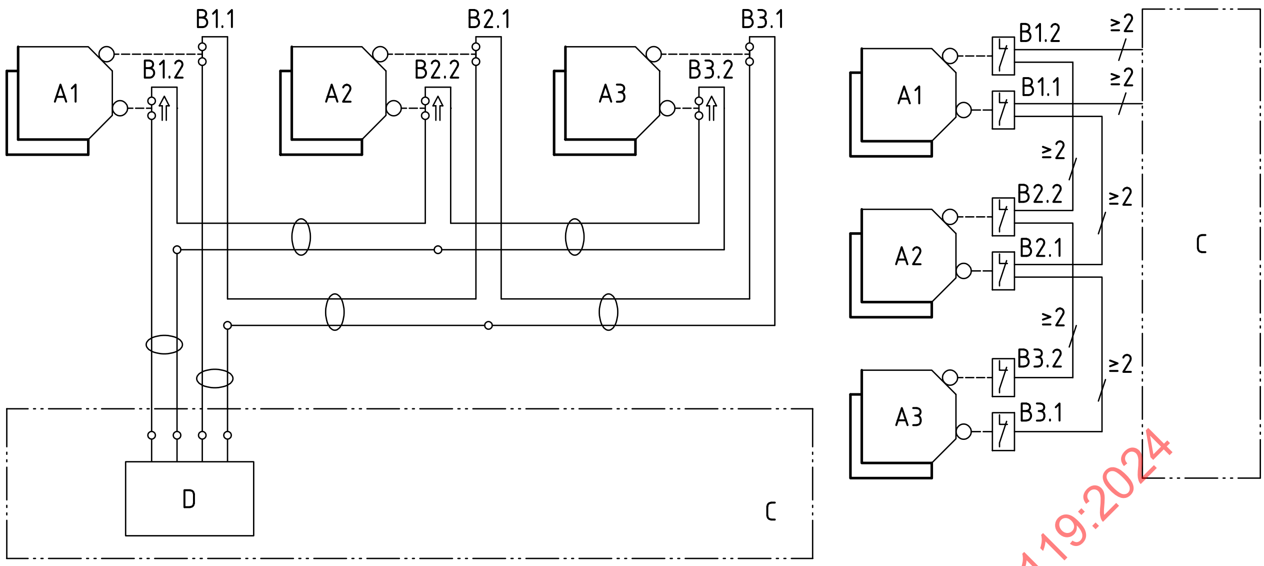
— single arrangement where two different contacts of a single interlocking device in the redundant channels of an interlocking circuit are applied for a single guard interlocking. Figures J.4 to J.6 show examples of single arrangements.



Key

A1, A2, A3	movable guards
B1.1, B1.2, B2.1, B2.2, B3.1, B3.2	interlocking devices with potential free contacts
C	electrical cabinet or enclosure
D	monitoring logic unit

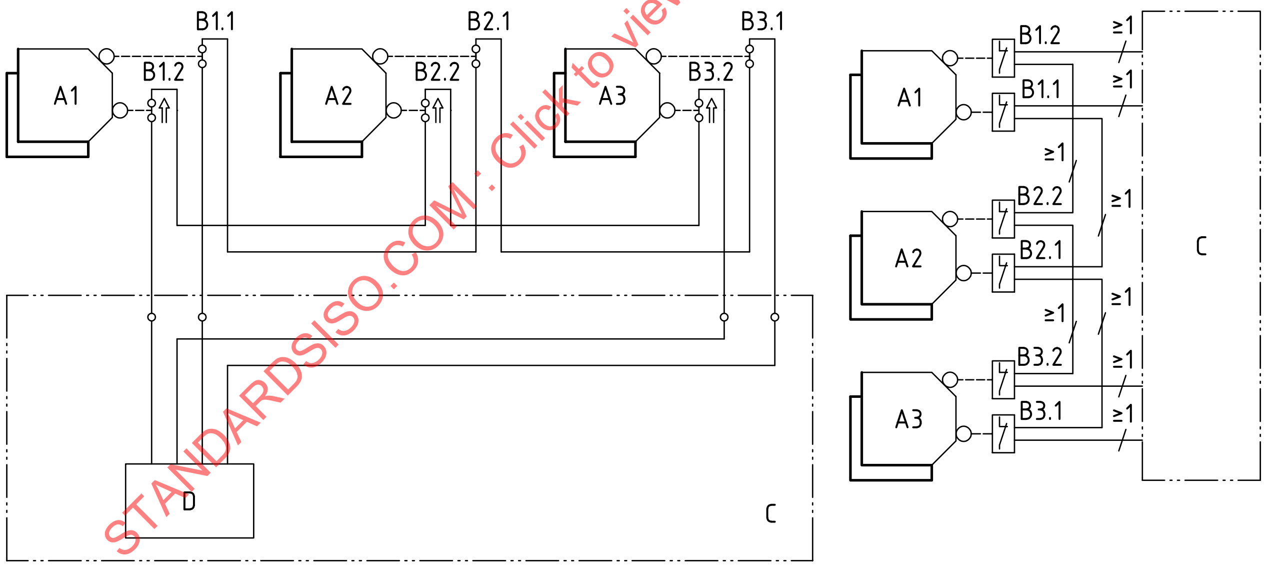
Figure J.1 — Redundant arrangement with star cabling



