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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

DRAFT INTERNATIONAL STANDARD

ISO/DIS 10218-2

ISO/TC 299

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Voting terminates on:
2021-03-05

Robotics — Safety requirements for robot systems in an industrial environment —

Part 2:

Robot systems, robot applications and robot cells integration

ICS: 25.040.30

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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.

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

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 299, Robotics.

This second edition cancels and replaces the first edition (ISO 10218-2:2011), which has been technically revised.

The main changes compared to the previous edition are as follows:

- incorporating safety requirements for collaborative applications (formerly, the content of ISO/TS 15066:2016);
- clarifying requirements for functional safety;
- adding requirements for cybersecurity to the extent that it applies.

A list of all parts in the ISO 10218 series can be found on the ISO website.

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

93 Introduction

94 This document has been created in recognition of the hazards that are presented by robots when they are
95 integrated and installed into robot systems, robot applications and robot cells. Part 1 of ISO 10218 addresses
96 robots as partly completed machines, while this document addresses robots integrated into complete
97 machines (systems) for specific applications.

98 This document is a type-C standard according to ISO 12100.

99 This document is of relevance for the following stakeholder groups representing the market players
100 regarding robot safety:

101 — robot manufacturers (small, medium and large enterprises);

102 — robot system/ application integrators (small, medium and large enterprises);

103 — health and safety bodies (regulators, accident prevention organisations, market surveillance, etc).

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

106 — robot system users/employers (small, medium and large enterprises);

107 — robot system users/employees (e.g. trade unions);

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

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

111 Robot systems and robot applications, and the extent to which hazards, hazardous situations and events, are
112 covered are indicated in the Scope of this document.

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

116 Hazards associated with robot systems and robot applications are well recognized, but the sources of the
117 hazards are frequently unique to a robot application. The number and type(s) of hazard(s) are directly
118 related to the nature of the automation process and the complexity of the application. The risks associated
119 with these hazards vary with the robot used, its safety functions, and the way in which it is integrated,
120 installed, programmed, used, and maintained. This document provides requirements for safety in the
121 integration and installation of robots into robot systems and robot applications. The requirements include
122 safeguarding of operators during integration, commissioning, functional testing, programming, operation,
123 maintenance and repair. Requirements for the robot can be found in ISO 10218-1.

124 Both parts of ISO 10218 deal with robotics in an industrial environment, which is comprised of workplaces
125 where the public is excluded or restricted from access because the people (operators) are working adults.
126 Other standards cover such topics as coordinate systems and axis motions, general characteristics,
127 performance criteria and related testing methods, terminology, and mechanical interfaces. It is noted that
128 these standards are interrelated and related to other International Standards.

129 For ease of reading this part of ISO 10218, the words “robot system” and “robot application” refer to
 130 “industrial robot system” and “industrial robot application” as defined in ISO 10218-1 and ISO 10218-2.
 131 “Robot” refers to “industrial robot”.

132 For understanding requirements in this document, a word syntax is used to distinguish requirements from
 133 guidance or recommendations. The word “shall” is used for mandatory requirements to comply with this
 134 document. The word “should” is used to identify guidance, suggestions, recommended actions or possible
 135 solutions for requirements, but alternatives are possible.

136 This document has been updated based on experience gained since the release of ISO 10218-1 and
 137 ISO 10218-2 in 2011. This document remains aligned with minimum requirements of a harmonized type-C
 138 standard for robot systems and robot applications in an industrial environment. Providing for a safe robot
 139 system or application depends on the cooperation of a variety of “stakeholders” – those entities that share
 140 in a responsibility for the ultimate purpose of providing a safe working environment. Stakeholders may be
 141 identified as manufacturers, suppliers, integrators, and users (the entity responsible for using robots), but
 142 all share the common goal of a safe (robot) machine. The requirements in this document can be assigned to
 143 one of the stakeholders but overlapping responsibilities can involve multiple stakeholders in the same
 144 requirements. While using this document, the reader is cautioned that all the requirements identified could
 145 apply to them, even if not specifically addressed by “assigned” stakeholder tasks.

146 It is important to emphasize that the term “collaborative robot” is not used in ISO 10218 as only the
 147 application can be developed, verified, and validated as a collaborative application. In addition, the term
 148 “collaborative operation” is not used in this edition.

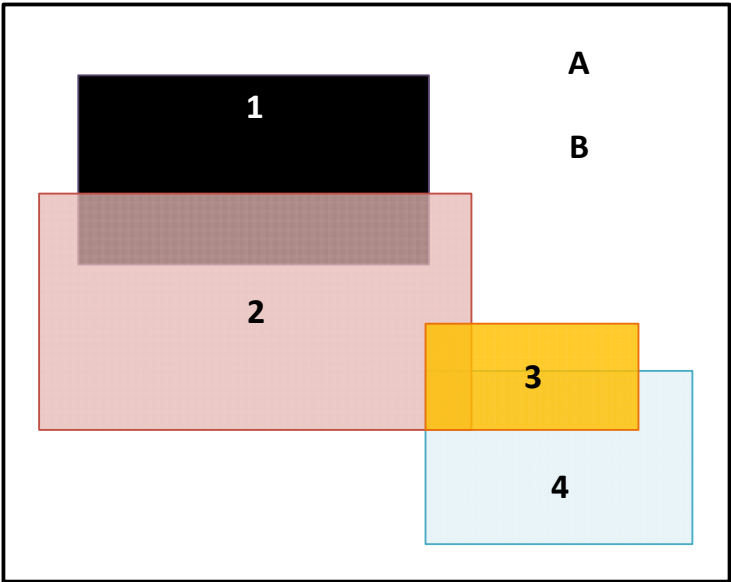
149 Revisions include:

- 150 — category 2 stopping functions;
- 151 — cybersecurity;
- 152 — definitions and abbreviations;
- 153 — details within the information for use clause;
- 154 — functional safety requirements;
- 155 — risk estimation parameters and thresholds;
- 156 — integrating the requirements of
 - 157 ■ ISO/TS 1506:2016 — Robots and robotic devices — Collaborative robots
 - 158 — hand-guided controls (HGC) requirements for collaborative applications;
 - 159 — power and force limiting (PFL) requirements for collaborative applications;
 - 160 — speed and separation monitoring (SSM) requirements for collaborative applications;
 - 161 ■ ISO/TR 20218-1:2018 — Robotics — Safety design for industrial robot systems — Part 1: End-
 162 effectors
 - 163 ■ ISO/TR 20218-2:2017 — Robotics — Safety design for industrial robot systems — Part 2: Manual
 164 load/ unload stations
 - 165 ■ RIA TR R15.806:2018 — A Guide to Testing Pressure and Force in Collaborative Robot Applications
- 166 — marking;
- 167 — mechanical strength and stability requirements;
- 168 — mode selection;
- 169 — power loss requirements;

— risk estimation parameters.

ISO 10218 deals with safety of robotics in an industrial environment. Other standards cover such topics as 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 related to other International Standards.

Figure 1 is a figurative representation of the relationship of machinery safety standards that can be used to support a robot application. The robot (1) is the scope of ISO 10218-1, while the robot system/ application/ cell (2) is covered by this document. A robot cell can include machines subject to their own type-C standards (3). Machines can be integrated into an integrated manufacturing system addressed by ISO 11161 (4). Relevant type-A and -B standards are depicted by A and B in Figure 1.



Key

- 1 robots (ISO 10218-1)
- 2 robot systems/ robot applications/ robot cells (ISO 10218-2)
- 3 machine type-C standards, as applicable
- 4 integrated manufacturing systems (ISO 11161)
- A type-A standard, i.e. ISO 12100 Risk assessment and risk reduction
- B type-B standards, e.g. safety aspects (type-B1) and safety device (type-B2)

Figure 1 — Graphical view of relationships between standards relating to the robot system, robot application and robot cell

Robotics — Safety requirements for robot systems in an industrial environment — Part 2: Robot systems, robot applications and robot cells integration

1 Scope

This document specifies requirements for the integration of industrial robot systems, industrial robot applications and industrial robot cells. The following is addressed:

- the design, integration, commissioning, operation, maintenance, decommissioning and disposal of the industrial robot system, application or cell;
- integration of machines and components to the industrial robot system, application or cell;
- information for use for the design, integration, commissioning, operation, maintenance, decommissioning and disposal of the industrial robot system, application or cell;

This document is not applicable to the following uses and applications:

- underwater;
- law enforcement;
- military (defence);
- airborne and space, including outer space;
- medical;
- healthcare of a person;
- prosthetics and other aids for the physically impaired;
- service robots, which provide a service to a person and as such the public can have access;
- consumer products, as this is household use to which the public can have access;
- lifting or transporting people;
- multi-purpose lifting devices or machinery, e.g. cranes, forklift trucks;
- mobile platforms;
- tele-operated manipulators.

NOTE: Applications for the automation of laboratories are not considered as medical or healthcare of a person.

This document deals with the significant hazards, hazardous situations or hazardous events when used as intended and under specified conditions of misuse which are reasonably foreseeable by the manufacturer.

Robot systems can be used for a broad range of applications and integrated into robot cell(s). Therefore, it is not possible to provide a list of all significant hazards, hazardous situations or events into which a robot and robot application can be integrated. Moreover, same kind of applications can have different levels of risk, resulting from different designs which correspond to the intended application (e.g. paint spraying on large or small parts, handling of a small harmful payload like a hot metal bolt or a large harmless payload like a box of paper tissues).

This document also provides basic requirements for industrial robots used in applications as following, but does not cover the entirely the hazards related to:

- underground use;
- hygienic requirements;
- due to the processing of any material, e.g. food, cosmetics, pharmaceutical, metal;
- nuclear environments;
- potentially explosive environments;
- use of robot systems in environments with hazardous ionizing and non-ionizing radiation levels;
- hazardous ionizing and non-ionizing radiation;
- handling loads the nature of which could lead to dangerous situations (e.g. molten metals, acids/bases, radiating materials);
- when the public or non-working adults have access.

Acoustic noise has been identified to be a significant hazard with industrial robot systems and is included in the scope of this document.

Other standards can be applicable to associated machinery and equipment in robot applications and robot cells.

