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Robots and robotic devices — Safety requirements for industrial robots —

Part 1: Robots

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

Partie 1: Robots

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Foreword

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

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

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

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

ISO 10218-1 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: Robots*

— *Part 2: Robot systems and integration*

Introduction

ISO 10218 has been created in recognition of the particular hazards that are presented by industrial robots and industrial robot systems.

This part of ISO 10218 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 ISO 10218.

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 ISO 10218 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 ISO 10218. 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, ISO 10218 is divided into two parts. This part of ISO 10218 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, ISO 10218-2 provides guidelines for the safeguarding of personnel during robot integration, installation, functional testing, programming, operation, maintenance and repair.

This part of ISO 10218 has been updated based on experience gained in developing the ISO 10218-2 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 ISO 10218 is not applicable to robots that were manufactured prior to its publication date.

Robots and robotic devices — Safety requirements for industrial robots —

Part 1: Robots

1 Scope

This part of ISO 10218 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 ISO 10218 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 ISO 10218.

This part of ISO 10218 does not apply to non-industrial robots, although the safety principles established in ISO 10218 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 ISO 10218-2.

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*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 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 programme

[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 part of ISO 10218:

— 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 ISO 10218-2.

NOTE 2 Adapted from ISO 8373:1994, definition 2.14.

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
control state that allows for the direct control by an operator

NOTE 1 Sometimes referred to as teach mode where programme 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 Programme

3.16.1
control programme
inherent set of instructions which defines the capabilities, actions, and responses of a robot

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

[ISO 8373:1994, definition 5.1.2]

3.16.2
task programme
set of instructions for motion and auxiliary functions that define the specific intended task of the robot system

NOTE 1 This type of programme 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
programme verification
execution of a task programme for the purpose of confirming the robot path and process performance

NOTE Verification can include the total path traced by the tool centre point during the execution of a task programme 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 programme 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
safety-rated monitored speed function that limits the robot speed to 250 mm/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.

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 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.

3.24.3
safeguarded space
space defined by the perimeter safeguarding

3.25
teach
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 centre 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 of 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 ISO 10218-2.

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 ISO 10218.

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 colour shall meet the requirements of IEC 60204-1.

5.3.4 Labelling

Actuating controls shall be labelled 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 alternative 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 purposes of this part of ISO 10218, safety-related control system performance is stated as:

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

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

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

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

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

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

5.4.2 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.

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.

5.4.3 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 that 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 1 — Comparison of emergency and protective stops

Parameter	Emergency stop	Protective stop
Location of initiation means	Operator has quick, unobstructed access	For protective devices, the location is determined by the minimum (safe) distance formulas described in ISO 13855
Initiation	Manual	Manual, automatic or may be automatically initiated by a safety-related function
Safety-related control system performance	Shall meet performance requirement in 5.4	Shall meet performance requirement in 5.4
Reset	Manual only	Manual or automatic
Use frequency	Infrequent	Variable; from every operation to infrequent
Purpose	Emergency	Safeguarding or risk reduction
Effect	Remove energy sources to all hazards	Safely control the safeguarded hazard(s)

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 the 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 in accordance with IEC 60204-1. The monitored standstill 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 centre 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. It should be possible to select speeds lower than 250 mm/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 labelling are illustrated in Annex E.

5.7.2 Automatic

In automatic mode, the robot shall execute the task programme 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 programme 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 programme 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 can be achieved. This mode is used for programme 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 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 centre-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 inoperative after no more than five minutes after the release of the enabling device.

The option to resume the higher speed and the time-out is 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 programme 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 centre-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 centre-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 centre-enabled position of the enabling device, the enabling device needs to be fully released. Going from fully compressed to the centre 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 centre-enabled position:

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

   2) when the enabling device design allows both switches to be held in the centre-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 centre-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 centre (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 centre-enabled position, a protective stop shall be initiated. The control system shall require that the enabling device be 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 the 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 the 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 in accordance with 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. ISO 10218-2 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. ISO 10218-2 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, 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) 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 programmes 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 travelled 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 programmes 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 programme. 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 travelled 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 programme. 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 centre 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

No.	Type or group	Example of hazards		Clause/ subclause reference
		Origin	Potential consequences	
1	**Mechanical hazards**	— movements (normal or unexpected) of any part of the robot arm (including back) — movements (normal or unexpected) of end-effector or any mobile part of robot cell — movements (normal or unexpected) of external axis — end-effector failure (separation) — movement of end-effector tool at servicing position — unintended movement of machines or robot cell parts during handling operations — materials and products falling or ejection — unintended movement of jigs or gripper — unintended release of tool — unintended movement of associated machine(s) — manipulation of products and materials, including ejection — movement or rotation of sharp tool on end-effector — movement of robot parts — motion of part with sharp edge held by robot — rotation of tool of the end-effector — rotation or movement of associated machine or machine tool in the robot cell — rotational motion of any robot axes — loose clothing, long hair	— crushing — shearing — cutting or severing — entanglement — drawing-in or trapping — impact — stabbing or puncture — friction, abrasion — high-pressure fluid/gas injection or ejection	Clause 4 5.2.1 5.2.3 5.5 5.6 5.7 5.8.4 5.9 5.10 5.11 5.12 5.13 5.14

