Presents:

Draft Standard

R15.06-201x

Industrial Robots and Robot Systems—Safety Requirements

This release of the Pre-publication draft for the projected 2012 edition of ANSI/RIA R15.06 was presented at the 2012 National Robot Safety Conference for the purpose of informing industry of the progress of the national adoption of the International Standard ISO 10218 which is complete and presented in its entirety herein. The document is currently in the process of being approved as an American National Standard.

Until approved by ANSI, some wording, but not the technical requirements, in this document may change.
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Foreword to R15.06 (not part of draft standard)

The objective of this standard is to enhance the safety of personnel using industrial robots and industrial robot systems by establishing requirements for the manufacture, integration, installation and safeguarding of industrial robots.

To accomplish this objective, the Robotic Industries Association Subcommittee R15.06 on Safety closely monitored the work of the ISO Working Group responsible for developing the ISO 10218 standard and provided personnel and substantive input to that group. This is a national adoption of ISO 10218-1:2011 and ISO 10218-2:2011 which are presented in their entirety. This total revision of the requirements for personal safety related to Industrial Robots updates and replaces ANSI/RIA/ISO 10218-1-2007 which is withdrawn.

ISO standards provide requirements for personnel safety in the design, construction and integration of machinery. Specific occupational health and safety requirements for users are not included as these regulations vary from one country or region to another and are subject to local authority. Where local, state or national codes and regulations exist, they take precedence over requirements in this voluntary standard. Additional user requirements will be disseminated during a transition period until ANSI/RIA R15.06-1999 is withdrawn.

Industry standards, including this one, are voluntary. The Robotic Industries Association makes no determination with respect to whether any robot, robot system, associated safety devices, manufacturer, or user is in compliance with this standard.

Suggestions for improvement of the standard are welcome. They should be sent to the:

Robotic Industries Association  
Subcommittee on Safety  
900 Victors Way, Suite 140  
Ann Arbor, MI 48108

Consensus for approval of this standard as an American National Standard was achieved by balloting of the R15 Standards Approval Committee of the Robotic Industries Association (an accredited standards developing organization). Committee approval of this standard does not necessarily imply that all committee members voted for its approval. At the time it approved this standard, the R15 Standards Approval Committee had the following members:

William Drotning, Chairman  
Sandia National Laboratories (Retired)

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Subcommittee R15.06 on Industrial Robot Safety, was chaired by Roberta Nelson Shea
Administrative services provided by Jeff Fryman of the Robotic Industries Association
Introduction to R15.06-2012

In adopting the International Standard, the R15.06 Subcommittee for Safety considered the variety of tasks necessary for the efficient and productive use of Industrial Robots. The operational scope and characteristics of a robot can be significantly different than other equipment and machines, and certain tasks may require persons to be in the proximity of the robot while drive power is available. An industrial robot frequently is not a stand-alone machine, but rather part of a system, which interacts with other machines and equipment.

To assist in the understanding of this standard, certain “stakeholders” have been assigned specific responsibilities. The robot manufacturer is addressed in Part 1, while the integrator and installer are addressed in Part 2. The manufacturer, integrator and installer have the requirement to provide "information for use" to the user of the robot and robot system. This information and instructions are intended to ensure that the user has the necessary information to safely use the equipment furnished to them. The user, while not specifically addressed, has the responsibility to use this information in developing training and safe work practices. When the user makes any changes to the robot or robot system as delivered by the original supplier, the user is acting in the capacity of a machine builder or integrator and has the explicit responsibility to comply with applicable portions of this standard.

Safety must be a conscious effort on the part of all parties (manufacturer, integrator, and user) throughout the life cycle of the robot system starting with the initial design and continuing through integration, implementation, use and maintenance, then culminating in disposal. Protective measures are applied, using the hierarchy of risk control, until risk reaches an acceptable level. Necessary components in workplace safety are the maintenance of, and adherence to, the system safety design. Personnel skills, training, and attitude are important factors in the administrative portion of the safety management system. This standard only serves to provide guidelines to a safe operation.

Terms which may be unique to the standard or have specific contextual meaning are defined in clause 3 of each part. The word “shall” is prescriptive, and describes mandatory requirements to comply with this standard. The word “should” is meant to be a recommendation or good practice and can be a very strong recommendation or advisory. The word “may” is permissive, and the word “can” indicates something is possible or a capability. Notes used throughout the document are informative, intended to provide explanations and additional information.

This standard is a complete revision of ANSI/RIA R15.06-1999(r2009) which will be withdrawn effective 31 December 2014. Changes were incorporated based on public comments received and the International Standard which itself was based on the R15.06 standard from 1999. Some of the most significant changes include:

- A total reorganization of the text presenting the ISO 10218-1 and ISO 10218-2 in their entirety. Changes to the ISO documents were limited to page formatting from ISO A4, spelling changes of words from the traditional British/ISO spelling (i.e. colour, centre) to common American spelling and decimal annotation of numbers. As both parts of the ISO documents are presented in one volume of R15.06, references between parts do not include the annotation of ISO 10218. These and other strictly editorial changes are annotated by the use of brackets [ ].

- Changing of selected terminology (e.g. reduced speed for slow speed and protective stop for safety stop), but not changes to functional requirements

- Additional requirements regarding new features offered on robots and the safe integration of the features

- Requirements for detachable and wireless pendants
− Change in requirements for safety control circuitry (functional safety)
− Change in control of robot motion to include safety-rated soft axis and space limiting
− Change in clearance requirements
− Requirements for collaborative robot operation (new feature)
− A Risk Assessment shall be performed and is no longer optional
− The robot does not include the end-effector – the robot system does
− The term “operator” applies to all persons performing tasks including maintenance and repair

The new requirements of this edition are not applicable to robots manufactured, or robot systems installed, prior to the publication of this edition provided such robots, robot systems, and robot cells are compliant with the R15.06 1999 edition.

Existing robot installations which are physically moved after publication of this standard but are re-installed exactly as they were installed (relative positions, layout, functionality, specification and safeguarding) require a review to determine if any new or revised hazard(s) have been introduced, but need no further action provided they were and remain fully compliant with the requirements of clauses 4 through 11 of the R15.06-1999. Installations changed subsequent to the publication of this edition are subject to the requirements of this edition. This does not preclude the voluntary updating of industrial robot systems and cells to the requirements in this edition.
Part 1 – [Industrial] Robots
Foreword [ISO 10218 Part 1]

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 10218-1 was prepared by Technical Committee ISO/TC 184, Automation systems and integration, Subcommittee SC 2, Robots and robotic devices.

This second edition cancels and replaces the first edition (ISO 10218-1:2006), which has been technically revised. It also incorporates Technical Corrigendum ISO 10218-1:2006/Cor.1:2007.

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

— Part 1: [Industrial] Robots
— Part 2: [Industrial] Robot systems and integration
Introduction [Part 1]

This standard has been created in recognition of the particular hazards that are presented by industrial robots and industrial robot systems.

This part of [the standard] is a type C standard as outlined in ISO 12100.

When provisions of a type-C standard are different from those which are stated in type-A or type-B standards, the provisions of the type-C standard take precedence over the provisions of the other standards for machines that have been designed and built in accordance with the provisions of the type-C standard.

The machinery concerned and the extent to which hazards, hazardous situations and events are covered are indicated in the Scope of this part of [the standard].

Hazards associated with robots are well recognized, but the sources of the hazards are frequently unique to a particular robot system. The number and type(s) of hazard(s) 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.

NOTE - Not all of the hazards identified by [this standard] apply to every robot, nor will the level of risk associated with a given hazardous situation be the same from robot to robot. Consequently, the safety requirements, or the protective measures, or both, can vary from what is specified in [this standard]. A risk assessment can be conducted to determine what the protective measures should be.

In recognition of the variable nature of hazards with different uses of industrial robots, [this standard] is divided into two parts. This part of [the standard] provides guidance for the assurance of safety in the design and construction of the robot. Since safety in the application of industrial robots is influenced by the design and application of the particular robot system integration, [Part 2 of this standard] provides guidelines for the safeguarding of personnel during robot integration, installation, functional testing, programming, operation, maintenance and repair.

This part of [the standard] has been updated based on experience gained in developing the [Part 2] guidance on system and integration requirements, in order to ensure it remains in line with minimum requirements of a harmonized type-C standard for industrial robots. Revised technical requirements include, but are not limited to, definition and requirements for singularity, safeguarding of transmission hazards, power loss requirements, safety-related control circuit performance, addition of a category 2 stopping function, mode selection, power and force limiting requirements, marking, and updated stopping time and distance metric and features.

This part of [the standard] is not applicable to robots which were manufactured prior to its publication date.
1 Scope
This part of [the standard] specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

This part of [the standard] does not address the robot as a complete machine. Noise emission is generally not considered a significant hazard of the robot alone, and consequently noise is excluded from the scope of this part of [the standard].

This part of [the standard] does not apply to non-industrial robots, although the safety principles established in [the standard] can be utilized for these other robots.

NOTE 1 – Examples of non-industrial robot applications include, but are not limited to, undersea, military and space robots, tele-operated manipulators, prosthetics and other aids for the physically impaired, micro-robots (displacement less than 1 mm), surgery or healthcare, and service or consumer products.

NOTE 2 – Requirements for robot systems, integration, and installation are covered in [Part 2].

NOTE 3 – Additional hazards can be created by specific applications (e.g. welding, laser cutting, machining). These system-related hazards need to be considered during robot design.

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 9283:1998, Manipulating industrial robots — Performance criteria and related test methods
ISO 10218-2, Robots and robotic devices – Safety requirements for industrial robots – Part 2: Robot systems and integration
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
IEC 60204-1, Safety of machinery — Electrical equipment of machines — Part 1: General requirements

1 NFPA 79, Electrical Standard for Industrial Machinery, contains the identical requirements as IEC 60204-1 for the purposes of this standard
3 Terms and definitions

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

3.1 actuating control
mechanical mechanism within a control device
EXAMPLE A rod which opens contacts.

3.2 automatic mode
operating mode in which the robot control system operates in accordance with the task program
[ISO 8373:1994, definition 5.3.8.1]

3.3 automatic operation
state in which the robot is executing its programmed task as intended
NOTE – Adapted from ISO 8373:1994, definition 5.5

3.4 collaborative operation
state in which purposely designed robots work in direct cooperation with a human within a defined workspace

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

3.6 drive power
energy source or sources for the robot actuators

3.7 end-effector
device specifically designed for attachment to the mechanical interface to enable the robot to perform its task
EXAMPLE Gripper, nutrunner, welding gun, spray gun.
[ISO 8373:1994, definition 3.11]

3.8 energy source
electrical, mechanical, hydraulic, pneumatic, chemical, thermal, potential, kinetic, or other source of power

3.9 hazardous motion
motion that is likely to cause personal physical injury or damage to health

3.10 industrial robot
automatically controlled, reprogrammable multipurpose manipulator, programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications.

NOTE 1 – The industrial robot includes:
- the manipulator, including actuators;
- the controller, including teach pendant and any communication interface (hardware and software).

NOTE 2 – This includes any integrated additional axes.

NOTE 3 – The following devices are considered industrial robots for the purpose of this [standard]:
- hand-guided robots;
- the manipulating portions of mobile robots;
- collaborating robots.

NOTE 4 – Adapted from ISO 8373:1994, definition 2.6.

3.11 industrial robot system

system comprising:
- industrial robot;
- end-effector(s);
- any machinery, equipment, devices, external auxiliary axes or sensors supporting the robot performing its task

NOTE 1 – The robot system requirements, including those for controlling hazards, are contained in [Part 2].


3.12 limiting device

means that restricts the maximum space by stopping or causing to stop all robot motion

3.13 local control

state of the system or portions of the system in which the system is operated from the control panel or pendant of the individual machines only

3.14 manual mode

color state that allows for the direct control by an operator

NOTE 1 – Sometimes referred to as teach mode where program points are set.

NOTE 2 – Adapted from ISO 8373:1994, definition 5.3.8.2.

3.15 pendant
teach pendant

hand-held unit linked to the control system with which a robot can be programmed or moved

[ISO 8373:1994, definition 5.8]

3.16 Program
3.16.1
control program

inherent set of instructions which defines the capabilities, actions, and responses of a robot

NOTE – This type of program is fixed and usually not modified by the user.

[ISO 8373:1994, definition 5.1.2]

3.16.2
task program

set of instructions for motion and auxiliary functions that define the specific intended task of the robot system

NOTE 1 – This type of program is normally generated by the user.
NOTE 2 – An application is a general area of work; a task is specific within the application.

[ISO 8373:1994, definition 5.1.1]

3.16.3
program verification

execution of a task program for the purpose of confirming the robot path and process performance

NOTE – Verification can include the total path traced by the tool center point during the execution of a task program or a segment of the path. The instructions can be executed in a single instruction or continuous instruction sequence. Verification is used in new applications and in fine tuning/editing of existing ones.

3.17
protective stop

type of interruption of operation that allows a cessation of motion for safeguarding purposes and which retains the program logic to facilitate a restart

3.18
robot actuator

powered mechanism that converts electrical, hydraulic, or pneumatic energy to effect motion

3.19
safety-rated

characterized by having a prescribed safety function with a specified safety-related performance

3.19.1
safety-rated monitored speed

safety-rated function that causes a protective stop when either the Cartesian speed of a point relative to the robot flange (e.g. the TCP), or the speed of one or more axes exceeds a specified limit value

3.19.2
safety-rated reduced speed

a safety-rated monitored speed function that limits the robot speed to 250 mm/s [10 in/s] or less

NOTE 1 – The safety-rated reduced speed limit value is not necessarily the value set in the reduced speed control function.
NOTE 2 – The difference between safety-rated monitored speed and safety-rated reduced speed is that safety-rated monitored speed limit can be set to speeds greater than 250 mm/s [10 in/s].

3.19.3 safety-rated soft axis and space limiting
safety-rated soft limit
limit placed on the range of motion of the robot by a software- or firmware-based system having a specified sufficient safety-related performance.

NOTE – The safety-rated soft limit might be the point where a stop is initiated, or it might ensure that the robot does not move beyond the limit.

3.19.4 safety-rated output
output signal having a specified sufficient safety-related performance

3.19.5 safety-rated zone output
safety-rated output indicating the state of the robot position relative to a safety-rated soft limit

NOTE – For example, the robot position can be inside the zone or outside the zone.

3.19.6 safety-rated monitored stop
condition where the robot is stopped with drive power active, while a monitoring system with a specified sufficient safety performance ensures that the robot does not move

3.20 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 may be synchronous using common mathematical correlation

NOTE 1 – A teach pendant is an example of a single control station.
NOTE 2 – Coordination can be done as master/slave.

3.21 single point of control
ability to operate the robot such that initiation of robot motion is only possible from one source of control and cannot be overridden from another initiation source

3.22 singularity
occurrence whenever the rank of the Jacobian matrix becomes less than full rank

NOTE – Mathematically, in a singular configuration, the joint velocity in joint space can become infinite to maintain Cartesian velocity. In actual operation, motions defined in Cartesian space that pass near singularities can produce high axis speeds. These high speeds can be unexpected to an operator.

3.23 reduced speed control
slow speed control
mode of robot motion control where the speed is limited to 250 mm/s [10 in/s] or less

NOTE – Reduced speed is intended to allow persons sufficient time to either withdraw from the hazardous motion or stop the robot.

3.24 space
three-dimensional volume
3.24.1 maximum space
space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end-effector and the workpiece

[ISO 8373:1994, definition 4.8.1]

3.24.2 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.

3.24.4 safeguarded space
space defined by the perimeter safeguarding

3.25 teach

3.25.1 teach programming
task programming
programming of the task performed by

a) manually leading the robot end-effector; or
b) manually leading a mechanical simulating device; or
c) using a teach pendant to step the robot through the desired positions

NOTE – Adapted from ISO 8373:1994, definition 5.2.3.

3.26 tool center point

TCP
point defined for a given application with regard to the mechanical interface coordinate system

[ISO 8373:1994, definition 4.9]

3.27 user
entity that uses robots and is responsible for the personnel associated with the robot operation

4 Hazard identification and risk assessment

Annex A contains a list of hazards that can be present with robots. A hazard analysis shall be carried out to identify any further hazards that may be present.

A risk assessment shall be carried out on those hazards identified in the hazard identification. This risk assessment shall give particular consideration to:

a) the intended operations at the robot, including teaching, maintenance, setting and cleaning;
b) unexpected start-up;
c) access by personnel from all directions;
d) reasonably foreseeable misuse of the robot;
e) the effect of failure in the control system; and
f) where necessary, the hazards associated with the specific robot application.
Risks shall be eliminated or reduced first by design or by substitution, then by safeguarding and other complementary measures. Any residual risks shall then be reduced by other measures (e.g. warnings, signs, training).

The requirements contained in Clause 5 derive from the iterative process consisting of applying safeguarding measures that are described in ISO 12100 to the hazards identified in Annex A.

NOTE 1 – ISO 12100 provides requirements and guidance in performing hazard identification and risk reduction.

