INTERNATIONAL STANDARD

ISO 10218-2

First edition
2011-07-01

Robots and robotic devices — Safety requirements for industrial robots —

Part 2:
Robot systems and integration

Robots et dispositifs robotiques — Exigences de sécurité pour les robots industriels —

Partie 2: Systèmes robots et intégration

Reference number
ISO 10218-2:2011(E)

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Published in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 10218-2 was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 2, *Robots and robotic devices*.

ISO 10218 consists of the following parts, under the general title *Robots and robotic devices — Safety requirements for industrial robots*:

— *Part 1: Robots*

— *Part 2: Robot systems and integration*

Introduction

This part of ISO 10218 has been created in recognition of the particular hazards that are presented by industrial robot systems when integrated and installed in industrial robot cells and lines.

Hazards are frequently unique to a particular robot system. The number and types of hazards are directly related to the nature of the automation process and the complexity of the installation.

The risks associated with these hazards vary with the type of robot used and its purpose and the way in which it is installed, programmed, operated, and maintained.

For the purpose of understanding requirements in this part of ISO 10218, a word syntax is used to distinguish absolute requirements from recommended practices or suggested actions. The word "shall" is used to identify requirements necessary for compliance with this part of ISO 10218. Such requirements have to be accomplished unless an alternative instruction is provided or a suitable alternative is determined by a risk assessment. The word "should" is used to identify suggestions, recommended actions or possible solutions for requirements, but alternatives are possible and the suggested actions are not absolute.

In recognition of the variable nature of hazards with the application of industrial robots, this part of ISO 10218 provides guidance for the assurance of safety in the integration and installation of robots. Since safety in the use of industrial robots is influenced by the design of the particular robot system, a supplementary, though equally important, purpose is to provide guidelines for the design, construction and information for use of robot systems and cells. Requirements for the robot portion of the system can be found in ISO 10218-1.

Providing for a safe robot system or cell depends on the cooperation of a variety of "stakeholders" – those entities that share in a responsibility for the ultimate purpose of providing a safe working environment. Stakeholders may be identified as manufacturers, suppliers, integrators and users (the entity responsible for using robots), but all share the common goal of a safe (robot) machine. The requirements in this part of ISO 10218 may be assigned to one of the stakeholders, but overlapping responsibilities can involve multiple stakeholders in the same requirements. While using this part of ISO 10218, the reader is cautioned that all of the requirements identified may apply to them, even if not specifically addressed by "assigned" stakeholder tasks.

This part of ISO 10218 is complementary and in addition to ISO 10218-1, which covers the robot only. This part of ISO 10218 adds additional information in line with ISO 12100 and ISO 11161, International Standards for requirements to identify and respond in a type-C standard to unique hazards presented by the integration, installation and requirements for use of industrial robots. New technical requirements include, but are not limited to, instructions for applying the new requirements in ISO 10218-1 for safety-related control system performance, robot stopping function, enabling device, programme verification, cableless pendant criteria, collaborating robot criteria and updated design for safety.

This part of ISO 10218 and ISO 10218-1 form part of a series of standards dealing with robots and robotic devices. Other standards cover such topics as integrated robotic systems, coordinate systems and axis motions, general characteristics, performance criteria and related testing methods, terminology, and mechanical interfaces. It is noted that these standards are interrelated and also related to other International Standards.

For ease of reading this part of ISO 10218, the words "robot" and "robot system" refer to "industrial robot" and "industrial robot system" as defined in ISO 10218-1.

Figure 1 describes the relationship of the scope of machinery standards used in a robot system. The robot alone is covered by ISO 10218-1, the system and cell is covered by this part of ISO 10218. A robot cell may include other machines subject to their own C level standards, and the robot system can be part of an integrated manufacturing system covered by ISO 11161 which in turn can also make reference to other relevant B and C level standards.

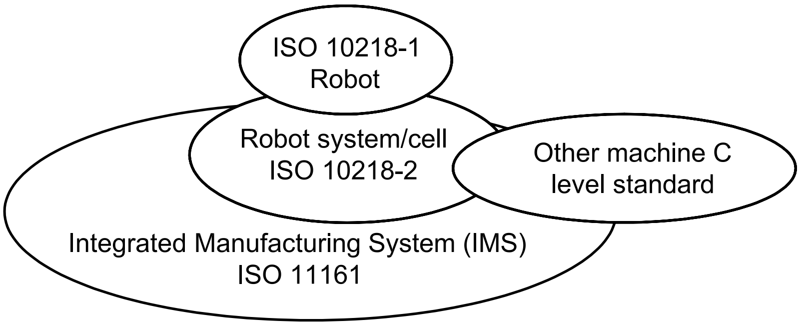


Figure 1 — Graphical view of relationships between standards relating to robot system/cell

Robots and robotic devices — Safety requirements for industrial robots —

Part 2:
Robot systems and integration

1 Scope

This part of ISO 10218 specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s). The integration includes the following:

a) the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;

b) necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;

c) component devices of the industrial robot system or cell.

This part of ISO 10218 describes the basic hazards and hazardous situations identified with these systems, and provides requirements to eliminate or adequately reduce the risks associated with these hazards. Although noise has been identified to be a significant hazard with industrial robot systems, it is not considered in this part of ISO 10218. This part of ISO 10218 also specifies requirements for the industrial robot system as part of an integrated manufacturing system. This part of ISO 10218 does not deal specifically with hazards associated with processes (e.g. laser radiation, ejected chips, welding smoke). Other standards can be applicable to these process hazards.

2 Normative references

The following referenced documents are indispensable for the application 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 4413, *Hydraulic fluid power — General rules and safety requirements for systems and their components*

ISO 4414, *Pneumatic fluid power — General rules and safety requirements for systems and their components*

ISO 8995-1, *Lighting of work places — Part 1: Indoor*

ISO 9946, *Manipulating industrial robots — Presentation of characteristics*

ISO 10218-1, *Robots and robotic devices — Safety requirements for industrial robots — Part 1: Industrial robots*

ISO 11161, *Safety of machinery — Integrated manufacturing systems — Basic requirements*

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

ISO 13849-1:2006, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for design*

ISO 13850, *Safety of machinery — Emergency stop — Principles for design*

ISO 13854, *Safety of machinery — Minimum gaps to avoid crushing of parts of the human body*

ISO 13855, *Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of the human body*

ISO 13856 (all parts), *Safety of machinery — Pressure-sensitive protective devices*

ISO 13857, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and lower limbs*

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

ISO 14119, *Safety of machinery — Interlocking devices associated with guards — Principles for design and selection*

ISO 14120, *Safety of machinery — Guards — General requirements for the design and construction of fixed and movable guards*

ISO 14122 (all parts), *Safety of machinery — Permanent means of access to machinery*

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

IEC 61496-1, *Safety of machinery — Electro-sensitive protective equipment — Part 1: General requirements and tests*

IEC 61800-5-2, *Adjustable speed electrical power drive systems — Part 5-2: Safety requirements — Functional*

IEC/TS 62046, *Safety of machinery — Application of protective equipment to detect the presence of persons*

IEC 62061:2005, *Safety of machinery — Functional safety of safety-related electrical, electronic and programmable electronic control systems*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10218-1 and ISO 12100 and the following apply.

3.1
application
intended use of the robot system, i.e. the process, the task and the intended purpose of the robot system

EXAMPLE Spot welding, painting, assembly, palletizing.

3.2
collaborative robot
robot designed for direct interaction with a human within a defined **collaborative workspace** (3.3)

3.3
collaborative workspace
workspace within the safeguarded space where the robot and a human can perform tasks simultaneously during production operation

3.4
control station
part of the robot system which contains one or more control devices intended to activate or deactivate functions of the system or parts of the system

NOTE The control station can be fixed in place (e.g. control panel) or movable (e.g. control pendant).

3.5
distance guard
guard that does not completely enclose a danger zone, but which prevents or reduces access by virtue of its dimensions and its distance from the danger zone

EXAMPLE Perimeter fence or tunnel guard.

3.6
integration
act of combining a robot with other equipment or another machine (including additional robots) to form a machine system capable of performing useful work such as production of parts

NOTE This act of machine building can include the requirements for the installation of the system.

3.7
integrator
entity that designs, provides, manufactures or assembles robot systems or integrated manufacturing systems and is in charge of the safety strategy, including the protective measures, control interfaces and interconnections of the control system

NOTE The integrator can be a manufacturer, assembler, engineering company or the user.

3.8
integrated manufacturing system
IMS
group of machines working together in a coordinated manner, linked by a material-handling system, interconnected by controls (i.e. IMS controls), for the purpose of manufacturing, treatment, movement or packaging of discrete parts or assemblies

[ISO 11161:2007, definition 3.1]

3.9
industrial robot cell
one or more robot systems including associated machinery and equipment and the associated safeguarded space and protective measures

3.10
industrial robot line
more than one robot cell performing the same or different functions and associated equipment in single or coupled safeguarded spaces

3.11
safe state
condition of a machine or piece of equipment where it does not present an impending hazard

3.12
simultaneous motion
motion of two or more robots at the same time under the control of a single control station and which may be coordinated or synchronous using a common mathematical correlation

3.13
space
three dimensional volume

3.13.1
operating space
operational space
portion of the **restricted space** (3.13.2) that is actually used while performing all motions commanded by the task programme

NOTE Adapted from ISO 8373:1994, definition 4.8.3.

3.13.2
restricted space
portion of the maximum space restricted by limiting devices that establish limits which will not be exceeded

NOTE Adapted from ISO 8373:1994, definition 4.8.2.

3.13.3
safeguarded space
space defined by the perimeter safeguarding

3.14
validation
confirmation by examination and provision of objective evidence that the particular requirements for a specific intended use are fulfilled

3.15
verification
confirmation by examination and provision of objective evidence that the requirements have been fulfilled

4 Hazard identification and risk assessment

4.1 General

4.1.1 The operational characteristics of robots can be significantly different from those of other machines and equipment, as follows:

a) robots are capable of high energy movements through a large operational space;

b) the initiation of movement and the path of the robot arm are difficult to predict and can vary, for example due to changing operational requirements;

c) the operating space of the robot can overlap a portion of other robots' operating space or the work zones of other machines and related equipment;

d) operators can be required to work in close proximity to the robot system while power to the machine actuators is available.

4.1.2 It is necessary to identify the hazards and to assess the risks associated with the robot and its application before selecting and designing appropriate safeguarding measures to adequately reduce the risks. Technical measures for the reduction of risk are based upon the following fundamental principles:

a) the elimination of hazards by design or their reduction by substitution;

b) preventing operators coming into contact with hazards or controlling the hazards by achieving a safe state before the operator can come into contact with it;

c) the reduction of risk during interventions (e.g. teaching).

4.1.3 The realization of these principles can involve:

a) designing the robot system to allow tasks to be performed from outside the safeguarded space;

b) the creation of a safeguarded space and a restricted space;

c) provision of other safeguards when interventions have to occur within the safeguarded space.

4.1.4 The type of robot, its application and its relationship to other machines and related equipment will influence the design and the selection of the protective measures. These shall be suitable for the work being done and permit, where necessary, teaching, setting, maintenance, programme verification and troubleshooting operations to be carried out safely.

4.2 Layout design

The design of the robot system and cell layout is a key process in the elimination of hazards and reduction of risks. The following factors shall be taken into account during the layout design process.

a) Establishing the physical limits (three dimensional) of the cell or line, including other parts of a larger cell or system (integrated manufacturing system):

    1) scale and origin for modelling the layout in design drawings;

    2) location and dimensions of the components within available facilities (scale).

b) Workspaces, access and clearance:

    1) identifying the maximum space of the robot system, establishing restricted and operating spaces, and identifying the need for clearances around obstacles such as building supports;

    2) traffic routes (pedestrian aisles, visitor routes, material movement outside the perimeter safeguarding of the cell or line);

    3) access and safe pathway to support services (electricity, gas, water, vacuum, hydraulic, ventilation) and control systems;

    4) access and safe pathway for service, cleaning, troubleshooting and maintenance purposes;

    5) cables/other hazards for slips, trips and falls;

    6) cable trays.

c) Manual intervention – the layout should be designed to allow tasks requiring manual intervention to be performed from outside the safeguarded space. Where this is not practicable and when the intervention requires powered movements of the machine(s), appropriate enabling devices shall be provided. The enabling devices may be designed to control:

    1) the whole robot cell;

2) a zone in the robot cell;

3) a selected machine or equipment within the cell.

NOTE See ISO 12100 for more information.

d) Ergonomics and human interface with equipment:

1) visibility of operations;

2) clarity of controls;

3) clear association of controls with robot;

4) regional control design traditions;

5) position of workpiece relative to the operator;

6) foreseeable misuse;

7) collaborative operation.

e) Environmental conditions:

1) ventilation;

2) weld spark.

f) Loading and unloading the workpieces/tool change.

g) Consideration of perimeter safeguarding.

h) Requirements for and location of emergency stop devices and possible zoning of the cell (e.g. local stops or full cell stop).

i) Requirements for and location of enabling devices.

j) Attention to the intended use of all components.

The risk assessment shall determine the additional space required beyond the restricted space to define the safeguarded space.

4.3 Risk assessment

4.3.1 General

Because a robot system is always integrated into a particular application, the integrator shall perform a risk assessment to determine the risk reduction measures required to adequately reduce the risks presented by the integrated application. Particular attention should be paid to instances where safeguards are removed from individual machines in order to achieve the integrated application.

Risk assessment enables the systematic analysis and evaluation of the risks associated with the robot system over its whole lifecycle (i.e. commissioning, set-up, production, maintenance, repair, decommissioning).

Risk assessment is followed, whenever necessary, by risk reduction. When this process is repeated, it gives the iterative process for eliminating hazards as far as practicable and for reducing risks by implementing protective measures.

Risk assessment includes:

— determination of the limits of the robot system (see 4.3.2);

— hazard identification (see 4.4);

— risk estimation;

— risk evaluation.

4.3.2 Limits of the robot system

The integration of a robot system begins with the specification of its intended use and limits described in ISO 12100, ISO 11161 and other applicable C level standards. This specification should include, for example:

a) use limits:

1) description of functions, intended use and reasonably foreseeable misuse;

2) description of the different user modes;

3) analysis of process sequences including manual intervention;

4) description of interfaces, tooling and equipment;

NOTE 1 It is advisable that the relevant C level standards for these devices be taken into account.

5) utility connections;

6) information supplied by the manufacturer, which is derived from the use of ISO 10218-1, including applied measures for risk reduction;

7) required power supply and their appliances;

8) required or anticipated user skills (competency);

b) space limits (see 5.5 describing layout):

1) required machine movement range;

2) required space for installation and maintenance;

3) required space for operator tasks and other human intervention;

4) reconfiguration capabilities (ISO 11161);

5) required access (see 5.5.2);

6) foundations;

7) required space for supply and disposal devices or equipment;

c) time limits:

1) intended life limit of the machinery and its components (wear parts, tools, etc.);

2) process flow charts and timings;

3) recommended service intervals;

d) other limits:

1) environmental (temperature, use indoors or outdoors, tolerance to dust and moisture, etc.);

2) required cleanliness level for the intended use and environment;

3) properties of processed materials;

4) hazardous environments;

5) lessons learned, i.e. study and comparison, including available accident and incident reports, of similar operations and systems.