Key

A1, A2, A3	movable guards
B1.1, B1.2, B2.1, B2.2, B3.1, B3.2	interlocking devices with potential free contacts
C	electrical cabinet or enclosure
D	monitoring logic unit

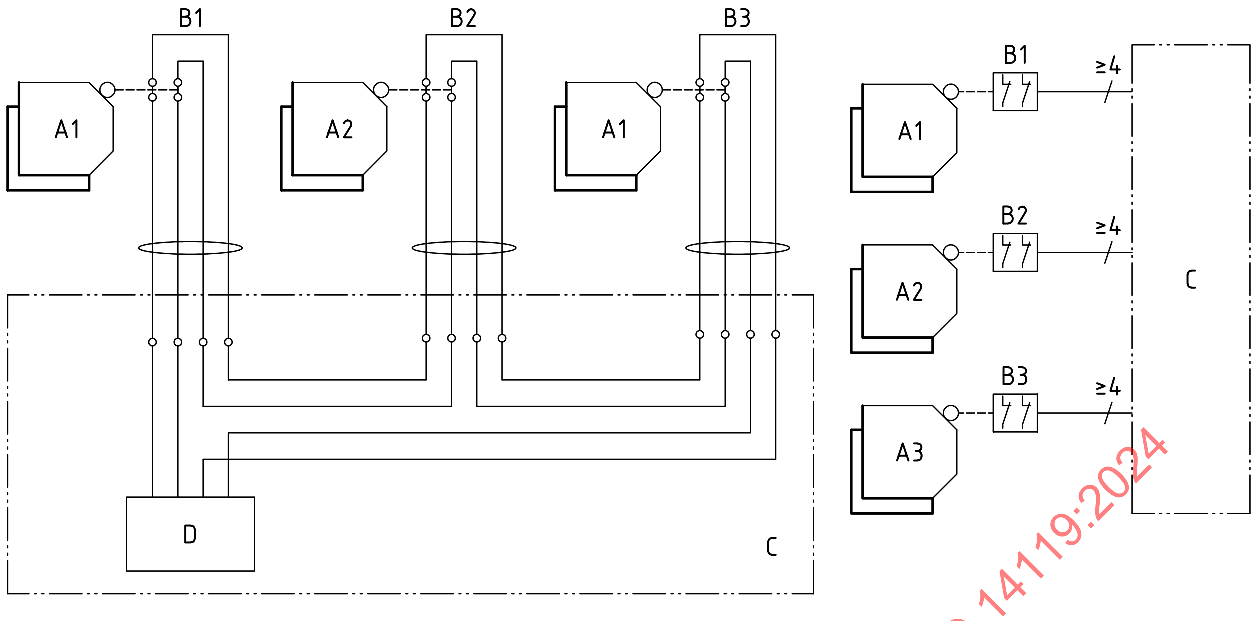
Figure J.2 — Redundant arrangement with branch (trunk) cabling