NOTE 2 – Hazard identification and risk assessment requirements for robot systems, integration, and installation are covered in Part 2.

5 Design requirements and protective measures

5.1 General

The robot shall be designed in accordance with the principles of ISO 12100 for relevant hazards. Significant hazards, such as sharp edges, are not dealt with by this part of the standard.

Robots shall be designed and constructed to comply with the requirements in 5.2 to 5.15.

5.2 General requirements

5.2.1 Power transmission components

Exposure to hazards caused by components such as motor shafts, gears, drive belts, or linkages which are not protected by integral covers (e.g. panel over a gear box) shall be prevented either by fixed guards or movable guards. The fixing systems of the fixed guards which are intended to be removed for routine service actions shall remain attached to the machine or the guard. Movable guards shall be interlocked with the hazardous movements in such a way that the hazardous machine functions cease before they can be reached. The safety-related control system performance of an interlocking system shall conform to the requirements of 5.4.

5.2.2 Power loss or change

Loss of, or variations in power shall not result in a hazard. Re-initiation of power shall not lead to any motion.

Robots shall be designed and constructed so that loss or change of electrical, hydraulic, pneumatic or vacuum power does not result in a hazard. If hazards exist that are not protected by design, then other protective measures shall be taken to protect against those hazards. Unprotected hazards of the expected use shall be identified in the information for use.

NOTE – See IEC 60204-1 for electrical power supply requirements.

5.2.3 Component malfunction

Robot components shall be designed, constructed, secured, or contained so that hazards caused by breaking or loosening, or releasing stored energy are minimized.

5.2.4 Sources of energy

A means of isolating any hazardous energy source to the robot shall be provided. This means shall be provided with capability of locking or otherwise securing in the de-energized position.
5.2.5 Stored energy

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

NOTE – Stored energy can occur in air and hydraulic pressure accumulators, capacitors, batteries, springs, counterbalances, flywheels, etc.

5.2.6 Electromagnetic compatibility (EMC)

The design and construction of the robot shall prevent hazardous motion or situations due to the expected effects of electromagnetic interference (EMI), radio frequency interference (RFI) and electrostatic discharge (ESD).

NOTE – See IEC 61000 for design information.

5.2.7 Electrical equipment

The robot electrical equipment shall be designed and constructed in accordance with the relevant requirements of IEC 60204-1.

5.3 Actuating controls

5.3.1 General

Actuating controls that initiate power or motion shall be designed and constructed to meet the performance criteria mentioned in 5.3.2 to 5.3.5.

5.3.2 Protection from unintended operation

Actuating controls shall be constructed or located so as to prevent unintended operation. For example, appropriately designed push-buttons or key selector switches in appropriate locations can be used.

5.3.3 Status indication

The status of the actuating controls shall be clearly indicated, e.g. power on, fault detected, automatic operation.

If an indicator light is used, it shall be suitable for its installed location and its color shall meet the requirements of IEC 60204–1.

5.3.4 Labeling

Actuating controls shall be labeled to clearly indicate their function.

5.3.5 Single point of control

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

5.4 Safety–related control system performance (hardware/software)

5.4.1 General

Safety-related control systems (electric, hydraulic, pneumatic, and software) shall comply with 5.4.2, unless the results of the risk assessment determine that an alternate performance criterion as described in 5.4.3 is appropriate. The safety-related control system performance of the robot 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 purpose of this part of the standard, 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 accordance with IEC 60204-1.

5.4.2 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 a 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; and
d) all reasonably foreseeable faults shall be detected.

These 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.

5.4.3 Other control system performance criteria

The results of a comprehensive risk assessment performed on the robot and its intended application may determine that a safety-related control system performance other than stated in 5.4.2 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.
5.5 Robot stopping functions

5.5.1 General

Every robot shall have a protective stop function and an independent emergency stop function. These functions shall have provision for the connection of external protective devices. Optionally, an emergency stop output signal may be provided. Table 1 shows a comparison of the emergency stop and protective stop functions.

<table>
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5.5.2 Emergency stop

The robot shall have one or more emergency stop functions (stop category 0 or 1, in accordance with IEC 60204-1).

Each control station capable of initiating robot motion or other hazardous situation shall have a manually initiated emergency stop function that:

a) complies with requirements of 5.4 and IEC 60204-1;
b) takes precedence over all other robot controls;
c) causes all controlled hazards to stop;
d) removes drive power from the robot actuators;
e) provides capability for controlling hazards controlled by the robot system;
f) remains active until it is reset; and
g) shall only be reset by manual action that does not cause a restart after resetting, but shall only permit a restart to occur.

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

When an emergency stop output signal is provided:

— the output shall continue to function when the robot power is removed; or
— if the output does not continue to function when the robot power supply is removed, an emergency stop signal shall be generated.
The emergency stop device shall be in accordance with IEC 60204-1 and ISO 13850.

5.5.3 Protective stop

The robot shall have one or more protective stop functions designed for the connection of external protective devices. The protective stop function performance shall comply with the requirements of 5.4.

This stop function shall cause a stop of all robot motion, remove or control power to the robot drive actuators, and allow for the control of any other hazard controlled by the robot. This stop may be initiated manually or by control logic.

At least one protective stop function shall be a stop category 0 or 1, as described in IEC 60204-1. The robot may have an additional protective stop function using stop category 2 as described in IEC 60204-1 that does not result in drive power being removed but does require monitoring of the standstill condition after the robot stops. Any unintended motion of the robot in the monitored standstill condition or detected failure of the protective stop function shall result in a category 0 stop according to IEC 60204-1. The monitored stand-still function performance shall comply with 5.4. This function may also be initiated from external devices (input stop signal from protective devices).

NOTE – A monitored category 2 stop function in accordance with IEC 60204-1 can be provided by an electric power drive system which corresponds to a safe operational stop (SOS) in accordance with IEC 61800-5-2.

The manufacturer shall include the stop category of every protective stop circuit input in the information for use.

5.6 Speed control

5.6.1 General

The speed of the robot end-effector mounting flange and of the tool center point (TCP) shall be controllable at selectable speeds. An off-set feature (defining the location of the TCP relative to the mounting flange) shall be provided to enable the TCP speed to be controlled.

5.6.2 Reduced speed control operation

When operating under reduced speed control, the speed of the TCP shall not exceed 250 mm/s [10 in/s]. It should be possible to select speeds lower than 250 mm/s [10 in/s] as the assigned limit.

5.6.3 Safety-rated reduced speed control

When provided, safety-rated reduced speed control shall be designed and constructed in accordance with 5.4.2 so that in the event of a fault, the speed of the TCP does not exceed the limit for reduced speed (see 5.6.2) and a protective stop is issued when a fault occurs.

5.6.4 Safety-rated monitored speed

When provided, the speed of the TCP or of an axis shall be monitored in accordance with 5.4.2. If the speed exceeds the limit selected, a protective stop shall be issued.

5.7 Operational modes

5.7.1 Selection

Operational modes shall be selectable with a mode selector which can be locked in each position (e.g. a key operated switch which can be inserted and extracted in each position).
Each position of the selector shall be clearly identifiable and shall exclusively allow one control or operating mode.

The selector can be replaced by another selection means which restricts the use of certain functions of the robot (e.g. access codes).

These means shall:

a) unambiguously indicate the selected operating mode; and

b) by themselves not initiate robot motion or other hazards.

An optional output(s) may be provided to indicate the mode selected. When provided for safety-related purposes, the output(s) shall comply with the requirements of 5.4 (see Annex D).

NOTE – Methods for mode labeling are illustrated in Annex E.

5.7.2 Automatic

In automatic mode, the robot shall execute the task program and the safeguarding measures shall be functioning.

Automatic operation shall be prevented if any stop condition is detected.

Switching from this mode shall result in a stop.

5.7.3 Manual reduced speed

Manual reduced-speed mode shall meet the requirements of 5.3.4 and 5.6 and shall allow a robot to be operated by human intervention. Automatic operation is prohibited in this mode. This mode is used for jogging, teaching, programming and program verification of the robot; it may be the mode selected when performing some maintenance tasks.

Manual control of the robot from inside the safeguarded space shall be performed with a reduced speed in conjunction with either of the following:

a) hold-to-run controls in conjunction with an enabling device in accordance with 5.8, or

b) for program verification only, a start/stop control in conjunction with an enabling device in accordance with 5.8.

Information for use shall contain appropriate instructions and warnings that, wherever possible, the manual mode of operation shall be performed with all persons outside the safeguarded space. Information for use shall also instruct that prior to selecting automatic mode, any suspended safeguards shall be returned to their full functionality.

NOTE – Previously, this mode was also known as T1 or teach.

5.7.4 Manual high speed

If this mode is provided, speeds greater than 250 mm/s [10 in/s] can be achieved. This mode is used for program verification only. In this case, the robot shall:

a) have a means to select manual high-speed mode which requires a deliberate action (e.g. a key switch on the robot control panel) and an additional confirming action;

b) provide a pendant conforming to 5.8 with a hold-to-run function in addition to the enabling device that permits robot motion to continue;

c) set an initial speed limit of up to, but not exceeding, 250 mm/s [10 in/s] upon selection of manual high-speed mode;

d) provide on the pendant a means for the operator to incrementally adjust the speed from the initial value to the full programmed value in multiple steps;
e) provide on the pendant an indication of the adjusted speed;
f) ensure that:
   – its speed is limited to the initial speed limit when the enabling device is re-initiated by placing the switch in the center-enabled position after either having been released or fully compressed, and
   – a separate deliberate action is required to return to the higher speed that was selected before the enabling device switch was released or compressed, and
   – the option to resume the higher speed using the separate action shall become inoperable after no more than five minutes after the release of the enabling device.

The option to resume the higher speed and the time-out are not safety-rated. Information for use shall contain appropriate instructions and warning that, wherever possible, the manual mode of operation shall be performed with all persons outside the safeguarded space. Information for use shall also instruct that prior to selecting automatic mode, any suspended safeguards shall be returned to their full functionality.

NOTE – This optional manual mode has previously been known as T2, or high-speed attended program verification.

5.8 Pendant controls

5.8.1 General

Where a pendant control or other teaching control device has the capability to control the robot from within the safeguarded space, the requirements in 5.3.5 and 5.8.2 to 5.8.7 shall apply.

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

5.8.2 Motion control

Motion of the robot initiated from the pendant or teaching control device shall be under reduced speed control as described in 5.6. When the controls contain provisions for selecting manual high speed, the robot shall meet the requirements in 5.7.4.

5.8.3 Enabling device

The pendant or teaching control device shall have a three-position enabling device in accordance with IEC 60204-1. When continuously held in a center-enabled position, the enabling device shall permit robot motion and any other hazards controlled by the robot. The enabling device shall have the performance characteristics outlined below.

NOTE 1 – It is important to consider the ergonomic issues of sustained activation in the design and installation of the enabling device.

NOTE 2 – Additional information on enabling is contained in Annex C.

a) The enabling device may be integral with, or physically separate from (e.g. a grip-type enabling device), the pendant control and shall operate independently from any other motion control function or device.

b) Release of or compression past the center-enabled position of the device shall stop hazards (e.g. robot motion) in accordance with 5.4 and 5.5.3.

c) After compression past the center-enabled position of the enabling device, the enabling device needs to be fully released. Going from fully compressed to the center position shall not permit robot motion.
d) When two or more enabling switches are provided on a single enabling device/pendant to allow alternating left- or right-handed operation, any or all switches can be in the center-enabled position:

   1) when only one of the switches is being used and is in the center-enabled position it shall function as described in b);

   2) when the enabling device design allows both switches to be held in the center-enabled position to allow changing from left- to right-hand operation, releasing one switch shall not cause a protective stop but fully depressing either switch shall override the control of the other switches and cause a protective stop.

   Information for use shall contain a description of this functional operation and a warning that a potential hazard could exist.

   NOTE 3 – If multiple switches are being held in the center-enabled position, it cannot be distinguished if one of them is intentionally released or it is unconsciously released as a result of an accident.

e) When more than one enabling device is in operation (i.e. more than one person is in the safeguarded space with an enabling device), motion shall only be possible when each device is held in the center (enabled) position at the same time.

f) Dropping the enabling device shall not result in a failure that would allow motion to be enabled.

g) If an enabling output signal is provided, then the output shall signal a stop condition when the safety-related system supply is off and shall comply with the requirements of 5.4.

h) When the mode is changed while the enabling device is in the center-enabled position, a protective stop shall be initiated. The control system shall require that the enabling device is released and re-enabled before drive power can be applied. See IEC 60204-1 for guidance on preventing the defeat of an enabling device.

5.8.4 Pendant emergency stop function

The pendant or teaching control device shall have an emergency stop function in accordance with 5.5.2.

5.8.5 Initiating automatic operation

It shall not be possible to activate robot automatic operation using the pendant or teaching control device exclusively. There shall be a means for a separate confirmation action located outside the safeguarded space prior to activating the automatic mode.

5.8.6 Cableless or detachable teach controls

Where pendant or other teaching controls have no cables connecting to the robot control, or where they may be detached, the following shall apply.

a) A visual indication shall be provided to show that the pendant is active, e.g. at the teach pendant display.

b) Loss of communication shall result in a protective stop for all robots being controlled when in manual reduced-speed or manual high-speed modes. Restoration of communication shall not restart robot motion without a separate deliberate action.

c) 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.
d) When applicable, the maximum response times for data communication (including error correction) and for loss of communication shall be stated in the information for use.

5.8.7 Control of multiple robots
Where a pendant control has the capability to control multiple robots, the requirements in 5.9 shall apply.

5.9 Control of simultaneous motion

5.9.1 Single pendant control
One or more robot controls may be linked to a single teach pendant. When so configured, the teach pendant shall have the capability to move one or more of the robots independently or in simultaneous motion. When in the manual operational mode, all functions of the robot system shall be under the control of the one pendant.

5.9.2 Safety design requirements
All robots in a robot system, designed for simultaneous motion, shall normally be in the same operating mode, e.g. manual or automatic; and in the same state, e.g. power on or power off. Capability shall be provided to allow one or more robots to be in a servo-disconnected state for the purpose of troubleshooting or running errors or in test cases. These disconnected robots are then not included in the simultaneous motion.

For the robots to be included in simultaneous motion, each robot shall be selected before it can be moved. To be selected, all robots shall be in the same operating mode (e.g. manual reduced speed). An indication shall be provided at the point of selection (e.g. at the pendant, control cabinet, or robot) of those robot(s) that have been selected. Only selected robot(s) shall be moved.

It shall also be possible to deactivate any robot, i.e. to have it in a power off state. An indication, clearly visible from within the safeguarded space, of those robot(s) that have been activated shall be provided.

Unexpected start-up of any robots not selected shall be prevented. This function shall comply with the requirements of 5.4.

5.10 Collaborative operation requirements

5.10.1 General
Robots designed for collaborative operation shall provide a visual indication when the robot is in collaborative operation and shall comply with one or more of the requirements in 5.10.2 to 5.10.5.

5.10.2 Safety-rated monitored stop
The robot shall stop when a human is in the collaborative workspace. The stop function shall comply with 5.4 and 5.5.3. The robot may resume automatic operation when the human leaves the collaborative workspace.

Alternatively, the robot may decelerate, resulting in a category 2 stop according to IEC 60204-1. Once stopped, this standstill shall be monitored by the safety-related control system in accordance with 5.4. Fault of the safety-rated monitored stop function shall result in a category 0 stop.
NOTE – This can include a monitored category 2 stop function in accordance with IEC 60204-1 provided by an electric power drive system that corresponds to an SOS in accordance with IEC 61800-5-2.

5.10.3 Hand guiding
When provided, hand guiding equipment shall be located close to the end-effector and shall be equipped with the following:

a) an emergency stop complying with 5.5.2 and 5.8.4, and

b) an enabling device complying with 5.8.3.

The robot shall operate with a safety-rated monitored speed function active (see 5.6.4). The safety-rated monitored speed limit shall be determined by the risk assessment.

5.10.4 Speed and separation monitoring
The robot shall maintain a determined speed and separation distance from the operator. These functions may be accomplished by integral features or a combination of external inputs. Detection of the failure to maintain the determined speed or separation distance shall result in a protective stop (see 5.5.3). The speed and separation monitoring functions shall comply with 5.4.2.

The robot is simply a component in a final collaborative robot system and is not in itself sufficient for a safe collaborative operation. The collaborative operation applications are dynamic and shall be determined by the risk assessment performed during the application system design. Information for use shall contain direction for implementing speed values and separation distances. Part 2 shall be used for designing collaborative operations. Additional information will be contained in ISO/TS 15066 (currently under preparation).

The relative speeds of the operator and robot need to be considered when calculating the minimum safe separation distance. Minimum distance requirements can be found in ISO 13855.

5.10.5 Power and force limiting by inherent design or control
The power or force limiting function of the robot shall be in compliance with 5.4. If any parameter limit is exceeded, a protective stop shall be issued.