NOTE 2 Other national standards and local codes can also provide important information on sources of power and requirements for safe handling and installation.

4.4 Hazard identification

4.4.1 General

The list of significant hazards for robot and robot systems contained in Annex A is the result of hazard identification and risk assessment carried out as described in ISO 12100.

Further hazards (e.g. fumes, gases, chemicals and hot materials) can be created by specific applications (e.g. welding, laser cutting, machining) and by the interaction of the robot system with other machines (e.g. crushing, shearing, impact). These hazards shall be addressed on an individual basis with a risk assessment for the specific application.

4.4.2 Task identification

In order to determine the potential occurrence of hazardous situations it is necessary to identify the tasks that are to be carried out by operators of the robot system and its associated equipment. The integrator shall identify and document these tasks. The user shall be consulted to ensure that all reasonably foreseeable hazardous situations (task and hazard combinations) associated with the robot cell are identified, including indirect interactions (e.g. persons having no tasks associated with the system but having exposure to hazards associated with the system). These tasks include, but are not limited to:

a) process control and monitoring;

b) workpiece loading;

c) programming and verification;

d) brief operator intervention not requiring disassembly;

e) set-up (e.g. fixture changes, tool change);

f) troubleshooting;

g) correction of malfunction(s) (e.g. equipment jams, dropped parts, event recovery and abnormal conditions);

h) control of hazardous energy (including fixtures, clamps, turntables and other equipment);

i) maintenance and repair;

j) equipment cleaning.

4.5 Hazard elimination and risk reduction

Having identified the hazards, it is necessary to assess the risks associated with the robot system before applying appropriate measures to adequately reduce the risks. Measures for the reduction of risk are based upon these fundamental principles:

a) the elimination of hazards by design or the reduction of their risk by substitution;

b) safeguarding to prevent operators coming into contact with hazards or to ensure the hazards are brought to a safe state before the operator can come into contact with them;

c) the provision of supplementary protective measures such as information for use, training, signs, personal protective equipment, etc.

The requirements contained in Clause 5 have been derived from the iterative process of applying risk reduction measures, in accordance with ISO 12100, to the hazards identified in Annex A. The integrator shall ensure that the risks identified in the risk assessment are adequately reduced by applying the requirements of Clause 5. If risks are not adequately reduced, further risk reduction measures shall be applied until they are adequately reduced.

5 Safety requirements and protective measures

5.1 General

The integration of robot systems and cells shall comply with the requirements of this part of ISO 10218. In addition, the robot cell or robot line shall be designed according to the principles of ISO 12100 for relevant hazards that are not specifically dealt with by this part of ISO 10218 (e.g. sharp edges). The design of the robot system should follow ergonomic principles to ensure that it is easy to operate and maintain. The robot system shall be designed to avoid exposing personnel to hazards.

NOTE 1 Not all of the hazards identified by this part of ISO 10218 apply to every robot system, nor will the level of risk associated with a given hazardous situation be the same from robot system to robot system.

NOTE 2 Recommended methods of verification of various requirements in this clause are found in Clause 6.

5.2 Safety-related control system performance (hardware/software)

5.2.1 General

Safety-related control systems (electric, hydraulic, pneumatic and software) shall comply with 5.2.2, unless the results of the risk assessment determine that an alternative performance criterion as described in 5.2.3 is appropriate. The safety-related control system performance of the robot system and any furnished equipment shall be clearly stated in the information for use.

NOTE 1 Safety-related control systems can also be called SRP/CS (safety-related parts of control systems).

For the purposes of this part of ISO 10218, safety-related control system performance is stated as:

— Performance Levels (PL) and categories as described in ISO 13849-1:2006, 4.5.1;

— Safety Integrity Levels (SIL) and hardware fault tolerance requirements as described in IEC 62061:2005, 5.2.4.

Those two standards address functional safety in similar but different methods. Requirements in those standards should be used for the respective safety-related control systems for which they are intended. The designer may choose to use either of the two standards. The data and criteria necessary to determine the safety-related control system performance shall be included in the information for use.

NOTE 2 The comparison with ISO 13849-1 and IEC 62061 is described in ISO/TR 23849.

Other standards offering alternative performance requirements, such as the term “control reliability” used in North America, may also be used. When using these alternative standards to design safety-related control systems, an equivalent level of risk reduction shall be achieved.

Any failure of the safety-related control system shall result in a stop category 0 or 1 in accordance with IEC 60204-1.

5.2.2 Performance requirement

Safety-related parts of control systems shall be designed so that they comply with PL=d with structure category 3 as described in ISO 13849-1:2006, or so that they comply with SIL 2 with hardware fault tolerance of 1 with a proof test interval of not less than 20 years as described in IEC 62061:2005.

This means in particular:

a) a single fault in any of these parts does not lead to the loss of the safety function,

b) whenever reasonably practicable, the single fault shall be detected at or before the next demand upon the safety function,

c) when the single fault occurs, the safety function is always performed and a safe state shall be maintained until the detected fault is corrected,

d) all reasonably foreseeable faults shall be detected.

The requirements a) to d) are considered to be equivalent to structure category 3 as described in ISO 13849-1:2006.

NOTE The requirement of single-fault detection does not mean that all faults will be detected. Consequently, the accumulation of undetected faults can lead to an unintended output and a hazardous situation at the machine.

5.2.3 Other control system performance criteria

The results of a comprehensive risk assessment performed on the robot system and its intended application may determine that a safety-related control system performance other than that stated in 5.2.2 is warranted for the application.

Selection of one of these other safety-related performance criteria shall be specifically identified, and appropriate limitations and cautions shall be included in the information for use provided with the affected equipment.

5.3 Design and installation

5.3.1 Environmental conditions

The robot system and protective measures of the robot cell shall be designed taking into account environmental conditions like surrounding temperature, humidity, electro-magnetic disturbances, lighting, etc. These can lead to some requirements for the surrounding environment due to technical restrictions.

The robot and robot system and cell components shall be chosen to withstand the expected operational and environmental conditions.

5.3.2 Location of controls

Operational controls and equipment (e.g. weld controller, pneumatic valves, etc.) requiring access during automatic operation shall be located outside the safeguarded space forcing a person using the control actuators to be outside the safeguarded space. Controls and equipment should be placed and constructed so as to allow a clear view of the robot restricted space.

5.3.3 Actuating controls

Actuating controls shall meet the requirements of IEC 60204-1. The controls shall be designed consistent with ISO 10218-1. The robot system shall not respond to any external remote commands or conditions that would cause hazardous situations.

5.3.4 Power requirements

All sources of robot and other equipment power (e.g. pneumatic, hydraulic, mechanical, electrical) shall meet the requirements as specified by the machine and component manufacturers. Electrical installations shall meet the requirements of IEC 60204-1. Hydraulic power installations shall meet the requirements of ISO 4413 and pneumatic power installations shall meet those of ISO 4414.

5.3.5 Equipotential bonding/earthing requirements (grounding)

Protective bonding and functional bonding shall meet the requirements of IEC 60204-1.

5.3.6 Isolating sources of energy

Means shall be provided to isolate hazardous energy sources without exposing personnel to a hazard. These means shall be lockable and/or secured only in the de-energized position.

The robot system should have a single supply disconnecting device for each type of energy source. For multiple robot or large installations, multiple disconnecting devices for each type of energy can be necessary. The span of control for each of these devices shall be clearly marked in the vicinity of the handle of the disconnecting device (e.g. text or symbol).

NOTE Energy sources can be electrical, mechanical, hydraulic, pneumatic, chemical, thermal, potential, kinetic, etc.

5.3.7 Control of stored energy

A means shall be provided for the control of and/or the controlled release of stored hazardous energy. A label shall be affixed to identify the stored energy hazard.

NOTE 1 Stored energy sources can be air or hydraulic pressure accumulators, capacitors, batteries, springs, counter balances, flywheels ,gravity, etc.

NOTE 2 A hanging axis can create a significant hazard depending on the frequency and duration of exposure (e.g. standing below the robot arm during setting). It is advisable that mechanical blocking or holding control systems designed to protect persons exposed to stored hazardous energy have control performance designed in accordance with 5.2.2 or 5.2.3, as determined by the risk assessment.

5.3.8 Robot system and cell stopping functions

5.3.8.1 General

Every robot system or cell shall have a protective stop function and an independent emergency stop function. The respective functions shall have the ability for the connection of additional protective or emergency stop devices.

5.3.8.2 Emergency stop function

Each control station capable of initiating motion or other hazardous functions shall have a manually initiated emergency stop function that complies with the requirements of IEC 60204-1 and ISO 13850.

The actuation of an emergency stop function shall stop all robot motion and other hazardous functions in the cell, or at the interface between cells and other areas of the workspace.

Robot systems shall have a single emergency stop function affecting all relevant parts of the system. In the case of larger systems (e.g. multiple robot or multiple cells), a separation of the span of control may be necessary. In such cases the span of control shall be set according to the requirements of the task(s) to be performed or characteristics of the system (e.g. equipment structure, position of perimeter safeguarding). The span of control shall be clearly marked in the vicinity of the emergency stop device (e.g. by text or symbol).

If the restricted spaces of two or more robots overlap, or if two or more robots are accessible within a common safeguarded space, this space shall be one workspace. All emergency stop devices for a workspace shall have the same span of control.

The span of control may include multiple workspaces. Information for use shall include information on the span of control of each emergency stop device.

Robot system emergency stops shall remain functional even if the control station is not active.

Selection of a category 0 or category 1 stop function in accordance with IEC 60204-1 shall be determined from the risk assessment.

The emergency stop function shall comply with at least the requirements in 5.2.2, unless the risk assessment determines that another performance criterion is appropriate.

NOTE Some protective stop circuits are automatically bypassed in the manual mode and would not be suitable for connecting emergency stop devices.

When an emergency stop output signal is provided either:

— the output shall continue to function when the robot system power is removed, or

— if the output does not continue to function when the robot system power supply is removed, an emergency stop signal shall be generated.

5.3.8.3 Protective stop

The robot system shall have one or more protective stop circuits designed for the connection of external protective devices. Selection of stop category 0 or 1 as described in accordance with IEC 60204-1 shall be determined by the risk assessment.

Stop category 2 may be applied if the external power drive system complies with IEC 61800-5-2.

This protective stop function shall cause a stop of all robot system motion, and cause cessation of any other hazardous functions controlled by the robot system. This stop may be initiated manually or by control logic.

The protective stop function performance shall comply with the requirements in 5.2.2 or 5.2.3.

5.3.9 Associated equipment shut-down

The robot system shall be installed so that shut-down of associated equipment does not result in a hazard or hazardous condition.

5.3.10 End-effector (end of arm tooling) requirements

End-effectors shall be designed and constructed so that:

a) loss or change of energy supply (e.g. electrical, hydraulic, pneumatic, vacuum supply) does not cause release of the load that would result in a hazardous condition;

b) the static and dynamic forces created by the load and the end-effectors together are within the load capacity and dynamic response of the robot;

c) wrist plates (mounting flange) and accessories properly align (couple);

d) detachable tools are securely attached while in use;

e) release of detachable tools only occurs in designated locations or under specific, controlled conditions, if the release could result in a hazardous situation;

f) the end-effector withstands the anticipated forces for its expected life.

When practicable, power can be supplied to end-effectors for troubleshooting without applying motive energy to the robot actuator(s).

NOTE This feature can be a useful option offered by robot manufacturers; however, it is not a requirement in ISO 10218-1.

The information for use shall include the intended life of end-effectors, based on expected parameters in normal operation if the failure of the end-effector would result in a potentially hazardous condition.

Prior to operation of the robot system, the robot tool centre point(s) (TCP) shall be adjusted using the offset feature provided by the robot manufacturer. Measures to avoid hazardous conditions shall be provided (e.g. mechanically protected pneumatic or vacuum hoses; self-retaining devices such as spring-loaded additional grips).

5.3.11 Emergency recovery procedure

The information for use shall include detailed instructions for fault recovery of robot system-related equipment together with the robot manufacturer's instructions on emergency or abnormal movement of the robot without drive power. If signs or labels are required, they shall be affixed or instructions for affixing shall be provided.

5.3.12 Warning signs

When warning signs on a robot or other piece of equipment in the system are obscured by the installation/integration, then other equally effective means of warning shall be provided (e.g. another warning sign in a visible location).

5.3.13 Lighting

The level of required task lighting shall be identified and specified in the information for use.

The robot system shall be supplied with integral lighting suitable for the operations concerned where the absence thereof is likely to cause a risk despite ambient lighting of normal intensity. The robot system shall be designed and constructed so that there is no area of shadow likely to cause nuisance, no irritating dazzle and no dangerous stroboscopic effects on moving parts due to the lighting. Internal parts requiring frequent inspection and adjustment, as well as maintenance areas, shall be provided with appropriate lighting. Illumination shall be at least 500 lx at the area where frequent inspection and adjustment is necessary (see ISO 8995-1).

NOTE Areas to be considered for lighting include work stations, entry areas, etc.

5.3.14 Application hazards

The integration of the robot system shall also take into account the application's hazards (e.g. fumes, gases, chemicals, hot materials) associated with the process and tooling (e.g. welding, laser cutting, machining).

Interface requirements to other machines shall follow the guidance of the manufacturer as specified in the information for use.

5.3.15 Enabling devices

Pendant and additional enabling devices and their integration shall comply with ISO 10218-1 (see Annex D for additional information).

When more than one person is required to be protected within the safeguarded space, an enabling device shall be provided to each person. All enabling devices associated with a single robot control shall have the same functionality (span of control).

Where personnel could be exposed to a hazardous situation (e.g. standing in the restricted space of an adjoining robot having overlapping restricted spaces while working on auxiliary equipment or other robot) during manual operation, control systems shall be interlocked such that enabling devices control all hazards in areas of the cell.

Interlocked hazardous machine functions shall require a separate act to restart after being controlled (stopped) by the enabling device.

NOTE 1 An interlocking enabling device's span of control depends on layout, the space, the anticipated tasks and the work locations anticipated for these tasks. Control measures complying with 5.2.2 can be designed to prevent overlapping robots from being active at the same time during manual operation.

NOTE 2 For process observation, see Annex F.

5.4 Limiting robot motion

5.4.1 General

Robot installations shall be designed and integrated so as to reduce the potential exposure of personnel to hazards. Robot systems can have a potentially large operating volume (maximum space), particularly when handling a large workpiece. Locating perimeter guards to safeguard persons from the hazards presented by the robot system (safeguarded space) at these maximum dimensions could result in enclosure of an unnecessarily large volume that exceeds the space required by the tasks the robots are required to perform (operating space). To reduce the safeguarded space, the maximum space can be limited by the provision of integral or external devices that restrict the movement of the robot system (restricted space).

5.4.2 Establishing safeguarded and restricted spaces

The safeguarded space shall be established by perimeter guarding. This shall be sited with due consideration of the location and layout of the machines and the hazards within the safeguarded space.

The restricted space of the robot system shall be established by means which limit the motion of the robot, end-effector, fixture and workpiece. The restricted space should be made smaller than the maximum space. The restricted space shall be within the safeguarded space and should match the operating space as close as is reasonably practicable.