Key

A1, A2, A3	movable guards
B1.1, B1.2, B2.1, B2.2, B3.1, B3.2	interlocking devices with potential free contacts
C	electrical cabinet or enclosure
D	monitoring logic unit

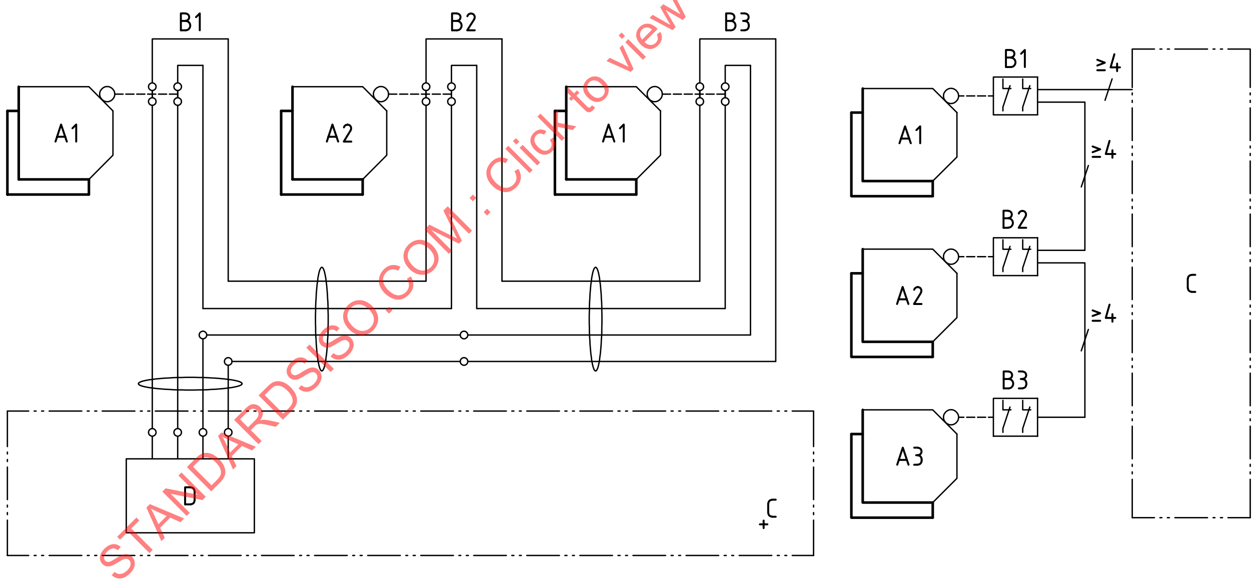
Figure J.3 — Redundant arrangement with loop cabling



Key

A1, A2, A3 movable guards
B1, B2, B3 interlocking devices with potential free contacts
C electrical cabinet or enclosure
D monitoring logic unit

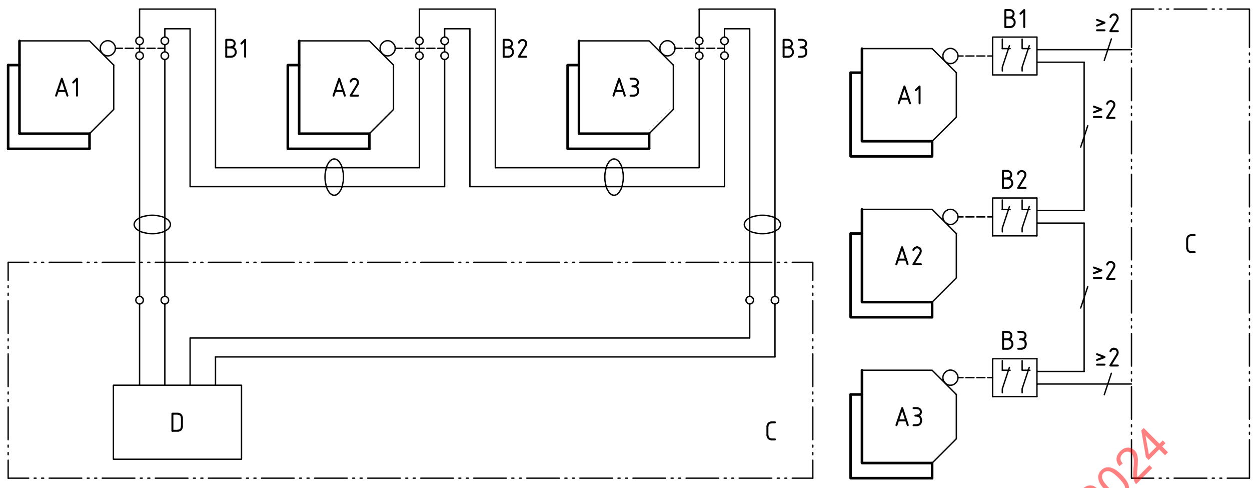
Figure J.4 — Single arrangement with star cabling