The robot is only a component in a final collaborative robot system and alone is not sufficient for a safe collaborative operation. The collaborative operation application shall be determined by the risk assessment performed during the application system design. Information for use shall include details for setting established parameter limits in the controlled robot. Part 2 shall be used for designing collaborative operations. Additional information will be contained in ISO/TS 15066 (currently under preparation).

5.11 Singularity protection
Motions defined in Cartesian space that pass near singularities can produce high axis speeds. These high speeds can be unexpected to an operator. When in the manual reduced-speed mode or hand guiding (see 5.10.3), the robot control shall do one of the following:

a) stop robot motion and provide a warning prior to the robot passing through or correcting for a singularity during coordinated motion (control wherein the axes of the robot arrive at their respective end points simultaneously, giving a smooth appearance to the motion and control wherein the motions of the axes are such that the TCP moves along a prescribed path) initiated from the teach pendant, or
b) generate an audible or visible warning signal and continue to pass through the singularity with the velocity of each link of the robot arm limited to a maximum speed of 250 mm/s [10 in/s], or

c) in the case that the singularity can be controlled without creating any hazardous motion, no additional protection is required.

5.12 Axis limiting

5.12.1 General

A means shall be provided to establish a restricted space around the robot by using limiting devices. A means for installing adjustable mechanical stops shall be provided to limit the motion of the axis with the greatest displacement motion (primary axis) of the robot. The robot shall comply with either 5.12.2 or 5.12.3, or both. This does not apply to robots with a limiting structure resulting from construction, e.g. parallel kinematic construction.

When the robot reaches an axis limit, the robot shall be stopped. Whether the robot motion can continue at the point of the axis limit or not should be stated in the information for use.

NOTE – This means can be met by the provision of engineering information and instructions for obtaining and installing external mechanical stops. Use of the optional feature of safety-rated soft axis and space limiting (see 5.12.3) also can also satisfy this requirement.

5.12.2 Mechanical and electro-mechanical axis limiting devices

Provisions for adjustable mechanical or non-mechanical limiting devices shall be provided for axes two and three (the axes with the second and third largest displacement motions).

Mechanical stops shall be capable of stopping robot motion at rated load, maximum speed conditions, and at maximum and minimum extension. Testing of mechanical hard stops shall be without any assisted stopping.

Alternative methods of limiting the range of motion may be provided only if they are designed, constructed and installed to meet the performance specified in 5.4.2.

The control circuit performance of electro-mechanical limiting devices shall comply with the requirements in 5.4. The robot control and task programs shall not change electro-mechanical limit device settings.

The adjustable devices allow the user to minimize the size of the restricted space. The degree of adjustment should be included in the required information for use as specified in 6.2.

Information for use shall include information on stopping time at maximum speed for electro-mechanical limiting devices including monitoring time and distance traveled before full stop is achieved. Additional information is given in Annex B.

NOTE 1 – Examples of non-mechanical limiting devices include devices such as stops that are positioned electrically, pneumatically or hydraulically, limit switches, light curtains, laser scanning devices and pull cords when used to limit robot travel and define the restricted space.

NOTE 2 – Mechanical stops include mechanical stops that are adjusted and then secured with fasteners.

5.12.3 Safety-rated soft axis and space limiting

Soft limits are software-defined limits to robot motion. Space limiting is used to define any geometric shape which may be used as an inclusionary or exclusionary zone, either limiting robot motion within the defined space, or preventing the robot from entering the defined space.
Safety-rated soft limits are permitted as a means to define and reduce the restricted space provided they can effect a stop of the robot at full-rated load and speed. The restricted space shall be defined at the actual expected stopping position that accounts for the stopping distance travel. The manufacturer shall state the capability in the information for use and shall disable safety-rated soft limits if this capability is not supported.

Control programs that monitor and perform soft axis and space limiting functions based on safety-rated soft limits shall comply with 5.4 and be changeable only by authorized personnel. If the safety-rated soft limit is violated, a protective stop shall be initiated. Motion during a limit violation shall be under reduced speed control as described in 5.6.3. Information on the active settings and configuration of the safety limits shall be capable of being viewed and documented with a unique identifier so that changes to the configuration can be easily identified.

A safety-rated soft limit shall be set as a stationary zone that cannot be changed without re-initialization of the safety-related sub-system and shall not be reconfigured during automatic execution of the task program. Authorization to change the safety-rated soft limit shall be protected and secure, e.g. require authorized persons to enter a password. Once set, safety-rated soft limits shall always become activated upon power up.

Information for use shall include information on stopping time at maximum speed for safety-rated soft limits including monitoring time and distance traveled before full stop is achieved. Additional information is given in Annex B.

Safety-rated zone outputs for use in dynamic restricted space applications shall comply with 5.4. The hardware configuration of the outputs shall be stated in the information for use.

NOTE 1 – Safety-rated soft axis limits can be particularly useful in controlling motion on the additional axes not fitted with limiting devices as described in 5.12.2.

NOTE 2 – Safety-rated soft space limits can be particularly useful in controlling motion in irregular shaped work areas or protecting against pinch-points created by obstructions.

NOTE 3 – An example of a unique identifier is a checksum, a unique value that is automatically generated by the robot system when the soft limit configuration is defined. Any change to the configuration will cause the generation of a new value.

5.12.4 Dynamic limiting devices

Dynamic limiting is the automatically controlled change in a robot’s restricted space during a portion of the robot system’s operation. 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 program. For this, the device and associated control systems shall be capable of stopping the robot motion under rated load and speed conditions and the associated safety-related control systems shall comply with 5.4.2, unless a risk assessment is performed and determines that another category is required.

5.13 Movement without drive power

The robot shall be designed so that the axes are capable of being moved without the use of drive power in emergency or abnormal situations. Where practicable, moving the axes shall be carried out by a single person. Controls shall be readily accessible but protected from unintended operation. Instructions for doing this shall be included in the information for use along with recommendations for training personnel on responding to emergency or abnormal situations.
The information for use shall include warnings that gravity and the release of braking devices can create additional hazards. Where practicable, warning notices shall be posted near to the activating controls.

5.14 Provisions for lifting
Instructions and provisions for lifting the robot and its associated components shall be provided and shall be adequate for handling the anticipated load.

EXAMPLE – Lifting hooks, eye bolts, threaded holes, fork pockets.

NOTE – For very small robots that can be easily handled by one person, instructions for proper safe lifting can be sufficient.

5.15 Electrical connectors
Electrical connectors that can cause a hazard if they are separated, or if they break away, shall be designed and constructed so as to prevent unintended separation.
Connectors shall be provided with a means to prevent cross-connection.

6 Verification and validation of safety requirements and protective measures

6.1 General
The robot manufacturer shall provide for the verification and validation of design and construction of robots including appropriate safeguarding devices in accordance with the principles described in Clauses 4 and 5.
The risk assessment 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, the level of risk associated with a given hazardous situation will not be the same from robot to robot. A risk assessment needs to be conducted to determine what the appropriate protective measures should be for a given robot.

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 task-based risk assessment;
— G review of specifications and information for use.

See Table F.1.

6.3 Required verification and validation
Annex F lists specific performance requirements that are identified as essential to the safety of the robot that shall be verified or validated, or both. Using appropriate methods, requirements shall be evaluated to determine if they have been adequately met by the design and construction of the robot.
NOTE 1 – The items listed in Table F.1 might not all apply to every robot. There might be instances where it will be impossible to verify and/or validate certain items.

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

NOTE 3 – It is the manufacturer’s responsibility to ensure that all applicable items are verified or validated, or both.

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

7 Information for use

7.1 General

Markings (e.g. signs, symbols) and instructional material (e.g. manuals for operation, maintenance) shall be provided by the manufacturer in accordance with ISO 12100 and IEC 60204-1.

When provided, machine warning devices (e.g. audible and visual signals) shall be in accordance with ISO 12100 and IEC 60204-1.

7.2 Instruction handbook

In addition to the requirements of 6.1, each robot shall be accompanied by an instruction handbook or appropriate media containing:

a) the business name, full address, and necessary contact information of the manufacturer and if necessary of the authorized representative or authorized supplier;

b) instruction for commissioning, programming and restarting procedure including installation requirements such as utility needs, floor loading, environmental conditions, etc.;

c) instructions for how the initial test and examination of the robot and its protective measures are to be carried out before first use and being placed into production, including functional testing of reduced speed control;

d) instructions for any test or examination necessary after change of component parts or addition of optional equipment (both hardware and software) to the robot which can affect the safety-related functions, including an emergency stop output signal as in 5.5.2 and common enabling circuit as in 5.8.3 d);

e) instructions for safe operation, setting and maintenance, including safe working practices, hazardous energy control procedures and the training required to achieve the necessary skill level of persons operating the equipment;

f) instructions on location and function of all control systems including diagrams of the interface of electrical, hydraulic, and pneumatic systems necessary for setup and installation;

NOTE – This does not include schematics of robot or other controls, components or proprietary property.

g) information on the capability of selecting high-speed control using the pendant;

h) instructions in order to inform the machine designer that restricted space shall be provided when the robot is foreseen to be used in manual high-speed;

i) information on installation of limiting devices, including number, location and degree of adjustment of mechanical limiting capability;
j) instructions on the number, location and implementation of any non-mechanical limiting devices;

k) capabilities of dynamic limiting, when included;

l) information on the actual expected stopping position that accounts for the stopping distance travel when using safety-rated soft limiting;

m) information on the number and operation of enabling devices and instructions for installation of additional devices including the data and criteria necessary to determine the safety-related control system performance;

n) information on the stopping time and distance or angle from initiation of stop signal of the three axes with the greatest displacement and motion in accordance with the metric in Annex B;

o) the safety-related control system performance of the robot safety functions as determined in 5.4;

p) the specification for any fluids or lubricants to be used in lubrication, braking, or transmission system internal to the robot, including guidance on correct selection, preparation, application and maintenance of process-unique expendables;

q) guidance on the means for the release of persons trapped in or by the machine;

r) instructions for movement of robot axes without drive power, including warnings that gravity and the release of braking devices can create additional hazards;

s) recommendations for training personnel on responding to emergency or abnormal situations;

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

u) procedures to avoid errors of fitting during maintenance of the machine;

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

w) response time of detection of loss of communication signal for cableless pendants;

x) information on unprotected hazards associated with expected use of the machine;

y) instructions and warnings that manual operation shall be performed with all persons outside the safeguarded space;

z) instructions that prior to selecting automatic mode any suspended safeguards shall be returned to full functionality;

aa) instructions for the proper storage of cableless pendants, if so configured;

bb) information on response time and loss of communication of cableless pendants, if so configured;

cc) information on the stop category of every protective stop circuit input.

Any changes or additions to the applicable information as provided by the manufacturer shall be provided by the party that makes the change or addition to the robot system.

7.3 Marking

Each robot shall be marked in a distinct, legible and durable manner with:
a) the manufacturer’s and, where appropriate, the authorized supplier’s business name and complete address;
b) the designation of type of machine (i.e. industrial robot) and model number or reference number (if any);
c) the month and year of manufacture;
d) the mass and/or weight of machine;
e) the maximum reach and load capacity;
f) supply data for electrical and, where applicable, hydraulic and pneumatic systems (e.g. minimum and maximum pneumatic pressures);
g) lifting points for transportation and installation purposes, where applicable;

Guards, protective devices and other parts that are part of the robot but not fitted shall be clearly identified for their purpose. Any other information needed for fitting shall be provided.
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

<table>
<thead>
<tr>
<th>No.</th>
<th>Type or group</th>
<th>Example of hazards</th>
<th>Origin</th>
<th>Potential consequences</th>
<th>Subclause reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>movements (normal or unexpected) of any part of the robot arm (including back)</td>
<td></td>
<td>– crushing</td>
<td>Clause 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– movements (normal or unexpected) of end-effector or any mobile part of robot cell</td>
<td></td>
<td>– shearing</td>
<td>5.2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– movements (normal or unexpected) of external axis</td>
<td></td>
<td>– cutting or severing</td>
<td>5.2.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– end-effector failure (separation)</td>
<td></td>
<td>– entanglement</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– movement of end-effector tool at servicing position</td>
<td></td>
<td>– drawing–in or trapping</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– unintended movement of machines or robot cell parts during handling operations</td>
<td></td>
<td>– impact</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– materials and products falling or ejection</td>
<td></td>
<td>– stabbing or puncture</td>
<td>5.8.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– unintended movement of jigs or gripper</td>
<td></td>
<td>– friction, abrasion</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– unintended release of tool</td>
<td></td>
<td>– high pressure fluid/gas injection or ejection</td>
<td>5.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– unintended movement of associated machine(s)</td>
<td></td>
<td></td>
<td>5.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– manipulation of products and materials, including ejection</td>
<td></td>
<td></td>
<td>5.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– movement or rotation of sharp tool on end-effector</td>
<td></td>
<td></td>
<td>5.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– movement of robot parts</td>
<td></td>
<td></td>
<td>5.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– motion of part with sharp edge held</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Type or group</td>
<td>Example of hazards</td>
<td>Subclause reference</td>
<td></td>
<td></td>
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<tr>
<td>-----</td>
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<td>---------------------</td>
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<tr>
<td></td>
<td></td>
<td>by robot</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– rotation of tool of the end-effector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– rotation or movement of associated machine or machine tool in the robot cell</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– rotational motion of any robot axes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– loose clothing, long hair</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– between robot arm and any fixed object</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– between end-effector and any fixed object (fence, beam, etc.)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– impossibility to go out robot cell (via cell door) for a trapped operator in automatic mode</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– between fixtures (falling in); between shuttles, utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– manipulation of products and materials, including ejection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– movement or rotation of sharp tool on end-effector or on external axes, part being handled, and associated equipment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– unintended motion of an end-effector (process-specific for grinding wheels, etc)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– unintended motion or activation of an end-effector or associated equipment (including external axes controlled by the robot)</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– unexpected release of potential energy from stored sources</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Electrical hazards</td>
<td>– contact with live parts or connections</td>
<td>Clause 4 5.2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– confusion of various voltages within a system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– contact with discrete components in the electrical (electronic) circuitry, i.e. capacitors</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– exposure to arc flash</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– process using high voltage or high frequency, i.e. electrostatic painting,</td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td>– electric shock</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>– burn or scald</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– inhalation of toxic fume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– eye damage by electric spark</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>– influence to pacemaker</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Type or group</td>
<td>Example of hazards</td>
<td>Subclause reference</td>
<td></td>
<td></td>
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<td>-----</td>
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<tr>
<td></td>
<td></td>
<td>Origin</td>
<td>Potential consequences</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>inductive heating</td>
<td>– burns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
|     |               | – welding applications using high voltage | – fire, explosion,
|     |               |                     | – radiation from heat
|     |               |                     | sources              |
| 3   | Thermal hazards | – hot surfaces associated with the end-effector; or associated equipment or workpiece | – inhalation of toxic
|     |               | – cold surfaces or objects | fumes                |
|     |               | – explosive atmosphere caused by the process, i.e. paint (atomized particles, powder painting), flammable solvents, grinding and milling dust | – dehydration         |
|     |               | – exposure to temperature extremes required to support the process |                     |
|     |               |                     | Clause 4             |
| 4   | Noise hazards | – loss of balance, disorientation in working area of robot cell | – effect on the hearing
<p>|     |               | – inability of two persons assigned to a task to coordinate their actions through normal conversation | and balance, awareness|
|     |               | – ambient noise level so high or distracting as to prevent hearing or understanding audible danger warning signals | – effect on speech communication, perception of acoustic signals |
|     |               | – Long term exposure to elevated noise levels | – loss of hearing |
|     |               |                     | Noise is excluded from the scope of this part of the standard |
| 5   | Vibration hazards | – loosening of connections, fasteners, components resulting in unexpected stopping or expulsion of parts | – fatigue            |
|     |               |                     | – neurological damage |
|     |               |                     | – vascular disorder   |
| 6   | Radiation hazards | – EMF interference with proper operation of the robot system | – burns            |
|     |               | – exposed to process-related radiation, i.e. arc welding, laser | – illness           |
|     |               |                     | Clause 4             |</p>
<table>
<thead>
<tr>
<th>No.</th>
<th>Type or group</th>
<th>Example of hazards</th>
<th>Subclause reference</th>
</tr>
</thead>
</table>
| 7   | Material/substance hazards     | – servicing, lubrication and changing components that are covered in fluids; cooling and process fluids  
– unexpected failures to the mechanical and electrical components of the robot system and the protection systems  
– poisoning  
– inhalation of corrosive fumes and dust  
– burns | Clause 4 |
| 8   | Ergonomic hazards              | – poorly designed teach pendant, human-machine interface (HMI) touch screen or operator panel too far or high  
– poorly designed loading/unloading post; long distance between components box location and loading/unloading area.  
– poorly designed enabling devices  
– inappropriate location of controls  
– inadvertent operation of controls  
– hard to reach, exposure to additional hazards due to inappropriate location of operating controls  
– hard to reach, exposure to additional hazards due to inappropriate location of components that require access for anticipated maintenance actions (troubleshooting, repair, adjustment)  
– recognition of hazards and hazardous situations is obscured because of poor area lighting  
– components in enclosures that block existing lighting  
– HMI units placed too high or low for convenient viewing | – fatigue  
– Impact  
– falling  
– loss of awareness  
– stress  
– consequence of human error | Clause 4  
5.3.3  
5.3.4  
5.14 |
<table>
<thead>
<tr>
<th>No.</th>
<th>Type or group</th>
<th>Example of hazards</th>
<th>Origin</th>
<th>Potential consequences</th>
<th>Subclause reference</th>
</tr>
</thead>
</table>
| 9   | Hazards associated with environment in which the machine is used | – environment-induced design concerns; i.e. installations in earthquake zones  
– misidentification of real problem and compound problem by making incorrect or unnecessary actions  
– one action or failure increases severity of harm; i.e. trying to avoid a sharp edge you come in contact with a hot surface instead | – force majeure  
– induced failures  
– unsafe reflex action | Clause 4 |
| 10  | Combinations of hazards | – unexpected movements of robot or end-effectors or associated machine  
– unpredictable behavior of machine controls due to electromagnetic interference or surges in energy source  
– robot system is directed to start by one person, but this action is not expected by another person  
– misinterpretation of collaborating robots or simultaneous motion  
– issued stop command stops the robot in an incomplete cycle  
– robot system speed can be adjustable resulting in various tasks being done at a variety of speeds  
– malfunctions of the control with consequent release of holding devices on the load table or at the end-effectors, to move under residual forces (inertia, gravity, spring/energy storage means) unexpectedly  
– unexpected movements of robot, end-effectors, auxiliary axis or associated equipment(s)  
– failure of a safeguarding device to function as expected  
– failure of an associated machine to function as expected  
– loose unsecured hoses and | – restoration of energy supply after an interruption  
– external influences on the power source  
– unanticipated start | Clause 4  
5.2.2  
5.2.3  
5.2.4  
5.2.5  
5.2.6  
5.2.7  
5.3.2  
5.3.3  
5.3.5  
5.4  
5.5  
5.7  
5.8  
5.9  
5.10 |
<table>
<thead>
<tr>
<th>No.</th>
<th>Type or group</th>
<th>Example of hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>components separate or whip about</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– components improperly installed creating unexpected motion/hazard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– high-speed rotational parts breaking or disengaging from part retention equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– overload of robot arm or associated equipment resulting in breaking or buckling of mechanical components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– contacted by process-related expulsion (i.e. spot welding)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– part retention device fails</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– unrestrained robot or associated machine part (maintained in position by gravity), falls or overturns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– handling mishaps during commissioning or decommissioning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– parts can fall off if not properly attached or installed improperly</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– insufficient lighting in operator zone or robot cell</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– obstacles on cell floor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– sliding floor</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– poor location of utilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– specific application hazards</td>
</tr>
</tbody>
</table>
Annex B
(normative)