The perimeter safeguards shall not be installed closer to the hazard than the restricted space. If the perimeter safeguard is designed to be the limiting device in accordance with 5.4.3, then the perimeter safeguard establishes a portion of the boundary for both the safeguarded and restricted spaces.

Additional safeguarding may be needed for operator work stations (e.g. parts loading location). Dynamic limiting (see 5.4.4), interlocking safeguards, and other safeguards can be used to ensure that an operator is not exposed to a hazard while at a work station.

5.4.3 Means for limiting motion

Limiting the motion of the robot system may be accomplished by means integral to the robot (e.g. safety-rated soft axis and space limiting or hard stops provided by the manufacturer), by installing external limiting devices, or by a combination of both. Limiting means are used to restrict the space in which a robot may perform its task, i.e. the restricted space is made smaller than the maximum space by use of limiting devices.

Limiting devices fall into two categories: mechanical limiting devices and non-mechanical limiting devices. Mechanical limiting devices physically restrain the robot from moving beyond a designed limit. Non-mechanical limiting devices do not limit the robot motion themselves, but rather initiate a stop through the robot control system. Non-mechanical limiting devices therefore require the integrator to take the robot stopping distance into account when establishing the restricted space of the robot.

Any associated safety controls connected to the robot controls shall meet the requirements in ISO 10218-1.

The limiting devices shall be correctly adjusted and secured. When a method of limiting the range of motion is required by the design, it shall comply with one of the following.

— If mechanical stops are provided, they shall meet the requirements for limiting devices in ISO 10218-1 and, when applicable, requirements for dynamic limiting devices in ISO 10218-1.

— If alternative methods of limiting the range of motion are provided, they shall be designed, constructed and installed to meet at least the requirements for axis limiting in ISO 10218-1. These methods shall comply with at least the requirements in 5.2.2 unless the risk assessment determines that another performance criterion is appropriate. The stopping distance associated with the limiting means shall be included in any calculation of the restricted space. See ISO 10218-1 for information and metric on stopping time and distance.

When non-mechanical limiting devices are used, including safety-rated soft axis and space limiting (see ISO 10218-1), the restricted space shall be determined based on the robot with actual load. If the speed of the robot is limited by a monitoring system satisfying 5.2.2, the restricted space may be based on the configured speed limit. Otherwise, the restricted space shall be based on the maximum speed of the robot.

If safety-rated soft axis and space limiting features built into the robot are used in accordance with the robot manufacturer's instructions, information about the programmed limits established by that means shall be included in the information for use.

In cases where the perimeter guard is designed to be the limiting device, the results of the risk assessment shall be used to determine the requirements for the design, strength and deflection for that guard.

NOTE 1 For robots designed to compensate speed based on actual load, it is possible for the maximum conditions to occur when the robot carries less than the rated load.

NOTE 2 The restricted space is defined where the robot motion actually stops, not by where a stop is initiated. This can be clearly defined by the location of mechanical limiting devices (e.g. hard stops). The location of non-mechanical limiting devices requires activation time and robot stopping distance to be considered. This includes safety-rated soft axis and space limiting configurations.

NOTE 3 Devices designed to protect the machine (e.g. over-current protection and collision sensors) are not suitable as limiting devices unless they are specifically designed, tested and determined to be suitable as a safety device for the purpose of limiting motion that complies with ISO 10218-1.

NOTE 4 Using a perimeter guard as a limiting device is normally practicable only when robots cannot cause hazardous deformations of the guard.

5.4.4 Dynamic limiting

Dynamic limiting is the automatically controlled change of a robot system's restricted space that occurs during a portion of the robot system's cycle. Control devices such as, but not limited to, cam-operated limit switches, light curtains or control-activated retractable hard stops may be utilized to further limit robot movement within the restricted space while the robot performs its task programme. For this, mechanical limiting devices shall be capable of stopping the robot motion under rated load and speed conditions. Associated safety-related control systems shall comply with the performance requirements of 5.2.

The location of the dynamic limiting zones shall be identified in the information for use. For non-mechanical limiting devices, these shall include both the zone boundary where a stop is initiated and the zone where the robot actually stops (the restricted space).

NOTE Dynamic limiting can be useful in designing two alternately selectable restricted spaces to increase work cell productivity by having one robot service two work stations.

5.5 Layout

5.5.1 Perimeter safeguarding

Perimeter safeguarding measures shall be implemented using guards or sensitive protective equipment in accordance with 5.10. The protective devices selection shall consider:

— the expected operating stresses;

— the influence of the processed material, especially feeding and removing materials from the robot system;

— other relevant external influences (e.g. a very dusty atmosphere precludes the use of an opto-electronic protective device).

Safety distances over and through mechanical guarding shall meet the requirements in ISO 13857. Minimum distances from interlocking guards and other trip devices shall meet the requirements in ISO 13855. Where crushing is prevented by the maintaining of minimum gaps, they shall meet the requirements in ISO 13854.

5.5.2 Access for interventions

When installing a robot system, a task-based risk assessment of the specific installation and anticipated tasks shall be performed to determine possible trapping or pinch points within the robot restricted space.

Tasks requiring the use of manual high-speed mode shall be provided a minimum clearance of 500 mm. This clearance is required between the calculated stopping location of the hazard and areas of the building, structures, perimeter guarding, utilities, other machines and equipment not specifically supporting the robot function that may create trapping or a pinch (see ISO 13854).

EXAMPLE Support for the robot function can include fixtures, load station, material handling equipment and process-related equipment.

Wherever practicable, the layout shall be designed to allow operator tasks to be performed from outside the safeguarded space. Where it is necessary to perform tasks within the safeguarded space there shall be safe and adequate access to the task locations. Access paths and means shall not expose operators to hazards, including slipping, tripping and falling hazards.

The design for access inside the safeguarded space shall consider, for example:

— cable channels, stumble areas;

— frequency of the required access for manual loading/unloading;

— physical characteristics of the load;

— abidance and observation areas;

— service positions (e.g. tip change);

— easily accessible maintenance units (e.g. outside the safeguarded space).

Permanent means of access shall be provided, taking into account the frequency and the ergonomic aspects of the task.

Controls (e.g. pendants, robot control cabinets) should be placed near the access means in order to improve ease of use by the operators. When electrical equipment containing elements that require access (e.g. for routine service) are mounted above the level of normal reach (e.g. on the roof of machine), a means for access shall be provided (e.g. a work platform). The results of a risk assessment shall be used to determine the appropriate means for providing access to the relevant devices between a height of 400 mm and 2 000 mm from the access level (see also IEC 60204-1).

Electric enclosures shall be mounted so that their doors can be fully opened and escape routes are always available even when doors are opened. This is fulfilled when:

a) doors can be easily pushed to a closed position, taking escape direction into account;

b) the remaining clearance is not less than 500 mm when the door is fully open (see also IEC 60364-7-729).

Selection and design of platforms, walkways, stairs, stepladders and fixed ladders shall be in accordance with the relevant parts of ISO 14122.

Safeguarding shall be provided to either prevent operator access between cells or to bring hazards in adjacent cells to a safe state before an operator can reach them.

Safeguarding shall be provided to reduce risks to operators due to the transfer of materials into and out of adjoining cells.

5.5.3 Material handling

The hazards associated with material handling (e.g. entanglement, falling material and the connections with the robot system) shall be considered in the risk assessment.

Where materials enter or exit the safeguarded space, measures shall be taken to prevent persons entering undetected into the hazard zone. These measures shall either prevent persons coming into contact with hazards or shall bring the hazards to a safe state before the hazards can be reached without creating additional hazards. The dimensions of the openings should be reduced to the minimum size required to allow passage of the material. (See 5.10.7.)

5.5.4 Process observation

Process observation should be performed from outside the safeguarded space. This can be accomplished by providing safe standing and observation locations (e.g. platforms, catwalks, remote vision systems), as determined by the results of a risk assessment.

When process observation can only be performed from inside the safeguarded space, the operation modes in accordance with 5.6.4.2 and 5.6.4.3 shall be used. When these operation modes are not applicable, a separate control mode shall be provided. This mode shall provide the safeguarding necessary to ensure that operators performing process observation are not placed in a hazardous situation. Additional information can be found in Annex F.

5.6 Robot system operational mode application

5.6.1 General

In a cell with more than one robot system, the operational mode may be selected individually on each robot system or common for all associated robot systems in the cell. If the operational mode is selected individually on each robot system, it is not necessary that all robot systems be switched to manual mode. Robots that are not operated manually shall remain in a safe state, independent of the operational mode selected, and not create a hazard.

The following requirements apply to a robot system or a robot cell. They do not include requirements for equipment within the robot cell that is not required for the robot task. A risk assessment shall be carried out to determine any further measures that have to be taken due to the risks presented by this other equipment. It is strongly recommended that when a robot system is operated in manual mode, all other equipment that is not required for the robot task be placed in, and maintained in, a safe state.

5.6.2 Selection

Unauthorized and/or inadvertent mode selection shall be prevented by suitable means.

These means shall only enable the selected mode and shall not by themselves initiate robot system operation or other hazardous operations from associated machinery. A separate actuation shall be required to initiate robot system operation.

Unambiguous indication of the selected operating mode shall be provided.

Changing the mode of operation shall not create a hazardous situation.

5.6.3 Automatic mode

5.6.3.1 General

Entering the safeguarded space in automatic mode shall lead to a protective stop of all equipment that could present a hazard or hazardous situation.

5.6.3.2 Selection of automatic mode

Selection of automatic mode of the robot system(s) shall not override or reset any protective stop or emergency stop condition.

Selection of automatic mode shall be done outside the safeguarded space. If using the pendant or teaching control to select automatic mode, a separate deliberate action outside the safeguarded space shall be required for initiation of automatic operation.

Switching from automatic mode shall result in a protective stop or emergency stop.

5.6.3.3 Initiation of automatic operation

Automatic operation shall be initiated from outside the safeguarded space.

Initiation of automatic operation shall only be possible when all associated safeguards are active.

5.6.3.4 Manual reset, start/restart and unexpected start-up

5.6.3.4.1 The start and the restart of the robot system shall be a perspicuous and simple operation. Start and restart shall require that relevant safety functions and/or protective measures be functional.

Safety-related control functions shall comply with at least the requirements in 5.2.2 unless the risk assessment determines that another performance criterion is appropriate.

5.6.3.4.2 A start interlock shall be provided to prevent automatic starting of hazardous operations when the power supply is switched on, or is interrupted and restored. The start interlock shall be reset by a deliberate human action.

A restart interlock shall be provided to prevent automatic restarting of hazardous operation after either:

a) actuation of a safeguarding function;

b) a change in operating mode of the cell.

Personnel shall be protected from start and restart of the robot cell when they are inside the safeguarded space, in accordance with ISO 14118.

Start and restart controls shall be manually actuated, located outside the safeguarded space and shall not be possible to activate from inside the safeguarded space.

The manual reset function shall fulfil all of the following:

— be provided through a separate and manually operated device within the safety-related control systems;

— only be achieved if all safety functions and safeguards are operative;

— not initiate motion or a hazardous situation by itself;

— be by deliberate action;

— enable the control system for accepting a separate start command;

— only be accepted by disengaging the actuator from its energized (on) position.

From each control position, the operator shall be able to ensure that no-one is in the safeguarded space. The location of start and reset actuating controls should allow a clear and unobstructed view of the safeguarded space.

If this is not practicable, presence sensing shall be provided to detect operators throughout the safeguarded space.

5.6.3.4.3 If presence sensing is not practicable, unexpected start-up shall be prevented by providing other protective measures. These protective measures can include:

a) multiple means for the isolation and lockout of the hazardous equipment located within the safeguarded space;

b) measures to lock a guard (gate) in the open position;

c) additional time-limited reset devices located inside the safeguarded space.

If this is not practicable, an audio-visual pre-start warning signal shall be provided that is:

— sufficient to be seen and heard from within the safeguarded space, and

— provided with a duration of the pre-start delay that is sufficient to allow egress by the operators from the safeguarded space.

A sufficient number of readily identifiable and easily accessible emergency stop devices shall be located within the safeguarded space to allow their operation during the pre-start delay.

NOTE For the hierarchy of selecting protective measures, see 4.5.

5.6.4 Manual mode

5.6.4.1 General

When manual intervention is required, local control shall be effected by a single pendant or similar control station meeting the requirements of ISO 10218-1.

NOTE This applies to any device used to control a robot from within the safeguarded space while drive power is applied to any of the robot axes or end-effector. This includes robots with powered lead-through teach controls, whether using robot-mounted manual controls or main/secondary teaching controls.

Whenever practicable, control devices and control stations shall be located so that the operator is able to observe the working area or hazard zone.

A stop control device shall be placed near each start control device.

The system shall be designed and constructed so that when the system is placed under local control, initiation of motion or change of local control selection from any other source is prevented.

5.6.4.2 Manual reduced speed

In manual reduced speed mode the velocity of the selected TCP shall not exceed 250 mm/s. It should be possible to select speeds lower than 250 mm/s. The results of a risk assessment shall determine if a maximum reduced speed lower than 250 mm/s is required and if other equipment in the robot system needs to be operated at a reduced speed.

In manual reduced speed mode, motion of the robot or any part of the robot system shall be possible only in conjunction with an enabling device in accordance with ISO 10218-1. The safety-related control performance of the enabling function shall be in accordance with 5.2.

5.6.4.3 Manual high-speed

This mode is intended to be restricted to programme verification only, and shall not be used for production. All manual jogging shall be at reduced speed. This mode shall only be provided in exceptional circumstances where the application requires the robot system to be operated in the manual high-speed mode. In manual high-speed mode, the speed of the selected TCP may exceed 250 mm/s. The robot system shall conform with the requirements of automatic operation mode of ISO 10218-1 and be provided with a pendant conforming to the requirements of ISO 10218-1, and require, in the information for use, that the pendant's enabling device be functionally tested for proper operation prior to initiating motion.

5.6.5 Remote access for manual intervention

A robot system may be network enabled (e.g. LAN, modem, and internet) which allows remote access for diagnostics, technical consultation and testing, etc.

If a robot system is to be remotely controlled by an operator who is physically away from the robot (e.g. in a distant office), the following shall be required:

a) manual remote control shall only be possible when the robot system is in manual mode;

b) at any one time, only one source of control – local or remote – shall be active (single point of control);

c) the type of control listed in b) shall not override local selection and cause any local hazardous situation;

d) activation of the manual remote control function shall be possible only from the local control;

e) all controller functions that may cause a hazard (e.g. motion of robot, forcing outputs that control hazardous equipment, changing values that influence the robot in a hazardous way, acknowledgement of safety functions, hold to run, etc.) shall be possible only from the single selected source of control;

f) it shall not be possible for remote changes to the parameters, related to limiting robot motion by means of safety-rated soft axis and space limiting as described in 5.4.3, to take effect without local action to confirm the acceptability of the change and that it did not create a hazard;

g) an indication at the local control (control panel, teach pendant, etc.) shall show that the robot system is being remotely controlled;

h) attended manual intervention shall only be possible when the robot system is in manual reduced speed;

i) if no one is in the safeguarded space and safeguards are active, remote functions may be performed without any local activities;

j) when a person is required to be in the safeguarded space, control functions by a remote operator that may cause a hazard can only be performed when the local operator enables the function by pressing an enabling device;

k) any equipment not needed for the remote action that could create a hazard shall be maintained in a safe state.