Key

A1, A2, A3 movable guards
B1, B2, B3 interlocking devices with potential free contacts
C electrical cabinet or enclosure
D monitoring logic unit

Figure J.5 — Single arrangement with branch (trunk) cabling



Key

A1, A2, A3	movable guards
B1, B2, B3	interlocking devices with potential free contacts
C	electrical cabinet or enclosure
D	monitoring logic unit

Figure J.6 — Single arrangement with loop cabling

Fault detection does not only depend on the way the interlocking devices are cabled but also on the way the signal evaluation is performed by the single monitoring logic unit. The following signal evaluation techniques shall be considered:

— signal evaluation of redundant channels with same polarity, where the monitoring logic unit evaluates redundant signals which have the same supply voltage;

— signal evaluation of redundant channels with inverse polarity, where the monitoring logic unit evaluates redundant signals in which one channel has the ground polarity;

NOTE 1 See IEC 60204-1:2016, 9.4.3.1, method a).

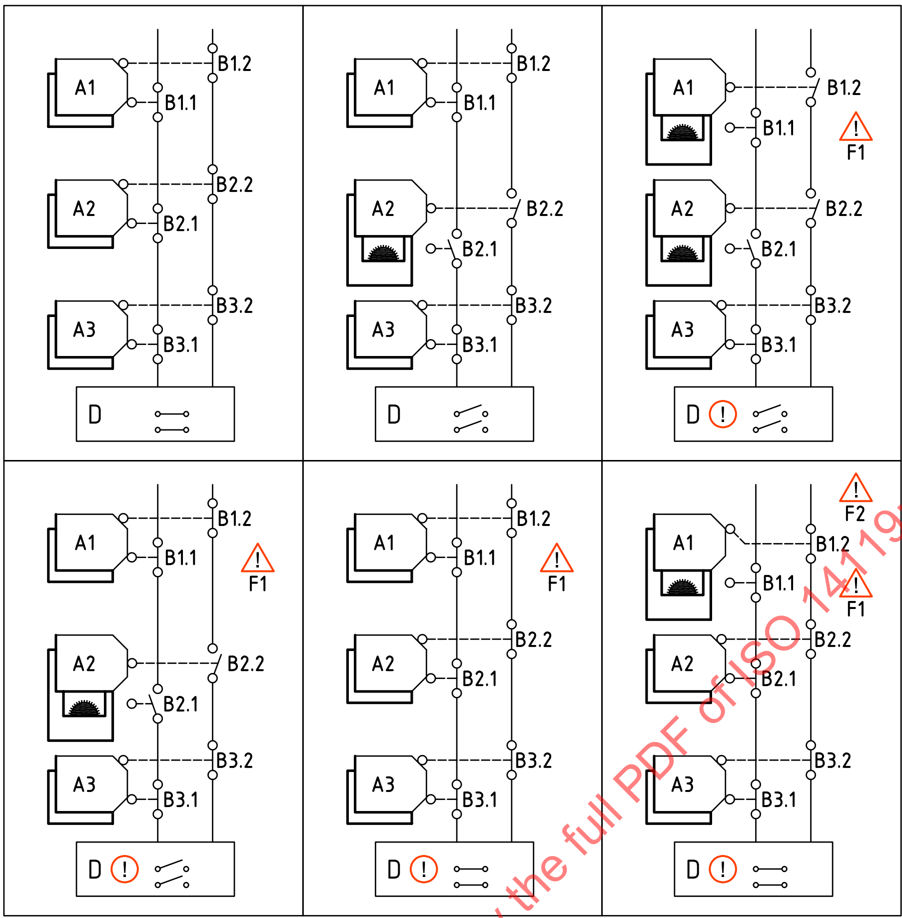
— signal evaluation of redundant channels with dynamic signals, where the monitoring logic unit evaluates redundant dynamic signals.