Stopping time and distance metric

This is a metric to be used in presenting information for use required in 7.2 n) to ensure standardized data from all the manufacturers. This information is needed to be able to calculate the safe distance in applying safeguarding devices. To make this information useful and practical, values need to be provided for varying steps up to maximum conditions to be able to predict actual running conditions.

Testing shall comply with the performance testing conditions described in ISO 9283:1998, clause 6, as applicable. This includes the following areas:

a) the manipulator shall be warmed up prior to testing;
b) the robot shall be mounted per manufacturer’s requirements;
c) environmental requirements of power, temperature, etc., shall be met;
d) a proper test procedure shall be established;
e) the method of measurement shall be described.

The manufacturer shall forecast the degradation of stopping performance due to normal use and recommend when the robot should be refurbished.

The data requirement is as follows:
— the stopping time shall be determined from the initiation of a stop signal to when all manipulator motion ceases;
— if validated simulation values are available, then these values may be obtained using simulation.

NOTE – This data varies depending on additive delays due to control system feature and configuration, i.e. cableless pendants.

The stopping distance shall be determined as the total distance traveled after the initiation of a stop signal. Distance shall be provided in linear or angular units as appropriate.

For stop category 0 in accordance with IEC 60204-1, the measurement procedures under maximum conditions (i.e. maximum speed, maximum load and maximum displacement) are sufficient. If the robot has a stop category 1, additional data or correction factors shall be provided. For stop category 1, the stopping time and distance values depending on the speed, load and extension shall be stated for 33%, 66% and 100% of maximum, unless these values based on the design can be derived from the maximum values. In this case, 100% maximum values need to be provided with formula for obtaining intermediate values.

The values used for speed, load, and extension shall represent maximum values. A description of how the integrator can perform its own measurement of stopping distances and time in a real cell with a real robot and with real tool and loads shall be provided by the manufacturer.

Data shall be provided for the three axis of greatest displacement. An example of possible presentation is shown in Figure B.1.
Key

X  speed, in mm/s
Y  stopping time, in s
a  load, in %.

NOTE  Axis 1 stopping time versus speed and payload, category 1 stop.

Figure B.1 — Example chart for stopping time
Annex C
(informative)

Functional characteristics of three-position enabling device

Key
1 position 1
2 position 2
3 position 3
4 ON
5 OFF
6 press
7 release
8 grip lightly
9 grip tightly

a When the operator part is pressed fully to position 3, the contact is opened again.
b When the operator part returns from position 3 to position 1, the contact shall remain opened without functionally passing position 2.

Figure C.1 — Functional characteristics of three-position enabling device
Annex D
(informative)

Optional features

D.1 General
The requirements contained in Clauses 4 to 7 are the minimum for ensuring the safety of a robot. Many additional features can be added to a robot to enhance safety, but are not necessarily required safety items in the traditional sense, or do not require specific safety-related performance criteria in accordance with ISO 13849-1 or similar standards.

The optional features described in this annex are listed in no specific order of importance or desirability. Robots equipped with these features will have greater flexibility in use and re-use, and greater potential safety-related performance.

NOTE 1 – The features in Clauses D.2, D.3 and D.4 are very important for providing installation flexibility, if ever the robot is re-deployed to an application other than the one for which it was originally designed and configured.

NOTE 2 – The features in Clauses D.5, D.6 and D.7, while not “safety-related” features, provide enhanced safety in robot systems.

D.2 Emergency stop output functions
a) Capability for emergency stop output functions as mentioned in 5.5.1. This provides for a common emergency stop (makes the robot emergency stop also be a system emergency stop).

b) Capability for emergency stop device to be functional without robot controller power in accordance with 5.5.2.

D.3 Enabling device features
a) Capability of enabling device output functions to interconnect enabling device(s) into a common circuit controlling multiple robots and equipment.

b) Capability to connect multiple additional enabling devices to one enabling circuit.

D.4 Mode selection
a) Capability to provide information as to the state of the mode selection to the safety-related control system.

b) Output shall comply with 5.7.1.

D.5 Anti-collision sensing
To be most effective in preventing harm to personnel, the robot should stop and create an awareness signal when a collision is sensed and not move to another position without operator intervention.

D.6 Maintaining path accuracy across all speeds
This would limit the perceived need to monitor a robot movement from a position of danger.
D.7 Safety-rated soft axis and space limiting
As described in 5.12.3, these limits would allow creation of exclusion space and inclusion space programming.

D.8 Stopping performance measurement
When supplied, a robot stopping performance measurement and monitoring should provide one or more of the following features:
   a) selection of mode to measure and record the stopping performance at the next demand;
   b) select the input event to define the start of the stopping event (e.g. safeguarding device input, protective stop signal);
   c) set limits for warning when these limits are exceeded.
Annex E  
(informative)

Labeling

Table E.1 offers examples of graphical symbols which can be used to denote the operational modes identified in 5.7. Additional descriptive text may be included with the graphical symbols in order to be as explicit as possible in providing information on the mode selection and expected performance.

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Mode</th>
<th>Graphical symbol</th>
<th>ISO 7000 reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7.2</td>
<td>Automatic</td>
<td></td>
<td>0017</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Manual reduced speed</td>
<td></td>
<td>0096</td>
</tr>
<tr>
<td>[5.7.4]</td>
<td>Manual high-speed</td>
<td></td>
<td>Pending²</td>
</tr>
</tbody>
</table>

² ISO approval of this symbol is pending. The symbol was published in the 2006 edition of ISO 10218-1 and will be added to the current ISO standard.
Annex F
(normative)

Means of verification of the safety requirements and measures

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

See 6.3 for notes on using this table.

**Table F.1 – Means of verification of the safety requirements and measures**

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Applicable safety requirements and/or measures</th>
<th>Verification and/or validation method (see 6.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>5.2</td>
<td><strong>General requirements</strong></td>
<td></td>
</tr>
<tr>
<td>5.2.1</td>
<td>Fixed or moveable guards are installed to prevent exposure to hazards such as shafts, gears, drive belts, or linkages</td>
<td>X</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Fixed guards intended to be removed for routine service have captive hardware</td>
<td>X</td>
</tr>
<tr>
<td>5.2.1</td>
<td>Movable guards are interlocked with the hazardous movements in such a way that the hazardous movements come to a stop before the hazards can be reached</td>
<td>X</td>
</tr>
<tr>
<td>5.2.1</td>
<td>The safety-related control system performance of an interlocking system conforms to 5.4.</td>
<td></td>
</tr>
<tr>
<td>5.2.2</td>
<td>Loss of, or unstable power does not result in a hazard</td>
<td>X</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Re-initiation of power does not initiate motion</td>
<td>X</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Loss of change of electrical, hydraulic, pneumatic or vacuum power does not result in a hazard</td>
<td>X</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Additional protective measures are taken to protect against hazards not protected by design</td>
<td>X</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Unprotected hazards of the expected use are identified in the information for use</td>
<td></td>
</tr>
<tr>
<td>5.2.3</td>
<td>Robot components are designed, constructed, secured, or contained so that hazards caused by breaking or loosening, or releasing stored energy are minimized</td>
<td>X</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Capability to lock or secure in the de-energized position isolated hazardous energy to the robot</td>
<td>X</td>
</tr>
<tr>
<td>5.2.5</td>
<td>Means provided for the controlled release of stored hazardous energy</td>
<td>X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Applicable safety requirements and/or measures</td>
<td>Verification and/or validation method (see 6.2)</td>
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</tr>
<tr>
<td>5.2.5</td>
<td>A label is affixed to identify the stored energy hazard</td>
<td>X</td>
</tr>
<tr>
<td>5.2.6</td>
<td>Expected effects of electromagnetic interference (EMI), radio frequency interference (RFI) and electrostatic</td>
<td>X     X     X</td>
</tr>
<tr>
<td></td>
<td>discharge (ESD) do not initiate hazardous motion</td>
<td></td>
</tr>
<tr>
<td>5.2.7</td>
<td>The robot electrical equipment is designed and constructed in accordance with the relevant requirements of</td>
<td>X     X     X     X</td>
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<tr>
<td></td>
<td>IEC 60204-1</td>
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<tr>
<td>5.3</td>
<td><strong>Actuating controls</strong></td>
<td></td>
</tr>
<tr>
<td>5.3.2</td>
<td>Actuating controls are constructed or located so as to prevent unintended operation</td>
<td>X     X</td>
</tr>
<tr>
<td>5.3.3</td>
<td>Status of the actuating controls is clearly indicated</td>
<td>X     X     X</td>
</tr>
<tr>
<td>5.3.3</td>
<td>If an indicator light is used, it is suitable for its installed location and its color meets the requirements</td>
<td>X     X</td>
</tr>
<tr>
<td></td>
<td>of IEC 60204-1</td>
<td></td>
</tr>
<tr>
<td>5.3.4</td>
<td>Actuating controls are labeled to clearly indicate their function</td>
<td>X</td>
</tr>
<tr>
<td>5.3.5</td>
<td>While the robot is under local pendant control or other teaching device control, initiation of robot motion</td>
<td>X     X     X</td>
</tr>
<tr>
<td></td>
<td>or change of local control selection from any other source is prevented</td>
<td></td>
</tr>
<tr>
<td>5.4</td>
<td><strong>Safety-related control system performance (hardware/software)</strong></td>
<td></td>
</tr>
<tr>
<td>5.4.1</td>
<td>The safety-related control system performance that the equipment meets is clearly stated in the information for use</td>
<td>X     X</td>
</tr>
<tr>
<td>5.4.1</td>
<td>The data and criteria necessary to determine the safety-related control system performance is included in the information for use</td>
<td>X</td>
</tr>
<tr>
<td>5.4.2</td>
<td>Safety-related parts of control systems comply with PL=d, with structure category 3, or with SIL 2 with a</td>
<td>X     X</td>
</tr>
<tr>
<td></td>
<td>hardware fault tolerance of 1, with a proof test interval of not less than 20 years</td>
<td></td>
</tr>
<tr>
<td>5.4.2</td>
<td>Single faults are detected at or before the next demand upon the safety function</td>
<td>X     X     X</td>
</tr>
<tr>
<td>5.4.2</td>
<td>When single faults occur, the safety function is always performed and a safe state is maintained until the</td>
<td>X     X     X</td>
</tr>
<tr>
<td></td>
<td>detected fault is corrected</td>
<td></td>
</tr>
<tr>
<td>5.4.2</td>
<td>All reasonably foreseeable faults are detected</td>
<td>X     X     X     X</td>
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</table>
### Subclause Applicable safety requirements and/or measures

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<td>A</td>
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#### 5.5 Robot stopping functions