The information for use shall include appropriate requirements for training both the remote and local operators for the remote tasks.

5.7 Pendants

5.7.1 General

Pendants and teaching control devices used inside the safeguarded space shall conform to the requirements in ISO 10218-1.

The emergency stop function on the pendant shall comply with 5.3.8.2.

Teach pendants equipped with a cable shall have a cable that is of sufficient length to allow the teacher to perform expected tasks in a safe manner (e.g. not going over the equipment to get to the teach point due to insufficient cable length). The cable shall be capable of withstanding the anticipated environmental conditions of the location in which it is to be used.

Provision for proper storage of the pendant shall be made in such a manner as to minimize the possibility of damage which may result in a hazard. Storage of detached pendants or cableless pendants shall minimize the possibility of mistaking an inactive emergency stop device as being active.

5.7.2 Requirements for cableless or detachable installations/communications

When cableless or detachable teach pendants are used with the robot system, the following shall apply:

a) pendant(s) shall be in compliance with ISO 10218-1;

b) the emergency stop function and the enabling device on the pendant shall comply with the requirements of ISO 10218-1;

c) the possibility of unintentionally controlling a robot system shall be avoided by:

   1) unambiguous means that identify the robot being operated,

   2) connection means to ensure integrity of communication (e.g. login, encryption, firewalls),

   3) unambiguous means to indicate connection continuity (e.g. screen display);

d) a single cableless teach pendant shall not be simultaneously connected to more than one robot system; this system can be composed of a single or multiple robots;

e) when in the manual mode, loss of communication (e.g. out of range, loss of battery power) on any active pendant (i.e. paired to a robot system) shall result in a protective or emergency stop for all controlled equipment; restoration of communication shall not allow a restart without a separate deliberate action (see ISO 10218-1 and IEC 60204-1);

f) an unambiguous means shall be provided to disconnect robot control from the pendant (e.g. a positive action by the operator), and when devices are logged out, it shall be clearly recognizable that the relevant safety functions are not active anymore; confusion between active and inactive emergency stop devices shall be avoided by providing appropriate storage or design; information for use shall contain a description of the storage or design;

g) the pendant shall provide a single point of control in accordance with ISO 10218-1.

5.7.3 Control of simultaneous motion

A single pendant may control simultaneous motion of a system with multiple robots. Each robot shall be selected before it can be activated. To be selected, all robots shall be in the same operational mode (e.g. manual reduced speed). An indication of which robots will be activated (selected to be moved) shall be provided in accordance with ISO 10218-1. Only the selected robots shall be activated. Any robot in the system not selected shall not move and shall not present hazards by means in accordance with 5.2.2.

NOTE This can be achieved by remaining in a protective stop condition.

5.7.4 Hand guiding of robot systems (collaborative robots)

Robot systems designed for collaborative operation may use hand guiding controls for the collaborative portion of the task. These same controls may be used for “lead through teach” methods. When such controls are included, they shall meet the requirements described in ISO 10218-1.

5.8 Maintenance and repair

5.8.1 General

The robot system shall be designed to include procedures for inspection and maintenance to ensure continued safe operation of the robot and robot system. The inspection and maintenance programme shall take into account the manufacturer's recommendations.

Information for use shall include requirements for periodic functional testing of the safety-related parts of equipment (e.g. emergency stop device, enabling device) to ensure proper operation.

5.8.2 Safeguarding requirements for maintenance

The robot system shall be designed and constructed in such a way as to allow safe access to all areas where intervention is necessary during operation, adjustment and maintenance. Maintenance should be performed from outside the safeguarded space. When it is necessary to perform maintenance within the safeguarded space, selection of the preferred means of safeguarding shall be as follows:

a) the system shall be provided with the local means of controlling and isolating hazardous energy (e.g. disconnector, pressure relief device, energy isolation control system); information for use shall contain details about maintenance tasks that require energy control and isolation, and those that are anticipated when hazardous energy would be required;

b) effective alternative protective measures shall be provided for minor servicing tasks that are anticipated and integral to production, performed without energy isolation; control measures for control of hazardous energy or position monitoring include one or more of the following:

  1) safeguard to allow safe performance of the task;

  2) placing the equipment in a predetermined safe monitored position or condition (deviations shall result in a protective stop condition);

  3) providing exclusive control for personnel entering the safeguarded space (procedures for exclusive control shall be defined and provided in the information for use);

4) providing a specific operating mode meeting at least the requirements in 5.2.2 for specific identified tasks.

5.8.3 Safeguarding of maintenance access points

When guards are provided to allow access for maintenance or servicing tasks, the guards shall be of sufficient size to allow easy access for the necessary tools, materials and personnel.

When fixed guards are provided for infrequent maintenance or servicing tasks, these shall be removable only by the use of a tool.

When frequent access for maintenance or routine servicing tasks is required, the access points shall be safeguarded by protective devices, preferably movable guards. These movable guards shall not initiate a starting command by reaching the safeguard position.

If it is possible to remain in the safeguarded area when the movable guard is closed, additional measures shall be used to prevent a restart. These include restart interlock, presence sensing, or facilities for locking the guard open. If a restart interlock in conjunction with presence sensing is provided, then, depending on the risk assessment, the presence-sensing device shall meet at a minimum the requirements of Type 2 from IEC 61496-1.

5.8.4 Safeguarding adjacent cells for maintenance

When electro-sensitive protective equipment (ESPE) with vertical detection fields is used to prevent unintended access to adjacent cells from within a cell for maintenance intervention, the approach speed and penetration factor used for the calculation of the minimum distance (safety) may, based on the risk assessment, deviate from those of ISO 13855.

NOTE When fixed guarding is used instead of ESPE, guidance can be found in 5.10.6.1.

5.9 Integrated manufacturing system (IMS) interface

5.9.1 General

Other machinery and equipment that is associated with the robot system but not directly controlled by the robot controller shall be included in the risk assessment, the zoning configurations, safeguarding and span of control implementation as presented in ISO 11161. Other machine specific “C” standards may also be applicable. The integration of the robot system shall also take into account hazards that are both controlled and not controlled by the robot, but are due to associated machinery and equipment that are inside the safeguarded space or entering/exiting the safeguarded space.

5.9.2 Emergency stop

Robot systems shall have a single emergency stop function affecting all relevant parts of the machine. The emergency stop function shall comply with 5.3.8.2.

The span of control may include multiple zones. Information for use shall include information on the span of control of each emergency stop device.

5.9.3 Safety-related parts of the IMS

Any safety-related control interfaces between the IMS and the robot system(s) shall comply with the requirements of 5.2.2. Protective devices shall protect against access to hazards within each zone of an IMS and additionally at the interfaces to adjacent zones (e.g. conveyors) when they are hazardous (see also 5.10).

5.9.4 Local control

Operational requirements shall determine the need for local control. When local control is selected, the IMS control system shall be notified of this condition and shall not be able to override the local control. The emergency and protective stop functions shall remain operational during local control.

Means of selecting and deselecting local control shall be in close proximity to the robot or machine or sub-assembly being placed under local control. Means of deselecting local control from within the safeguarded space shall not initiate hazardous conditions. If local control can be deselected from within the safeguarded space, a separate confirmation from outside the safeguarded space shall be necessary prior to any hazardous conditions being present.

5.9.5 Enabling device

When there is a need for additional enabling devices they shall comply with 5.3.15. The enabling device function shall be interlocked consistent with zones of the IMS where the incorporated robot systems, machinery or related processes are capable of concurrent movement during manual operation.

5.9.6 Mode selection

Mode selection shall comply with ISO 10218-1.

5.9.7 Task zone implementation

The IMS shall be designed to facilitate safe manual interventions, including maintenance. For some manual interventions, it can be impractical to stop the whole IMS, in which case the IMS shall be segregated into zone(s) where operators can perform their tasks safely while the remainder of the IMS can be operating in different operational modes.

The integration of the robot system into a task zone shall be in accordance with ISO 11161.

5.10 Safeguarding

5.10.1 General

When design does not either remove hazards or adequately reduce the risks, safeguarding shall be applied. Access to hazardous areas shall be protected by safeguards such as guards and protective devices. Complementary protective measures, for example, personal protective equipment, training and information for use, can also be required. See also 4.5.

Guards and protective devices can be used to:

— prevent access to the hazard(s);

— cause hazard(s) to cease before access;

— prevent unintended operation;

— contain parts and tooling;

— limit other process hazards (noise, laser, radiation, etc.).

Guards and protective devices shall meet the requirements of ISO 12100.

ISO 12100 gives further requirements for the selection of safeguarding and further complementary measures.

Annex B shows an overview of some of the standards applicable to protective measures.

5.10.2 Perimeter safeguarding

Guards (distance or enclosure, see also 5.10.4) or sensitive protective devices (see also 5.10.5) shall be used for perimeter safeguarding.

The selection of perimeter safeguarding shall take into account all the hazards within the safeguarded space – not just those associated with the robot system. Examples of hazards include:

a) other machinery, equipment and processes;

b) falling or ejected objects;

c) erratic or excessive machine stopping time;

d) inability of the machinery to stop part way through a cycle;

e) emission hazards (e.g. noise, vibration, radiation, harmful substances).

Selection shall also consider the task requirements, for example:

— frequency of access;

— loading and unloading of materials;

— maintenance;

— quality inspection;

— proximity to the hazard;

— process requirements.

5.10.3 Minimum (safety) distances

5.10.3.1 General

All safeguards shall be securely installed and located at a distance such that the hazard cannot be accessed, i.e. personnel cannot reach over, under, around or through the safeguard.

5.10.3.2 Minimum (safety) distances for guards

Fixed and moveable guards shall meet the requirements of ISO 14120 and their minimum distance from any hazard shall be determined according to the relevant requirements of ISO 13857. When preventing access with guards, ISO 13857 shall be used to determine the minimum safe distance.

The minimum distances associated with openings in guards shall meet the relevant requirements of ISO 13857.

5.10.3.3 Minimum (safety) distances for protective devices

The minimum distance for protective devices providing a trip function (for example, interlocking devices, sensitive protective equipment which signal a protective stop when actuated) shall be determined according to the relevant requirements of ISO 13855.

When protective devices provide a presence-sensing function to prevent starting or restart (for example, when they continually sense a person or part of a person in their detection zone and maintain a protective stop), minimum distance is not a requirement, but the devices shall comply with 5.10.5.3.

NOTE When presence-sensing safeguarding devices solely safeguard against start or restart hazards, other safeguarding devices are used to prevent access or cause the hazard to cease before access.

5.10.3.4 Minimum (safety) distances for providing clearances

When protective devices provide a trip function to provide protection against lack of clearance (see 5.5.2), the minimum distance shall be calculated using ISO 13855 with the robot speed as the approach speed (i.e. K = the robot speed).

When protective devices provide a presence-sensing function to provide clearance (see 5.5.2), minimum distance is not a requirement, but the devices shall comply with 5.10.5.3.

5.10.4 Requirements for guards

5.10.4.1 General

All guards shall meet the applicable requirements of ISO 12100 and ISO 14120. Interlocking devices associated with guards shall meet the requirements of ISO 14119.

Fixed guards shall only be removable by the use of a tool. Their fixing systems shall remain attached to the guards or to the machinery when the guards are removed. The requirement does not necessarily apply to fixed guards that are only liable to be removed, for example, when the machinery is completely overhauled, is subject to major repairs or is dismantled for transfer to another site.

The perimeter safeguarding shall not be installed closer to the hazard than the restricted space, unless either:

— the perimeter safeguarding is designed to be the limiting device in accordance with 5.4.3, or

— a risk assessment determines that other safeguarding is appropriate.

5.10.4.2 General requirements for fixed distance guards

The openings in any fixed guard shall not allow a person to reach over, under, around or through (an opening or gap) the guard and access a hazard.

ISO 13857 shall be used to determine the appropriate dimensions for the opening from the bottom of the guard to adjacent standing surfaces and any openings in the guards. For minimum safety distances, see 5.10.3.2.

The height of the guard shall be at least 1 400 mm from adjacent walking surfaces.

5.10.4.3 General requirements for interlocked movable guards

Interlocking devices associated with moveable guards shall meet the requirements of ISO 14119.

Movable guards at their closed position shall prevent operators reaching hazardous areas.

Movable guards shall open laterally or away from the hazard, and not into the safeguarded space.

Interlocking shall be provided to bring any hazards to a safe state before an operator can gain access to the hazard through the guard. To achieve this, movable guards shall be positioned in accordance with ISO 13855 (see also 5.10.3.2).

Movable guards used to initiate starting on closure (control guards) shall meet the requirements of ISO 14120.

The interlocking function shall meet at least the requirements of 5.2.2. The reset actuators shall be in accordance with 5.6.3.4.

5.10.4.4 General requirements for movable guards with guard locking

When it is possible for the operator to open an interlocked movable guard and reach the hazard area before the hazard is brought to a safe state, guard locking shall be provided in addition to the control interlock.

This guard locking shall comply with the following:

a) only permit the actuation of hazardous machine function as long as the guard is closed and locked (e.g. a door in a fence);

b) keep the guard in the closed and locked position as long as the risk of harm due to hazardous functions of the machine exists.

When process parameters, such as speed, are being used as a condition for locking or unlocking, then this forms part of the safety function and shall meet the same functional safety requirements as the interlocking function.

5.10.4.5 Movable guards allowing access into the safeguarded space

The safeguarded space shall be designed, constructed or fitted with a means of preventing a person from being trapped inside. For example, this may be accomplished by providing for manual opening of movable guards from inside the safeguarded space, regardless of the state of the energy supply, or providing a means of locking access gates in their open position.

5.10.5 Sensitive protective equipment

5.10.5.1 General

Sensitive protective equipment is typically selected when an application requires frequent access, personnel interaction with the machine, good visibility of the machine or process, or when it is not ergonomic to provide fixed guarding. However, some characteristics of particular applications can preclude the use of sensitive protective equipment as the sole protective measure. Examples of these characteristics are:

a) possibility that the machinery will eject materials, swarf or component parts;

b) risk of injury from thermal or other radiation;

c) unacceptable noise levels;

d) an environment likely to adversely affect the function of the protective equipment;

e) a material being processed which can influence the effectiveness of the protective measure.

Where such situations exist, additional or other safety measures can be required.

ESPE, such as light curtains and laser scanners, shall comply with the relevant parts of IEC 61496-1.

Pressure-sensitive protective equipment, such as mats, edges and bumpers, shall meet the relevant requirements of ISO 13856.

The applications of these devices should comply with IEC/TS 62046.

5.10.5.2 Sensitive protective equipment used to initiate a protective stop

Where the sensitive protective equipment is used to initiate a protective stop, it shall be positioned at a distance from each hazard sufficient to ensure the hazard is removed or otherwise obtains a safe condition before any part of an approaching operator can reach the hazard.

NOTE 1 Hazards can exist at different locations within the safeguarded space and the distance needs to ensure that each hazard is controlled.