NOTE 2 Dynamic signals can be generated with, e.g. test pulses, frequency modulation.

Fault masking can result from direct fault masking or unintended reset of a fault.

J.2.2 Direct fault masking

Direct fault masking is caused by opening and closing a faulty interlocking guard while another non-faulty interlocking guard is open (see Figure J.7).



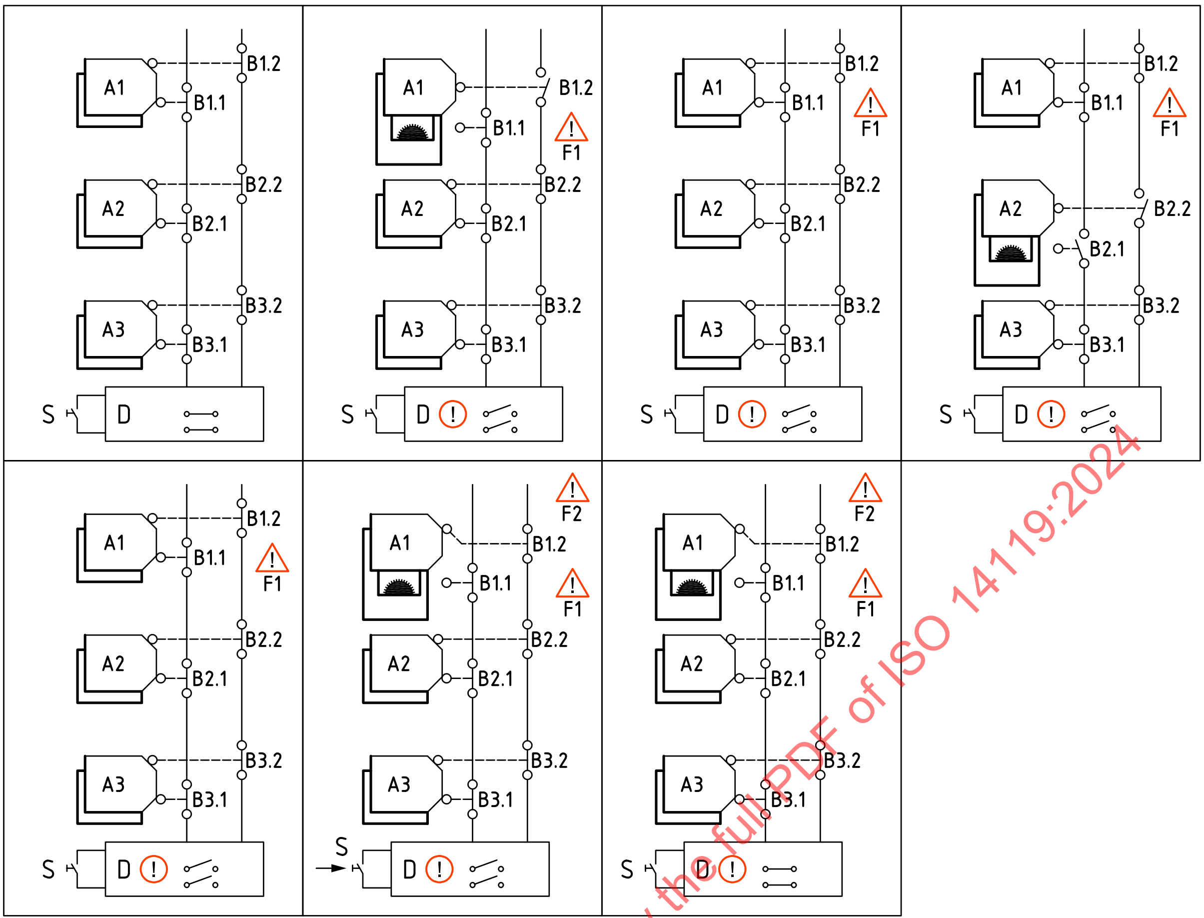
Key

A1, A2, A3	movable guards
B1.1, B1.2, B2.1, B2.2, B3.1, B3.2	interlocking devices with potential free contacts
D	monitoring logic unit
F1, F2	fault of interlocking device

Figure J.7 — Direct fault masking

J.2.3 Unintended reset of a fault

After a fault in the interlocking device of one movable guard occurs and is initially detected, the actuation of another movable guard leads to the unintended reset of the detected fault (see Figure J.8).