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<tr>
<td>5.5.1</td>
<td>Every robot has a protective stop function and an independent emergency stop function</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Stop functions have provisions for the connection of external protective devices</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Robot has one or more emergency stop circuits</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Each control station has a manual initiated emergency stop function</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Emergency stop function can only be reset by manual action which enables a restart but does not cause the restart</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Selection of category 0 or 1 determined by risk assessment</td>
</tr>
<tr>
<td>5.5.2</td>
<td>When the feature of an emergency stop output signal is provided, the output continues to function when the robot power is removed, or an emergency stop signal is generated if the output does not continue to function.</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Emergency stop device complies with IEC 60204-1 and ISO 13850</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Robot has one or more protective stop functions with external connection capability</td>
</tr>
<tr>
<td>5.5.3</td>
<td>The protective stop function performance complies with the requirements of 5.4</td>
</tr>
<tr>
<td>5.5.3</td>
<td>This stop function causes a stop of all robot motion, removes or controls power to the robot drive actuators, and allows for the control of any other hazard controlled by the robot system</td>
</tr>
<tr>
<td>5.5.3</td>
<td>At least one protective stop function is category 0 or 1</td>
</tr>
<tr>
<td>5.5.3</td>
<td>When an additional protective stop function using stop category 2 is provided, any unintended motion of the robot in the safe stand-still condition or detected failure of the protective stop function results in stop category 0 in accordance with IEC 60204-1</td>
</tr>
<tr>
<td>5.5.3</td>
<td>If provided, safe stand-still and monitoring function performance complies with 5.4</td>
</tr>
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<tr>
<td>5.5.3</td>
<td>Information for use includes the description of the stop category of every protective stop circuit input</td>
</tr>
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<td>5.6</td>
<td><strong>Reduced speed control</strong></td>
</tr>
<tr>
<td>5.6.1</td>
<td>Speed of mounting flange and a selected TCP is controllable at selectable speeds</td>
</tr>
<tr>
<td>5.6.1</td>
<td>An off-set feature is provided to allow the TCP speed to be controlled</td>
</tr>
<tr>
<td>5.6.2</td>
<td>When operating under reduced speed control, the speed of the TCP does not exceed 250mm/s [10 in/s]</td>
</tr>
<tr>
<td>5.6.3.1</td>
<td>When provided, safety-rated reduced speed control complies with 5.4.2 to ensure reduced speed limit is not exceeded in a fault condition</td>
</tr>
<tr>
<td>5.6.4</td>
<td>When provided, the speed of the TCP is monitored in accordance with 5.4.2</td>
</tr>
<tr>
<td>5.6.4</td>
<td>If the speed exceeds the limit selected, a protective stop is issued</td>
</tr>
<tr>
<td>5.7</td>
<td><strong>Operational modes</strong></td>
</tr>
<tr>
<td>5.7.1</td>
<td>Operational modes are selectable with a selector that can be locked in each position</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Each selector is clearly identifiable and allows only one mode be selected at one time</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Alternative selection means provide unambiguous indication of selected mode and by themselves do not initiate robot motion or hazards</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Optional outputs to indicate selected mode for safety-related purposes comply with 5.4</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Safeguarding measures are functioning when robot task program is executed in automatic mode</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Automatic operation is prevented if any stop condition is detected</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Switching from automatic mode results in a stop</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Manual reduced-speed mode meets the requirements of 5.3.4 and 5.6</td>
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<tr>
<td>5.7.3</td>
<td>Manual reduced-speed mode allows the robot to be operated by human intervention</td>
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<tr>
<td>5.7.3</td>
<td>Manual control from inside the safeguarded space is at reduced speed with a hold-to-run control and an enabling device</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Information for use contains instructions that wherever possible, manual mode operations are performed with all persons outside the safeguarded space</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Information for use contains instructions that suspended safeguards shall be returned to full functionality prior to selecting automatic mode</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Selection requires a deliberate action and an additional confirming action</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Initial speed upon selection does not exceed 250mm/s [10 in/s]</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Pendant provided conforming to 5.8 with a hold-to-run function in addition to the enabling device</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Means provided to incrementally adjust the speed from the initial value to the full programmed value in multiple steps</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Pendant indicates adjusted speed</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Speed of the robot is limited to the initial speed limit when the enabling device is re-initiated by placing the switch in the center-enabled position after being either released or fully compressed</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Optionally a separate deliberate action is required to return to the higher speed that was selected before the enabling device switch was released or compressed</td>
</tr>
<tr>
<td>5.7.4</td>
<td>The option to resume the higher speed using the separate action becomes inoperative after no more than five minutes after the release of the enabling device</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Information for use contains appropriate instructions and warning that, wherever possible, the manual mode of operation is to be performed with all persons outside the safeguarded space</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Information for use instructs that any suspended safeguards are to be returned to their full functionality prior to selecting automatic mode</td>
</tr>
<tr>
<td>5.8</td>
<td><strong>Pendant controls</strong></td>
</tr>
<tr>
<td>5.8.2</td>
<td>Motion of the robot initiated from the pendant or teaching control device is under reduced speed control as described in 5.6</td>
</tr>
<tr>
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</tr>
<tr>
<td>5.8.2</td>
<td>When the controls contain provisions for selecting manual high-speed, the robot meets requirements of 5.7.4</td>
</tr>
<tr>
<td>5.8.3</td>
<td>Pendant has a three-position enabling device</td>
</tr>
<tr>
<td>5.8.3</td>
<td>When continuously held in a center-enabled position, the enabling device permits robot motion and any other hazards controlled by the robot</td>
</tr>
<tr>
<td>5.8.3 a)</td>
<td>Enabling device operates independently from all other motion control functions/devices</td>
</tr>
<tr>
<td>5.8.3 b)</td>
<td>Release of enabling device/compression past center position stops hazards</td>
</tr>
<tr>
<td>5.8.3 c)</td>
<td>Going from fully compressed to the center position does not permit robot motion</td>
</tr>
<tr>
<td>5.8.3 d)</td>
<td>Multiple switches on an enabling device: when only one switch is in center position, release of switch/compression past center position stops hazards</td>
</tr>
<tr>
<td>5.8.3 d)</td>
<td>Multiple switches on an enabling device: compression of any switch past center position causes a protective stop</td>
</tr>
<tr>
<td>5.8.3 d)</td>
<td>Multiple switches on an enabling device: when more than one switch is in the center position, releasing additional switches does not cause a protective stop</td>
</tr>
<tr>
<td>5.8.3 d)</td>
<td>Information for use contains a description of the dual enable switch functionality and a warning that potential hazards exist</td>
</tr>
<tr>
<td>5.8.3 e)</td>
<td>Multiple enabling devices: motion not possible unless all enabling devices are in the center position</td>
</tr>
<tr>
<td>5.8.3 f)</td>
<td>Dropping an enabling devices does not result in a failure that allows motion to be enabled</td>
</tr>
<tr>
<td>5.8.3 g)</td>
<td>Enabling output signal signals a stop condition when safety-related power supply is off</td>
</tr>
<tr>
<td>5.8.3 g)</td>
<td>Enabling output signal complies with 5.4</td>
</tr>
<tr>
<td>5.8.3 h)</td>
<td>Protective stop initiated when mode changes while enabling device is in center position</td>
</tr>
<tr>
<td>5.8.3 h)</td>
<td>After mode change with enabling device in center position, enabling device needs to be released and re-enabled before drive power can be applied</td>
</tr>
<tr>
<td>5.8.4</td>
<td>Pendant has a stop function according to 5.5.2</td>
</tr>
<tr>
<td>Subclause</td>
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<tr>
<td>5.8.4</td>
<td>Pendant emergency stop function uses a device whose presentation is that of an emergency stop device, in accordance with ISO 13850</td>
</tr>
<tr>
<td>5.8.5</td>
<td>Automatic operation cannot be activated exclusively from the pendant</td>
</tr>
<tr>
<td>5.8.5</td>
<td>A means for separate confirmation action from outside the safeguarded space is provided</td>
</tr>
<tr>
<td>5.8.6</td>
<td>Visual indication has been provided, identifying if the pendant is active</td>
</tr>
<tr>
<td>5.8.6</td>
<td>Loss of communication to the pendant results in a protective stop</td>
</tr>
<tr>
<td>5.8.6</td>
<td>Restoration of communication does not restart robot motion without a separate deliberate action</td>
</tr>
<tr>
<td>5.8.6</td>
<td>Confusion between active and inactive emergency stop devices is avoided by providing appropriate storage or design</td>
</tr>
<tr>
<td>5.8.6</td>
<td>Information for use contains a description of the storage or design</td>
</tr>
<tr>
<td>5.8.6</td>
<td>The maximum response time for data communication and for loss of communication is included in the information for use</td>
</tr>
<tr>
<td>5.8.7</td>
<td>The capability to control multiple robots meets the requirements in 5.9</td>
</tr>
<tr>
<td>5.9</td>
<td><strong>Control of simultaneous motion</strong></td>
</tr>
<tr>
<td>5.9.1</td>
<td>The teach pendant has the capability to move one or more of the robots independently or in simultaneous motion</td>
</tr>
<tr>
<td>5.9.1</td>
<td>When in the manual operational mode, all functions of the robot system are under the control of the one pendant</td>
</tr>
<tr>
<td>5.9.2</td>
<td>Capability is provided to allow one or more robots to be in a servo-disconnected state</td>
</tr>
<tr>
<td>5.9.2</td>
<td>All robots in a robot system selected for simultaneous motion are in the same operating mode and in the same state prior to motion</td>
</tr>
<tr>
<td>5.9.2</td>
<td>Each robot must be selected before it can be moved and an indication of those robot(s) that have been selected has been provided at the point of selection</td>
</tr>
<tr>
<td>Subclause</td>
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<td></td>
<td><strong>Verification and/or validation method (see 6.2)</strong></td>
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<tr>
<td><strong>5.9.2</strong></td>
<td>An indication, clearly visible from within the safeguarded space, has been provided indicating those robot(s) that have been activated</td>
</tr>
<tr>
<td><strong>5.9.2</strong></td>
<td>Unexpected start-up of any robots not selected has been prevented; this function complies with the requirements of 5.4</td>
</tr>
<tr>
<td><strong>5.10</strong></td>
<td><strong>Collaborative operation requirements</strong></td>
</tr>
<tr>
<td><strong>5.10.1</strong></td>
<td>Robots designed for collaborative operation provide a visual indication when the robot is in collaborative operation</td>
</tr>
<tr>
<td><strong>5.10.1</strong></td>
<td>Robots comply with one or more of the requirements in 5.10.2 to 5.10.5</td>
</tr>
<tr>
<td><strong>5.10.2</strong></td>
<td>The robot stops when a human is in the collaborative workspace</td>
</tr>
<tr>
<td><strong>5.10.2</strong></td>
<td>The stop function complies with 5.4 and 5.5.3.</td>
</tr>
<tr>
<td><strong>5.10.2</strong></td>
<td>If utilizing a category 2 stop, the standstill is monitored by the safety related control system in accordance with clause 5.4</td>
</tr>
<tr>
<td><strong>5.10.2</strong></td>
<td>Fault of the safety-rated monitored stop function results in a category 0 stop</td>
</tr>
<tr>
<td><strong>5.10.3</strong></td>
<td>Hand guiding equipment is located close to the end-effector</td>
</tr>
<tr>
<td><strong>5.10.3</strong></td>
<td>Hand guiding equipment has an emergency stop complying with 5.5.2 and 5.8.4</td>
</tr>
<tr>
<td><strong>5.10.3</strong></td>
<td>Hand guiding equipment has an enabling device complying with 5.8.3</td>
</tr>
<tr>
<td><strong>5.10.3</strong></td>
<td>The robot operates with a safety-rated monitored speed function in effect, with a speed limit determined by the risk assessment</td>
</tr>
<tr>
<td><strong>5.10.3</strong></td>
<td>The speed monitoring function complies with 5.4</td>
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<tr>
<td><strong>5.10.3</strong></td>
<td>If the monitored speed exceeds the determined speed limit, a protective stop is issued</td>
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<tr>
<td><strong>5.10.4</strong></td>
<td>The robot is able to maintain a determined speed and separation distance</td>
</tr>
<tr>
<td><strong>5.10.4</strong></td>
<td>The speed and separation monitoring functions comply with 5.4.2</td>
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<tr>
<td><strong>5.10.4</strong></td>
<td>Failure to maintain the determined speed or separation distance results in a protective stop</td>
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<tr>
<td><strong>5.10.4</strong></td>
<td>The collaborative operation application has been determined by the risk assessment</td>
</tr>
<tr>
<td><strong>5.10.4</strong></td>
<td>Information for use contains direction for implementing speed values and separation distances</td>
</tr>
<tr>
<td><strong>5.10.4</strong></td>
<td>Part 2 has been used for designing collaborative operations</td>
</tr>
<tr>
<td><strong>5.10.5</strong></td>
<td>The robot limits dynamic power output, static force, and speed or energy in compliance with 5.4</td>
</tr>
<tr>
<td><strong>5.10.5</strong></td>
<td>If any parameter limit is exceeded, a protective stop is issued</td>
</tr>
<tr>
<td><strong>5.10.5</strong></td>
<td>The collaborative operation application is determined by the risk assessment performed during the application system design</td>
</tr>
<tr>
<td><strong>5.10.5</strong></td>
<td>Information for use includes details for setting parameter limits to the robot controller</td>
</tr>
<tr>
<td><strong>5.11</strong></td>
<td><strong>Singularity protection</strong></td>
</tr>
<tr>
<td><strong>5.11</strong></td>
<td>The robot control stops robot motion and provides a warning prior to the robot passing through or correcting for a singularity during coordinated motion initiated from the teach pendant</td>
</tr>
<tr>
<td><strong>5.11</strong></td>
<td>The robot control generates an audible or visible warning signal and continues to pass through the singularity with the velocity of each link of the robot arm limited to a maximum speed of 250 mm/s [10 in/s]</td>
</tr>
<tr>
<td><strong>5.11</strong></td>
<td>In the case that singularity can be controlled without creating any hazardous motion, no additional protection is required</td>
</tr>
<tr>
<td><strong>5.12</strong></td>
<td><strong>Axis limiting</strong></td>
</tr>
<tr>
<td><strong>5.12.1</strong></td>
<td>A means for installing adjustable mechanical stops is provided to limit the motion of the primary axis</td>
</tr>
<tr>
<td><strong>5.12.1</strong></td>
<td>The robot complies with either 5.12.2 or 5.12.3 or both (unless excepted due to a limiting structure resulting from construction)</td>
</tr>
<tr>
<td><strong>5.12.1</strong></td>
<td>When the robot reaches an axis limit, the robot is stopped</td>
</tr>
<tr>
<td><strong>5.12.2</strong></td>
<td>Provisions for adjustable mechanical or non-mechanical limiting devices are provided for axes two and three</td>
</tr>
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</tr>
<tr>
<td>5.12.2</td>
<td>Mechanical stops are capable of stopping robot motion at rated load, maximum speed conditions, and at maximum and minimum extension</td>
</tr>
<tr>
<td>5.12.2</td>
<td>Testing of mechanical hard stops was done without assisted stopping</td>
</tr>
<tr>
<td>5.12.2</td>
<td>The control circuit performance of electro-mechanical limiting devices complies with the requirements in 5.4</td>
</tr>
<tr>
<td>5.12.2</td>
<td>The robot control and task programs do not change electro-mechanical limit device settings</td>
</tr>
<tr>
<td>5.12.2</td>
<td>Information for use includes information on stopping time at maximum speed for electro-mechanical limiting devices including monitoring time and distance traveled before full stop is achieved</td>
</tr>
<tr>
<td>5.12.3</td>
<td>When using safety-rated soft limits, the restricted space is defined at the actual expected stopping position that accounts for the stopping distance travel</td>
</tr>
<tr>
<td>5.12.3</td>
<td>The capability for safety-rated soft limits, if supported, is stated in information for use</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Control programs using safety-rated soft limiting comply with 5.4</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Control programs for the safety-rated soft limiting are changeable only by authorized personnel</td>
</tr>
<tr>
<td>5.12.3</td>
<td>If the safety-rated soft limit is violated, a protective stop is initiated</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Motion during the recovery of a safety-rated soft limit violation is under reduced speed control</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Information on the active settings and configuration of the safety limits is capable of being viewed and is documented with a unique identifier so that changes to the configuration can be easily identified</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Information for use includes information on stopping time at maximum speed for safety-rated soft limits including monitoring time and distance traveled before full stop is achieved</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Safety-rated zone outputs for use in dynamic restricted space applications comply with 5.4</td>
</tr>
<tr>
<td>5.12.3</td>
<td>The hardware configuration of the outputs is stated in the information for use</td>
</tr>
<tr>
<td>Subclause</td>
<td>Applicable safety requirements and/or measures</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>5.12.3</td>
<td>A safety-rated soft limit cannot be changed without re-initialization of the safety-related sub-system and cannot be reconfigured during automatic execution of the task program</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Authorization to change the safety-rated soft limit is protected and secure</td>
</tr>
<tr>
<td>5.12.3</td>
<td>Safety-rated soft limits, if used, always become activated upon power up</td>
</tr>
<tr>
<td>5.12.4</td>
<td>Dynamic limiting devices and associated control systems are capable of stopping the robot motion under rated load and speed conditions and the associated safety-related control systems comply with 5.4.2, unless a risk assessment has determined that another category is required</td>
</tr>
<tr>
<td>5.13</td>
<td><strong>Movement without drive power</strong></td>
</tr>
<tr>
<td>5.13</td>
<td>The robot is designed so that the axes are capable of being moved by a single person (if practicable) without the use of drive power in emergency or abnormal situations</td>
</tr>
<tr>
<td>5.13</td>
<td>Controls are readily accessible but protected from unintended operation</td>
</tr>
<tr>
<td>5.13</td>
<td>Instructions for doing this are included in the information for use along with recommendations for training personnel on responding to emergency or abnormal situations</td>
</tr>
<tr>
<td>5.13</td>
<td>Information for use includes warnings that gravity and the release of braking devices can create additional hazards</td>
</tr>
<tr>
<td>5.13</td>
<td>Where practicable, warning notices are posted near to the activating controls</td>
</tr>
<tr>
<td>5.14</td>
<td><strong>Provisions for lifting</strong></td>
</tr>
<tr>
<td>5.14</td>
<td>Instructions and provisions for lifting the robot and its associated components are provided and are adequate for handling the anticipated load</td>
</tr>
<tr>
<td>5.15</td>
<td><strong>Electrical connectors</strong></td>
</tr>
<tr>
<td>5.15</td>
<td>Electrical connectors that can cause a hazard if they are separated, or if they break away, are designed and constructed so as to prevent unintended separation</td>
</tr>
<tr>
<td>5.15</td>
<td>Connectors are provided with a means to prevent cross-connection</td>
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</tbody>
</table>

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Bibliography

[2] ISO 7000, Graphical symbols for use on equipment — Index and synopsis
[4] ISO 9409 (all parts), Manipulating industrial robots — Mechanical interfaces
[5] ISO 9946, Manipulating industrial robots — Presentation of characteristics
[7] ISO 13855, Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of the human body
[8] ISO 14118, Safety of machinery — Prevention of unexpected start-up
[10] ISO 14120, Safety of machinery — Guards — General requirements for the design and construction of fixed and movable guards
[12] IEC 61000-6-2, Electromagnetic compatibility (EMC) — Part 6-2: Generic standards — Immunity for industrial environments

\(^3\) Under preparation
Part 2 – [Industrial] robot systems and integration
Foreword [ISO 10218 Part 2]

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: [Industrial] Robots

Part 2: [Industrial] Robot systems and integration
Introduction [Part 2]

This part of [the standard] 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 [the standard], 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 [the standard]. 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 [the standard] 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 [Part 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 [the standard] may be assigned to one of the stakeholders; but overlapping responsibilities can involve multiple stakeholders in the same requirements. While using this part of [the standard], 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 [the standard] is complementary and in addition to [Part 1], which covers the robot only. This part of [the standard] 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 [Part 1] for safety-related control system performance, robot stopping function, enabling device, program verification, cableless pendant criteria, collaborating robot criteria and updated design for safety.

This part of [the standard] and [Part 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 [the standard], the words “robot” and “robot system” refer to “industrial robot” and “industrial robot system” as defined in [Part 1].
Figure 1 describes the relationship of the scope of machinery standards used in a robot system. The robot alone is covered by [Part 1], the system and cell is covered by this part of [the standard]. 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](image)
Part 2: Industrial robot systems and integration

1 Scope
This part [of the standard] specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in [Part 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.