Table A.1 — List of significant hazards (*continued*)

No.	Type or group	Example of hazards		Subclause reference
		Origin	**Potential consequences**	
		— between robot arm and any fixed object — between end-effector and any fixed object (fence, beam, etc.) — impossibility to go out robot cell (via cell door) for a trapped operator in automatic mode — between fixtures (falling in); between shuttles, utilities — manipulation of products and materials, including ejection — movement or rotation of sharp tool on end-effector or on external axes, part being handled, and associated equipment — unintended motion of an end-effector (process-specific for grinding wheels, etc.) — unintended motion or activation of an end-effector or associated equipment (including external axes controlled by the robot) — unexpected release of potential energy from stored sources		
2	**Electrical hazards**	— contact with live parts or connections — confusion of various voltages within a system — contact with discrete components in the electrical (electronic) circuitry, i.e. capacitors — exposure to arc flash — process using high voltage or high frequency, i.e. electrostatic painting, inductive heating — welding applications using high voltage	— electric shock — burn or scald — inhalation of toxic fume — eye damage by electric spark — influence to pacemaker	Clause 4 5.2.4 5.2.5 5.2.6 5.2.7 5.15
3	**Thermal hazards**	— hot surfaces associated with the end-effector; or associated equipment or workpiece — cold surfaces or objects — explosive atmosphere caused by the process, i.e. paint (atomized particles, powder painting), flammable solvents, grinding and milling dust — exposure to temperature extremes required to support the process	— burns — fire, explosion — radiation from heat sources — inhalation of toxic fumes — dehydration	Clause 4

Table A.1 — List of significant hazards (*continued*)

No.	Type or group	Example of hazards		Subclause reference
		Origin	Potential consequences	
4	**Noise hazards**	— loss of balance, disorientation in working area of robot cell — inability of two persons assigned to a task to coordinate their actions through normal conversation — ambient noise level so high or distracting as to prevent hearing or understanding audible danger warning signals — long-term exposure to elevated noise levels	— effect on the hearing and balance, awareness — effect on speech communication, perception of acoustic signals — loss of hearing	Noise is excluded from the scope of this part of ISO 10218
5	**Vibration hazards**	— loosening of connections, fasteners, components resulting in unexpected stopping or expulsion of parts	— fatigue — neurological damage — vascular disorder	Clause 4 5.2.3
6	**Radiation hazards**	— EMF interference with proper operation of the robot system — exposed to process-related radiation, i.e. arc welding, laser	— burns — illness	Clause 4
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 A.1 — List of significant hazards (*continued*)

No.	Type or group	Example of hazards		Subclause reference
		Origin	Potential consequences	
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 behaviour 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) and become a missile — malfunctions of the control with consequent release of robot arm brake; release of brake causes robot elements 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 components separate or whip about — components improperly installed creating unexpected motion/hazard — high-speed rotational parts breaking or disengaging from part retention equipment — overload of robot arm or associated equipment resulting in breaking or buckling of mechanical components	— 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 A.1 — List of significant hazards (*continued*)

No.	Type or group	Example of hazards		Subclause reference
		Origin	Potential consequences	
		— contacted by process-related expulsion (i.e. spot welding) — part retention device fails — unrestrained robot or associated machine part (maintained in position by gravity) falls or overturns — handling mishaps during commissioning or decommissioning — parts can fall off if not properly attached or installed improperly — insufficient lighting in operator zone or robot cell — obstacles on cell floor — sliding floor — poor location of utilities — specific application hazards		

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 as 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.

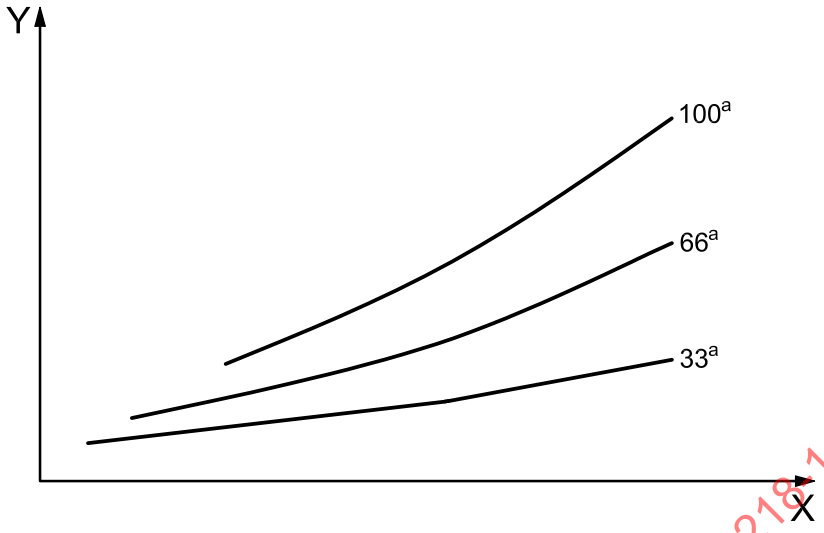
NOTE This data varies depending on additive delays due to control system feature and configuration, i.e. cableless pendants.