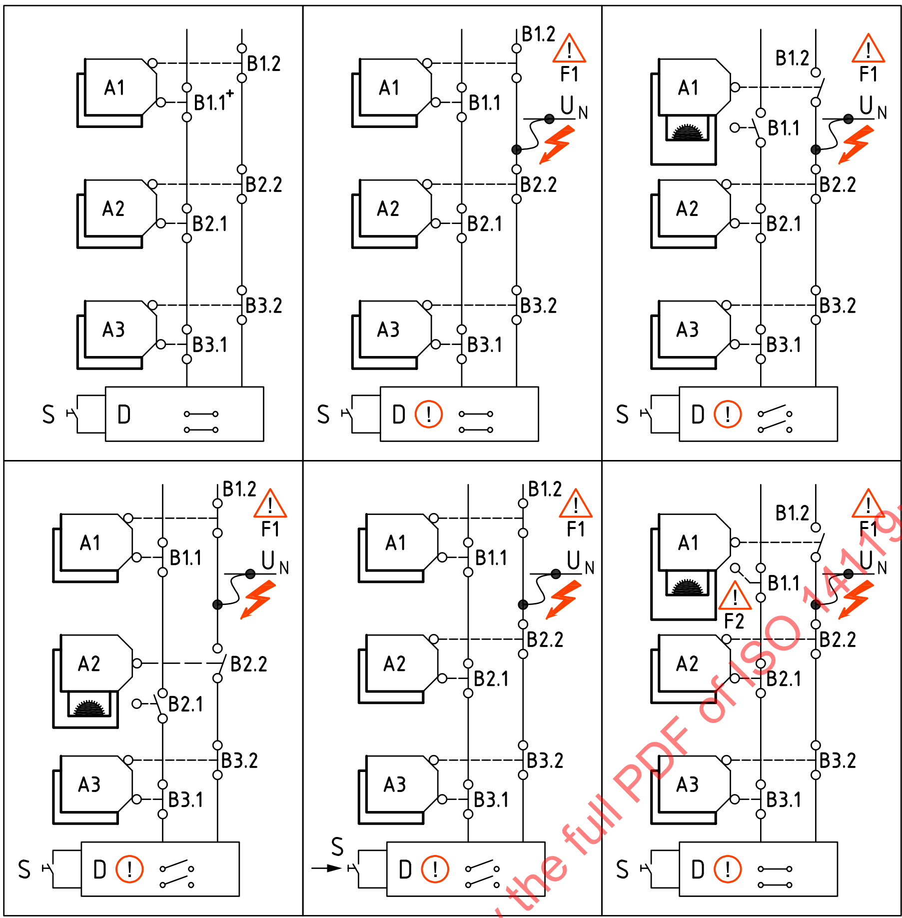


Key

A1, A2, A3	movable guards
B1.1, B1.2, B2.1, B2.2, B3.1, B3.2	interlocking devices with potential free contacts
D	monitoring logic unit
S	reset control device of the monitoring logic unit
F1, F2	fault of interlocking device

Figure J.8 — Unintended reset of a fault

The unintended reset is also possible after a fault in the cabling is initially detected. The opening of any movable guard with an interlocking device connected between the fault and the monitoring logic unit, leads to the unintended reset of the detected fault (see Figure J.9).



Key

A1, A2, A3	movable guards
B1.1, B1.2, B2.1, B2.2, B3.1, B3.2	interlocking devices with potential free contacts
D	monitoring logic unit
S	reset control device of the monitoring logic unit
F1, F2	fault of interlocking device
U_N	nominal voltage of the channel

Figure J.9 — Cable fault with unintended reset

J.3 Methodology for evaluation of DC for series-connected interlocking devices

— Step 1: Determine DC (see ISO 13849-1:2023, Annex E) of every single position switch which is a part of the safety function(s).