Part 2 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 [the standard]. This part [of the standard] also specifies requirements for the industrial robot system as part of an integrated manufacturing system. This part [of the standard] 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 between two levels
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

3 Terms and definitions
For the purposes of this document, the terms and definitions given in [Part 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 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

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4 NFPA 79, Electrical Standard for Industrial Machinery, contains the identical requirements as IEC 60204-1 for the purposes of this standard
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 program

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 [protective measures] shall be suitable for the work being done and permit, where necessary, teaching, setting, maintenance, program 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 modeling 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 Part 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 [the standard]. 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 [the standard] (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 [the standard] 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 alternate 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 [the standard], 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 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 [Part 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 should have control performance designed in accordance with 5.2.2 or 5.2.3, as determined appropriate 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 [Part 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 center 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 [Part 1] (see Annex D in this part 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 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 – 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 [Part 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 Part 1 and, when applicable, requirements for dynamic limiting devices in Part 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 Part 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 [Part 1, Annex B] 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 Part 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 [Part 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 program. 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 [20 inches]. 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 2000 mm [16 in and 79 in] 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 [20 in] 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 are 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 is 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.

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5 Plain to the understanding especially because of clarity and precision of presentation
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 fulfill 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 lock out 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 shall be 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 [Part 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 [10 in/s]. It should be possible to select speeds lower than 250 mm/s [10 in/s]. The results of a risk assessment shall determine if a maximum reduced speed lower than 250 mm/s [10 in/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 [Part 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 program 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 [10 in/s]. The robot system shall conform with the requirements of automatic operation mode of [Part 1] and be provided with a pendant conforming to the requirements of [Part 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 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 requirements in Part 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 [Part 1];

b) the emergency stop function and the enabling device on the pendant shall comply with the requirements of [Part 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 [Part 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 [Part 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 [Part 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 [Part 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 program 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 subassembly 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 [Part 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 equipment

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 [signals a protective stop when actuated] 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 1400 mm [55 inches] 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 $\kappa$ used for calculating minimum distances in accordance with ISO 13855 is 1600 mm/s [63 inches/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, for example, 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.

NOTE 1 – Requirements for collaborative workspaces are given in 5.11.

For heights up to 1400 mm [55 inches] 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 1000 mm (40 in) and 1400 mm (55 in) 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 (5 inches). 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 fulfill 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 1400mm [55 inches].

Measures other than fixed [or interlocked] guards can apply, for example:

- electro-sensitive protective equipment;
- pressure [sensitive protective] 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 Part 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 pre-determined tasks;
— possible when all required protective measures are active; and
— for robots with features specifically designed for collaborative operation complying with [Part 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 Part 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 labeled with the symbol shown in Figure 2.

Figure 2 — Suggested labeling 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 Part 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. Safety-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 (20 in) 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 may 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. [Part 1] provides requirements and performance features for robots used in collaborative operation as described 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 [Part 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 [Part 1], is issued;
b) the operator shall have a guiding device that meets the requirements of [Part 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 [Part 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 [Part 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 [Part 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 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 center(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 programs – 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, vapors, dust and vibration generated with reference to the measuring methods used;
g) technical documentation about electrical equipment (see IEC 60204 series);

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, behavior 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 re-starting 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, 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 **De-commissioning**

Information relating to de-commissioning, 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 Part 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 center 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>
<thead>
<tr>
<th>No.</th>
<th>Type or group</th>
<th>Example of hazards</th>
<th>Potential consequences</th>
<th>Subclause reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— movements of any part of the robot arm (including back), end-effector or mobile parts of robot cell</td>
<td>— crushing</td>
<td>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; 5.3.2; 5.3.6; 5.3.7; 5.3.8.2 d); 5.3.9; 5.3.10; 5.5.1; 5.5.2; 5.5.3; 5.5.3 a); 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</td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— movements of external axis (including end-effector tool at servicing position)</td>
<td>— shearing</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— movement or rotation of sharp tool on end-effector or on external axes, part being handled, and associated equipment</td>
<td>— cutting or severing</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>—rotational motion of any robot axes</td>
<td>— entanglement</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— materials and products falling or ejection</td>
<td>— drawing–in or trapping</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— end-effector failure (separation)</td>
<td>— impact</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— loose clothing, long hair</td>
<td>— stabbing or puncture</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— between robot arm and any fixed object</td>
<td>— friction, abrasion</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— between end-effector and any fixed object (fence, beam, etc.)</td>
<td>— high pressure fluid/gas injection or ejection</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— between fixtures (falling in); between shuttles, utilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Mechanical hazards</td>
<td>— impossibility of exiting robot cell (via cell door) for a trapped operator in automatic mode</td>
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<tr>
<td>No.</td>
<td>Type or group</td>
<td>Example of hazards</td>
<td>Subclause reference</td>
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<td>1</td>
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<tr>
<td>2</td>
<td>Electrical hazards</td>
<td>contact with live parts or connections (Electrical cabinet, terminal boxes, control panels at machine)</td>
<td>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</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>— unintended movement of jigs or gripper</td>
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<td></td>
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<td>— unintended release of tool</td>
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<td></td>
<td></td>
<td>— unintended movement of machines or robot cell parts during handling operations</td>
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<td></td>
<td></td>
<td>— unintended motion or activation of an end-effector or associated equipment (including external axes controlled by the robot, process specific for grinding wheels, etc)</td>
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<td></td>
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<td>— unexpected release of potential energy from stored sources</td>
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<td></td>
<td></td>
<td>— electrocution</td>
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<td></td>
<td></td>
<td>— shock</td>
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<td></td>
<td></td>
<td>— burn</td>
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<td></td>
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<td></td>
<td></td>
<td>— projection of molten particles</td>
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<tr>
<td></td>
<td>Thermal hazards</td>
<td>hot surfaces associated with the end-effector; or associated equipment or work piece (e.g. welding torches, hot materials in forging presses, injection molding, grinding and de-</td>
<td>5.3; 5.5.2; 5.5.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>— burn (hot or cold)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>— radiation injury</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Type or group</td>
<td>Example of hazards</td>
<td>Origin</td>
<td>Potential consequences</td>
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<td></td>
<td>burring)</td>
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<td></td>
<td></td>
<td>— cold surfaces or objects (cryogenic processes)</td>
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<td></td>
<td></td>
<td>— explosive atmosphere caused by the process, i.e. paint (atomized particles, powder painting), flammable solvents, grinding and milling dust</td>
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<tr>
<td></td>
<td></td>
<td>— temperature extremes required to support the process [molten materials; ovens for cooking or heating (autoclaves); freezer or chillers, etc.]</td>
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<td></td>
<td></td>
<td>— flammable materials (Inside dust collector systems, cleaning tanks, sealant applicators)</td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td>Noise hazards</td>
<td>— specific applications which are sources of high noise (e.g. a water jet cutter, stamping presses, pumps and valving, metal removing operations)</td>
<td></td>
<td>— loss of hearing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— noise level preventing hearing or understanding audible danger warning signals including inability of persons to coordinate their actions through normal conversation</td>
<td></td>
<td>— loss of balance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— any other (e.g. mechanical) as a consequence of ambient conditions or distraction</td>
<td></td>
<td>— loss of awareness, disorientation</td>
</tr>
<tr>
<td>5</td>
<td>Vibration hazards</td>
<td>— direct contact with the source</td>
<td></td>
<td>— fatigue</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— loosening of connections, fasteners</td>
<td></td>
<td>— neurological damage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— misalignment of components or parts</td>
<td></td>
<td>— vascular disorder</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>— impact</td>
</tr>
<tr>
<td>6</td>
<td>Radiation hazards</td>
<td>— EMF interference with proper operation of the robot system</td>
<td></td>
<td>— burn</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— exposed to process related radiation, i.e. arc welding, laser.</td>
<td></td>
<td>— damage to eyes and skin</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>— related illnesses</td>
</tr>
<tr>
<td>No.</td>
<td>Type or group</td>
<td>Example of hazards</td>
<td>Potential consequences</td>
<td>Subclause reference</td>
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</tr>
</tbody>
</table>
| 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 3e), 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 | — 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; |
<table>
<thead>
<tr>
<th>No.</th>
<th>Type or group</th>
<th>Example of hazards</th>
<th>Potential consequences</th>
<th>Subclause reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Origin</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>problem and compound problem by making incorrect or unnecessary actions</td>
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<tr>
<td></td>
<td></td>
<td>action increases severity of harm; i.e. in avoiding a sharp edge contact is made with a hot surface instead</td>
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<tr>
<td></td>
<td></td>
<td>unintended release of holding devices allowing motion under residual forces (inertia, gravity, spring/energy storage means)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>failure of a safeguarding device to function as expected</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Annex B
(informative)

Relationship of ISO standards related to protective devices

**A- Type Standards**
- ISO 12100-1
- ISO 14121-1
- ISO 12100-2

**B- Type Standards**
- ISO 13854
- ISO 13855

**C- Type Standard**
- ISO 13857

**Guards**
- ISO 14120

**Fixed guards:**
- Fences, barriers, covers removable by using tools

**Movable guards:**
- Doors, gates, covers, manually or power operated

**Interlocking devices:**
- ISO 14119
  - Mats & floors: ISO 13856-1
  - Edges: ISO 13856-2
  - Bumpers: ISO 13856-3

**Sensitive protective equipment (SPE)**
- Application: IEC TS 62046

**Pressure sensitive protective equipment (PSPE)**

**Electro-sensitive protective equipment (ESPE)**
- IEC 61496.1
  - Light curtains, light grids (AOPD): IEC 61496-2
  - Laser Scanners (AOPDD): IEC 61496-3
  - Safety Cameras (VBPD): IEC-TS 61496-4

**Limiting devices**
- Fixed devices
- Portable devices
  - speed
  - travel
  - force
  - pressure

**Protective devices**

**Safety distances:**
- ISO 13857

**Minimum gaps to avoid crushing:**
- ISO 13854

**Positioning of protective equipment:**
- ISO 13855

**Safety related parts of control systems:**
- ISO 13849-1 / 2

**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

<table>
<thead>
<tr>
<th>Person B</th>
<th>Position 1</th>
<th>Position 2</th>
<th>Position 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position 1</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>Position 2</td>
<td>OFF</td>
<td>ENABLED</td>
<td>OFF</td>
</tr>
<tr>
<td>Position 3</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

The machine operation shall be ENABLED only when BOTH enabling devices are in position 2 – the center-enabled position.
Annex E
(informative)

Conceptual applications of collaborative robots

NOTE For requirements see 5.11

<table>
<thead>
<tr>
<th>Type of application</th>
<th>Description</th>
<th>Safeguards</th>
<th>Objectives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand-over window</td>
<td>autonomous automatic operation within safeguarded space</td>
<td>fixed or sensitive guards around the workspace</td>
<td>loading, Unloading, testing, benching, cleaning, service</td>
</tr>
<tr>
<td></td>
<td>robot moves into window</td>
<td>reduced speed and reduced workspace near the window</td>
<td></td>
</tr>
<tr>
<td></td>
<td>no interruption of automatic operation during access</td>
<td>no robot workspace outside the window</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>when lower edge of the window less than 1000 mm</td>
<td></td>
</tr>
<tr>
<td>Interface window</td>
<td>autonomous automatic operation within safeguarded space</td>
<td>fixed or sensitive guards around the workspace</td>
<td>automatic stacking/de-stacking, guided assembling, guided filling/un-filling, testing, benching, cleaning, service</td>
</tr>
<tr>
<td></td>
<td>robot stops at an interface window and can then be moved then manually outside the interface.</td>
<td>reduced speed and reduced workspace outside and near the window</td>
<td></td>
</tr>
<tr>
<td>Collaborative workspace</td>
<td>autonomous automatic operation within a common (collaborative) workspace</td>
<td>person detection system using one or more sensors</td>
<td>common assembling, common handling, testing benching, cleaning, service</td>
</tr>
<tr>
<td></td>
<td>robot reduces speed and/or stops when a person enters the common (collaborative) workspace</td>
<td>reduced speed according to the distance (5.11.5.4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>robot stops safely when prohibited space accessed and possible automatic restart after clearance if properly safeguarded</td>
<td></td>
</tr>
<tr>
<td>Inspection</td>
<td>autonomous automatic operation within safeguarded space. a person enters the collaborative workspace while robot continues operation with reduced speed and reduced travel</td>
<td>fixed or sensitive guards around the workspace</td>
<td>inspection and tuning of processes, e.g. welding application</td>
</tr>
<tr>
<td></td>
<td></td>
<td>person detection system or enabling device</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>reduced speed and reduced workspace after entering the workspace</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>measures against misuse</td>
<td></td>
</tr>
<tr>
<td>Hand-guided robot</td>
<td>application specific workspace</td>
<td>reduced speed</td>
<td>hand-guided assembling, painting, etc.</td>
</tr>
<tr>
<td></td>
<td>moving by hand guiding</td>
<td>hold-to-run control</td>
<td></td>
</tr>
<tr>
<td></td>
<td>moving hand guided along a path</td>
<td>collaborative workspace depending on hazards of the application</td>
<td></td>
</tr>
</tbody>
</table>
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 behavior 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 analyze the requirements for the behavior 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 and B11.20

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 system 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