2 Normative references

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

ISO 3864-1:2011, *Graphical symbols — Safety colours and safety signs — Part 1: Design principles for safety signs and safety markings*

ISO 3864-2:2016, *Graphical symbols — Safety colours and safety signs — Part 2: Design principles for product safety labels*

ISO 3864-3:2012, *Graphical symbols — Safety colours and safety signs — Part 3: Design principles for graphical symbols for use in safety signs*

- 249 ISO 3864-4:2011, *Graphical symbols — Safety colours and safety signs — Part 4: Colorimetric and photometric*
250 *properties of safety sign materials*
- 251 ISO 4413:2010, *Hydraulic fluid power — General rules and safety requirements for systems and their components*
- 252 ISO 4414:2010, *Pneumatic fluid power — General rules and safety requirements for systems and their components*
- 253 ISO 7010:2019, *Graphical symbols — Safety colours and safety signs — Registered safety signs*
- 254 ISO 8995-1:2002, *Lighting of work places — Part 1: Indoor*
- 255 ISO/DIS 10218-1:2020, *Robotics — Safety requirements for robotics in an industrial environment — Part 1:*
256 *robots*
- 257 ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*
- 258 ISO 13732-1:2006, *Ergonomics of the thermal environment — Methods for the assessment of human responses*
259 *to contact with surfaces — Part 1: Hot surfaces*
- 260 ISO 13732-3:2005, *Ergonomics of the thermal environment — Methods for the assessment of human responses*
261 *to contact with surfaces — Part 2: Cold surfaces*
- 262 ISO 13849-1:2015, *Safety of machinery — Safety-related parts of control systems — Part 1: General principles for*
263 *design*
- 264 ISO 13850:2015, *Safety of machinery — Emergency stop — Principles for design*
- 265 ISO 13854:2017, *Safety of machinery — Minimum gaps to avoid crushing of parts of the human body*
- 266 ISO 13855:2010, *Safety of machinery — Positioning of safeguards with respect to the approach speeds of parts of*
267 *the human body*
- 268 ISO 13856-1:2013, *Safety of machinery — Pressure-sensitive protective devices — Part 1: General principles for*
269 *design and testing of pressure-sensitive mats and pressure-sensitive floors*
- 270 ISO 13856-2:2013, *Safety of machinery — Pressure-sensitive protective devices — Part 2: General principles for*
271 *design and testing of pressure-sensitive edges and pressure-sensitive bars*
- 272 ISO 13856-3:2013, *Safety of machinery — Pressure-sensitive protective devices — ISO 13856-2:2013, Safety of*
273 *machinery — Pressure-sensitive protective devices — Part 3: General principles for design and testing of pressure-*
274 *sensitive bumpers, plates, wires and similar devices*
- 275 ISO 13857:2019, *Safety of machinery — Safety distances to prevent hazard zones being reached by upper and*
276 *lower limbs*
- 277 ISO 14118:2017, *Safety of machinery — Prevention of unexpected start-up*
- 278 ISO 14119:2013, *Safety of machinery — Interlocking devices associated with guards — Principles for design and*
279 *selection*
- 280 ISO 14120:2015, *Safety of machinery — Guards — General requirements for the design and construction of fixed*
281 *and movable guards*

- 282 ISO 14122-1:2016, *Safety of machinery — Permanent means of access to machinery — Part 1: Choice of fixed*
283 *means and general requirements of access*
- 284 ISO 14122-2:2016, *Safety of machinery — Permanent means of access to machinery — Part 2: Working platforms*
285 *and walkways*
- 286 ISO 14122-3:2016, *Safety of machinery — Permanent means of access to machinery — Part 3: Stairs, stepladders*
287 *and guard-rails*
- 288 ISO 14122-4:2016, *Safety of machinery — Permanent means of access to machinery — Part 4: Fixed ladders*
- 289 ISO 14738:2002, *Safety of machinery — Anthropometric requirements for the design of workstations at machinery*
- 290 ISO 15534-1:2000, *Safety of machinery — Ergonomic design for the safety of machinery — Part 1: Principles for*
291 *determining the dimensions required for openings for whole-body access into machinery*
- 292 ISO 15534-2:2000, *Safety of machinery — Ergonomic design for the safety of machinery — Part 2: Principles for*
293 *determining the dimensions required for access openings*
- 294 ISO 19353:2005, *Safety of machinery — Fire prevention and protection*
- 295 ISO 20607:2019, *Safety of machinery — Instruction handbook — General drafting principles*
- 296 ISO 20643:2005, *Mechanical vibration — Hand-held and hand-guided machinery — Principles for evaluation of*
297 *vibration emission*
- 298 IEC 60073:2002, *Basic and safety principles for man-machine interface, marking and identification - Coding*
299 *principles for indication devices and actuators*
- 300 IEC 60204-1:2016, *Safety of machinery — Electrical equipment of machines — Part 1: General requirements*
- 301 IEC 60825-1:2014, *Safety of laser products - Part 1: Equipment classification and requirements*
- 302 IEC 61310-1:2007, *Safety of machinery — Indication, marking and actuation — Part 1: Requirements for visual,*
303 *acoustic and tactile signals*
- 304 IEC 61310-2:2007, *Safety of machinery — Indication, marking and actuation — Part 2: Requirements for marking*
- 305 IEC 61310-3:2007, *Safety of machinery — Indication, marking and actuation — Part 3: Requirements for location*
306 *and operation of actuators*
- 307 IEC 61496-1:2012, *Safety of machinery — Electro-sensitive protective equipment — Part 1: General requirements*
308 *and tests*
- 309 IEC 61496-2:2013, *Safety of machinery — Electro-sensitive protective equipment — Part 2: Particular*
310 *requirements for equipment using active opto-electronic protective devices (AOPDs)*
- 311 IEC 61496-3:2018, *Safety of machinery — Electro-sensitive protective equipment — Part 3: Particular*
312 *requirements for active opto-electronic protective devices responsive to diffuse Reflection (AOPDDR)*

313 IEC/TS 61496-4-2:2014, *Safety of machinery — Electro-sensitive protective equipment — Part 4-2: Particular*
 314 *requirements for equipment using vision based protective devices (VBPD) — Additional requirements when using*
 315 *reference pattern techniques (VBPDPP)*

316 IEC/TS 61496-4-3:2015, *Safety of machinery — Electro-sensitive protective equipment — Part 4-3: Particular*
 317 *requirements for equipment using vision based protective devices (VBPD) — Additional requirements when using*
 318 *stereo vision techniques (VBPDST)*

319 IEC 61508-2:2010, *Functional safety of electrical/electronic/programmable electronic safety-related systems —*
 320 *Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems*

321 IEC 62046:2018, *Safety of machinery — Application of protective equipment to detect the presence of persons*

322 IEC 62061:2005 +A1:2012+A2:2015, *Safety of machinery — Functional safety of safety-related electrical,*
 323 *electronic, and programmable electronic control systems*

324 IEC 62745:2017, *Safety of machinery — Requirements for cableless control systems of machinery*

325 IEC/TS 62998-1:2019, *Safety of machinery — Safety-related sensors used for the protection of persons*

326 **3 Terms, definitions and abbreviations**

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

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

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

331 — IEC Electropedia: available at <http://www.electropedia.org/>

332 **3.1 Robot, robot system, robot application, application, collaborative, robot cell**

333 **3.1.1**

334 **industrial environment**

335 workplace where the public is restricted from access or not reasonably expected to be present for the intended
 336 tasks and robot applications (3.1.4)

337 NOTE 1 to entry: This includes manufacturing, laboratory automation/ production, pharmaceutical automation/
 338 production, packing, packaging, palletizing, warehousing, logistics, loading/ unloading and more.

339 **3.1.2**

340 **industrial robot**

341 **robot**

342 automatically controlled, reprogrammable multipurpose manipulator(s) (3.2.5), programmable in three or
 343 more axes (3.2.1), which can be either fixed in place or fixed to a mobile platform (3.2.8) for use in automation
 344 applications in an industrial environment (3.1.1)

345 NOTE 1 to entry: The industrial robot includes:

346 — the manipulator (3.2.5), including robot actuators (3.2.10) controlled by the robot controller;

347 — the robot controller.

348 NOTE 2 to entry: This includes any auxiliary axes that are integrated into the kinematic solution.

349 NOTE 3 to entry: The following are considered industrial robots:

- 350 — the manipulating portion(s) of mobile robots, where a mobile robot consists of a mobile platform (3.2.8) with an
351 integrated manipulator (3.2.5) or robot;
- 352 — robots with hand-guided controls (HGC);
- 353 — robots with power and force limited (PFL) capabilities;
- 354 — robots with built-in speed and separation monitoring (SSM) safety functions (3.10.3).

355 **3.1.3**

356 **industrial robot system**

357 **robot system**

358 machine comprising:

- 359 — industrial robot (3.1.2);
- 360 — end-effector(s) (3.2.2);
- 361 — any end-effector sensors and equipment (e.g. vision systems, adhesive dispensing, weld controller) needed
362 to support the intended task;
- 363 — task program (3.4.1.1)

364 **3.1.4**

365 **robot application**

366 **industrial robot application**

367 a machine comprising:

- 368 — industrial robot system (3.1.3);
- 369 — workpiece(s);
- 370 — any obstacle or object that has influence on the risk assessment of the intended use

371 **3.1.5**

372 **application**

373 intended use and purpose of the robot (3.1.2) or robot system (3.1.3), i.e. the process, the task(s)

374 EXAMPLE: Manipulating, processing, machining, inspection, spot welding, painting, assembly, palletizing.

375 **3.1.6 3.1.5**

376 **collaborative application**

377 an application (3.1.5) that contains one or more collaborative task(s) (3.1.7)

378 NOTE 1 to entry: Collaborative applications (3.1.6) can include collaborative tasks (3.1.7) and non-collaborative tasks.

379 **3.1.7**

380 **collaborative task**

381 a portion of the robot sequence where both the robot application (3.1.4) and operator(s) (3.9.2) are within the
382 same safeguarded space (3.11.1.4)

3.1.8**industrial robot cell****robot cell**

one or more robot applications (3.1.4) including associated:

- machinery and equipment;
- safeguarded space(s) (3.11.1.4);
- safeguards (3.14)

3.2 Robot, robot system, robot application – sub-assemblies and components**3.2.1****axis**

actuated (e.g. rotating about a pivot, linear) mechanical joint that provides at least one degree of freedom

3.2.2**end-effector**

device specifically designed for attachment to the mechanical interface (3.2.7) to enable the robot (3.1.2) to perform its task

EXAMPLE: Gripper, welding gun, spray gun.

NOTE 1 to entry: End-effectors are sometimes known as end-of-arm tooling (EOAT).

3.2.2.1**gripper**

end-effector (3.2.2) designed for seizing and holding workpieces

NOTE 1 to entry: Various types of grippers and the terms grip, grasp, grasping and releasing are defined in ISO 14539:2000.

[Source: ISO 14539:2000, definition 4.1.2. Modified with addition of the note.]

3.2.3**fixture**

device used to hold in position an item as part of the handling or assembling process in a robot application (3.1.4), but not as an end-effector (3.2.2)

3.2.4**manual load/unload station**

part of the robot application (3.1.4) designed for the direct manual intervention for the placement and removal of parts or workpieces for processing by the robot system (3.1.3)

3.2.5**manipulator**

mechanism consisting of an arrangement of segments, jointed or sliding relative to one another

NOTE 1 to entry: A manipulator (3.2.5) includes robot actuators (3.2.10).