— Step 2: Improve the resistance to fault masking if required by enhancing the design or changing the diagnostic method (refer to Clause 7, Clause 8 and ISO 13849-2:2012, Annex D).

  — Improve DC using a different diagnostic measure (see ISO 13849-1:2023, Annex E).

  — Improve cabling in order to reduce fault possibilities or to allow fault exclusion.

  — Select other type of interlocking device in order to allow fault exclusion.

— Step 3: Limit the DC of the position switch to the maximum achievable DC by applying one of the methods given in J.4.

— Step 4: Improve DC if required according to J.5.

J.4 Limitation of DC by effects of series-connected devices

J.4.1 General

According to 9.5, with respect to serial wiring of contacts (without additional diagnostics), the effect of possible fault masking shall be carefully taken into consideration where DC is required for the design of the interlocking function.

Possible fault masking can lead to a fault accumulation. Therefore, the achievable DC shall be estimated using one of the methods described in J.4.2 or J.4.3. Nevertheless, the maximum achievable PL is limited to PL d and the maximum DC is limited to medium.

NOTE The probability of occurrence of faults due to random and systematic failures cannot be fully known. Therefore, any degradation of the diagnostics function can result in an increased probability of dangerous failures. This is not acceptable for higher levels of risk, therefore PL and DC are limited.

J.4.2 Simplified method for the determination of the maximum achievable DC

Table J.1 provides a simplified approach for the determination of the maximum achievable DC taking into account the probability of masking.

Table J.1 — Maximum achievable DC (simplified method)

Number of frequently used movable guards[a,b]	Number of other (non-frequently used) movable guards[c]	Maximum achievable DC[d]
0	2 to 4	Medium
	5 to 30	Low
	>30	None
1	1	Medium
	2 to 4	Low
	≥5	None
>1	≥0	None

[a] If the actuation frequency is higher than once per hour.

[b] If the number of operators capable of opening separate guards exceeds one, then the number of frequently used movable guards shall be increased by one.

[c] The number of additional movable guards may be reduced by one range for each of the following conditions met:

— when the minimum distance between any of the guards is more than 5 m; or

— when none of the other movable guards is directly reachable from the position where the operator actuates a frequently used movable guard.

[d] In all cases, if it is foreseeable that fault masking will occur (e.g. multiple movable guards will be open at the same time as part of normal operation or service), then the DC is limited to none.

J.4.3 Regular method for the determination of the maximum achievable DC

J.4.3.1 Estimation of the fault masking probability (FM)

The fault masking probability (FM) is dependent on several parameters that should be considered including:

— number of series-connected devices;

— actuation frequency of each movable guard;

— distance between the movable guards;

— accessibility of the movable guards;

— number of operators.

For the determination of the FM, Table J.2 shall be applied.

Table J.2 — Fault masking probability (FM)

Number of frequently used movable guards[a,b]	Number of other (non-frequently used) movable guards[c]	Fault masking probability level (FM)[d]
0	2 to 4	1
	5 to 30	2
	>30	3
1	1	1
	2 to 4	2
	≥5	3
>1	≥0	3

[a] If the actuation frequency is higher than once per hour.

[b] If the number of operators capable of opening separate guards exceeds one, then the number of frequently used movable guards shall be increased by one.

[c] The number of additional movable guards may be reduced by one range for each of the following conditions met:

— when the minimum distance between any of the guards is more than 5 m; or

— when none of the other movable guards is directly reachable from the position where the operator actuates a frequently used movable guard.

[d] In all cases, if it is foreseeable that fault masking will occur (e.g. multiple movable guards will be open at the same time as part of normal operation or service), then the FM level is 3.

J.4.3.2 Determination of the maximum achievable DC

The maximum achievable DC depends on the FM level and the type of cabling used in combination with the switch arrangement and the diagnostic capabilities given by the signal evaluation techniques applied. Table J.3 to Table J.5 show the maximum reachable DC depending on those parameters. Different types of switches are not taken into account in the tables because they can be evaluated using their mean time to dangerous failure ($MTTF_D$) value and the DC according to ISO 13849-1 and limiting DC to the range given in Table J.3 to Table J.5.