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Safety requirements and/or measures</th>
<th>Verification and/or validation methods (see 6.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>5.2</td>
<td>Safety-related control system performance (hardware/software)</td>
<td></td>
</tr>
<tr>
<td>5.2.1</td>
<td>Statement of performance capabilities and data and criteria to determine the performance in information for use.</td>
<td>X</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Performance is PL=d, structure category 3.</td>
<td></td>
</tr>
<tr>
<td>5.2.2</td>
<td>Performance is SIL 2, hardware fault tolerance 1 with proof test interval not less than 20 years.</td>
<td></td>
</tr>
<tr>
<td>5.2.3</td>
<td>Results of risk assessment used to determine performance</td>
<td></td>
</tr>
<tr>
<td>5.3</td>
<td>Design and installation</td>
<td></td>
</tr>
<tr>
<td>5.3.1</td>
<td>System designed and selected based on conditions.</td>
<td></td>
</tr>
<tr>
<td>5.3.2</td>
<td>Automatic mode selection shall be outside the safeguarded area.</td>
<td></td>
</tr>
<tr>
<td>5.3.3</td>
<td>Actuating controls meet the requirements of IEC 60204-1.</td>
<td></td>
</tr>
<tr>
<td>5.3.3</td>
<td>Robot system shall not respond to any ext. remote control commands or conditions causing hazardous situations</td>
<td></td>
</tr>
<tr>
<td>5.3.4</td>
<td>All power sources shall meet the manufacturer’s requirements</td>
<td></td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>5.3.4</td>
<td>Electrical enclosure doors shall be mounted to be fully opened and escape routes are always available</td>
<td>X</td>
</tr>
<tr>
<td>5.3.5</td>
<td>Protective bonding shall meet IEC 60204-1</td>
<td>X</td>
</tr>
<tr>
<td>5.3.6</td>
<td>Hazardous energy isolation means provided</td>
<td>X</td>
</tr>
<tr>
<td>5.3.6</td>
<td>Hazardous energy isolation means shall be clearly marked</td>
<td></td>
</tr>
<tr>
<td>5.3.7</td>
<td>Means of controlled release of hazardous energy shall be provided</td>
<td>X</td>
</tr>
<tr>
<td>5.3.7</td>
<td>Means of controlled release of hazardous energy shall be clearly marked</td>
<td></td>
</tr>
<tr>
<td>5.3.8.1</td>
<td>Robot system is provided with a protective stop</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.1</td>
<td>Robot system is provided with an independent emergency stop</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.1</td>
<td>Protective and emergency stops shall have provisions for connection of ext. protective devices</td>
<td></td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Each control station capable of initiating robot motion or other hazardous functions shall have an emergency stop</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Actuation stops all robot motion and other hazardous functions in the cell</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Has a single emergency stop for the system or spans of control for multiple functions</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>All emergency stop devices in a single workspace have the same span of control</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Information on span of control is in information for use</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Emergency stop function shall comply with 5.3.8.2</td>
<td>X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
</tr>
<tr>
<td>-----------</td>
<td>---------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Emergency stop function shall be either stop category 0 or 1</td>
<td>X     X     X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>Emergency stop function shall comply with PL=d, category 3 unless the risk assessment determines other performance criteria</td>
<td>X</td>
</tr>
<tr>
<td>5.3.8.2</td>
<td>If provided, the Emergency stop output signal shall continue to function when the robot system power supply is removed, otherwise it shall generate an emergency stop signal</td>
<td>X     X     X</td>
</tr>
<tr>
<td>5.3.11</td>
<td>Emergency recovery procedures are provided in the information for use.</td>
<td>X</td>
</tr>
<tr>
<td>5.3.11</td>
<td>Emergency recovery procedures signs or labels are affixed to the robot system or instructions for affixing are provided.</td>
<td>X</td>
</tr>
<tr>
<td>5.3.12</td>
<td>Obscured warning signs have been replaced with equally effective means of warnings.</td>
<td>X</td>
</tr>
<tr>
<td>5.3.13</td>
<td>Level of task lighting has been identified and specified in the information for use.</td>
<td>X     X     X     X</td>
</tr>
<tr>
<td>5.3.13</td>
<td>Integral lighting suitable to the operation has been provided</td>
<td>X     X     X     X     X</td>
</tr>
<tr>
<td>5.3.14</td>
<td>The integration of the robot system takes into account the application’s hazards.</td>
<td>X     X     X     X     X</td>
</tr>
<tr>
<td>5.3.14</td>
<td>Interface requirements to other machines follows the guidance of the manufacturer as specified in information for use.</td>
<td>X     X     X     X     X</td>
</tr>
<tr>
<td>5.3.15</td>
<td>Additional enabling devices and their integration comply with [Part 1, Clause 5.8.3]</td>
<td>X     X     X     X     X</td>
</tr>
<tr>
<td>5.3.15</td>
<td>Sufficient additional enabling devices for the expected number of personnel within the safeguarded space are provided.</td>
<td>X     X     X     X     X     X</td>
</tr>
<tr>
<td>5.3.15</td>
<td>Multiple enabling devices associated with a single robot control have the same functionality.</td>
<td>X     X     X     X     X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>5.3.15</td>
<td>Enabling devices are interlocked in areas of the cell where personnel are exposed to a hazard from additional robot or other equipment.</td>
<td>X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.3.15</td>
<td>Additional interlocked equipment requires a separate re-start</td>
<td>X X X X X X X</td>
</tr>
<tr>
<td>5.4</td>
<td>Limiting robot motion</td>
<td></td>
</tr>
<tr>
<td>5.4.2</td>
<td>The safeguarded space has been established by perimeter guarding with due considerations of location and layout and hazards within.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.2</td>
<td>The restricted space of the robot has been established by means which limit the motion of the robot, end-effector, fixture, and workpiece.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.2</td>
<td>The restricted space lies within the safeguarded space.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.2</td>
<td>The perimeter safeguards are not installed closer to the hazard than the restricted space or the perimeter safeguard is designed to be the limiting device in accordance with 5.4.3.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Mechanical robot limiting means comply with [part 1, clause 5.12.2]</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Non-mechanical robot limiting means comply with [Part 1, clause 5.12]</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Control systems used for non-mechanical robot limiting means comply with [Part 1, 5.2.2] unless a risk assessment determines another performance.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>The stopping distance associated with the limiting means has been included in any calculation of the restricted space.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>The limiting devices have been correctly adjusted and secured.</td>
<td>X X X X X X X X X X X X X X X X X X X X X X X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>5.4.3</td>
<td>When non-mechanical limiting devices are used, including safety-rated soft axis and space limiting (Part 1, 5.12.3), the restricted space has been determined based on the robot with actual load.</td>
<td>X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>If the speed of the robot is limited by a monitoring system satisfying 5.2.2, the restricted space may be based on actual speed. Otherwise, the restricted space is based on the maximum speed of the robot.</td>
<td>X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>Information about the programmed safety-rated and space limits are included in information for use.</td>
<td>X</td>
</tr>
<tr>
<td>5.4.3</td>
<td>In cases where the perimeter guard is designed to be the limiting device, the results of the risk assessment has been used to determine the requirements for the design, strength and deflection for that guard.</td>
<td>X</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Dynamic mechanical limiting devices are capable of stopping the robot under rated load and speed</td>
<td>X</td>
</tr>
<tr>
<td>5.4.4</td>
<td>Safety controls associated with dynamic limiting comply with the performance requirements of 5.2.</td>
<td>X</td>
</tr>
<tr>
<td>5.4.4</td>
<td>The location of the dynamic limiting zones have been identified in the information for use.</td>
<td>X</td>
</tr>
<tr>
<td>5.5</td>
<td>Layout</td>
<td>X</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Perimeter safeguarding has been implemented in accordance with 5.10</td>
<td>X</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Protective device selection considers expected operating stresses, influence processed material and other relevant external influences</td>
<td>X</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Safety distances over or through mechanical guarding comply with ISO 13857</td>
<td>X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Minimum Safety distances from interlocking guards comply with ISO 13855</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.1</td>
<td>Minimum gaps to prevent crushing comply with ISO 13854</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Minimum clearance of 500 mm is maintained in task areas requiring the use of manual high-speed</td>
<td>X      X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Where practicable layout design allows tasks to be performed outside the safeguarded space</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Safe and adequate access to task locations within safe guarded space has been provided</td>
<td>X      X      X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Access paths and means are free of hazards</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Permanent means of access provided for high frequency tasks</td>
<td>X      X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Access means provided to electrical equipment mounted above normal reach</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Access means provided to devices between 400 mm and 2000 mm from access level</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Platforms, walkways, stairs, stepladders and fixed ladders are selected/designed in accordance with ISO 14122</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Safeguarding is provided between adjacent cells</td>
<td>X      X      X      X</td>
</tr>
<tr>
<td>5.5.2</td>
<td>Safeguarding of adjoining cells during material transfer has been provided</td>
<td>X      X      X      X</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Persons entering the hazard zone where materials enter and exit the safeguarded space are detected</td>
<td>X      X      X</td>
</tr>
<tr>
<td>5.5.3</td>
<td>Safeguarding measures prevent contact with hazards or bring hazards to a safe state</td>
<td>X      X      X</td>
</tr>
</tbody>
</table>
### Subclause 5.5.4
Operation modes in accordance with 5.6.4.2, 5.6.4.3 or a separate control mode is provided for process observation inside safeguarded space

<table>
<thead>
<tr>
<th>Verification and/or validation methods (see 6.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

### Subclause 5.6
**Robot system operational mode application**

<table>
<thead>
<tr>
<th>5.6.1</th>
<th>Robot systems not selected for operation remain in a safe state in a multi robot cell</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.6.1</th>
<th>Other robots in cell not being operated manually do not create a hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.6.2</th>
<th>Unauthorized and/or inadvertent mode selection is prevented</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.6.2</th>
<th>Selection means only enables selected mode and not operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.6.2</th>
<th>Separate actuation required to initiate robot operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.6.2</th>
<th>Unambiguous indication of operating mode provided</th>
</tr>
</thead>
<tbody>
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<table>
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<tr>
<th>5.6.2</th>
<th>Changing mode of operation does not create hazard</th>
</tr>
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<th>Entering safeguarded space while in automatic mode causes a protective stop</th>
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<th>Selection of automatic mode does not override protective stop or emergency stop condition</th>
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<th>Selection of automatic mode is located outside safeguarded space</th>
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<table>
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<th>5.6.3.2</th>
<th>Switching from automatic mode causes a stop</th>
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<th>Automatic operation is initiated from outside the safeguarded space</th>
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<table>
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<th>Initiation of automatic mode only possible when all safeguards are active</th>
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</tr>
<tr>
<td>5.6.3.4</td>
<td>Start and restart is a simple operation.</td>
</tr>
<tr>
<td>5.6.3.4</td>
<td>Protective measures are functional prior to start and restart</td>
</tr>
<tr>
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<td>Safety-related control function complies with 5.2.2</td>
</tr>
<tr>
<td>5.6.3.4</td>
<td>Manually actuated interlocks for start and restart provided</td>
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<tr>
<td>5.6.3.4</td>
<td>Personnel are protected from start and restart while in the safeguarded space</td>
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<tr>
<td>5.6.3.4</td>
<td>Manually actuated start and restart controls can not be activated from inside safeguarded space</td>
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<tr>
<td>5.6.3.4</td>
<td>Functional safety and protective measures provided to ensure no one is in the safeguarded space prior to start and restart</td>
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<td>5.6.3.4</td>
<td>Presence sensing or audio-visual pre-start warning signal provided when necessary</td>
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<td>Accessible emergency stop devices are provided within safeguarded space</td>
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<td>Local control during manual intervention uses pendant</td>
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<td>5.6.4.1</td>
<td>Location of control devices allows observation of work area</td>
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<tr>
<td>5.6.4.1</td>
<td>Stop control device placed near each start control device</td>
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<td>5.6.4.1</td>
<td>Control prevented from other sources during local control</td>
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<tr>
<td>5.6.4.2</td>
<td>Adjustment of TCP using offset feature has been accomplished</td>
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<tr>
<td>5.6.4.2</td>
<td>Maximum velocity of TCP less than 250 mm/s [10 in/s].</td>
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<tr>
<td>5.6.4.2</td>
<td>Determination if slower speed required</td>
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<td>Subclause</td>
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<td>5.6.4.2</td>
<td>Functional enabling device required for motion</td>
</tr>
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<td>5.6.4.3</td>
<td>Requirements of [Part 1] and of pendants met</td>
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<tr>
<td>5.6.4.3</td>
<td>Information for use contains functional test of enabling device</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Remote control only possible while in manual mode</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Only a single control source during remote control is active at one time</td>
</tr>
<tr>
<td>5.6.5</td>
<td>No overriding of local selection or causing hazardous conditions due to remote control</td>
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<tr>
<td>5.6.5</td>
<td>Activating Remote function only possible from local operation control</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Restrictions exist for remotely changing safety-rated soft axis and space limiting parameters</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Indication of active remote control exists</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Remote control is prevented when in manual high-speed</td>
</tr>
<tr>
<td>5.6.5</td>
<td>Information for use provides requirements for manual remote intervention</td>
</tr>
<tr>
<td>5.7</td>
<td><strong>Pendants</strong></td>
</tr>
<tr>
<td>5.7.1</td>
<td>Pendants used inside safeguarded space conform to [Part 1, 5.8]</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Pendant emergency stop complies with 5.3.8.2</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Cabled pendants have sufficient cable length and durability.</td>
</tr>
<tr>
<td>5.7.1</td>
<td>Pendant storage provided to prevent damage</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
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</tr>
<tr>
<td>5.7.2</td>
<td>Cableless or detachable pendants meet requirements in [Part 1, 5.8.6]</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Emergency stop and enabling device comply with [Part 1, 5.8]</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Unintentional control is avoided</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Cableless pendant not simultaneously connected to more than one robot system</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Loss of signal causes stop and deliberate action to restart</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Disconnect and storage meets requirements</td>
</tr>
<tr>
<td>5.7.2</td>
<td>Single point of control is provided</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Multi-robot pendant control has indication of which robots are being controlled</td>
</tr>
<tr>
<td>5.7.3</td>
<td>All multi-robots selected are in the same mode of operation</td>
</tr>
<tr>
<td>5.7.3</td>
<td>Robots not selected do not present a hazard</td>
</tr>
<tr>
<td>5.7.4</td>
<td>Hand guided controls meet requirements of [Part 1, 5.10.3]</td>
</tr>
<tr>
<td>5.8</td>
<td>Maintenance and repair</td>
</tr>
<tr>
<td>5.8.1</td>
<td>Procedures for inspection and maintenance are provided and take into account manufacturer's recommendations and allow for continued safe operation.</td>
</tr>
<tr>
<td>5.8.1</td>
<td>Information for use includes requirements for periodic functional testing of the safety-related parts of equipment</td>
</tr>
<tr>
<td>5.8.2</td>
<td>System designed for safe access for maintenance</td>
</tr>
<tr>
<td>5.8.2</td>
<td>System has means to control hazardous energy with use details in information for use</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
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<tr>
<td></td>
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</tr>
<tr>
<td>5.8.2</td>
<td>System has adequate alternative safeguards for tasks identified to be performed without energy isolation</td>
</tr>
<tr>
<td>5.8.3</td>
<td>The guards are of sufficient size to allow easy access</td>
</tr>
<tr>
<td>5.8.3</td>
<td>Fixed guards provided for infrequent maintenance or servicing tasks are removable only by the use of a tool</td>
</tr>
<tr>
<td>5.8.3</td>
<td>Frequent access points are safeguarded by protective devices, preferably movable guards. Movable guards do not initiate a starting command by reaching the safeguarding position.</td>
</tr>
<tr>
<td>5.8.3</td>
<td>Additional protective measures are provided when it is possible to remain in the safeguarded area when the movable guard is closed</td>
</tr>
<tr>
<td>5.8.3</td>
<td>A presence-sensing device used in conjunction with a restart interlock meets at a minimum the requirements of Type 2 from IEC 61496-1.</td>
</tr>
</tbody>
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5.9 Integrated Manufacturing System (IMS) Interface