3.2.6**mass per manipulator (*M*)**

mass of all moving parts of the robot (3.1.2)

- 420 **3.2.7**
421 **mechanical interface**
422 end-effector (3.2.2) mounting surface at the end of the manipulator (3.2.5) to which the end-effector (3.2.2) is
423 attached
- 424 **3.2.8**
425 **mobile platform**
426 assembly of the components which enables locomotion and provides the structure by which to affix a
427 manipulator (3.2.5) or robot (3.1.2)
- 428 **3.2.9**
429 **payload**
430 payload is the mass of all that is attached to the manipulator (3.2.5), including the end-effector (3.2.2) and
431 workpiece. The payload can be, but is not limited to, the payload attached to the mechanical interface (3.2.7) of
432 the robot (3.1.2).
- 433 **3.2.10**
434 **robot actuator**
435 powered mechanism that converts energy to effect motion
- 436 NOTE 1 to entry: Energy can be electrical, hydraulic, pneumatic or more.
- 437 **3.2.11**
438 **tool centre point (TCP)**
439 point defined for a given application with regard to the mechanical interface (3.2.7) coordinate system
- 440 NOTE 1 to entry: The TCP setting defines the location of the TCP relative to the mechanical interface (3.2.7).
- 441 **3.3 Controls**
- 442 **3.3.1**
443 **control station**
444 part of the robot cell (3.1.8) or application (3.1.5), which contains one or more control devices intended to
445 activate or deactivate functions of the application (3.1.5) or parts of the application (3.1.5)
- 446 NOTE 1 to entry: The control station (3.3.1) can be fixed in place, e.g. control panel or can be movable (pendant (3.3.1.1)
447 which is also referred to as a portable control station).
- 448 NOTE 2 to entry: The portable or hand-held control station (3.3.1.1) for a robot (3.1.2) is referred to as a teach
449 pendant (3.3.1.2).
- 450 **3.3.1.1**
451 **pendant**
452 hand-held control station (3.3.1)
- 453 NOTE 1 to entry: Teach pendant (3.3.1.2) refers to a pendant can program, move or actuate a robot (3.1.2).

3.3.1.2**teach pendant**

hand-held control station (3.3.1) linked to the robot controller with which a robot (3.1.2) can be programmed, moved, or actuated

NOTE 1 to entry: The teach pendant can be integrated to also be linked to the end-effector (3.2.2) and other parts of the robot application (3.1.4).

3.3.2**local control**

state of the system or portions of the system in which operation is effected from the control station (3.3.1) or teach pendant (3.3.1.2) of the individual machine(s) or portions of the machine(s)

3.3.3**single-point-of-control**

ability to operate the robot (3.1.2) such that initiation of robot motion is only possible from one source of control and cannot be overridden from another initiation source

3.3.4**span-of-control**

predetermined portion of the robot (3.1.2), robot system (3.1.3), robot application (3.1.4) robot cell (3.1.8) or machinery that is under control of a specific device for a safety function (3.10.3)

NOTE 1 to entry: Protective devices (3.55) and emergency stop devices could initiate a stop of a machine, a portion of a machine, or an incomplete machine, i.e. a robot (3.1.2).

3.3.5**simultaneous motion**

motion, of two or more robots (3.1.2) at the same time under the control of a single control station (3.3.1), which can be coordinated or can be synchronous

NOTE 1 to entry: A teach pendant (3.3.1.2) is an example of a single control station (3.3.1).

3.3.6**mode****operating mode**

characterization of the way and the extent to which the operator (3.9.2) intervenes in the control equipment

NOTE 1 to entry: In the context of this standard, mode refers to the control state of the robot (3.1.2), e.g. automatic mode (3.38.2), manual (3.38.1).

3.3.6.1**manual mode**

control state that allows for the direct control by an operator (3.9.2)

NOTE 1 to entry: Sometimes referred to as teach mode where program points and robot attributes are set.

3.3.6.2**automatic mode**

control state that allows executing programmed tasks

492 **3.4 Program-related**

493 **3.4.1.1**

494 **task program** (*noun*)

495 set of instructions for motion and auxiliary functions that define the specific intended task of the robot system
496 (3.1.3)

497 NOTE 1 to entry: This type of program is generated by the integrator (3.16) or user (3.18).

498 NOTE 2 to entry: The task program can include functions of other machinery within the robot application (3.1.4).

499 **3.4.2**

500 **task programming** (*verb*)

501 **teach** (*verb*)

502 programming of the task performed by

503 a) manually by lead-through; or

504 b) using a teach pendant (3.3.1.2) to move the robot (3.1.2) through the desired positions; or

505 c) using hand-held device to program without causing motion; or

506 d) remote generation of instructions

507 **3.4.3**

508 **program verification** (*noun*)

509 execution of a task program (3.4.1.1) for confirming the robot path and process performance

510 NOTE 1 to entry: Verification can include the total path traced by the tool centre point during the execution of a task
511 program (3.4.1.1) or a segment of the path. The instructions can be executed in a single instruction or continuous
512 instruction sequence. Verification is used in new applications (3.1.5) and in fine-tuning/editing of existing ones.

513 **3.5 Contact-related**

514 **3.5.1**

515 **body model**

516 representation of the human body consisting of individual body segments characterized by biomechanical
517 properties

518 **3.5.2**

519 **compliant**

520 exhibiting deformation of material or mechanism when subjected to a force; the reciprocal of stiff; e.g.,
521 compliant linkage, compliant surface

522 **3.5.3**

523 **quasi-static contact**

524 contact to an operator (3.9.2) from moving part(s) of an application (3.1.5), where the body part can be clamped
525 between a moving part of the application (3.1.5) and another fixed or moving part of the application (3.1.5)

526 NOTE 1 to entry: This includes contact 3.9.2 from the manipulator (3.2.5), moving parts attached to the manipulator (e.g.
527 cables, hoses), end-effector (3.2.2), and workpiece.

3.5.4**transient contact**

brief contact to an operator (3.9.2) from moving part(s) of an application (3.1.5) where the body part is not clamped and can recoil or retract from the moving part of the application (3.1.5)

NOTE 1 to entry: This includes contact from the manipulator (3.2.5), moving parts attached to the manipulator (e.g. cables, hoses), end-effector (3.2.2), and workpiece.

3.6 Power**3.6.1****drive power**

energy source or sources enabling the robot actuators (3.2.10) to apply force or torque

3.6.2**energy source**

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

3.7 Hazard-related**3.7.1****hazard**

potential source of harm

NOTE 1 to entry: The term “hazard” can be qualified in order to define its origin (for example, mechanical hazard, electrical hazard) or the nature of the potential harm (for example, electric shock hazard, cutting hazard, toxic hazard, fire hazard).

NOTE 2 to entry: The hazard envisaged by this definition either

- is permanently present during the intended use of the machine (for example, motion of hazardous moving elements, electric arc during a welding phase, unhealthy posture, noise emission, high temperature), or
- can appear unexpectedly (for example, explosion, crushing hazard as a consequence of an unintended/unexpected start-up, ejection as a consequence of a breakage, fall as a consequence of acceleration/deceleration).

[Source ISO 12100:2010, 3.6, modified by deletion of note 3]

3.7.2**hazardous motion**

motion that can cause personal physical injury or damage to health

3.7.3**hazardous situation**

circumstance in which a person is exposed to at least one hazard (3.7.1)

NOTE 1 to entry: The exposure can result in harm immediately or over a period of time.

[SOURCE: ISO 12100:2010, 3.10.]

3.8**integration**

act of combining a robot (3.1.2) with an end-effector (3.2.2) and other equipment or another machine including additional robot systems (3.1.3) to form a robot application (3.1.4) capable of performing useful work such as production of parts

566 NOTE 1 to entry: This act of machine building can include the requirements for the installation of the machinery and
567 equipment associated with the application (3.1.5).

568 3.9 Roles

569 3.9.1

570 integrator

571 entity that designs, provides, or assembles robot systems (3.1.3), robot applications (3.1.4), or robot cells (3.1.8)
572 and oversees the safety strategy, including the protective measures, control interfaces and interconnections of
573 the control system(s)

574 NOTE 1 to entry: The integrator can be a manufacturer, assembler, engineering company or the user (3.9.3).

575 3.9.2

576 operator

577 person or persons using, operating, adjusting, maintaining, cleaning, repairing, troubleshooting, transporting,
578 commissioning and disassembling

579 NOTE 1 to entry: This definition includes person or persons that can be expected at or near machinery, even if not
580 performing a task associated with the specific machinery.

581 3.9.3

582 user

583 entity that uses robot applications (3.1.4) and robot cells (3.1.8) and is responsible for the operator(s) (3.9.2)
584 associated with the robot applications (3.1.4) and robot cells (3.1.8)

585 3.10 Functional safety-related

586 3.10.1

587 safe state

588 state of the Equipment Under Control (EUC) when safety is achieved

589 NOTE 1 to entry: In going from a potentially hazardous condition to the final safe state, the EUC may have to go through a
590 number of intermediate safe states. For some situations, a safe state exists only so long as the EUC is continuously
591 controlled. Such continuous control may be for a short or an indefinite period of time.

592 [SOURCE: IEC 61508-4:2010, 3.1.13, modified]

593 3.10.2

594 protective stop

595 type of interruption of operation that causes a cessation of motion for protective and safeguarding purposes
596 and which retains the information of the state of the robot (3.1.2), including its program, to facilitate a restart

597 NOTE 1 to entry: This type of stop can also apply to the robot system (3.1.3), robot application (3.1.4) and other machinery
598 and sub-assemblies.

- 599 **3.10.3**
 600 **safety function**
 601 function of the machine whose failure can result in an immediate increase of the risk(s)
- 602 [SOURCE: ISO 12100:2010, 3.30 and ISO 13849-1:2015, 3.1.20]
- 603 **3.10.3.1**
 604 **monitored-standstill**
 605 safety function (3.10.3) that monitors a condition where the robot (3.1.2) is stopped with drive power active
- 606 NOTE 1 to entry: In ISO 10218-2:2011, this type of stop was called “safety-rated monitored stop”.
- 607 NOTE 2 to entry: This safety function (3.10.3) can also apply to the robot system (3.1.3), robot application (3.1.4), robot
 608 cell (3.1.8) and other machinery.
- 609 **3.10.3.2**
 610 **monitored-speed**
 611 safety function (3.10.3) that limits the speed to a configured value
- 612 NOTE 1 to entry: This safety function (3.10.3) can also apply to the robot system (3.1.3), robot application (3.1.4), robot
 613 cell (3.1.8) and other machinery.
- 614 **3.10.3.3**
 615 **reduced-speed**
 616 safety function (3.10.3) that limits the speed to be no greater than 250 mm/s
- 617 NOTE 1 to entry: This safety function (3.10.3) can also apply to the robot system (3.1.3), robot application (3.1.4), robot
 618 cell (3.1.8) and other machinery.
- 619 **3.10.3.4**
 620 **soft axis and space limiting**
 621 **soft limit**
 622 safety function(s) (3.10.3) with monitored limit(s) placed on the range of motion of the robot (3.1.2)
- 623 **3.10.3.5**
 624 **soft axis and space limiting output**
 625 **soft limit output**
 626 safety function output (3.10.3.6) of the state of the robot position relative to a soft axis or space limiting
 627 (3.10.3.4) safety function (3.10.3)
- 628 NOTE 1 to entry: For example, the robot position can be inside or outside the limit(s) of the soft axis and space limiting
 629 (3.10.3.4) safety function(s) (3.10.3).
- 630 **3.10.3.6**
 631 **safety function output**
 632 output signal having a specified safety-related performance
- 633 **3.10.3.7**
 634 **safety function input**
 635 input signal having a specified safety-related performance

636 **3.11 Space and zone related**

637 **3.11.1**

638 **space**

639 three-dimensional volume

640 NOTE 1 to entry: In the context of ISO 10218-1, space refers to the robot (3.1.2).

641 NOTE 2 to entry: In the context of ISO 10218-2, space refers to either the robot system (3.1.3) or robot application (3.1.4).