NOTE 1 “Supply (U_N) voltage wire” in Table J.3 to Table J.5 means a wire carrying a supply voltage U_N, intended for purposes other than interlocking.

NOTE 2 A possibility for a fault is a short-circuit between any wire and permanent supply voltage, which is carried in one wire of the cable. Another possibility for a fault is a short-circuit between any wire and a shielding which is connected to ground. Table J.3 to Table J.5 are used for different cablings and considering these fault possibilities.

Table J.3 — Maximum achievable DC for unprotected multicore cable without a supply voltage (U_N) wire

Arrangement	Cabling	Signal evaluation	Maximum achievable DC FM = 3	FM = 2	FM = 1
Single arrangement	Branch/ Star	Same polarity (U_N/U_N)	None	Low	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	None	Low	Medium
	Loop	Same polarity (U_N/U_N)	None	Low	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	Medium	Medium	Medium
Redundant arrangement	Branch/ Star	Same polarity (U_N/U_N)	None	Low	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	None	Low	Medium
	Loop	Same polarity (U_N/U_N)	Medium	Medium	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	Medium	Medium	Medium

Table J.4 — Maximum achievable DC for unprotected multicore cable with a supply voltage (U_N) wire

Arrangement	Cabling	Signal evaluation	Maximum achievable DC FM = 3	FM = 2	FM = 1
Single arrangement	Branch/ star	same polarity (U_N/U_N)	None	Low	Medium
		inverse polarity (U_N/GND)	None	Low	Medium
		dynamic signals	Low	Medium	Medium
	Loop	same polarity (U_N/U_N)	None	Low	Medium
		inverse polarity (U_N/GND)	None	Low	Medium
		dynamic signals	Medium	Medium	Medium
Redundant arrangement	Branch/ star	same polarity (U_N/U_N)	None	Low	Medium
		inverse polarity (U_N/GND)	None	Low	Medium
		dynamic signals	Low	Medium	Medium
	Loop	same polarity (U_N/U_N)	None	Low	Medium
		inverse polarity (U_N/GND)	None	Low	Medium
		dynamic signals	Medium	Medium	Medium

Table J.5 — Maximum achievable DC for protected multicore cable with or without a supply voltage (U_N) wire

Position switch arrangement	Cabling	Signal evaluation of redundant channels with	Maximum achievable DC		
			FM = 3	FM = 2	FM = 1
Single arrangement	Branch/ star	Same polarity (U_N/U_N)	Medium	Medium	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	Medium	Medium	Medium
	Loop	Same polarity (U_N/U_N)	Medium	Medium	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	Medium	Medium	Medium
Redundant arrangement	Branch/ star	Same polarity (U_N/U_N)	Medium	Medium	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	Medium	Medium	Medium
	Loop	Same polarity (U_N/U_N)	Medium	Medium	Medium
		Inverse polarity (U_N/GND)	None	Low	Medium
		Dynamic signals	Medium	Medium	Medium

J.4.4 Interlocking devices with potential free contacts and other potential free contacts of devices with different functionality connected in series

Fault masking can occur even if other contacts are non-safety related, e.g. series-connected devices containing a non-safety related limit switch within a safety related circuit. In such cases, the probability of fault masking cannot be estimated with the methods of this annex.

J.5 Avoiding fault masking

To avoid fault masking of interlocking devices with potential free contacts, the following methods can be applied:

— use of additional contacts individually connected to a monitoring device in combination with appropriate diagnostic procedures to avoid fault masking;

— avoiding connecting in series of interlocking devices and use of individual safety inputs in the logic controller for each interlocking device;

— use of interlocking devices with internal diagnostics and monitored outputs.

J.6 Application examples in an integrated machinery system (IMS)

J.6.1 Application example 1

Figure J.10 shows an integrated machinery system (IMS) with a perimeter guard. This guard also includes several interlocked movable guards (doors A, B, C, D, F) and a material entry exit area safeguarded with an active optoelectronic protective device (AOPD) (E).