<table>
<thead>
<tr>
<th>Subclause</th>
<th>Safety requirements and/or measures</th>
<th>Verification and/or validation methods (see 6.2)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>A  B  C  D  E  F  G  H  I</td>
</tr>
<tr>
<td>5.9.1</td>
<td>Risk assessment and integration of the system considers hazards posed by other equipment in the safeguarded space</td>
<td>X  X  X  X  X  X  X  X  X</td>
</tr>
<tr>
<td>5.9.2</td>
<td>IMS has a single emergency stop function affecting all relevant parts of the machine</td>
<td>X  X  X  X  X  X  X  X  X</td>
</tr>
<tr>
<td>5.9.2</td>
<td>Emergency stop complies with 5.3.8.2</td>
<td>X  X  X  X  X  X  X  X  X</td>
</tr>
<tr>
<td>5.9.2</td>
<td>Information for use includes information on the span of control of each emergency stop device</td>
<td>X  X  X  X  X  X  X  X  X</td>
</tr>
<tr>
<td>5.9.3</td>
<td>Safety-related controls between the IMS and robot comply with 5.2.2.</td>
<td>X  X  X  X  X  X  X  X  X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
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</tr>
<tr>
<td>5.9.3</td>
<td>Safety circuits affect hazardous movements within a zone and at the interfaces to adjacent zones</td>
<td>X X X X X X X</td>
</tr>
<tr>
<td>5.9.4</td>
<td>IMS control system is notified of local control selection</td>
<td>X X X</td>
</tr>
<tr>
<td>5.9.4</td>
<td>Local control cannot be overridden by IMS</td>
<td>X X X</td>
</tr>
<tr>
<td>5.9.4</td>
<td>Emergency and protective stop functions remain operational during local control</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.9.4</td>
<td>Means of selecting local control is in close proximity to items being controlled.</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.9.4</td>
<td>Deselecting local control does not initiate hazardous conditions from within the safeguarded space</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.9.4</td>
<td>If deselecting can occur inside safeguarded space, then a separate confirmation is required from outside the cell</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.9.5</td>
<td>Additional enabling devices comply with 5.3.15</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.9.5</td>
<td>Enabling device is interlocked consistent with IMS zones</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.9.6</td>
<td>Mode selection complies with [Part 1, 5.7.1]</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.9.7</td>
<td>IMS is designed for safe manual interventions, including zoning if necessary</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.9.7</td>
<td>Integration of the robot system into a task zone is in accordance with ISO 11161</td>
<td>X X X</td>
</tr>
<tr>
<td>5.10</td>
<td>Safeguarding</td>
<td></td>
</tr>
<tr>
<td>5.10.1</td>
<td>Guards and protective devices meet the requirements of ISO 12100</td>
<td>X</td>
</tr>
<tr>
<td>5.10.2</td>
<td>Selection of perimeter safeguards takes into account all hazards and tasks.</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.10.3.1</td>
<td>Safeguards are securely installed and located properly</td>
<td>X X X X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
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<td></td>
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<td>A</td>
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<tr>
<td>5.10.3.2</td>
<td>Fixed and moveable guards meet the requirements of ISO 14120</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>The minimum distance from any hazard of the fixed and moveable guards is determined</td>
<td></td>
</tr>
<tr>
<td></td>
<td>according to the relevant requirements of ISO 13857.</td>
<td></td>
</tr>
<tr>
<td>5.10.3.2</td>
<td>When preventing access with guards, ISO 13857 is used to determine the minimum safe distance.</td>
<td></td>
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<tr>
<td>5.10.3.3</td>
<td>Presence-sensing protective devices that prevent start or restart comply with 5.10.5.3</td>
<td>X</td>
</tr>
<tr>
<td>5.10.3.4</td>
<td>Presence-sensing protective devices to provide clearance comply with 5.10.5.3</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.1</td>
<td>All guards meet the applicable requirements of ISO 12100 and ISO 14120</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.1</td>
<td>Interlocking devices associated with guards meet applicable requirements</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.1</td>
<td>Fixed guards require tools to remove</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.1</td>
<td>Where required, fixing systems are attached to the guards or machinery when removed</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.1</td>
<td>Perimeter safeguarding is not installed closer to the hazard than the restricted space (see exceptions in 5.10.4)</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.2</td>
<td>The gap between the bottom of the guard and the floor or other gap in the guard cannot allow a person to reach over, under, around or through the guard and reach a hazard.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.2</td>
<td>The height of the guard is at least 1400 mm.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Interlocking devices associated with moveable guards meet applicable requirements</td>
<td>X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Movable guards at their closed position prevent operators reaching hazardous areas.</td>
<td>X</td>
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<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
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</tr>
<tr>
<td>5.10.4.3</td>
<td>Movable guards open laterally or away from the hazard, and not into the safeguarded space.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Interlocking is provided to bring any hazards to a safe state before an operator can gain access.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Movable guards are positioned properly (see also 5.10.3.2)</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Movable guards used to initiate starting on closure (control guards) meet applicable requirements.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Movable guard interlocking function achieves at least requirements of 5.2.2.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.3</td>
<td>Movable guard reset actuators are in accordance with 5.6.3.4.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.4</td>
<td>Where required, guard locking is provided in addition to the control interlock.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.4</td>
<td>Guard locking complies with 5.10.4.4 a) and b).</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.4</td>
<td>Process parameters used as a condition for locking or unlocking meet the same functional safety requirements as the interlocking function.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.4.4</td>
<td>Safeguarded space has a means to prevent a person from being trapped inside.</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.5.1</td>
<td>Electro-sensitive and pressure sensitive protective equipment meets the applicable requirements</td>
<td>X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>Sensitive protective equipment used to initiate a protective stop is properly positioned</td>
<td>X X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>Sensitive protective equipment is securely installed and located such that an operator cannot circumvent the detection zone</td>
<td>X X X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
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</tr>
<tr>
<td>5.10.5.2</td>
<td>A protective stop is initiated if the sensitive protective equipment is actuated while the hazardous conditions are operating</td>
<td>X   X   X   X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>Following an actuation, the hazardous conditions being safeguarded by the sensitive protective equipment are prevented from any hazardous motion or situation until the sensitive protective equipment is reset.</td>
<td>X   X   X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>Reset of the sensitive protective equipment does not by itself initiate hazardous conditions.</td>
<td>X   X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>The minimum safe distance formula is used to determine the minimum distance of the sensitive protective equipment for all directions of approach, using the maximum extension of moving parts towards the direction of approach.</td>
<td>X   X   X   X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>Where part of an operator can remain in the safeguarded space, additional measures are provided to prevent hazardous situations</td>
<td>X   X   X   X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>If it is possible for an operator to be hidden from the location of a reset control, supplementary protective measures to prevent resetting the restart interlock are provided.</td>
<td>X   X   X   X</td>
</tr>
<tr>
<td>5.10.5.2</td>
<td>Resetting of a restart interlock requires a deliberate human action.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.5.3</td>
<td>Presence-sensing sensitive protective equipment used to prevent a start is used in conjunction with other safety measures</td>
<td>X   X   X   X</td>
</tr>
<tr>
<td>5.10.5.3</td>
<td>Presence-sensing devices are positioned and configured so that a person or part of a person will be detected throughout the detection zone.</td>
<td>X   X</td>
</tr>
<tr>
<td>5.10.5.3</td>
<td>Where necessary, supplementary measures are provided to ensure that the detection zone cannot be circumvented.</td>
<td>X   X   X   X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
</tr>
<tr>
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<td>------------------------------------------------------------------------------------------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>5.10.6.1</td>
<td>Measures are provided to ensure that operators are not exposed to further hazards due to the operation of the manual material-handling station.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.6.1</td>
<td>Measures have been taken to prevent the exposure of the operator to application-related hazards.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.6.2</td>
<td>Measures are provided to prevent the operator accessing hazards from motions of manual stations</td>
<td>X</td>
</tr>
<tr>
<td>5.10.6.2</td>
<td>The gap between a moving station and any fixed elements does not exceed 120 mm.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.6.3</td>
<td>When presence sensing is used to detect the operator in a shared workspace, the detection zone of the device covers the entire shared workspace area.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.6.3</td>
<td>When a restart interlock is provided in a shared workspace, measures are provided to prevent inadvertent resetting of the restart interlock.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.6.3</td>
<td>When manual reset is provided in a shared workspace, the whole of the shared workspace is visible from the reset device or further measures have been applied.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.7</td>
<td>Material entry and exit openings are the minimum dimensions necessary.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.7</td>
<td>Crushing/shearing hazards between the material and the sides of the opening are prevented.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.7</td>
<td>Access to the hazard is prevented or detected.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.7</td>
<td>ESPE allows the passage of materials either by a muting function or by a change in protection area (e.g. blanking).</td>
<td>X</td>
</tr>
<tr>
<td>5.10.7</td>
<td>The muting function fulfills the requirements of ISO 13849-1.</td>
<td>X</td>
</tr>
<tr>
<td>Subclause</td>
<td>Safety requirements and/or measures</td>
<td>Verification and/or validation methods (see 6.2)</td>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>5.10.7</td>
<td>The functional safety level for the muting and a change in protection area (e.g. blanking) is at least the same level as the functional safety level determined by the risk assessment for the ESPE.</td>
<td>A</td>
</tr>
<tr>
<td>5.10.8</td>
<td>Measures have been provided to prevent operator access or cause hazards to cease within adjacent cells</td>
<td>X</td>
</tr>
<tr>
<td>5.10.8</td>
<td>Fixed guards used to prevent access to hazards in adjacent cells, have a minimum height of 1400 mm.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.8</td>
<td>The selection of measures other than fixed guards are in accordance with 4.5.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.8</td>
<td>Measures muted for production operations meet the functional safety level determined by the risk assessment.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.9</td>
<td>End-effectors and tool changing systems have been designed and constructed such that loss or restoration of energy supply does not lead to a hazard.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.9</td>
<td>The tool changing system design ensures that misuse does not lead to a hazardous situation.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.9</td>
<td>Tool changing is only possible in the tool changing position.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.9</td>
<td>The tool changing system withstands the expected static and dynamic requirements.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.10</td>
<td>Muting has been limited to only necessary processes</td>
<td>X</td>
</tr>
<tr>
<td>5.10.10</td>
<td>A person cannot remain undetected in the hazardous zone when muting is terminated.</td>
<td>X</td>
</tr>
<tr>
<td>5.10.10</td>
<td>The muting function is initiated and terminated automatically provided the muting conditions are correct.</td>
<td>X</td>
</tr>
<tr>
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</tr>
<tr>
<td></td>
<td></td>
<td>A    B    C    D    E    F    G    H    I</td>
</tr>
<tr>
<td>5.10.10</td>
<td>The muting function achieves an equivalent level of safety performance as the protective function being muted.</td>
<td>X    X    X    X    X    X</td>
</tr>
<tr>
<td>5.10.10</td>
<td>The level of performance of the muting function does not adversely affect the level of performance of the protective function.</td>
<td>X    X    X    X    X</td>
</tr>
<tr>
<td>5.10.10</td>
<td>In the event of a failure of the muting function, subsequent muting is prevented until the failure is corrected.</td>
<td>X    X    X</td>
</tr>
<tr>
<td>5.10.10</td>
<td>Description of muting means, location, zones, and functionality is included in information for use.</td>
<td>X    X</td>
</tr>
<tr>
<td>5.10.11</td>
<td>Tasks requiring the suspension of safeguards have a dedicated mode of operation</td>
<td>X    X    X    X    X    X</td>
</tr>
<tr>
<td>5.10.11</td>
<td>Selection of the mode of operation is by secure means.</td>
<td>X    X    X    X</td>
</tr>
<tr>
<td>5.10.11</td>
<td>When safeguards are automatically suspended, the requirements in 5.10.11 a) to f) are met.</td>
<td>X    X    X    X</td>
</tr>
<tr>
<td>5.10.11</td>
<td>When safeguards are automatically suspended, equipment not required for the tasks is in a protective stop condition or under the direct control of the operator.</td>
<td>X    X    X</td>
</tr>
<tr>
<td>5.10.11</td>
<td>Information for use has been provided related to critical situations when it is necessary to manually suspend safeguards.</td>
<td>X</td>
</tr>
<tr>
<td>5.11</td>
<td><strong>Collaborative robots</strong></td>
<td></td>
</tr>
<tr>
<td>5.11.1</td>
<td>Information for use contains description of required safeguards and mode selection</td>
<td>X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Integrator has conducted a risk assessment that considers the entire collaborative workspace.</td>
<td>X    X    X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Robots in collaborative space meet the requirements of [Part 1, 5.10]</td>
<td>X    X    X</td>
</tr>
<tr>
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<td>--------------------------------------------------</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Protective device(s) for presence detection meet the requirements outlined in 5.2.2</td>
<td>X X X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Additional protective device(s) in collaborative workspace meet the requirements in 5.2</td>
<td>X X X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Safeguarding has been designed and installed to prevent or detect persons from advancing further into the cell (beyond the collaborative workspace).</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Robot stops and hazards cease if intrusion into the safeguarded space beyond the collaborative workspace occurs.</td>
<td>X X X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Perimeter safeguarding prevents or detects persons from entering the non-collaborative safeguarded space.</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.11.2</td>
<td>Other connected machines within the collaborative workspace which have safety-related functions comply with 5.2.2 unless risk assessment deems otherwise.</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.11.3</td>
<td>Collaborative workspace where direct human robot interaction takes place is clearly defined (e.g. floor marking, signs, etc)</td>
<td>X X X</td>
</tr>
<tr>
<td>5.11.3</td>
<td>Robot performance features in conjunction with protective devices comply with 5.2.2</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.11.3</td>
<td>If more than one person is involved in the collaborative operation, each person is protected with controls complying with 5.2.2</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.11.3</td>
<td>The collaborative workspace allows easy performance of tasks</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.11.3</td>
<td>Location of equipment does not introduce additional hazards</td>
<td>X X X X</td>
</tr>
<tr>
<td>5.11.3</td>
<td>Additional protective measures are present to prevent exposure to trapping or pinch hazards in areas where less than 500 mm clearance exists.</td>
<td>X X X X X</td>
</tr>
<tr>
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<td>-----------------------------------------------</td>
</tr>
<tr>
<td>5.11.4</td>
<td>Changing from autonomous operation to collaborative and back does not endanger personnel.</td>
<td>X X X X X X X X</td>
</tr>
<tr>
<td>5.11.5.1</td>
<td>Appropriate collaborative robot operation safety feature(s) has been selected</td>
<td>X X</td>
</tr>
<tr>
<td>5.11.5.1</td>
<td>Detected failure of selected safety features results in a protective stop in accordance with 5.3.8.3</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.11.5.1</td>
<td>If a detected failure occurs, autonomous operation only resumes after a deliberate restart from outside the collaborative workspace</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.11.5.2</td>
<td>If using safety-rated monitored stop technology, when a person enters collaborative space the robot motion stops and maintains safety-rated monitored stop</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.11.5.3</td>
<td>If hand-guiding, when robot reaches the hand-over position a safety-rated monitored stop in accordance with [Part 1, 5.5] is issued</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.11.5.3</td>
<td>The hand-guiding device meets the requirements of [Part 1, 5.10.3]</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.11.5.3</td>
<td>If hand-guiding, clear visibility of the entire collaborative workspace exists.</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.11.5.3</td>
<td>When the operator releases the hand-guiding device, a safety-rated monitored stop in accordance with [Part 1, 5.5] is issued</td>
<td>X X X X X X</td>
</tr>
<tr>
<td>5.11.5.4</td>
<td>If using speed and position monitoring technology, robots in collaborative space meet the requirements of [Part 1, 5.10.4]</td>
<td>X X X X X</td>
</tr>
<tr>
<td>5.11.5.4</td>
<td>Parameters have been determined by risk assessment and guidance provided by ISO/TS 15066</td>
<td>X X X</td>
</tr>
<tr>
<td>5.11.5.5</td>
<td>If using power and force limiting technology, robots in collaborative space meet the requirements of [Part 1, 5.10.5]</td>
<td>X X X X</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
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<th>Safety requirements and/or measures</th>
<th>Verification and/or validation methods (see 6.2)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>5.11.5.5</strong></td>
<td>Parameters have been determined by risk assessment and guidance provided by ISO/TS 15066</td>
<td>A B C D E F G H I</td>
</tr>
<tr>
<td><strong>5.12</strong></td>
<td><strong>Commissioning of robot systems</strong></td>
<td>X X X</td>
</tr>
<tr>
<td><strong>5.12.1</strong></td>
<td>Commissioning plan includes information for protective measures (interim safeguards) needed during commissioning.</td>
<td>X X X X</td>
</tr>
<tr>
<td><strong>5.12.2</strong></td>
<td>Interim safeguards protect against hazards identified in risk assessment</td>
<td>X X X X</td>
</tr>
<tr>
<td><strong>5.12.3</strong></td>
<td>Interim safeguards have been identified in the information for use</td>
<td>X</td>
</tr>
<tr>
<td><strong>5.12.3</strong></td>
<td>Initial start-up procedure plan includes items listed in 5.12.3 as a minimum.</td>
<td>X</td>
</tr>
</tbody>
</table>
Bibliography


[5] ISO 14123-2, Safety of machinery - Reduction of risks to health from hazardous substances emitted by machinery — Part 2: Methodology leading to verification procedures

[6] ISO 14159, Safety of machinery — Hygiene requirements for the design of machinery

[7] ISO 14738, Safety of machinery — Anthropometric requirements for the design of workstations at machinery


[10] ISO/TR 23849, Guidance on the application of ISO 13849-1 and IEC 62061 in the design of safety-related control systems for machinery

[11] IEC 60204 (all parts), Safety of machinery — Electrical equipment of machines

[12] IEC 60364-7-729, Low-voltage electrical installations — Part 7-729: Requirements for special installations or locations — Operating or maintenance gangways


[16] IEC 62079, Preparation of instructions — Structuring, content and presentation

[17] EN 563, Safety of machinery — Temperatures of touchable surfaces — Ergonomics data to establish temperature limit values for hot surfaces

[18] EN 1093 (all parts), Safety of machinery — Evaluation of the emission of airborne hazardous substances


6 Under preparation.
[21] EN 1837, Safety of machinery — Integral lighting of machines

[22] EN 12198 (all parts), Safety of machinery — Assessment and reduction of risks arising from radiation emitted by machinery

[23] CEN/TR 14715, Safety of machinery — Ionizing radiation emitted by machinery — Guidance for the application of technical standards in the design of machinery in order to comply with legislative requirements

[24] BGIA/DGUV study — Procedural Guideline for the Arrangement of Workplaces with Collaborative Robots
Bibliography for ANSI/RIA R15.06

The references contained in Part 1 and Part 2 and their respective Bibliographies are references used in the original ISO documents. They are appropriate for compliance with this standard and for conformance with International Standards or when an EU Declaration of Conformity is required.

The following documents (listed alphabetically, not by significance) contain useful information in application of robot systems and some contain similar but not identical information as some of the references in this standard:

ANSI/AIHA Z10; Occupational Health and Safety Management Systems
ANSI/ASME B20.1; Safety Standard for Conveyors and Related Equipment
ANSI/ASSE A1264.1; Safety Requirements for Workplace Walking/Working Surfaces and Their Access; Workplace, Floor, Wall and Roof Openings; Stairs and Guardrails Systems
ANSI/ASSE A1264.2; Standard for the Provision of Slip Resistance on Walking/Working Surfaces
ANSI/ASSE Z244.1; Control of Hazardous Energy – Lockout/Tagout and Alternative Methods
ANSI/ASSE Z490.1; Criteria for Accepted Practices in Safety, Health and Environmental Training
ANSI/ASSE Z590.3; Prevention through Design: Guidelines for Addressing Occupational Risks in Design and Redesign Processes
ANSI/IESNA RP-7-01, Lighting Industrial Facilities (ISO 8995-1)
ANSI/ISO 12100; Safety of Machinery – General principles for design – Risk assessment and risk reduction
ANSI/NEMA Z535.1; Safety colors
ANSI/NEMA Z535.2; Environmental and facility safety signs
ANSI/NEMA Z535.3; Criteria for safety symbols
ANSI/NEMA Z535.4; Product safety signs and labels
ANSI/NEMA Z535.5; Safety tags and barricade tapes (for temporary hazards)
ANSI/NEMA Z535.6; Product safety information in product manuals, instructions, and other collateral materials
ANSI B11.0; Safety of Machinery; General Requirements and Risk Assessment
ANSI B11.19; Performance Requirements for Safeguarding
ANSI B11.20; Safety Requirements for Integrated Manufacturing Systems (ISO 11161)
B11.TR3; Risk Assessment and Risk Reduction – A Guide to Estimate, Evaluate and Reduce Risks Associated with Machine Tools
B11.TR6; Safety Control Systems for Machine Tools (reference for control reliability)
CAN/CSA Z432; Safeguarding of machinery
CAN/CSA Z434; Industrial Robots and Robot Systems – General Safety Requirements
CAN/CSA Z460; Control of Hazardous Energy – Lockout and Other Methods
CAN/CSA Z1002; *Hazard identification and elimination – Risk assessment and control*

NFPA 70E; *Standard for Electrical Safety in the Workplaces*

NFPA 79; *Electrical Standard for Industrial Machinery* \(^7\)

RIA TR15.306; *Risk Assessment Methodology* \(^8\)

RIA TR15.406; *Safeguarding requirements for industrial robot systems* \(^9\)

UL 61496; *Standard for Electro-Sensitive Protective Equipment (all parts) (IEC 61496)*

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\(^7\) References to requirements in IEC 60204-1 used in this standard are identical to requirements in NFPA 79

\(^8\) Under development

\(^9\) Under development