642 NOTE 3 to entry: See Annex B for illustrations of spaces.

643 **3.11.1.1**

644 **maximum space**

645 space (3.11.1) that can be reached by the moving parts of the robot (3.1.2)

646 NOTE 1 to entry: In the context of ISO 10218-1, maximum space refers to the robot (3.1.2).

647 NOTE 2 to entry: In the context of ISO 10218-2, maximum space refers to either the robot system (3.1.3) or robot
648 application (3.1.4).

649 NOTE 3 to entry: In the context of mobile platforms (3.2.8), maximum space is indeterminate.

650 **3.11.1.2**

651 **operating space**

652 portion of the restricted space (3.11.1.3) that is used while performing all motions commanded by the task
653 program (3.4.1.1)

654 NOTE 1 to entry: In the context of ISO 10218-1, operating space refers to the robot (3.1.2).

655 NOTE 2 to entry: In the context of ISO 10218-2, operating space refers to either the robot system (3.1.3) or the robot
656 application (3.1.4).

657 **3.11.1.3**

658 **restricted space**

659 portion of the maximum space (3.11.1.1) restricted by limiting devices (3.11.1.3.1)

660 NOTE 1 to entry: When the restricted space refers to the robot system (3.1.3), this includes the space (3.11.1) reached by
661 the end-effector (3.2.2), see ISO 10218-2.

662 NOTE 2 to entry: When the restricted space refers to the robot application (3.1.4), this includes the space (3.11.1) reached
663 by the end-effector (3.2.2) and workpiece(s), see ISO 10218-2.

664 **3.11.1.3.1**

665 **limiting device**

666 means that reduces the range of motion to a portion of the maximum space (3.11.1.1), resulting in the restricted
667 space (3.11.1.3)

668 NOTE 1 to entry: The ISO 12100:2012 definition of a limiting device is broader, encompassing more than motion. In
 669 ISO 12100, it is a device that prevents a machine or hazardous machine condition(s) from exceeding a designed limit (space
 670 limit, pressure limit, load moment limit, etc.).

671 NOTE 2 to entry: Limiting device(s) can be fulfilled by safety function(s) (3.10.3). See safeguard (3.14).

672 **3.11.1.4**

673 **safeguarded space**

674 the space where safeguards (3.14) are active or where the perimeter safeguard provides protection

675 NOTE 1 to entry: This sometimes refers to the space within perimeter safeguarding. See distance guard (3.14.1), which
 676 provides the examples that a perimeter guard and a tunnel guard are distance guards (3.14.1).

677 NOTE 2 to entry: The safeguarded space can change dynamically.

678 NOTE 3 to entry: This definition applies to Part 2.

679 **3.11.2**

680 **zone**

681 **3.11.2.1**

682 **detection zone**

683 zone within which a specified test piece is detected by the sensitive protective equipment (3.15)

684 NOTE 1 to entry: The detection zone may also be a point, line or plane.

685 NOTE 2 to entry: Adapted from IEC 61496-1:2004, definition 3.4.

686 [SOURCE: ISO 13855:2010, 3.1.8, modified by addition of “sensitive” before “protective equipment”]

687 **3.11.2.2**

688 **hazard zone**

689 any space within and/or around machinery in which a person can be exposed to a hazard (3.7.1)

690 [SOURCE: ISO 12100:2010, 3.11]

691 **3.11.2.3**

692 **task zone**

693 any predetermined space within and/or around the robot application (3.1.4) in which operators (3.9.2) can
 694 perform a specified activity

695 **3.12**

696 **protective separation distance**

697 shortest permissible distance between any moving hazardous part of the robot application (3.1.4) and any
 698 operator (3.9.2)

699 NOTE 1 to entry: This value can be fixed or variable.

700 **3.13**

701 **protective measure:**

702 measure intended to achieve risk reduction, implemented:

703 — by the designer (inherently safe design, safeguarding and complementary protective measures, information
704 for use); and/or

705 — by the user (organization: safe working procedures, supervision, permit-to-work systems; provision and
706 use of additional safeguards; use of personal protective equipment; training).

707 [SOURCE: ISO 12100:2010, 3.19]

708 **3.14**
709 **safeguard**
710 guards or protective devices (3.14.3)

711 NOTE 1 to entry: Protective devices (3.14.3) include a broad range of means by which to reduce or control risks, for
712 example:

713 — interlocking devices for guards,

714 — sensitive protective equipment (SPE) (3.15),

715 — safety functions (3.10.3) that replace a protective device (3.14.3), e.g. limiting device (3.11.1.3.1) provided by soft axis
716 and space limiting (3.10.3.4),

717 — limiting devices (3.11.1.3.1),

718 — limited movement control device.

719 [Source ISO 12100, 3.26, modified with addition of note 1.]

720 **3.14.1**
721 **distance guard**
722 guard that does not completely enclose a hazard zone (3.11.2.2), but which prevents or reduces access by its
723 dimensions and its distance from the hazard zone (3.11.2.2)

724 EXAMPLES: Perimeter guard or tunnel guard.

725 **3.14.2**
726 **impeding device**
727 any physical obstacle (low barrier, rail, fixture, etc.) which, without totally preventing access to a hazard zone
728 (3.11.2.2), reduces the probability of access to this zone by offering an obstruction to free access

729 [SOURCE: ISO 12100:2010, 3.29]

730 **3.14.3**
731 **protective device**
732 safeguard (3.14) other than a guard

733 NOTE 1 to entry: Examples of types of protective devices include:

734 — **active optoelectronic protective device (AOPD)**: device whose sensing function is performed by optoelectronic
735 emitting and receiving elements detecting the interruption of optical radiation, generated within the device, by an
736 opaque object present in the specified detection zone.

737 NOTE: IEC 61496 gives detailed provisions.

- **enabling device**: additional manually operated device used in conjunction with a start control and which, when continuously actuated, allows a machine to function.
- **hold-to-run control device**: control device which initiates and maintains machine functions only as long as the manual control (actuator) is actuated.
- **interlocking device (interlock)**: mechanical, electrical or other type of device, the purpose of which is to prevent the operation of hazardous machine functions under specified conditions (generally as long as a guard is not closed).
- **limiting device** (3.11.1.3.1): device which prevents a machine or hazardous machine condition(s) from exceeding a designed limit (space limit, pressure limit, load moment limit, etc.).
- **limited movement control device**: control device, a single actuation of which, together with the control system of the machine, permits only a limited amount of travel of a machine element.
- **mechanical restraint device**: device which introduces into a mechanism a mechanical obstacle (for example, wedge, spindle, strut, scotch) which, by virtue of its own strength, can prevent any hazardous movement.
- **sensitive protective equipment (SPE)** (3.15): equipment for detecting persons or parts of persons which generates an appropriate signal to the control system to reduce risk to the persons detected.

NOTE: The signal can be generated when a person or part of a person goes beyond a predetermined limit — for example, enters a hazard zone (3.11.2.2) — (tripping) or when a person is detected in a predetermined zone (presence sensing), or in both cases.

- **two-hand control device**: control device which requires at least simultaneous actuation by both hands in order to initiate and to maintain hazardous machine functions, thus providing a protective measure only for the person who actuates it.

NOTE: ISO 13851 gives detailed provisions.

[SOURCE: ISO 12100:2010, 3.18]

3.15

sensitive protective equipment (SPE)

equipment for detecting persons or parts of persons which generates an appropriate signal to the control system to reduce risk to the persons detected

[Source ISO 12100:2010, 3.28.5]

3.15.1

presence-sensing device (PSD)

sensitive protective equipment that creates a sensing field, area or plane for detecting the presence of a body part or the whole of a person

NOTE 1 to entry: Pressure-sensitive protective devices can be used as tripping devices as well as presence-sensing devices, as mentioned in ISO 12100:2010, NOTE: to 3.28.5.

[Source ISO 13856-3:2013, 3.2]

3.15.2

electro-sensitive protective equipment (ESPE)

assembly of devices and/or components working together for protective tripping or presence-sensing purposes and comprising at a minimum:

- a sensing device,

778 — controlling/monitoring devices,

779 — output signal switching devices

780 [Source ISO 13855:2010, 3.1.4 and IEC 61496-1:2004, 3.5]

781 **3.15.2.1**

782 **pressure-sensitive protective device (PSPD)**

783 sensitive protective equipment of the “mechanically activated trip” type intended to detect the touch of a person
784 or body part of a person and which can also act as impeding device (3.11.1.3.1)

785 NOTE 1 to entry: A pressure-sensitive protective device consists of a sensor or sensors, which generates a signal when
786 pressure is applied to part of its outer surface, and a control unit, which responds to the signal from the sensor and
787 generates an output signal(s) to the control system of a machine.

788 NOTE 2 to entry: Pressure-sensitive protective devices can be used as tripping devices as well as presence-sensing devices,
789 as mentioned in ISO 12100:2010, NOTE: to 3.28.5.

790 NOTE 3 to entry: For the definitions of sensitive protective equipment (3.15) and impeding device (3.14.2), see
791 ISO 12100:2010, 3.28.5 and 3.29, respectively.

792 [Source ISO 13856-3:2013, 3.1]

793 **3.16 Verification and validation**

794 **3.16.1**

795 **validation**

796 confirmation, through the provision of objective evidence, that the requirements for a specific intended use or
797 application (3.1.5) have been fulfilled

798 NOTE 1 to entry: Validation determines if the specification accomplishes what was intended, e.g. that a specified limit is
799 acceptable for its purpose. Validation includes functional testing and fault insertion

800 [Source: ISO 9000:2015, 3.8.13, modified with addition of the note]

801 **3.16.2**

802 **verification**

803 confirmation, through the provision of objective evidence, that specified requirements have been fulfilled

804 NOTE 1 to entry: Verification determines if the design meets its specification, e.g. that a measurement is less than the
805 specified limit.