Sensitive protective equipment shall be securely installed and located such that an operator cannot circumvent (i.e. cannot reach over, under, around or through) the detection zone and reach a hazard. The following functionality shall be provided:

a) a protective stop shall be initiated if the sensitive protective equipment is actuated while the hazardous conditions are operating;

b) following an actuation, the hazardous conditions being safeguarded by the sensitive protective equipment shall be prevented from any hazardous motion or situation until the sensitive protective equipment is reset;

c) when the sensitive protective equipment is reset, the hazardous conditions being safeguarded by the sensitive protective equipment can operate, but the reset of the sensitive protective equipment does not by itself initiate their operation.

The formulae in ISO 13855 shall be used to determine the minimum distance from the hazard (danger zone) to the sensitive protective equipment for all directions of approach.

NOTE 2 The minimum value of K used for calculating minimum distances in accordance with ISO 13855 is 1 600 mm/s.

Where an operator, or part of an operator, can remain in the safeguarded space, additional measures shall be provided to prevent hazardous situations arising, such as unexpected start-up. Such measures can include, for example:

— provision of a restart interlock;

— sensing the presence of an operator in the safeguarded space (e.g. ESPE or pressure mats) to maintain a protective stop.

NOTE 3 If presence-sensing protective equipment is used, it is advisable to ensure that operators cannot circumvent the detection zone, e.g. by climbing on to parts of the machinery.

If it is possible for an operator to be hidden from view at the reset control, supplementary protective measures to prevent resetting the restart interlock shall be provided (e.g. time-limited additional reset control inside the safeguarded space). Resetting of the restart interlock shall be performed by a deliberate human action, for example operation of a manual actuator. See also 5.6.3.3.

5.10.5.3 Sensitive protective equipment used for presence sensing to prevent a start

Where the sensitive protective equipment is only used for a presence-sensing function (i.e. it continually senses the presence of a person or part of a person in its detection zone), it shall be used in conjunction with other safety measures (for example, interlocking guards), as necessary to ensure that the machine(s) is/are in a non-hazardous state before hazards can be reached.

The detection zone of presence-sensing devices shall be positioned and configured so that a person or part of a person will be detected throughout the detection zone. Where necessary, supplementary measures shall be provided to ensure that the detection zone cannot be circumvented, for example by operators remaining between the detection zone and the hazard zone or by reaching over the detection zone into the hazard zone. Examples of measures to prevent persons remaining between the detection zone and the hazard zone are:

— use of sloping surfaces to prevent standing on machine frame/feet;

— making the inside surfaces of fencings free of protrusions that can be climbed on.

5.10.6 Safeguarding at manual loading, unloading or handling stations (manual stations)

5.10.6.1 General

Measures shall be provided to ensure that operators are not exposed to further hazards due to the operation of the manual production interface station (for example, crushing, shearing, entanglement hazards).

Allowable gaps and openings shall follow the guidance in 5.10.4.1. Manual stations shall be designed to ensure that the operator cannot access hazards within the safeguarded space. [See also a), b), c) below.]

NOTE 1 Requirements for collaborative workspaces are given in 5.11.

For heights up to 1 400 mm additional protective measures can be taken to:

a) prevent the exposure of the operator to application-related hazards within the safeguarded space, e.g. ejected parts, welding sparks, etc.;

b) prevent the operator from accessing hazards inside the safeguarded space or bring these hazards within the safeguarded space to a safe state before they can be accessed;

c) ensure that when a robot system and an operator have access to the same (shared) workspace, they cannot occupy the workspace at the same time; this can be accomplished by:

   1) preventing any part of a robot system from entering a workspace occupied by an operator, or bringing the robot system to a safe state before it can reach the operator; and

   2) preventing the operator from entering a workspace occupied by any part of the robot system, or bringing the robot system to a safe state before the operator can reach it.

NOTE 2 For ergonomic reasons, heights between 1 000 mm and 1 400 mm might be acceptable depending on the protection effect given by the shape of the barrier and the results of the risk assessment.

5.10.6.2 Additional requirements for moving manual stations

Moving manual stations (for example, rotating turntables, sliding jigs) can themselves be hazardous. Measures shall be provided to prevent the operator accessing these hazards or to bring these hazards to a safe state before they can be accessed.

The gap between the moving station and any fixed elements (for example, machine parts, guards), including additional protective measures, shall not exceed 120 mm. Additional measures might be necessary to prevent shearing and trapping hazards.

5.10.6.3 Additional requirements for manual stations with a shared workspace

When presence sensing is used to detect the operator in the shared workspace, the detection zone of the device shall include the entire shared workspace area.

When presence sensing is not practicable, a restart interlock shall be provided. Other measures shall be provided to prevent inadvertent resetting of the restart interlock, so preventing the robot system from moving into the workspace while the operator remains in the workspace. Such measures can include the provision of a separate manual reset.

When manual reset is provided, the whole of the shared workspace shall be visible from the reset device. If this is not possible, further measures shall be applied, for example, time-limited additional reset control inside the safeguarded area.

5.10.7 Safeguarding of openings for material flow

Openings into the safeguarded space to allow material entry and exit shall be the minimum dimensions necessary to allow the material to pass. Possible crushing/shearing hazards between the material and the sides of the opening shall be avoided or supplementary protective measures shall be taken to avoid them (for example by the use of hinged interlocked doors).

If access to a hazard is possible, measures depending on the risk assessment shall be taken to prevent access or detect a person or a part of a person entering and bring the hazard to a safe state before it can be reached. (See ISO 13857 for partial body entry and Annex C.)

Where openings for material entry and exit are guarded using ESPE, the ESPE shall allow the passage of materials either by one of the following functions, and access to the safeguarded space shall be prevented by the material itself, or by other means (see also IEC/TS 62046):

a) a muting function that temporarily deactivates the ESPE function allowing material to pass through (entry/exit);

b) a change in protection area (e.g. blanking) that enables materials to pass through; in this case the minimum distance indicated by the manufacturer of the ESPE shall be observed (see IEC/TS 62046).

The muting function shall fulfil the requirements of ISO 13849-1.. The performance level of the muting and blanking functions shall not adversely affect the performance level of the safety function determined by the risk assessment for the ESPE. See also 5.10.10.

5.10.8 Safeguarding multiple adjacent robot cells

Measures shall be provided to ensure that operators in a cell are not exposed to hazards from adjacent cells.

Measures shall be provided to either prevent operator access to adjacent cells from within a cell, or bring hazards within adjacent cells to a safe state before operators would be exposed to hazards in or caused by adjacent cells.

When fixed guards are used for this purpose, the required height depends on the hazards in both cells (because access can be gained from either cell to the other) but it shall be a minimum of 1 400 mm.

Measures other than fixed guards can apply, for example:

— electro-sensitive protective equipment;

— pressure mats;

— simultaneous shut-down of adjoining cells.

The selection of the appropriate measures shall be in accordance with 4.5.

When the protective devices need to be muted for production operations, the functional safety level for muting shall be at least the same level as the functional safety level determined by the risk assessment.

5.10.9 Safeguarding of tool changing systems

End-effectors and tool changing systems shall be selected or designed such that loss or restoration of energy supply does not lead to a hazard. If this is not practicable, other safety measures shall be provided to mitigate against any hazards.

If a tool changing system is used, then the tool changing system design shall ensure that misuse does not lead to a hazardous situation. Release or disconnection of the end-effector(s), using the tool change function, shall be prevented at positions where release would lead to a hazard.

The tool changing system shall withstand the expected static and dynamic requirements (e.g. emergency-stop-situation, loss of energy).

5.10.10 Muting

Muting is the temporary automatically controlled suspension of the safeguarding function during a portion of the robot system's cycle.

Muting shall only be provided when it is necessary for the process being performed on the machine. It shall be implemented such that a person cannot remain undetected in the hazardous zone when muting is terminated.

Muting may be used in conjunction with any safeguarding device that electrically signals a protective stop.

Muting is permitted when at least one of the following conditions is met:

a) safety is maintained by other means (e.g. the access to the hazardous area is obstructed by the passing material);

b) personnel are not exposed to a hazard;

c) the hazard cannot be accessed without a stop being initiated.

The muting function shall be initiated and terminated automatically. This may be achieved by the use of appropriately selected and placed sensors or, in some cases, by signals from the safety-related control system (which may include safety-rated soft axis and space limiting in accordance with ISO 10218-1). Incorrect signals, sequence, or timing of the muting sensors or signals shall not allow a mute condition (see IEC 61496-1).

The muting function shall achieve an equivalent level of safety-related control system performance as determined by the risk assessment for the protective function being muted. The performance level of the muting function shall not adversely affect the performance level of the protective function. In the event of a failure, subsequent muting shall be prevented until the failure is corrected.

Depending on the risk assessment, an indicator to show when the muting function is active can be required. This indicator warns that the normal protective function is suspended.

Muting information, including the means, location, zones, and functionality, shall be included in the information for use.

5.10.11 Suspension of safeguards

Tasks that require the suspension of safeguards, for example robot teaching, shall have a dedicated mode of operation that automatically selects the appropriate safeguards, as determined by the risk assessment, for the task.

The selection of the mode of operation shall be by secure means (e.g. by a lockable selection device, password, access code) and shall meet the requirements of 5.2.2.

The following requirements shall be met:

a) it shall not be possible to resume automatic operation with the mode activated;

b) automatic operation shall only be initiated from outside the safeguarded space;

c) the control mode function shall have an equivalent level of performance to the protective function being suspended;

d) in the event of a fault in the suspending function, subsequent suspension shall be prevented until the fault is corrected;

e) a visual indication that safety devices are suspended shall be provided at the mode selection device, the cell entrance(s) and any affected operator stations;

f) alternative protective measures shall be activated to control all hazards; these alternative protective measures shall provide an equivalent level of protection.

Where safeguards are to be suspended, the following shall be applicable:

— machinery and equipment not required for the task shall be in the protective stop condition;

— machinery and equipment required for the task shall be under the direct control of the operator.

The integrator shall provide information for use for critical situations when it is necessary to manually suspend safeguards, e.g. troubleshooting and exchange of a safeguarding device.

5.11 Collaborative robot operation

5.11.1 General description of purpose

Collaboration is a special kind of operation between a person and a robot sharing a common workspace. It is only:

— used for predetermined tasks;

— possible when all required protective measures are active; and

— for robots with features specifically designed for collaborative operation complying with ISO 10218-1.

NOTE See Annex E for examples of application.

The integrator shall include in the information for use the safeguards and mode selection required for collaboration operation.

5.11.2 General requirements

Due to the potential reduction of the spatial separation of human and robot in the collaborative workspace, physical contact between the human and the robot can occur during the operation. Protective measures shall be provided to ensure the operator's safety at all times.

The following requirements shall all be fulfilled.

a) The integrator shall conduct a risk assessment as described in 4.3 (see Annex E for examples of applications). The risk assessment shall consider the entire collaborative task and workspace, including, as a minimum:

   1) robot characteristics (e.g. load, speed, force, power);

   2) end-effector hazards, including the workpiece (e.g. ergonomic design, sharp edges, protrusions, working with tool changer);

   3) layout of the robot system;

   4) operator location with respect to proximity of the robot arm (e.g. prevent working under the robot);

   5) operator location and path with respect to positioning parts, orientation to structures (e.g. fixtures, building supports, walls) and location of hazards on fixtures;

   6) fixture design, clamp placement and operation, other related hazards;

7) design and location of any manually controlled robot guiding device (e.g. accessibility, ergonomic, etc.);

8) application-specific hazards (e.g. temperature, ejected parts, welding splatters);

9) limitations caused by the use of necessary personal protective equipment;

10) environmental considerations [e.g. chemical, radio frequency (RF), radiation, etc.];

11) performance criteria of the associated safety functions.

b) Robots integrated into a collaborative workspace shall meet the requirements of ISO 10218-1.

c) Protective devices used for presence detection shall meet the requirements of 5.2.2.

d) Additional protective devices used in a collaborative workspace shall meet the requirements of 5.2.

e) The safeguarding shall be designed to prevent or detect any person from advancing further into the safeguarded space beyond the collaborative workspace. Intrusion into the safeguarded space beyond the collaborative workspace shall cause the robot to stop and all hazards to cease.

f) The perimeter safeguarding shall prevent or detect any person from entering the non-collaborative portion of the safeguarded space.

g) If other machines, which are connected or attached to the robot system and present a potential hazard, are in the collaborative workspace itself then the safety-related functions of these machines shall comply, at a minimum, with the requirements of 5.2.

Robots configured for collaborative operation should be labelled with the symbol shown in Figure 2.

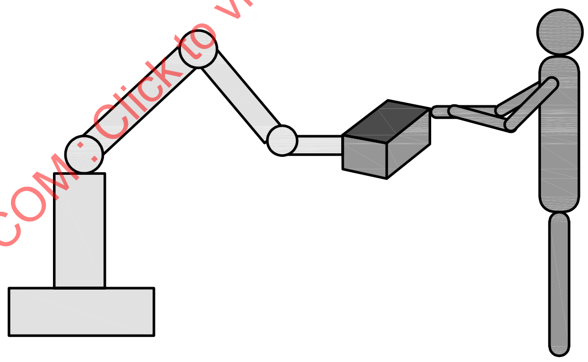


Figure 2 — Suggested labelling design

5.11.3 Requirements for collaborative workspaces

The collaborative workspace where the operator(s) can interact directly with the robot shall be clearly defined (e.g. floor marking, signs, etc.).

Persons/operators shall be safeguarded by a combination of protective devices and compliance with robot performance features allowed in ISO 10218-1, which will cause all hazards to cease in accordance with 5.2.2.

In any case where more than one person (operator) is involved in a collaborative operation, each person shall be protected with controls complying with 5.2.2.

The design of the collaborative workspace shall be such that the operator can easily perform all tasks and the location of equipment and machinery shall not introduce additional hazards. Safe-rated soft axes and space limiting should, whenever possible, be used to reduce the range of possible free motions.

The robot system should be installed to provide a minimum clearance of 500 mm (20 in) from the operating space of the robot (including arm, any attached fixture and the workpiece) to areas of building, structures, utilities, other machines, and equipment that allow whole body access and may create a trapping or a pinch point. Where this minimum clearance is not provided, additional protective measures to stop robot motion shall be taken to provide protection while personnel are within 500 mm of the trapping or pinch hazard in a static environment. If there is dynamic motion (e.g. line tracking), special considerations may be needed. (See ISO 13854.)

NOTE These parameters can be different for systems designed to comply with 5.11.5.4 and 5.11.5.5.

5.11.4 Change between autonomous operation and collaborative operation

The change point between autonomous operation and collaborative operation is a particularly critical part of a collaborative application. It shall be designed in a way that the robot cannot endanger personnel when changing from the autonomous operation to the collaborative operation and back to the autonomous operation.

5.11.5 Operation in the collaborative workspace

5.11.5.1 General

When designing a collaborative operation, one or more of the safety features in 5.11.5.2 to 5.11.5.5 shall be appropriately selected to ensure a safe work environment for all personnel exposed to potential hazards in the workcell. ISO 10218-1 provides requirements and performance features for robots used in collaborative operation, as described in 5.11.5.2 to 5.11.5.5.