The stopping distance shall be determined as the total distance travelled 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 axes 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

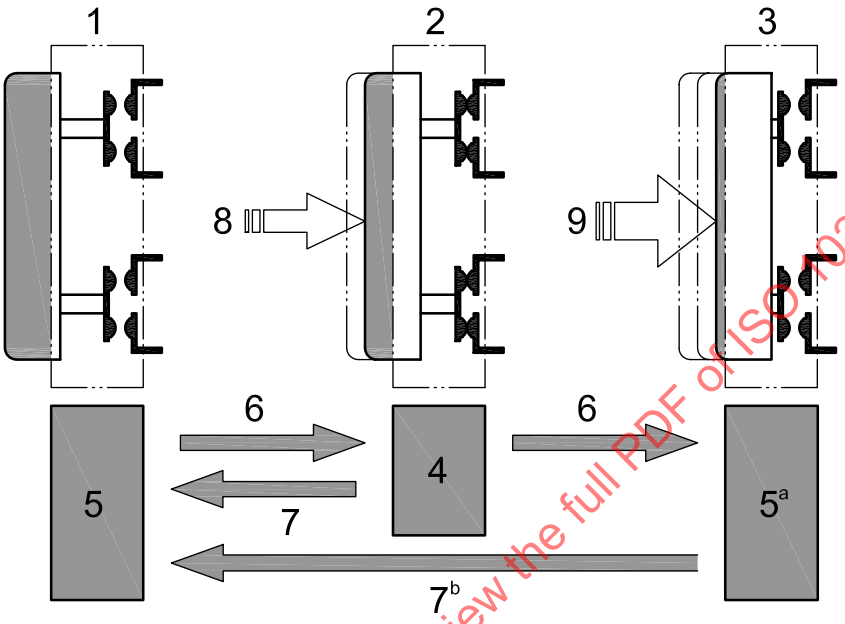
[a] Load, in %.

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 specified 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 reuse, 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);

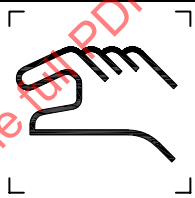
c) set limits for warning when these limits are exceeded.

Annex E
(informative)

Labelling

Table E.1 offers examples of graphical symbols that 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 E.1 — Robot operational mode labels

Subclause	Mode	Graphical symbol	ISO 7000 reference
5.7.2	Automatic		0017
5.7.3	Manual reduced speed		0096

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 validated, or both.

See 6.3 for notes on using this table.

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

Subclause	Applicable safety requirements and/or measures	Verification and/or validation method (see 6.2)						
		A	B	C	D	E	F	G
5.2	**General requirements**							
5.2.1	Fixed or moveable guards are installed to prevent exposure to hazards such as shafts, gears, drive belts, or linkages	X			X			
5.2.1	Fixed guards intended to be removed for routine service have captive hardware		X					X
5.2.1	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		X	X	X	X		
5.2.1	The safety-related control system performance of an interlocking system conforms to 5.4					X		
5.2.2	Loss of, or unstable power does not result in a hazard		X		X	X		
5.2.2	Re-initiation of power does not initiate motion		X		X	X		
5.2.2	Loss or change of electrical, hydraulic, pneumatic or vacuum power does not result in a hazard		X		X			
5.2.2	Additional protective measures are taken to protect against hazards not protected by design	X						X
5.2.2	Unprotected hazards of the expected use are identified in the information for use						X	X
5.2.3	Robot components are designed, constructed, secured, or contained so that hazards caused by breaking or loosening, or releasing stored energy are minimized	X	X		X			
5.2.4	Capability to lock or secure in the de-energized position isolated hazardous energy to the robot	X	X	X		X		
5.2.5	Means provided for the controlled release of stored hazardous energy		X			X		X
5.2.5	A label is affixed to identify the stored energy hazard	X						
5.2.6	Expected effects of electromagnetic interference (EMI), radio frequency interference (RFI) and electrostatic discharge (ESD) do not initiate hazardous motion		X	X		X		
5.2.7	The robot electrical equipment is designed and constructed in accordance with the relevant requirements of IEC 60204-1	X	X			X		X