806 [Source ISO 9000:2015, 3.8.12, modified with addition of the note]

807 3.17

808 Abbreviations

Symbol or Abbreviation	Term	Definition or occurrence			
		Reference	Table	Figure	Equation
A	Surface area (2-dimensional) of contact	M.1, M.2, M.3.4		M.2	M.1, M.5, M.6
A	Avoidability	C.2.1.4.1	C.7, C.8		
A1	Avoidable	C.2.1.4.1, C.2.2	C.7, C.8, E.1, E.4		
A2	Reasonably avoidable	C.2.1.4.1, C.2.2	C.7, C.8, E.1, E.4		
A3	Not avoidable	C.2.1.4.1, C.2.2	C.7, C.8, E.1, E.4		
AIS	Abbreviated Injury Scale	M.3.1	M.3 footnote b		
AIS 1	Abbreviated Injury Scale 1	M.3.1	M.3 footnote b		
AOPD	Active Opto-electronic Protective Device	3.14.3, 5.8.5.1, J.2.7		J.3, J.7, K.3	J.3, J.7, K.3
AOPDDR	Active Opto-electronic Protective Devices Responsive to Diffuse Reflection	3.14.3, 5.8.5.1, J.2.7, J.2.8, K.2.3		J.6, K.4	J.6, K.4
AP	Possibility of avoidance	C.2.1.4.1, C.2.1.4.2, C.2.1.4.4, C.2.4.2, C.2.4.2.2	C.6, C.7		
Av	Probability of avoiding or limiting harm	C.2.2, E.2.2	C.8, E.2, E.3		E.1
Av1	Probability of avoiding or limiting harm 1	C.2.2	C.8		
Av3	Probability of avoiding or limiting harm 3	C.2.2	C.8		
Av5	Probability of avoiding or limiting harm 5	C.2.2	C.8		
C	intrusion distance	L	L.1	L.1	L.1
Cat	Category	5.5.3, C.1, E.2.1	D.1, E.1, E.4		
CL	Claim Limit (of a SIL)	E.2.2	E.2, E.3		E.1
D	Distance	L	L.1	L.1	
D	Dominant body side	M	M.3		
D	Duration of a single exposure in minutes	C.2.1.3.4			C.1
DL	Harm/ damage likelihood	C.2.1.3.5.4, C.2.3.4	C.5		
E	Transfer energy	M	M.5		M.1, M.2
E	Resulting exposure value	C.2.1.3.4			C.1
E0	Exposure prevented	C.2.2, E.2.3	C.8		
E1	Low exposure to hazard	C.2.1.3.2, C.2.2	C.8, E.4		

Symbol or Abbreviation	Term	Definition or occurrence			
		Reference	Table	Figure	Equation
E2	High exposure to hazard	C.2.1.3.2, C.2.2	C.8, E.4		
EMC	Electromagnetic Compatibility	5.5.9			
EOAT	End-Of-Arm Tooling	3.29			
ESPE	Electro-sensitive Protective Equipment	3.56.2, 5.8.6.1, 5.12.3, I.4.2, J.2.5, K.1, K.2.3			I.2, K.3
EUC	Equipment Under Control	3.43			
F	Frequency	C.2.1.3.4			E.1
F1	Frequency 1	C.2.2	C.8		
F2	Frequency 2	C.2.2	C.8		
Fr	Frequency and duration of exposure	E.2.2	E.2, E.3		E.1
Fr3	Frequency and duration of exposure 3	C.2.2	C.8		
Fr5	Frequency and duration of exposure 5	C.2.2	C.8		
F_{max}	Threshold force, quasi-static contact	M, N.2.4.6	Table M. 3	N.7	M.1, M.6
F_T	Threshold force, transient contact (multiplier of quasi-static force)	M, N.2.4.6	Table M. 3	N.7	M.2, M.5
F_{SA}	Actual maximum force, quasi-static contact	N.2.4.6		N.7	
F_{TA}	Actual maximum force, transient contact	N.2.4.6		N.7	
F_{Trig}	Trigger force	N.2.4.6			
H	Hour	C	C.3		
HFT	Hardware Fault Tolerance	5.5.2, 5.5.3, D	D.1		
HGC	Hand-Guided Control	Introduction, 3.1.2, 4.3.1, 5.5.7.2, 5.13.5, 5.13.5.1, 5.13.5.2, I.2.2.2, I.4.1, ,		I.1	
HP	Hazard perception	C.2.1.4.2, C.2.1.4.4, C.2.4.2, C.2.4.2.2	C.6, C.7		
I/O	Input(s)/Output(s)	D	D.2, F.1		
IH	Incident history	C.2.1.3.5.4, C.2.3.4	C.5		
IMS	Integrated manufacturing system	5.3.1, 5.3.3, 5.3.5,			
K	Effective spring constant for a specific body region	M	M.4		M.1, M.2, M.5, M.6
K1	Hardness of damping material	N.1.5	N.1		
K2	Spring constant stiffness	N.1.5	N.1		

Symbol or Abbreviation	Term	Definition or occurrence			
		Reference	Table	Figure	Equation
M	Total mass of moving parts of the robot (manipulator)	M		M.3	M.4
Min	Minute	C	C.3		
m_H	Effective mass of the human body region and the effects of that body region being connected to other body regions	M	Table M. 4 , N.1	M.2	M.3
m_L	Effective mass of the payload for the robot application (specified maximum payload of the application)	M		M.3	M.6
m_R	Effective mass of the robot system as a function of robot posture and motion	M	M.6	M.2, M.4	M.3, M.4
ND	Non-dominant body side	M	M.3		
n_{op}	Mean number of annual operations	D	D.2		
Nr	Factor for the number of persons exposed	C.2.1.3.4			C.1
O1	Probability of occurrence – low	C.2.1.3.5.1, C.2.3.1, C.2.2 E.2.1	C.5 C.8 E.1		
O2	Probability of occurrence – medium	C.2.1.3.5.1, C.2.3.1, C.2.2 E.2.1	C.5 C.8 E.1		
O3	Probability of occurrence – high	C.2.1.3.5.1, C.2.3.1, C.2.2 E.2.1	C.5 C.8 E.1		
OS	Operator skill / information	C.2.1.4.2, C.2.14.2.2, C.2.1.4.4	C.6, C.7		
P_{max}	Threshold pressure, quasi-static contact	M, N.2.4.6	Table M. 3	N.7	M.1, M.6
P_T	Threshold pressure, transient contact (multiplier of quasi-static pressure)	M, N.2.4.6	Table M. 3	N.7	M.2, M.5
P_{SA}	Actual maximum pressure, quasi-static contact	N.2.4.6		N.7	
P_{TA}	Actual maximum pressure, transient contact	N.2.4.6		N.7	
PFH_d	average Probability of dangerous Failure per Hour	D	D.1		
PFL	Power and Force Limiting	Introduction, 3.1.2, 4.3.1, 5.8.1, 5.9.4, 5.13.5.1, 5.13.6.1, 5.13.7, 5.13.7.1, 5.13.5.3, 5.13.7.4, I.4.3, J.1.2.1, M.1, M.1, M.3.2, N.1.1, N.2.1, N.4, N.4.3,	C.1	I.3	

Symbol or Abbreviation	Term	Definition or occurrence			
		Reference	Table	Figure	Equation
PFMD	Pressure and/or Force Measuring Device	N.1.1, N.1.2, N.2.4.2, N.2.4.3, N.2.4.4, N.5.2, N.5.3, N.5.4		N.1, N.2, N.3, N.4	N.1
PL	Performance Level	C.1, D, E.1	C.1, D.1		
PLa	Performance Level a	E.2.1	E.1		
PLb	Performance Level b	E.2.1	E.1		
PLc	Performance Level c	E.2.1	C.1 E.1		
PLd	Performance Level d	E.2.1	C.1, E.1		
PLe	Performance Level e	C.1, E.2.1	E.1		
PL_r	Performance Level required	4.1, E.2.1, E.2.3, I.4.3	E.1, E.4		
Pr	Probability of occurrence of hazardous event	E.2.2	E.2, E.3		E.1
Pr1	Probability of occurrence of hazardous event 1	C.2.2	C.8		
Pr2	Probability of occurrence of hazardous event 2	C.2.2	C.8		
Pr3	Probability of occurrence of hazardous event 3	C.2.2	C.8		
PSD	Presence sensing device	3.56.1, 5.13.6.1			
PSPD	Pressure-sensitive protective device	3.56.3			
P_{Trig}	Trigger pressure	N.2.4.6			
S1	Severity parameter – minor	C.2.1.3, C.2.2, E.2.1	C.2, C.8, E.1, E.4		
S2	Severity parameter – moderate	C.2.1.3, C.2.2, E.2.1	C.2, C.8, E.1, E.4		
S3	Severity parameter – Serious	C.2.1.3, C.2.2, E.2.1	C.2, C.8, E.1, E.4		
S4	Severity parameter – Catastrophic	C.2.1.3, C.2.2, E.2.1	C.2, C.8, E.1		
Se	Severity	E	E.3, C.8		
Se1	Severity 1	C.2.2	C.8		
Se2	Severity 2	C.2.2	C.8		
Se3	Severity 3	C.2.2	C.8		
Se4	Severity 4	C.2.2	C.8		
S_h	Contribution to the protective separation distance attributable to the operator's change in location until the robot application has stopped	L	L.1	L.1	L.1

Symbol or Abbreviation	Term	Definition or occurrence			
		Reference	Table	Figure	Equation
S_p	Protective separation distance	L	L.1	L.1	L.1
S_{pt_0}	Minimum separation time at t_0 (present or current time)	L	L.1	L.1	
S_r	Contribution to the protective separation distance attributable to the robot application reaction time	L	L.1	L.1	L.1, L.4
S_s	Contribution to the protective separation distance that occurs while the robot application is stopping until it stops	L	L.1	L.1	L.6
SIL	Safety Integrity Level	Annex D, E.2.2	D.1, E.2, E.3		
SILCL	Safety Integrity Level (SIL) Claim Limit (for subsystems)	4.1, E.2.2	E.2		E.1
SIL 1	Safety Integrity Level 1	E.2.2	E.3		
SIL 2	Safety Integrity Level 2	E.2.2	E.3		
SIL 3	Safety Integrity Level 3	E.2.2	E.3		
SR	System Robustness	C.2.1.3.5.4	C.5		
SSM	Speed and Separation Monitoring	Introduction, 3.33, 4.3.1, 5.8.1, 5.13.5.1, 5.13.6, 5.13.6.2, I.4.2, L, L.2,	C.1, F.1	I.2	
SPE	Sensitive Protective Equipment	3.51, 3.55, 3.56, 5.8.5.6, Annex B, J.2.1, J.2.2, J.2.4, J.2.7, J.2.8			B.5, B.6, J.3
T	Time	C, L	C.3, L.1	L.1	
T, dt	Time (T) and the differential for the integration variable (dt)	L	L.1	L.1	L.2, L.4, L.6
t_0	Present or current time	L		L.1	L.1
T_r	Reaction time of the robot application, excluding the time for the robot application to come to a stop	L	L.1	L.1	L.2
T_s	Stopping time of the robot application, from the activation of the stop command until the robot application has stopped	L	L.1	L.2	L.2
t_{trig}	Trigger time	N			
TCP	Tool Centre Point	3.32,, 5.1.9, 5.5.3,			
μ	Reduced mass of the two-body system	M			M.2, M.3, M.5, M.6
VBPD	Vision-Based Protective Devices	3.14.3, 5.8.5.1,			
v_h	Directed speed of an operator in the safeguarded space in the direction of the moving part of the robot application	L		L.1	L.2

Symbol or Abbreviation	Term	Definition or occurrence			
		Reference	Table	Figure	Equation
v_r	Directed speed of the robot application in the direction of an operator in the safeguarded space	L		L.1	L.4, L.5
v_s	Speed of the robot application during stopping, from the activation of the stop command until the robot has halted	L		L.1	L.6
v_{rel}	Relative speed between moving parts of the robot application and human body region	M		M.2	M.2, M.5
$v_{rel\ max}$	Maximum relative speed between moving parts of the robot application and human body region	M		M.4	M.6
V_{Ro}	Speed of approach towards a fixed structure	M		M.5	
ω	Rotational speed	M		M.3	
Z_d	Position uncertainty of the operator as measured by the PSD, resulting from the accuracy of the sensing system measurement	L		L.1	L.1
Z_r	Position uncertainty of the robot application, resulting from the accuracy of the robot application position measurement system	L		L.1	L.1

4 Risk assessment

4.1 General

A robot system integrator shall perform a risk assessment in accordance with ISO 12100.