Any detected failure of the selected safety features of the collaborative operation shall result in a protective stop in accordance with 5.3.8.3. Autonomous operation shall not be resumed after such a stop until reset by a deliberate restart action outside the collaborative workspace.

5.11.5.2 Safety-rated monitored stop

If there is no person in the collaborative workspace the robot operates autonomously. If a person enters the collaborative workspace the robot shall stop moving and maintain a safety-rated monitored stop in accordance with ISO 10218-1 in order to allow direct interaction of an operator and the robot (e.g. loading a part to the end-effector).

5.11.5.3 Hand guiding

Hand-guided operation shall be permitted, provided that the following requirements are met:

a) when the robot reaches the hand-over position, a safety-rated monitored stop, in accordance with ISO 10218-1, is issued;

b) the operator shall have a guiding device that meets the requirements of ISO 10218-1 to move the robot to the intended position;

c) the operator shall have clear visibility of the entire collaborative workspace;

d) when the operator releases the guiding device, a safety-rated monitored stop in accordance with ISO 10218-1 is issued.

5.11.5.4 Speed and separation monitoring

Robot systems designed to maintain a safe separation between the operator and the robot in a dynamic manner shall use robots that comply with the requirements of ISO 10218-1.

Robot speed, minimum separation distance and other parameters shall be determined by risk assessment.

NOTE Additional information and guidance on collaborative robot operations will be contained in ISO/TS 15066 (currently under preparation).

5.11.5.5 Power and force limiting by design or control

Robot systems designed to control hazards by power or force limiting shall use robots which comply with ISO 10218-1.

Parameters of power, force, and ergonomics shall be determined by risk assessment.

NOTE Additional information and guidance on collaborative robot operations will be contained in ISO/TS 15066 (currently under preparation).

5.12 Commissioning of robot systems

5.12.1 General

A commissioning plan shall include information for protective measures for persons during commissioning of robot systems. These measures may also apply to robot systems after significant changes or after maintenance that could affect their safe operation.

5.12.2 Selection of interim safeguards

Interim safeguards shall protect personnel against the same hazards as originally identified by the risk assessment. If the intended safeguards are not yet available or in place prior to initiating power-on start-up testing and verification, an appropriate means of safeguarding shall be in place before proceeding.

NOTE During the initial assembly of a robot cell, protection might be required before all the final safeguards are installed. Therefore, it is advisable that alternative safeguarding, such as chains or portable walls, be put in place to provide effective protection for personnel during the initial start-up of the equipment. Factors to consider in selecting the alternative safeguards can include: training level of personnel involved, time period of this interim situation, accessibility of this cell to other personnel, the type of equipment operating, which equipment is operating at a given time, and hazards presented by this equipment.

As a minimum, awareness barriers shall be installed to define the restricted space.

All interim safeguards shall be identified in information commissioning, and included in the information for use.

Interim safeguards and protective measures could include:

a) the same as for the finished system, but installed in an interim manner;

b) different devices used in optional applications;

c) temporary obstructions;

d) specific written procedures;

e) awareness means;

f) specific training.

5.12.3 Initial start-up procedure plan

An initial start-up procedure shall be established and shall include, but not necessarily be limited to, the following:

a) It shall be verified before applying power, that the following have been installed as intended:

   1) mechanical mounting and stability;

   2) electrical connections;

   3) utility connections;

   4) communications connections;

   5) peripheral equipment and systems;

   6) limiting devices for restricting the maximum space.

b) Instructions shall be provided that all persons shall exit the safeguarded space prior to applying drive power.

c) It shall be verified after applying power that:

   1) emergency stop circuit/devices are functional;

   2) each axis moves and is restricted as intended;

   3) robot responds to basic operating system motion commands as expected;

   4) awareness means (audio/visual) function as expected;

   5) all safeguarding devices or interim safeguards function as expected;

   6) reduced speed control is activated and functioning as expected.

NOTE This is especially critical during initial power-on to ensure that the robot and equipment move/operate in the expected manner.

6 Verification and validation of safety requirements and protective measures

6.1 General

The robot system manufacturer or integrator shall provide for the verification and validation of design and construction of robot systems including appropriate safeguarding devices in accordance with the principles described in Clauses 4 and 5.

The risk assessment(s) should be reviewed to assess if all reasonably foreseeable hazards have been identified and corrective actions taken.

NOTE Since not all hazards identified in Annex A apply to every robot system, the level of risk associated with a given hazardous situation will not be the same from robot system to robot system, and specific robot system(s) applications include hazards not identified in Annex A. A risk assessment needs to be conducted to determine what the appropriate protective measures should be for a given robot system.

6.2 Verification and validation methods

Verification and validation can be satisfied by methods including but not limited to:

—A visual inspection;

—B practical tests;

—C measurement;

—D observation during operation;

—E review of application-specific schematics, circuit diagrams and design material;

—F review of safety-related application software and/or software documentation;

—G review of task-based risk assessment;

—H review of layout drawings and documents;

—I review of specifications and information for use.

See Table G.1.

6.3 Required verification and validation

Annex G lists specific performance requirements that are identified as essential to the safety of the robot system that shall be verified or validated. Using appropriate methods, requirements shall be evaluated to determine if they have been adequately met by the design and construction of the system.

NOTE 1 Not all items listed in Table G.1 necessarily apply to every robot system. There might be instances where it will be impossible to verify and/or validate certain items.

NOTE 2 Table G.1 is neither comprehensive nor limiting. There might be additional verification requirements depending on specific robot system design.

NOTE 3 It is the integrator's responsibility to ensure that all applicable items are verified and/or validated.

NOTE 4 If using Table G.1 as a checklist, the contents need to be reviewed and limited to represent the actual robot system configuration being evaluated and the suitable method for that evaluation.

6.4 Verification and validation of protective equipment

It shall be verified whether or not protective equipment installed to mitigate identified hazards is used in a way that is consistent with the manufacturers' instructions and is appropriately applied to the robot system(s).

a) Prevention of access to the hazard shall be achieved by:

   1) causing the hazard to cease before access,

   2) preventing the creation of a hazard by unintended operation,

   3) containing parts and tooling (e.g. loose objects, flying projectiles),

   4) controlling other process hazards (e.g. noise, laser, radiation).

b) The installed protective equipment shall be verified as to:

   1) type of guards, size of openings, placing of guards, correct safety distances, heights,

2) reset control not being possible to actuate from inside the safeguarded space,

3) types of protective devices, detecting capabilities, placing of protective devices, correct safety distances, sizes, etc., and

4) bypass and muting functions.

c) It shall be verified that complementary protective measures are provided:

1) instructions,

2) training materials,

3) warnings,

4) personal protective equipment,

5) procedures,

6) other appropriate measures.

NOTE Each protective measure might not address each criterion in a) to c), depending on the hazard being protected.

7 Information for use

7.1 General

Information for use shall contain the information and instructions necessary for the safe and correct use of the system and shall provide information and warnings to the user about any residual risks. Information for use from component machine manufacturers shall also be included.

It shall consist of items such as documents, signs, signals, symbols or diagrams used to convey important safety-related information to the user.

The style and content of the different parts of the information for use should reflect the level of education, technical understanding and competence of the intended reader. It should be written in a language appropriate for the intended user.

The information shall reflect both the intended use and foreseeable misuse of the integrated system.

Where required to mitigate a hazard, the information shall include

— training requirements,

— personal protective equipment requirements,

— requirements for additional guards or protective devices (see ISO 12100).

The information for use of the integrated robot system shall be in accordance with the requirements of ISO 12100.

NOTE 1 See also IEC 62079 for structuring and presentation of information for use.

NOTE 2 See also IEC 60204-1.

7.2 Instruction handbook

7.2.1 General

The instruction handbook shall take the different phases of the robot system's use into account, including transport, assembly and installation, commissioning, operational use (including start-up, shut-down, setting, teaching/programming or process change over, operation, cleaning, fault finding and maintenance) and, where relevant, decommissioning, dismantling and disposal.

The instruction handbook shall include the interfaces (physical, mechanical, functional) between the robot system and upstream and downstream processes.

In particular, the instruction handbook shall include the information contained in 7.2.2 to 7.2.10.

7.2.2 Handling

Information relating to transport, handling and storage of the robot system shall include, for example:

a) storage conditions for the individual machines;

b) dimensions, mass value(s), position of the centre(s) of gravity;

c) indications for handling (e.g. drawings indicating application points for lifting equipment).

7.2.3 Installation and commissioning

Information relating to installation and commissioning of the robot system shall include, for example:

a) fixing/anchoring and vibration dampening requirements;

b) assembly and mounting conditions;

c) space needed for use and maintenance;

d) permissible environmental conditions (e.g. temperature, moisture, vibration, electromagnetic radiation);

e) instructions for connecting the robot system to power supplies (particularly about protection against electrical overloading);

f) advice about waste removal/disposal;

g) if necessary, recommendations about protective measures which have to be taken by the user; [e.g. additional or interim safeguards (see ISO 12100), safety distances, safety signs and signals];

h) instructions for how the initial test and examination of the robot system and its guarding system are to be carried out before first use and before being placed into production, including functional testing of reduced speed control.

7.2.4 Information for commissioning test or initial start-up procedure

This information shall include, but is not necessarily limited to, the following:

a) before applying power, verify that:

   1) the robot has been properly mechanically mounted and is stable;

   2) the electrical connections are correct and the power (i.e. voltage, frequency, interference levels) is within the specified limits;

3) the proper electrical earth (equalizing potential) is provided;

4) the safety-related parts of the control system are properly installed;

5) the other utilities (e.g. water, air, gas) are properly connected and within specified limits;

6) the peripheral equipment including interlocks is properly connected;

7) the limiting devices that establish the restricted space (when utilized) are installed;

8) the appropriate safeguarding means are applied;

9) the physical environment is as specified (e.g. lighting and noise levels, temperature, humidity, atmospheric contaminants);

10) the proper version of all programmes – normal control and safety-related – have been validated and are the versions that are installed (engineering change management);

b) after applying the power, verify that:

1) the start, stop and mode selection (including the key lock switches) control devices function as intended;

2) each axis moves and is restricted as intended;

3) emergency stop and protective stop (where included) circuits and devices are functional;

4) it is possible to disconnect and isolate the external power sources;

5) the teach and playback capabilities function correctly;

6) environmental conditions are considered for compatibility [e.g. explosion, corrosiveness, humidity, dust, temperature, electromagnetic interference (EMI), radio frequency interference (RFI) and electrostatic discharge (ESD)];

7) all safeguards, protective devices, enabling devices, and interlocks function as intended;

8) all other safeguarding is in place (e.g. barriers, warning devices);

9) in manual mode, the robot operates properly and can handle the product or workpiece;

10) in automatic (normal) operation, the robot operates properly and can perform the intended task at the rated speed and load.

The commissioning test or initial start-up procedures should also be performed after completion of any maintenance task or system modification that could affect the integrity of the robot system(s) as designed and installed.

7.2.5 System information

Information relating to the robot system itself shall include, for example:

a) detailed description of the system, its fittings, its guards and/or protective devices;

b) comprehensive range of applications for which the robot system is intended, including prohibited usages, if any, taking into account variations of the original robot system, if appropriate;

c) safety requirements specification describing the safety functions performed by the control system and their safety integrity, discrete stopping circuits, safety controllers and safe communications;

d) other controller functions, operator panels, teach pendants, enabling devices and awareness indicators;

e) diagrams (layout, control, electrical, hydraulic, pneumatic, etc.);

f) data concerning other hazards, for example, radiation, gases, vapours, dust and vibration generated with reference to the measuring methods used;

g) technical documentation about electrical equipment (see IEC 60204 series of parts);

h) specifications for equipotential bonding requirements (grounding). Electrical ground (equalizing potential) shall be provided in accordance with IEC 60204-1;

i) documents attesting that the robot system complies with mandatory requirements;

j) modifications made to the protective measures that were originally provided with the component machines;

k) end-effector (end-of-arm tooling) load analysis, behaviour in event of energy loss, human intervention considerations, maintenance and intended life;

l) interface requirements to other machines;

m) location of dynamic limiting zones;

n) intended life of the system.

7.2.6 Use of the system

Information relating to the use of the integrated robot system shall include, for example:

a) residual risk, those risks that could not be eliminated by the protective measures taken by the designer;

b) particular risks that may be generated by certain applications, by the use of certain fittings, and about specific safeguards that are necessary for such applications;

c) reasonably foreseeable misuse and prohibited usages;

d) material flow;

e) intended use;

f) task zones and associated residual risks (see ISO 11161);

g) operator tasks, locations and routes to perform the tasks;

h) spans of control of the various control and protective devices (see ISO 11161) (e.g. protective devices, reset of protective devices, enabling devices, emergency stops, control stations, disconnecting means);

i) description of manual controls (actuators), enabling devices, protective stops;

j) setting and adjustment;

k) modes and means for stopping (especially emergency stop);

l) fault identification and location, repair, and restarting after an intervention;

m) personal protective equipment that needs to be used and training required;

n) instructions for any test or examination necessary after change of component parts or addition of optional equipment (both hardware and software) which can affect the safety functions;

o) instructions that disconnected pendants shall be removed from access;

p) instructions for fault and emergency recovery of system equipment;

q) training requirements for remote control operations;

r) storage locations or design of unused cableless pendants to prevent use of an inactive emergency stop;

s) requirements for periodic functional testing of safety-related equipment;

t) guidance on correct selection, preparation, application, and maintenance of process unique expendables.

7.2.7 Maintenance

Information for maintenance shall include, for example:

a) nature and frequency of inspections for safety functions;

b) instructions relating to maintenance operations which require a definite technical knowledge or particular skills and hence should be carried out exclusively by skilled persons (e.g. maintenance staff, specialists);

c) instructions relating to maintenance operations (e.g. replacement of consumable parts) which do not require specific skills and hence may be carried out by users (e.g. operators);

d) drawings and diagrams enabling maintenance personnel to carry out their task rationally (especially fault-finding tasks);

e) information to replace safety-related parts (e.g. manufacturer part number, specification of the parts);

f) contact information for the manufacturer(s) to allow for replacement of parts;

g) tasks that require energy control and isolation;

h) safe working practice for manual suspension of safeguards.

7.2.8 Decommissioning

Information relating to decommissioning, dismantling and disposal shall be included.

7.2.9 Emergency situations

Information for emergency situations shall include, for example:

a) type of fire-fighting equipment to be used;

b) warning about possible emission or leakage of harmful substance(s);

c) means to fight their effects (if practicable).

7.2.10 Robot specific

Information specific to the robot(s) shall include, for example:

a) information in accordance with ISO 9946;

b) information in accordance with ISO 10218-1;

c) where applicable, information on manual high-speed control using the pendant;

d) instruction on installation of limiting devices, including number, location and degree of adjustment of hard stop capability, including instructions on the number, location and implementation of any non-mechanical limiting devices, and capabilities of dynamic limiting, when included;

e) information on the number and operation of enabling devices and instructions for installation of additional devices;

f) information on the stopping time and distance or angle of the three axes with the greatest displacement and motion;

g) the specification for any fluids or lubricants to be used in lubrication, braking, or transmission system internal to the robot;

h) information defining the limits for the range of motion and load capacity, including maximum mass, position of the centre of gravity of the workpiece and work holding fixture;

i) information on relevant standards the robot or robot system meets, including any that have been certified by a third party;

j) when applicable, instructions on synchronized motion of robots and special training necessary for the programmers/operators;

k) instructions on emergency or abnormal movement of the robot without drive power;

l) programmed limits established by the use of safety-rated soft axis and space limiting features;

m) for robot systems designed for collaborative operation, declaration that the robot is suitable for integration as a collaborative robot, with a reference to 5.11 that identifies the requirements met and type of operations.