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

NOTE 2: Annex A contains a list of hazards that can be present with robot systems, robot applications, robot cells, including end-effectors and manual load/ unload stations.

NOTE 3: Annex C contains safety function performance requirements with a choice of using the listed performance or performing a risk assessment using the parameters and thresholds of Annex C.2 for risk estimation.

NOTE 4: Annex E contains examples for determining the PLr or SILCL when the risk estimation parameters of Annex C.2 are used. See 5.3.

NOTE 5: See IEC 60812 for information about failure mode effects analysis.

NOTE 6: See Annex C and ISO 14121-2.

The integrator should seek participation of the user when conducting the risk assessment.

4.2 Characteristics of robot systems, robot applications and robot cells

The characteristics of robot systems, robot applications and robot cells can be significantly different from those of other machines and equipment. The risk assessment shall include the following aspects, if relevant:

- a) robot systems and their workpieces are capable of high energy movements through a large space;
- b) the initiation of movement and the path of the robot system are difficult to predict and can vary;

EXAMPLE: Changes and variations can be due to handling of various size parts, changing motion paths based on conditions that are not obvious, and running different program.

- c) the operating space of the robot system and its workpiece(s) can overlap
 - a portion of other robot systems' operating space(s) and their workpiece(s);
 - the task zones for other machines and related equipment;
 - task zones of operators.
- d) end-effector selection and design can be used to reduce risks due to hazards of the end-effector and of workpiece(s).
 - end-effectors interact with workpieces and other parts of the robot application;
 - cleaning and maintenance can require frequent interactions, e.g. extended operator interaction with an adaptive fixture for variable presentation of work piece or assembly;
 - troubleshooting is also a consideration;

NOTE: See 5.9 and Annex I.

- e) robot systems and applications can vary greatly, as will the tasks associated with these uses. Tasks can include:
 - 1) commissioning;
 - 2) process control and monitoring;
 - 3) workpiece loading;
 - 4) performing operations on the workpiece(s);
 - 5) teaching, programming and verification;
 - 6) brief operator intervention not requiring disassembly;
 - 7) set-up (e.g. fixture changes, end-effector exchange, process equipment refresh or adjustment);
 - 8) troubleshooting;
 - 9) correction of malfunction(s) (e.g. equipment jams, dropped parts, event recovery and abnormal conditions);
 - 10) control of hazardous energy (including fixtures, clamps, turntables, and other equipment);

- 11) maintenance and repair;
- 12) equipment cleaning;
- 13) application changes;
- 14) re-deployment of the robot application or robot cell;
- 15) decommissioning;
- 16) disposal.

4.3 Characteristics of collaborative applications

4.3.1 General

In addition to 4.2, the risk assessment of collaborative applications shall include the following aspects, if relevant:

- a) operators can work near the robot system while power to the robot actuators and end-effector(s) are available;

NOTE 1: See 4.2. d).

- b) collaborative applications can use one or more of the following technologies for an application:

- Hand-guiding controls (HGC) (5.13.5);
- Speed and separation monitoring (SSM) (5.13.6);
- Power and force limiting (PFL) (5.13.7).

- b) there is the potential intended or reasonably foreseeable unintended contact situations from the moving parts of the robot application to operator(s);

- c) collaborative applications can have additional tasks to those listed in 4.2e); these collaborative tasks can include the following:

- 1) during production or normal operation, there can be greater frequency and duration of
 - operator presence in the safeguarded space with a moving robot application (e.g. collaborative assembly with external fixtures);
 - contact (e.g. hand guiding, physical interaction with tool or workpiece);
 - operator interaction with the robot application.

- 1) transitioning between non-collaborative and collaborative use;

- 2) automatic or manual restart of motion after the collaborative application has been completed;

3) tasks involving more than one operator.

Operator tasks not associated with the collaborative application could have travel path(s) through a collaborative application's safeguarded space, requiring this additional consideration when determining the collaborative application layout and access requirements.

NOTE 2: See Layout, 5.4. See Annex B for illustrations of spaces, Annex M for collaborative application biomechanical limits and Annex N for pressure and force measurement.

4.3.2 Risk assessment for contacts between moving parts of the robot application and operator(s)

Risk assessment shall consider means by which possible contact shall not result in harm to the operator. This shall be achieved by:

- a) identifying conditions in which such contact would occur;
- b) evaluating the risk potential for such contacts;
- c) designing the robot application and safeguarded space so that such contact is infrequent and avoidable;
- d) applying risk reduction measures to keep the contact situations below threshold limit values.

For the purposes of risk assessment, any such potential contact should consider that the operator is not protected by any risk reduction measures, including personal protective equipment. This identification shall consider the following criteria for potential contact events:

- exposed operator body regions;
- origin of contact events, i.e. intentional action as part of intended use vs. unintentional contact or reasonably foreseeable misuse;
- probability or frequency of occurrence;
- type of contact event, i.e. quasi-static or transient;
- contact surface areas, speeds, forces, pressures, momentum, mechanical power, energy, and other quantities characterizing the physical contact event.

NOTE 1: Mechanical power is the rate of doing work, or the amount of energy consumed per unit time. It does not correspond to the electrical power rating on an electronic device, such as a motor.

Hazards due to sharp, pointed, shearing, or cutting edges, such as needles, shears, or knives, and parts which could cause injury shall not be present in the contact area.

NOTE 2: Suitable housings, covers or separating planes can be used to mitigate potential hazards.

NOTE 3: There can be other hazards besides contact, including process hazards.

Contact exposure to sensitive body regions, including the skull, forehead, larynx, eyes, ears, or face shall be avoided according to 5.13.7.3. If not practicable, guards and/or protective devices shall be applied.

4.3.3 Risk reduction for contact between moving parts of the robot application and operator(s)

Risk reduction measures to address quasi-static and transient contact events are either passive (a) or active (b). Passive safety design measures address the mechanical design of the robot system, whereas active risk reduction measures implement technical aspects including one or more of the following: inherently safe design, safeguarding, and/or safety functions for the application.

a) Passive safety design measures include:

- 1) increasing the contact surface area;
- 2) rounded edges and corners;
- 3) smooth surfaces;
- 4) compliant surfaces to absorb energy, extend energy transfer time, or reduce impact forces:
 - padding, cushioning;
 - deformable components;
- 5) compliant joints or links;
- 6) limiting moving masses.

b) Active risk reduction measures include inherently safe design, safeguarding, and/or use of safety functions that:

- 1) limit forces or torques;
- 2) limit velocities of moving parts;
- 3) use protective devices and /or safety function(s) such as:
 - soft axis and space limiting safety function(s);
 - monitored-standstill safety function(s);
 - protective device(s) implemented to anticipate or detect contact, e.g. proximity or contact detection to reduce forces exerted during contact event(s).

As determined by the application risk assessment, application of protective measures shall address the expected exposure of the operator.

NOTE: A combination of safety functions can be required, e.g. the force limiting safety function can be effective only up to a certain speed limit. In such a case, an additional speed limiting safety function could be necessary.

Any clamping event between the collaborative application and human body regions shall occur in a way such that the operator shall be able to escape independently and easily from the clamping condition.

5 Safety requirements and/or protective/risk reduction measures

5.1 General

Robot applications shall comply with the safety requirements and/or protective/risk reduction measures of this clause. In addition, they shall be designed according to the principles of ISO 12100:2010 for relevant but not significant hazards which are not dealt with by this document.

5.2 Design

The design shall be based on the information for use provided with the robot and the associated machinery and equipment.

Figure 2 shows the organization of clause 5 and how it follows the machine lifecycle as described in ISO 12100.

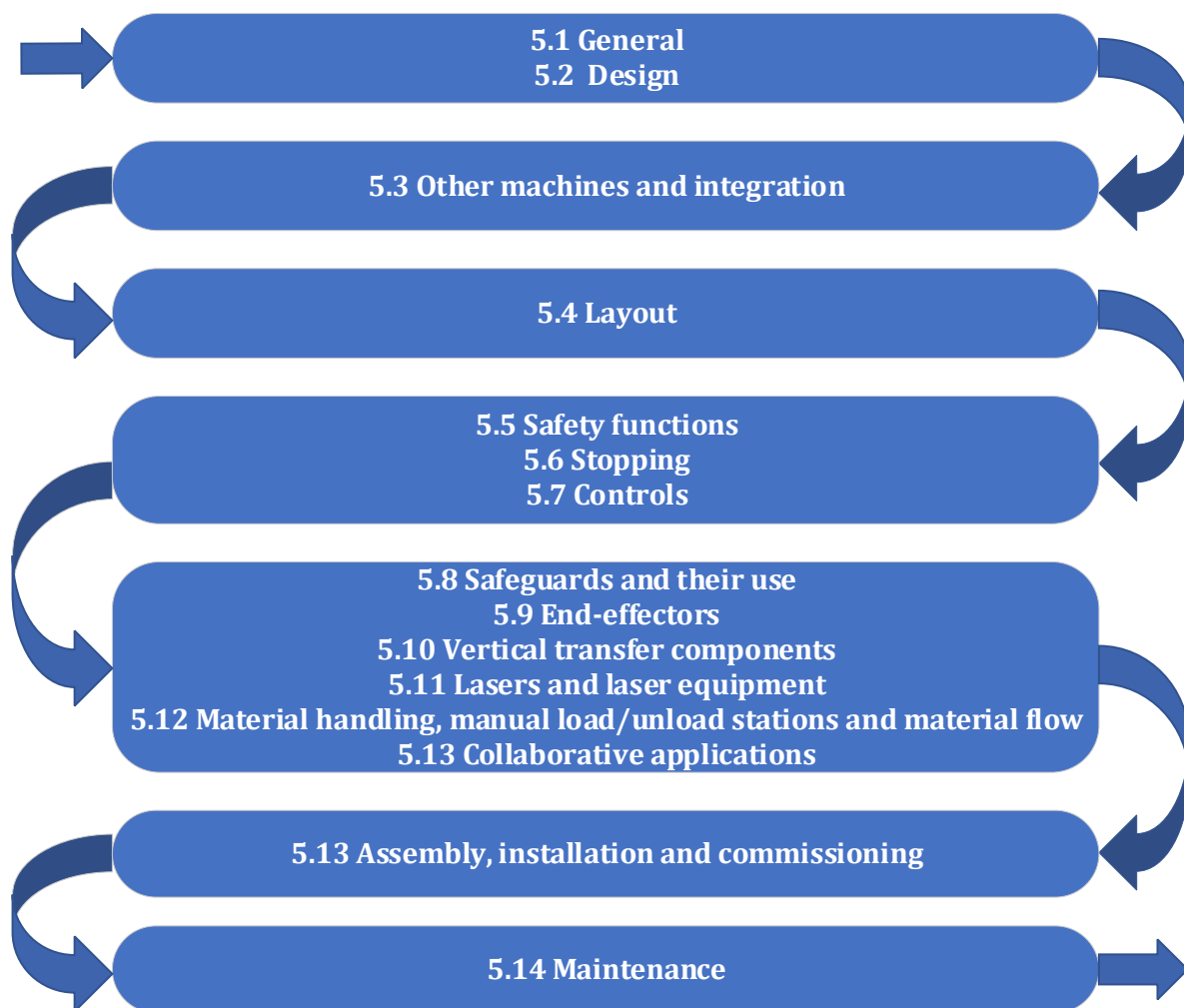


Figure 2 – Clause 5 structure according to the machine lifecycle

NOTE: Methods of verification and validation of the requirements in this clause are in Clause 6 and Annex X.

953 **5.2.1 Materials, mechanical strength and mechanical design**

954 **5.2.1.1 General**

955 Robot systems and applications shall be designed and constructed to prevent hazardous situation(s) which
956 result from failure due to fatigue and wear. Design and construction shall take due account to the lifecycle
957 intended use (e.g. transportation, installation, operating conditions and maintenance in accordance with the
958 Clause 7, information for use).

959 Machinery shall be designed and constructed to take account of the constraints (e.g. protective gloves and
960 control device push button dimensions) to which the operator is subject as a result of the use of personal
961 protective equipment for the intended application.

962 **5.2.1.2 Materials**

963 Materials shall:

- 964 a) be selected to be appropriate for the intended use (e.g. resistance to corrosion, abrasion, impacts, fatigue,
965 deformation, ageing);
- 966 b) not endanger persons' safety or health;
- 967 c) be non-toxic in all reasonably foreseeable conditions of use;
- 968 d) not be prone to emission of toxic or flammable fumes;
- 969 e) retain their properties in the reasonably foreseeable range of climatic and workplace conditions, including
970 temperature variations or sudden changes.

971 Where fluids are used, machinery must be designed and constructed to prevent risks due to filling, use, recovery
972 or draining.

973 **5.2.1.3 Mechanical strength**

974 The parts of the robot application shall be designed and constructed to withstand the loads expected for the
975 intended application and the expected operating conditions.

976 The parts of the robot application involved in lifting operations (e.g. lifting work pieces or tools) shall be
977 designed and constructed to:

- 978 — withstand an overload in static tests without permanent deformation or patent defect, where strength
979 calculations shall have a minimum static test coefficient of 1,25;
- 980 — undergo, without failure, dynamic tests using the maximum payload multiplied by the dynamic test
981 coefficient, where the dynamic test coefficient shall be at least 1,1.

982 Dynamic tests shall be performed at specified speeds. If simultaneous movements can be programmed, the tests
983 shall be done using the least favourable conditions.

Where complete ropes are used for lifting functions, the ropes and their endings shall have a minimum working coefficient of 5. Where chains are used for lifting functions, they shall have a minimum working coefficient of 4.

5.2.1.4 Mechanical design

The parts of the robot application shall be designed and constructed such that

— exposed sharp edges and corners unnecessary for the robot application shall be eliminated; and

— hazardous projections shall be reduced as far as reasonably practicable.

Hazardous mechanisms that enable motion shall be installed or mounted such they are normally inaccessible.

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 according to ISO 14120. The fixing systems of the fixed guards which are intended to be removed for routine service actions shall remain attached to the robot, machine or equipment or remain attached to 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.

Where a risk of rupture or disintegration remains despite the measures taken, the parts concerned must be mounted, positioned and/or guarded in such a way that any fragments will be contained, preventing hazardous situations.

The design shall ensure that errors when fitting or refitting certain parts which could be a source of risk shall be prevented by the design and construction of such parts. If not practicable, information for use shall be provided at least on the parts themselves and/or their housings.

5.2.2 Provisions for lifting or moving

Instructions and provisions for lifting or moving parts of the robot application shall be provided when intended to be moved after initial installation. The provisions shall be capable of handling the anticipated load.

NOTE 1: For the lifting or moving of robots, the information provided by the manufacturer can be sufficient, which could include a specific robot pose.

NOTE 2: The robot system could be transported with parts mounted on the robot, e.g. end-effector, wiring, hoses.

5.2.3 Hazardous substances

Robot applications shall be designed and constructed in such a way that risks of inhalation, ingestion or contact of hazardous materials and substances shall be prevented.

Where the use of hazardous substances cannot be eliminated, the robot application shall be designed such that those substances can be contained, evacuated, precipitated by water spraying, filtered or treated by another effective method.

Where the application does not allow the total enclosure of the substances during normal operation, containment and/or evacuation shall be designed to be effective.

5.2.4 Stability

The parts of the robot systems shall be affixed to the floor or parts of the building structure or shall be stable itself for installation, operation and use such that tipping and falling-over are prevented.

Where components are used that move on rails, they shall be provided with means to prevent derailment when practicable. If risk of derailment persists due to a failure of a rail or of a running component, means shall be provided to prevent the components or workpiece from falling or overturning.

NOTE: The component could be the robot.

5.2.5 Temperature and fire risks

The design of the robot application shall be such that the temperatures of accessible surfaces are according to the ISO 13732 series. Where there is a risk of fire or overheating, the design principles of ISO 19353 shall be applied.

5.2.6 Special equipment

The robot application shall be supplied with the special equipment and accessories to enable it to be adjusted, maintained and used safely.

NOTE: Usual workplace equipment, e.g. ladders, spanners, hexagonal keys, is not considered to be special equipment.

5.2.7 Position holding

When position holding without drive power is required for the application, it shall comply with 5.1.2 of ISO 10218-1. When the position holding means is provided as part of the robot, it shall be implemented in accordance with the robot's information for use.

Hazardous motion of the robot application shall be prevented by position holding when drive power is lost. Position holding can be achieved using mechanical devices (e.g. brakes, pins, or other technology).

Position holding can be provided by a:

a) safety function to prevent hazardous situations whereby operators are crushed or impacted by the robot system and/or workpiece(s), other machines and sub-assemblies.

and/or

b) means to maintain posture and/or position of the robot system and workpiece(s) to prevent hazardous situation(s) and damage of workpiece or robot system.

NOTE 1: When provided by a safety function, the capability of configurable monitored park position(s) can be provided. See Annex O, O.7.1.

NOTE 2: See 5.5.4 for failure or fault detection.

NOTE 3: See 5.2.9 about power loss or change.

Position holding means shall be designed and constructed to withstand an overload during static testing according to 5.2.1.3.

5.2.8 Additional axis (axes)

Additional axes that are associated with lifting or holding a suspended mass, (e.g. machinery, sub-assemblies, equipment, the robot, a payload) shall comply with relevant requirements in this document. When additional axis motion might affect the TCP speed in reduced-speed manual mode, the requirements of 5.5.6.1 shall apply to the additional axes.

If the robot application has additional axis (axes) being operated in coordination with one another, each axis can move at different speeds. Safeguarding and/or safety functions shall be implemented to protect operators from the risks associated with the speed differences.

For calibration or other isolated movements of an additional axis, speeds greater than the reduced-speed are permitted when operators are protected according to 5.7.2.3.3d). It shall not be possible to actuate other axes when an additional axis operates at greater than reduced-speed.

5.2.9 Power loss or change

Loss or change of electrical, hydraulic, pneumatic or vacuum power shall not result in a hazard situation.

Re-initiation of power shall not lead to any hazardous movements or a change of the safety-related parameters.

The robot system, robot application and robot cell shall comply with ISO 14118 to prevent unexpected start-up.

NOTE 1: See IEC 60204-1 for electrical power supply requirements, see ISO 4431 for hydraulics and ISO 4414 for pneumatics requirements.

When the drive power is lost or changes, initiation of hazardous motion of the robot system, machinery and equipment shall be prevented by position holding (5.2.7) .

NOTE 2: See 5.9 for end-effectors.

5.2.10 Component malfunction

Robot application components shall be designed, constructed, secured, or contained so that risks caused by breaking or loosening, or releasing, including those related to stored energy, are prevented as far as practicable.

5.2.11 Hazardous energy

5.2.11.1 General

Hazardous energy can take many forms: kinetic, gravity, pneumatic, hydraulic, thermal, chemical, etc. The sources of these energies can sometimes be readily identified, however often the sources are hidden or not obvious, e.g. accumulators, capacitors, batteries, springs, counterbalances, flywheels, heat as an outcome due to friction or other reactions.

NOTE: This document does not cover hazards associated with nuclear, potentially explosive environments, and radiation. See Scope 1.

5.2.11.2 Control and controlled release of stored energy

Stored energy shall not cause hazardous situation(s). A means shall be provided for the containment and/or controlled release of stored hazardous energy. If the hazardous energy is kinetic (e.g. spring balancer, gas balancer), there shall be a means to secure it in the de-energized position.

Safe release or containment shall be provided in accordance with ISO 14118.