7.3 Marking

The robot system shall be marked visibly, legibly and indelibly with the following minimum particulars:

— the business name and full address of the manufacturer and, where applicable, his authorized representative,

— designation of the machinery,

— designation of series or type,

— serial number, if any,

— the year of construction, that is the year in which the manufacturing process is completed,

— if machinery is designed and constructed for use in a potentially explosive atmosphere, it shall be marked accordingly.

Annex A
(informative)

List of significant hazards

Table A.1 provides a list of significant hazards for robot and robot systems.

NOTE The list in Table A.1 is derived from ISO 12100.

Table A.1 — List of significant hazards

No.	Type or group	Example of hazards — Origin	Example of hazards — Potential consequences	Subclause reference
1	**Mechanical hazards**	— movements of any part of the robot arm (including back), end-effector or mobile parts of robot cell — movements of external axis (including end-effector tool at servicing position) — movement or rotation of sharp tool on end-effector or on external axes, part being handled, and associated equipment — rotational motion of any robot axes — materials and products falling or ejection — end-effector failure (separation) — loose clothing, long hair — between robot arm and any fixed object — between end-effector and any fixed object (fence, beam, etc.) — between fixtures (falling in); between shuttles, utilities — impossibility of exiting robot cell (via cell door) for a trapped operator in automatic mode — unintended movement of jigs or gripper — unintended release of tool — unintended movement of machines or robot cell parts during handling operations — unintended motion or activation of an end-effector or associated equipment (including external axes controlled by the robot, process specific for grinding wheels, etc.) — unexpected release of potential energy from stored sources	— crushing — shearing — cutting or severing — entanglement — drawing-in or trapping — impact — stabbing or puncture — friction, abrasion — high-pressure fluid/gas injection or ejection	4.1; 4.2; 4.2 d) 6); 4.2 f); 4.3; 4.4; 4.4.1; 4.4.2 d); 4.4.2 f); 4.5; 5.2; 5.2.1; 5.2.2; 5.2.3; 5.3; 5.3.2; 5.3.6; 5.3.7; 5.3.8.2; 5.3.9; 5.3.10; 5.5.1; 5.5.2; 5.5.3; 5.5.4; 5.6.4; 5.8; 5.9; 5.10.2; 5.10.3; 5.10.6.1; 5.10.6.2; 5.10.6.4; 5.10.7; 5.11; 5.11.4; 5.11.5.4

Table A.1 (*continued*)

No.	Type or group	Example of hazards — Origin	Example of hazards — Potential consequences	Subclause reference
2	**Electrical hazards**	— contact with live parts or connections (electrical cabinet, terminal boxes, control panels at machine) — confusion of various voltages within a system, electrical cabinet and terminals, i.e. drive power, control power (24 V versus 110 V) — contact with discrete components in the electrical (electronic) circuitry, i.e. capacitors — exposure to arc flash — process using high voltage or high frequency, i.e. electrostatic painting, inductive heating — welding applications using high voltage	— electrocution — shock — burn — projection of molten particles	4.4.1; 5.3.2; 5.3.6; 5.3.7; 5.8.2; 5.10.6.1; 5.10.6.2; 5.10.7
3	**Thermal hazards**	— hot surfaces associated with the end-effector, or associated equipment or work piece (e.g. welding torches, hot materials in forging presses, injection moulding, grinding and de-burring) — cold surfaces or objects (cryogenic processes) — explosive atmosphere caused by the process, i.e. paint (atomized particles, powder painting), flammable solvents, grinding and milling dust — temperature extremes required to support the process [molten materials; ovens for cooking or heating (autoclaves); freezer or chillers, etc.] — flammable materials (inside dust collector systems, cleaning tanks, sealant applicators)	— burn (hot or cold) — radiation injury	5.3; 5.5.2; 5.5.4
4	**Noise hazards**	— specific applications which are sources of high noise (e.g. a water jet cutter, stamping presses, pumps and valving, metal removing operations) — noise level preventing hearing or understanding audible danger warning signals, including inability of persons to coordinate their actions through normal conversation	— loss of hearing — loss of balance — loss of awareness, disorientation — any other (e.g. mechanical) as a consequence of ambient conditions or distraction	Noise is excluded from the scope of this part of ISO 10218
5	**Vibration hazards**	— direct contact with the source — loosening of connections, fasteners — misalignment of components or parts	— fatigue — neurological damage — vascular disorder — impact	4.2 , 4.3, 4.4, 4.5, 5.5.2, 5.5.9
6	**Radiation hazards**	— EMF interference with proper operation of the robot system — exposed to process-related radiation, i.e. arc welding, laser.	— burn — damage to eyes and skin — related illnesses	4.2, 4.3, 4.4, 4.5, 5.5.2, 5.5.9

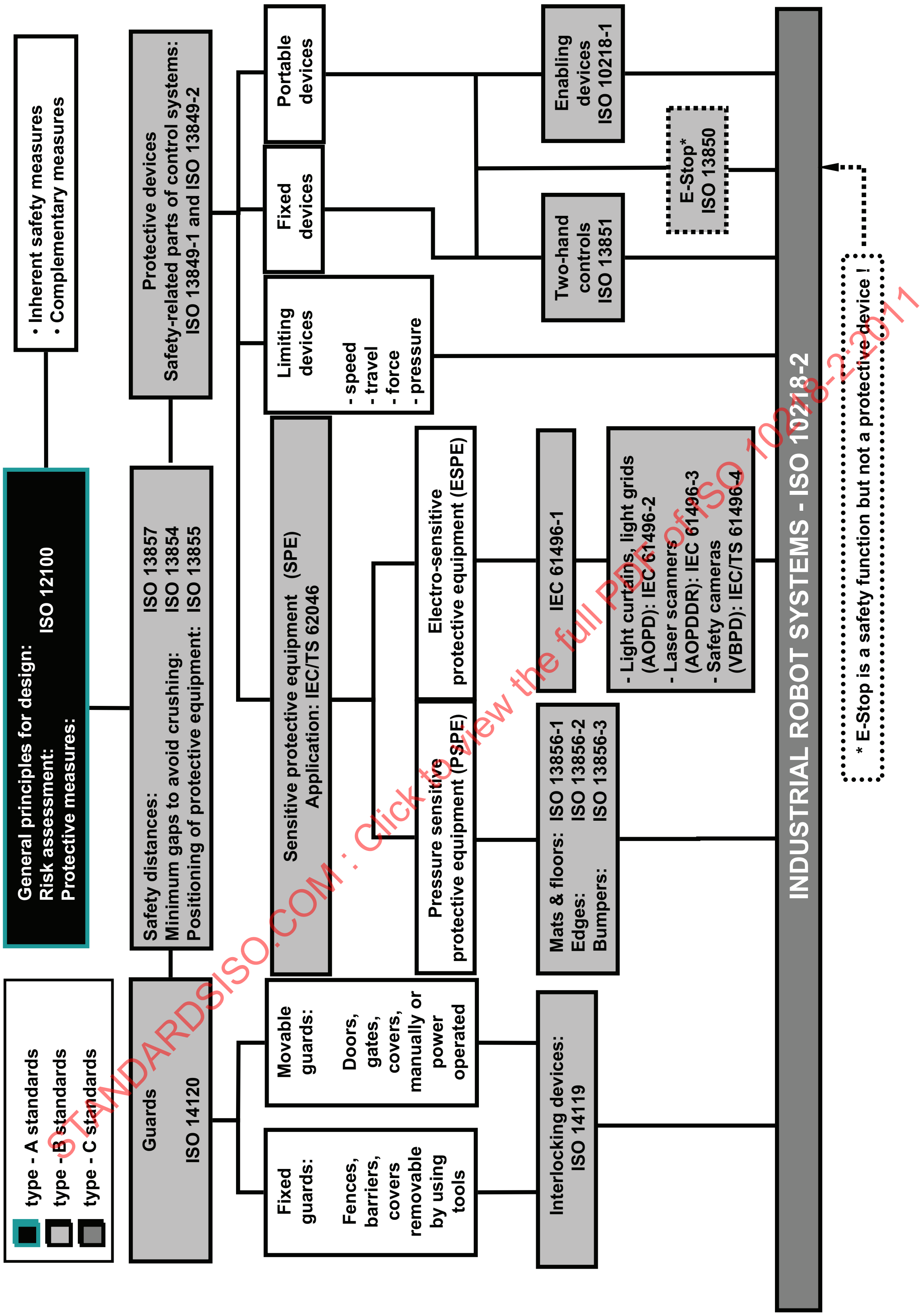
Table A.1 (*continued*)

No.	Type or group	Example of hazards — Origin	Example of hazards — Potential consequences	Subclause reference
7	**Material/ substance hazards**	— contact with components covered in harmful fluids — failures of mechanical and electrical components — corrosive fumes and dust	— sensitization — fire — chemical burn — inhalation illnesses	4.2, 4.3, 4.4, 4.5, 5.5.2, 5.5.3
8	**Ergonomic hazards**	— poorly designed teach pendant, HMI touch screen or operator panel (too far or high) — poorly designed loading/unloading post (e.g. long distance between components box location and loading/ unloading area) — poorly designed enabling devices — inappropriate location or identification of controls (e.g. hard to reach) — inappropriate location of components that require access (troubleshooting, repair, adjustment) — obscured hazards, inadequate or blocked local lighting	— unhealthy postures or excessive effort (repetitive strain) — fatigue	4.2 d); 4.3; 4.4; 4.5; 5.3.2; 5.3.13; 5.5; 5.5.2; 5.5.3; 5.9
9	**Hazards associated with environment in which the machine is used**	— installations in earthquake zones — electromagnetic interference or surges in energy source — moisture — temperature	— burn, — disease or illness — slipping, falling — respiratory damage — impact	4.1; 4.2; 5.2; 5.3; 5.5
10	**Combinations of hazards**	— robot system directed to start by one person, but this action is not expected by another person — hazards encountered due to multiple failures/situations — misidentification of actual problem and compound problem by making incorrect or unnecessary actions — action increases severity of harm, i.e. in avoiding a sharp edge, contact is made with a hot surface instead — unintended release of holding devices allowing motion under residual forces (inertia, gravity, spring/energy storage means) — failure of a safeguarding device to function as expected	— any other consequence of combinations of hazards and hazardous situations	4.2; 4.3; 4.4; 4.5; 5.2; 5.3.10; 5.6.3.3; 5.8; 5.9; 5.9.1;

Annex B

(informative)

Relationship of standards related to protective devices


type - A standards
type - B standards
type - C standards
General principles for design: ISO 12100
Risk assessment:
Protective measures:
• Inherent safety measures
• Complementary measures
Guards
ISO 14120
Safety distances: ISO 13857
Minimum gaps to avoid crushing: ISO 13854
Positioning of protective equipment: ISO 13855
Protective devices
Safety-related parts of control systems:
ISO 13849-1 and ISO 13849-2
Fixed guards:
Fences, barriers, covers removable by using tools
Movable guards:
Doors, gates, covers, manually or power operated
Sensitive protective equipment (SPE)
Application: IEC/TS 62046
Limiting devices
- speed
- travel
- force
- pressure
Fixed devices
Portable devices
Pressure sensitive protective equipment (PSPE)
Electro-sensitive protective equipment (ESPE)
Interlocking devices:
ISO 14119
Mats & floors: ISO 13856-1
Edges: ISO 13856-2
Bumpers: ISO 13856-3
IEC 61496-1
- Light curtains, light grids
(AOPD): IEC 61496-2
- Laser scanners
(AOPDDR): IEC 61496-3
- Safety cameras
(VBPD): IEC/TS 61496-4
Two-hand controls
ISO 13851
E-Stop*
ISO 13850
Enabling devices
ISO 10218-1
INDUSTRIAL ROBOT SYSTEMS - ISO 10218-2
* E-Stop is a safety function but not a protective device !

Annex C
(informative)

Safeguarding material entry and exit points

C.1 General considerations to prevent access at conveyors

Material transfer systems can be an integral part of an industrial robot system, conveying materials into and out of the safeguarded space. Typically, they include conveyors of all types (e.g. belt conveyors, powered and non-powered roller conveyors, slat conveyors, etc.) and due to their diversity it is impossible to describe all the various safeguarding requirements. A risk assessment always has to be conducted to ensure that all hazards are identified, evaluated and controlled appropriately. The following should be considered.

a) Means for safe access (e.g. interlocked door) should be made as convenient as possible to intervention points to prevent personnel from seeking access through the material transfer system.

b) Material transfer systems should not have any open area that allows access to any hazard.

c) Risk of access alongside the conveyor (e.g. prevented using sloping surfaces).

d) Risk of overstepping or whole body access (e.g. prevented by side guards, height of conveyor, ESPE).

e) Risk of grasping to hang over the conveyor.

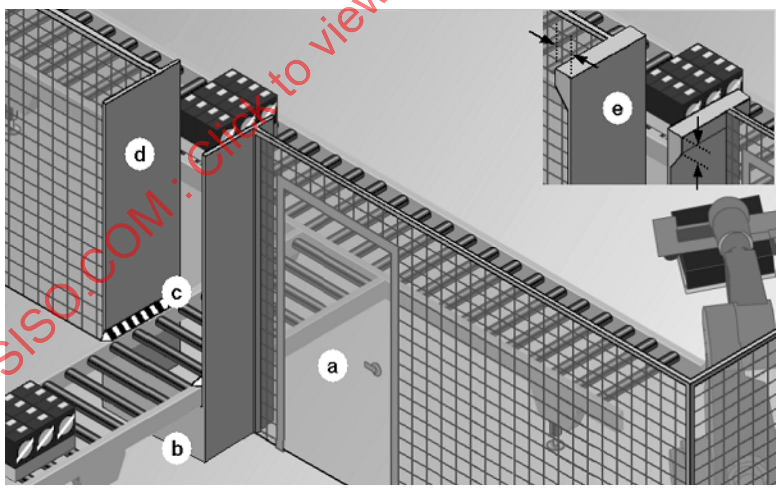


Figure C.1 — Examples of prevention measures against access at conveyors

C.2 Example of small openings

The dimensions of the opening should be adapted to the dimensions of the materials.

No hazard zone should be reachable from the opening.