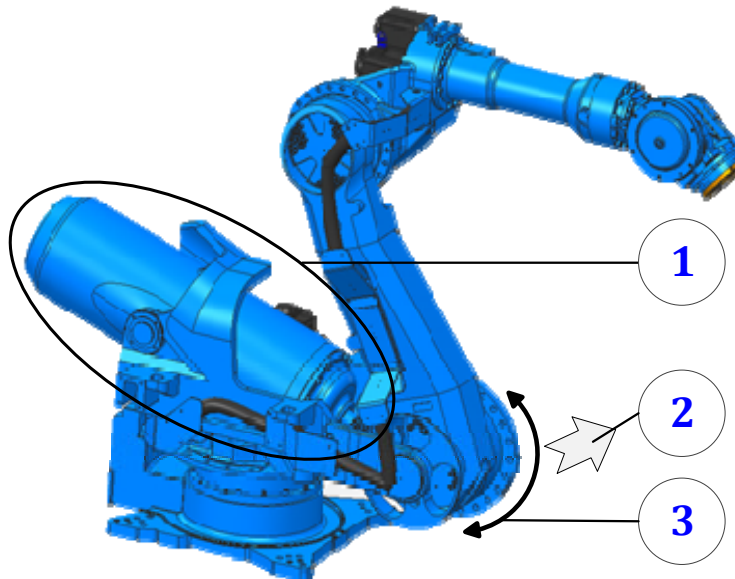
A label shall be affixed to identify the robot system's stored energy hazard.

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

NOTE 2: Axes that do not maintain position (e.g. axis or axes that hang, drop, sink, drift) can create a significant risk depending on the task and frequency or duration of exposure (e.g. standing below the axis (axes) during setting).

Figure 3 shows an example of stored energy in a spring balancer.

EXAMPLE: A hazardous situation can occur when a motor is removed, even though the energy to the robot is isolated as shown in Figure 3. Upon release, the unexpected motion due to the energy in the spring balancer can cause crushing, entrapment and more.



Key

- 1 spring balancer
- 2 motor removal (direction of motion removal)
- 3 motion direction

Figure 3 — Example of stored energy in a spring balancer

1101 5.2.11.3 Isolation of sources

1102 Means of isolating the robot system and robot application from any hazardous energy source shall be provided.
1103 This means shall be provided with capability of locking or otherwise securing only in the de-energized position.

1104 The robot application should have a single supply disconnecting device for each type of energy source (e.g.
1105 electrical, hydraulic, pneumatic). For multiple robot applications and robot cells, multiple disconnecting devices
1106 for each type of energy can be necessary.

1107 Each isolation device shall be readily identifiable as to what it isolates (e.g., by durable marking where
1108 necessary). The span-of-control for each of these devices shall be clearly marked near the disconnecting device
1109 (e.g. text or symbol).

1110 For electrical supply disconnecting devices, clause 5.3.1 of IEC 60204-1:2016 shall apply.

1111 For energy separation and dissipation requirements, ISO 14118 shall apply.

1112 5.2.12 Electrical, pneumatic and hydraulic parts

1113 Electrical parts shall be designed and implemented in accordance with the relevant requirements of
1114 IEC 60204-1.

1115 Pneumatic parts of the robot system and application shall be designed and implemented according to the
1116 relevant requirements of ISO 4414.

1117 Hydraulic parts of the robot system and application shall be designed and implemented according to the
1118 relevant requirements of ISO 4413.

1119 NOTE: For requirements related to specific sub-assemblies, and components and machines, see relevant IEC or
1120 ISO standards, e.g. IEC 60269, IEC 60745, IEC 60947, ISO 13850.

1121 Electric, hydraulic and pneumatic connectors shall be selected to prevent erroneous connections when this
1122 could lead to a hazardous situation. Where this is not practicable connectors shall be labelled to lessen the
1123 likelihood of erroneous connection(s).

1124 5.2.13 Tool Centre Point (TCP) setting

1125 When the capability to enter Tool Centre Point (TCP) settings has been provided in the robot (Part 1, 5.1.9) and
1126 failure to enter these settings can create a hazard, the TCP setting shall be entered in accordance with the robot
1127 information for use.

1128 NOTE: For additional axis requirements, see 5.2.8.

1129 5.2.14 Payload setting

1130 Where the payload setting is provided in the robot (Part 1, 5.1.10) and failure to enter these settings can create
1131 a hazard, the payload setting shall be entered in accordance with the robot information for use.

1132 NOTE: The payload setting can be determined by the robot application.

5.2.15 Cybersecurity

If a cybersecurity assessment of the robot system/ robot application/ robot cell has identified that a threat could result in (safety) risk(s), cybersecurity measures shall be provided to prevent unauthorized access to the control system(s) of robot system(s) and robot application(s), its hardware, software, configuration data and the robot application program.

Cybersecurity measures can include the following:

- securing;
 - network connections (e.g. locking unused Ethernet and USB ports);
 - configuration of communication networks;
- changing default configurations (e.g. usernames, user passwords, IP addresses and safety authentication).

NOTE: For further information, see ISO/TR 22100-4: 2018.

5.3 Robot cell integration with other machines and sub-assemblies

5.3.1 General

Other machinery and equipment can be associated with the robot application or robot cell. These machines can have type-C standards that are applicable.

When machines are integrated and not directly controlled by the robot application controller, ISO 11161 Integrated Manufacturing Systems can be applicable.

Any safety-related control interfaces between the robot application(s) and other machines and, if applicable, an IMS (Integrated Manufacturing System) shall comply with the requirements of 5.5 and Annex C.

Safeguarding shall protect operators against access to the following hazards:

- from other machines;
- within each hazard zone of a robot application and robot cell; and
- at the interfaces to adjacent hazard zones (e.g. conveyors)

5.3.2 Span-of-control for all stops

In the case of multiple robot systems, multiple robot cells or other machinery, 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, entry locations through perimeter safeguarding, location of other protective devices, hazards inside the safeguarded space).

NOTE: See ISO 11161 for information about span-of-control.

5.3.3 Span-of control of emergency stop function

Actuation of an emergency stop function shall stop all hazardous motion of the robot system, workpiece and other hazardous functions in the robot application, and at the interface(s) between robot systems, robot applications and robot cells.

The span-of-control shall be either perspicuous or clearly marked near the emergency stop device (e.g. by text or symbol).

The emergency stop functions for the robot and its end-effector shall have the same span-of-control.

In the event of additional risks due to hazards in the remainder of the robot application, the risk assessment can be used to determine whether these risks share the same span-of-control.

All emergency stop devices for the same hazard zone shall have the same span-of-control.

NOTE: See ISO 13850 for more information about the emergency stop span-of-control. ISO 11161 has information about span-of-control for an Integrated Manufacturing System (IMS).

5.3.4 Operational modes with multi-robot systems or robot cells

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

NOTE: See 5.6, 0 and 5.13.

5.3.5 Local control, remote control and single-point-of-control

The following shall be fulfilled:

- determining what is considered remote control shall be according to 5.7.6.1

- local control shall be according to 5.7.6.2,

- remote control shall be according to 5.7.6.3

- single-point-of-control shall be according to 5.7.5.

When local control (5.7.6.2) is selected, other machines and the IMS control system shall be notified of this condition. Local control shall not be overridden by remote controls.

The emergency and protective stop functions shall remain operational during both local control and remote control, in accordance with 5.6.1.

5.3.6 Automatic workpiece feeding

Where workpieces are automatically fed, the risk of robot system breakage shall be minimized by the design and integration.

5.4 Layout

5.4.1 General

The design shall be such that the operator can safely perform all intended and reasonably foreseeable tasks. The location of equipment and machinery should not introduce additional hazards. If additional hazards are introduced, protective measures shall be applied to the resulting risks due to these hazards, in accordance with Clauses 4 and 5.

Robot applications and cells shall be designed and constructed so that risks due to access of controls and equipment (e.g. weld controller, pneumatic valves, etc.) during automatic operation have been assessed and the risks reduced.

Specific installation and anticipated tasks shall be reviewed to eliminate trapping and crushing possibilities within the robot application restricted space.

EXAMPLE : Support for the robot system function can include fixtures, manual load/unload station (5.12.2), material handling equipment (5.10), end-effector changing systems (5.9) and process-related equipment.

The layout shall allow operator tasks to be performed from outside the safeguarded space. Where it is necessary to perform tasks within the safeguarded space(s) 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 shall consider, for example:

- cable channels, places where operators could stumble;
- frequency of the required access for manual loading/unloading;
- physical characteristics of the load;
- abidance and observation zones;
- service positions (e.g. tip change) ;
- easily accessible maintenance locations.

Permanent means of access shall be provided, considering the frequency and the ergonomic aspects of the task.

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

Workstations shall be designed according to ISO 14738. Access openings shall be designed according to ISO 15534-2. Openings for whole body access shall comply with ISO 15534-1.

NOTE: See ISO/TR 22100-3 for guidance on ergonomics standards.

Components which have to be changed frequently shall be capable of being removed and replaced easily and safely.

5.4.2 Design

The layout design of the robot system and robot application is a key step in the elimination of hazards and reduction of risks. The use and limits shall be considered during the layout design process.

— use limits;

— space limits;

— time limits;

— end-effector limits.

5.4.3 Considerations

Other considerations shall include:

a) manual intervention;

b) design to allow tasks requiring manual intervention to be performed from outside the safeguarded space;

EXAMPLE: Loading and unloading the workpieces and the end-effector exchange system can be located outside the safeguarded space for ease of access.

c) Ergonomics and human interface with equipment:

1) visibility of the robot application and activities associated with the equipment;

2) clear association of controls with robot system;

3) local or user control design specifications;

4) position of workpiece relative to the operator;

5) consideration of avoiding a machine determined work rate;

6) avoiding tasks that requires lengthy concentration;

7) foreseeable misuse.

d) requirements for and location of emergency stop devices and possible spans-of-control (e.g. local or robot application or robot cell stops);

e) requirements for and location of additional enabling devices;

f) the intended use of all components;

g) specifications:

1) robot safety functions, including speed monitoring and limiting devices;

2) robot mass, payload, velocity, form and geometry;

- 3) end-effector safety functions, if any;
- 4) end-effector mass, form and geometry;
- 5) workpiece(s) mass, form and geometry.

5.4.4 Considerations for collaborative applications

Since collaborative applications can present unique risks, the following factors shall be addressed:

- a) the spatial (three dimensional) limits of the safeguarded spaces;

NOTE: Established limits can be static or dynamic.

- b) access and clearance, and contacts:

- 1) influences on the safeguards (e.g. material storage, workflow requirements, obstacles);
- 2) the intended and reasonably foreseeable contact(s) from portions of the robot application to an operator, including pressure, force, and body location of contact;
- 3) object features (e.g. sharp edges, hot surfaces, etc.) around or in the space where trapping between robot application and object could occur.

- c) ergonomics and human interface with equipment:

- 1) possible stress, fatigue, or lack of concentration arising from the collaborative applications;
- 2) ease of error or misuse (intentional or unintentional) by operator;
- 3) possible reflex behaviour of operator to movement of the robot system, workpiece and related equipment;
- 4) inability to predict potential motion of the robot application;
- 5) required training level and skills of the operator;
- 6) acceptable biomechanical limits of contacts from the robot application to operators, under intended use and reasonably foreseeable misuse;
- 7) potential consequences of single or repetitive contacts from the robot application to operators.

- d) transitions (time limits):

- 1) starting and ending of collaborative tasks;
- 2) transitions from collaborative tasks to other tasks.

NOTE: See Annex M for power and force threshold values.