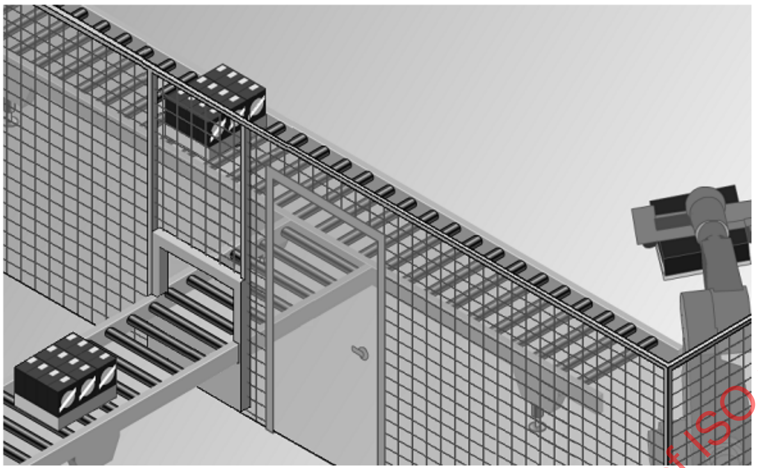


Figure C.2 — Material entry through small openings in guards

C.3 Example for tunnels

Tunnels with adequate depth prevent reaching hazardous areas.

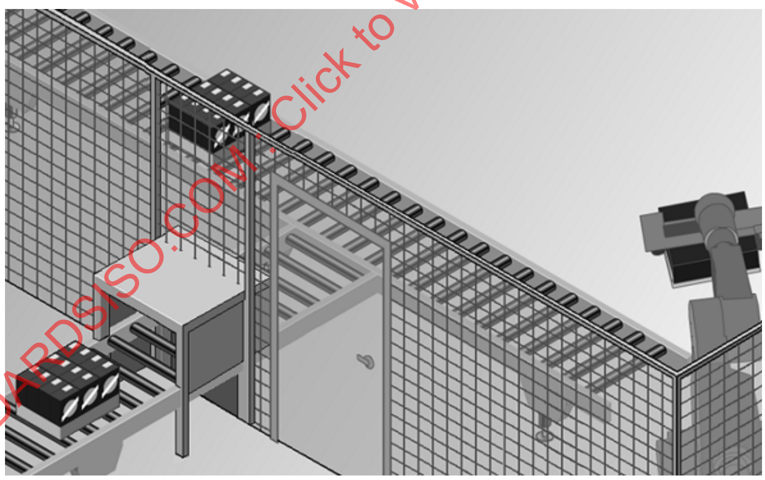


Figure C.3 — Tunnel used to increase distance to the hazard

C.4 Example of safeguarding with ESPE

The ESPE senses body access; however, product passage is allowed due to muting (shown with crossing photo beams).

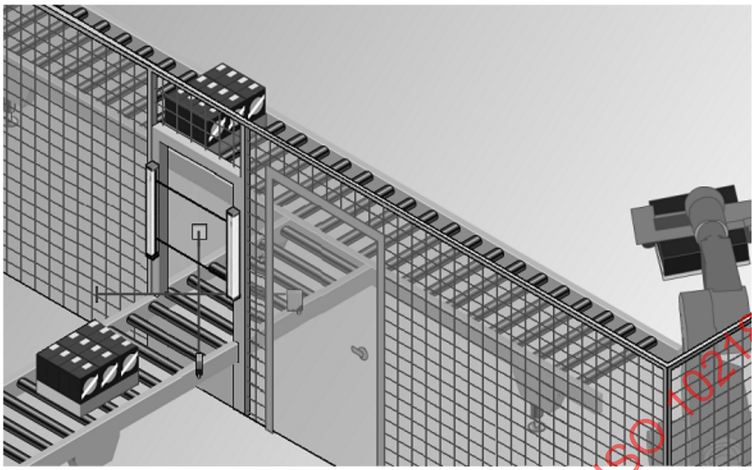


Figure C.4 — Safeguarding with ESPE

Annex D
(informative)

Operation of more than one enabling device

Table D.1 — Truth table for machine operation and positions of two enabling devices

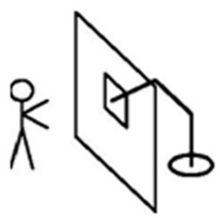
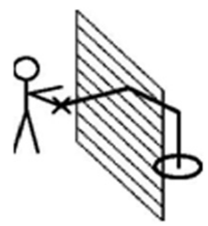
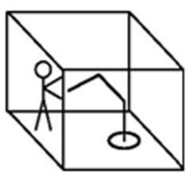
		Person A		
		Position 1	Position 2	Position 3
Person B	Position 1	OFF	OFF	OFF
	Position 2	OFF	ENABLED	OFF
	Position 3	OFF	OFF	OFF

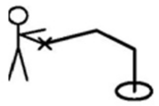
The machine operation shall be **ENABLED** only when **BOTH** enabling devices are in position 2 — the centre-enabled position.

Annex E
(informative)

Conceptual applications of collaborative robots

NOTE For requirements, see 5.11.

Type of application		Description	Safeguards	Objectives
	Hand-over window	— autonomous automatic operation within safeguarded space — robot moves into window — no interruption of automatic operation during access	— fixed or sensitive guards around the workspace — reduced speed and reduced workspace near the window — no robot workspace outside the window — when lower edge of the window less than 1 000 mm safeguards according to 5.10.3	— loading, unloading — testing, benching, cleaning — service
	Interface window	— autonomous automatic operation within safeguarded space — robot stops at an interface window and can then be moved manually outside the interface	— fixed or sensitive guards around the workspace — reduced speed and reduced workspace outside and near the window — hold-to-run control for guided movement	— automatic stacking/ de-stacking — guided assembling — guided filling/ un-filling — testing, benching, cleaning — service
	Collaborative workspace	— autonomous automatic operation within a common (collaborative) workspace — robot reduces speed and/or stops when a person enters the common (collaborative) workspace	— person-detection system using one or more sensors — reduced speed according to the distance (5.11.5.4) — robot stops safely when prohibited space accessed and possible automatic restart after clearance if properly safeguarded	— common assembling — common handling — testing benching, cleaning — service
	Inspection	— autonomous automatic operation within safeguarded space — a person enters the collaborative workspace while robot continues operation with reduced speed and reduced travel	— fixed or sensitive guards around the workspace — person-detection system or enabling device — reduced speed and reduced workspace after entering the workspace — measures against misuse	— inspection and tuning of processes, e.g. welding application

Type of application		Description	Safeguards	Objectives
	Hand-guided robot	— application-specific workspace — moving by hand guiding — moving hand guided along a path	— reduced speed — hold-to-run control — collaborative workspace depending on hazards of the application	— hand-guided assembling, painting, etc.

Annex F
(informative)

Process observation

F.1 General

Process observation is to be understood as a combination of technical safety measures and requirements for safe behaviour that offers maximum practicable protection to the operator by limiting velocities and transverse paths and disconnecting movements that are not required.

Temporary observation of automatic processes should occur, while protective measures are reduced as far as necessary by applying alternative protective measures. Technical safety measures should be carried out in such a way that reasonably foreseeable misuse will be prevented.

This form of action should be the subject of intense contact between the integrator and the future user in order to be able to analyse the requirements for the behaviour of the operator and translate them into action.

In case of residual risk such as the ejection of molten metal particles, a concept according to Figure F.1 should be established.

See additional information on process observation in ISO 11161.

NOTE This annex is derived from ISO 11161:2007, Annex D.

F.2 Comments on the process observation

See Figure F.1.

a) Is there a need for “closer” observation of the working process? Can the working process be controlled by the relevant modes of operation laid down in the appropriate type-C standards? Would additional systems, such as video cameras or structure-borne noise devices, be helpful?

   Have there been further consultations with the future user? Has the user sufficiently explained that an additional mode of operation is absolutely necessary for the intended production (e.g. due to considerably varying tolerances, correction of manufacturing, quality check)?

b) Have the results of the consultations and, in particular, the reasons for the additional mode of operation, been recorded? Does the application of that additional mode of operation in comparison to normal operation remain restricted to a necessary extent in the scope of the intended use?

c) The intended use of the robot system with application of the additional mode of operation should be exactly specified and should be included in the technical documentation. For the hazard analysis and the risk assessment, the safety strategy (see Clause 4) should include the intended use. The particular conditions (person close to the process) should be taken into account.

d) The avoidance of hazards by means of design measures is of the highest priority for the risk reduction. Due to the fact that this is difficult to manage, technical safety measures for risk reduction should be considered in particular. The technical measures should aim to, on the one hand, reduce the risks and, on the other hand, restrict the additional mode of operation to the largest extent to the required minimum, in order to prevent misuse, for example by:

   1) safe limiting of speed and transverse paths to the required level only;

2) manual restart of moving parts after standstill;

3) safe disconnection of such hazardous movements/axes that are not required for that mode of operation;

4) prevention of automatic tool changing;

5) prevention of pallet changing;

6) prevention from putting the cooling lubricant under high pressure;

7) manual acknowledgement of cooling agent release (eye injury);

8) easy accessibility of devices for stopping in case of emergency (emergency stop);

9) authorized access only, e.g. by key switch or password.

e) If a sufficient risk reduction has been achieved by technical means, the additional mode of operation may be provided.

f) The iterative process should be continued until the technical measures are exhausted.

g) If the risk assessment shows that the remaining risk is not acceptable, the integrator should check whether the user can make the necessary contribution to the risk reduction by additional means, such as:

1) particular qualification of employees;

2) providing regular instructions (written proof);

3) personal protective equipment (e.g. protective glasses, protective shoes, wearing of suitable clothing);

4) attaching operating instructions concerning the additional mode of operation.

h) If the integrator obtains information that the user is not able to make the above contribution, no additional mode of operation should be provided for the robot system.

i) If the integrator obtains information that the user is able to make an adequate contribution by additional measures, such measures should be recorded under agreement between the integrator and the user and should be included as a requirement in the operation manual and as markings or warning signs on the robot system.

j) All information relating to the additional mode of operation should be recorded in the operation manual:

1) intended use;

2) precautions against foreseeable misuse;

3) description of operation and functions;

4) measures to be taken by the user according to steps e) and f);

5) other requirements concerning maintenance and control.

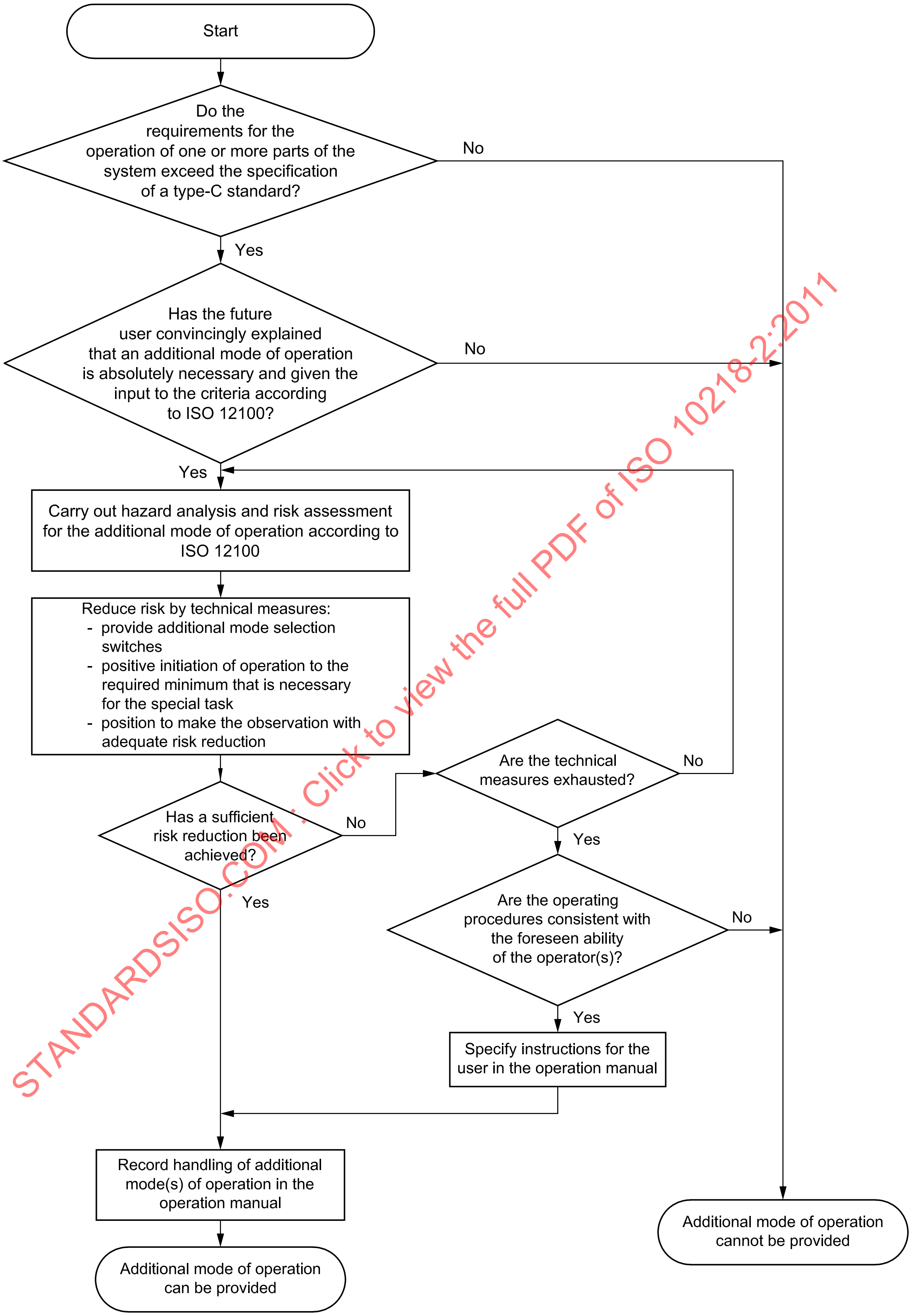


Figure F.1 — Safeguarding during process observation

Annex G
(normative)

Means of verification of the safety requirements and measures

Table G.1 lists specific performance requirements that are identified as essential to the safety of the robot that shall be verified or validated, or both.

See 6.3 for notes on using this table.

Table G.1 — Means of verification of the safety requirements and measures

Subclause	Safety requirements and/or measures	Verification and/or validation methods (see 6.2)								
		A	B	C	D	E	F	G	H	I
5.2	**Safety-related control system performance (hardware/software)**									
5.2.1	Statement of performance capabilities and data and criteria to determine the performance in information for use.	X								X
5.2.2	Performance is PL=d, structure category 3.					X	X			X
5.2.2	Performance is SIL 2, hardware fault tolerance 1 with proof test interval not less than 20 years.					X	X			X
5.2.3	Results of risk assessment used to determine performance.							X		X
5.3	**Design and installation**									
5.3.1	System designed and selected based on conditions.	X			X					X
5.3.2	Automatic mode selection shall be outside the safeguarded area.	X	X			X				
5.3.3	Actuating controls meet the requirements of IEC 60204-1.	X								
5.3.3	Robot system shall not respond to any ext. remote control commands or conditions causing hazardous situations.		X		X					
5.3.4	All power sources shall meet the manufacturer's requirements.	X		X		X				X
5.3.4	Electrical enclosure doors shall be mounted to be fully opened and escape routes are always available.	X	X	X	X					
5.3.5	Protective bonding shall meet IEC 60204-1.	X		X						
5.3.6	Hazardous energy isolation means provided.	X	X			X				
5.3.6	Hazardous energy isolation means shall be clearly marked.	X								
5.3.7	Means of controlled release of hazardous energy shall be provided.	X	X			X				
5.3.7	Means of controlled release of hazardous energy shall be clearly marked.	X								