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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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Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.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

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ISO/TC 299

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Part 1: Industrial robots

ICS: 25.040.30

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Contents

Foreword	7
Introduction	9
1 Scope	11
2 Normative references	12
3 Terms, definitions and abbreviations	13
3.1 Terms and definitions	13
3.1.1 Robot, robot system, robot application, application	13
3.1.2 Sub-assemblies and components of robots, robot systems and robot applications	15
3.1.3 Controls-related	16
3.1.4 Program-related	18
3.1.5 Power-related	18
3.1.6 Hazard-related	19
3.1.7 Roles	19
3.1.8 Functional safety-related	20
3.1.9 Spaces, zones and distances	21
3.1.10 Risk reduction measures	23
3.1.11 Verification and validation	24
3.2 Abbreviated terms	24
4 Risk Assessment	25
5 Design and protective measures	26
5.1 Robot design	26
5.1.1 General	26
5.1.2 Materials, mechanical strength and mechanical design	26
5.1.3 Handling, lifting and transportation	27
5.1.4 Packaging	27
5.1.5 Stability	27
5.1.6 Temperature and fire risks	27
5.1.7 Special equipment	27
5.1.8 Position holding	28
5.1.9 Auxiliary axis (axes)	28
5.1.10 Power loss or change	28
5.1.11 Component malfunction	28
5.1.12 Hazardous energy	28
5.1.13 Electrical, pneumatic and hydraulic parts	29
5.1.14 Tool centre point (TCP) setting	30
5.1.15 Payload setting	30
5.1.16 Cybersecurity	30
5.1.17 Robot class	31
5.2 Robot controls	32
5.2.1 General	32
5.2.2 Protection from unexpected start- up	32
5.2.3 Singularity	32
5.2.4 Interlocking functions	32
5.2.5 Status indication and warning devices	32
5.2.6 Labelling	33
5.2.7 Single point of control	33

5.2.8	Modes	33
5.2.9	Means of controlling the robot	35
5.2.10	Means of initiating automatic operation	37
5.3	Safety functions	37
5.3.1	General.....	37
5.3.2	Functional safety standards.....	37
5.3.3	Performance	38
5.3.4	Failure or fault detection.....	38
5.3.5	Parametrization of safety functions	38
5.3.6	Communications.....	39
5.3.7	Electromagnetic compatibility (EMC)	40
5.4	Robot stopping functions	40
5.4.1	General.....	40
5.4.2	Emergency stop.....	41
5.4.3	Protective stop.....	42
5.4.4	Other stop.....	42
5.5	Other safety functions	43
5.5.1	Start and restart interlocking.....	43
5.5.2	Speed limit(s) monitoring.....	43
5.5.3	Enabling function	44
5.6	Simultaneous motion.....	45
5.7	Limiting robot motion	46
5.7.1	General.....	46
5.7.2	Mechanical axis limiting devices.....	46
5.7.3	Electro-mechanical axis limiting devices	47
5.7.4	Soft axis and space limiting.....	47
5.7.5	Dynamic limiting	47
5.8	Movement without drive power	47
5.9	Lasers and laser equipment.....	48
5.10	Capabilities for collaborative applications.....	48
5.10.1	General.....	48
5.10.2	Hand-guided controls (HGC)	48
5.10.3	Speed and separation monitoring (SSM).....	49
5.10.4	Power and force limiting (PFL) by inherent design or safety function(s).....	49
6	Verification and validation of safety requirements and protective measures	50
6.1	General.....	50
6.2	Verification and validation.....	50
7	Information for use	50
7.1	General.....	50
7.2	Signals and warning devices	50
7.3	Marking.....	50
7.4	Signs (pictograms) and written warnings.....	51
7.5	Instruction handbook.....	51
7.5.1	General.....	51
7.5.2	Identification.....	52
7.5.3	Intended use.....	52
7.5.4	Installation	52
7.5.5	Stopping	53
7.5.6	Commissioning and programming.....	53
7.5.7	Operation and setting.....	53
7.5.8	Singularity	53

7.5.9	Hazardous energy.....	53
7.5.10	Movement without drive power.....	54
7.5.11	Cybersecurity	54
7.5.12	Functional safety.....	54
7.5.13	Teach pendants.....	57
7.5.14	Integration into a robot system	57
7.5.15	Maintenance.....	57
7.5.16	Protection against electrical shock.....	58
7.5.17	Abnormal and emergency situations.....	58
7.5.18	Handling, lifting and transportation	58
Annex A (informative) List of significant hazards		59
Annex B (informative) Illustrations spaces		63
Annex C (normative) Safety functions		67
Annex D (normative) Required safety function information		71
Annex E (normative) Test methodology for Class I robots		
	– maximum force per manipulator (F_{MPM}).....	73
E.1	General.....	73
E.2	Test methodology for Class I robots	73
Annex F (informative) Symbols.....		81
Annex G (normative) Means of verification and validation of the design and protective measures.....		83
Annex H (normative) Stopping time and distance measurement		97
Annex I (informative) Optional features.....		99
I.1	General.....	99
I.2	Emergency stop safety function outputs	99
I.3	Enabling device functionality	99
I.4	Mode selection output	99
I.5	Anti-collision sensing.....	99
I.6	Maintaining path accuracy across all speeds.....	100
I.7	Optional capabilities.....	100
I.7.1	Configurable position for as a monitored position safety function	100
I.7.2	Stopping performance safety function(s) or non-safety measurement.....	100
I.7.3	Real-time interfaces safety function	100
Annex ZA (informative) Relationship between this European Standard and the essential requirements of Directive 2006/42/EC aimed to be covered.....		101
Bibliography.....		103

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*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 310, *Advanced automation technologies and their applications*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 10218-1:2011), which has been technically revised.

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

- incorporating safety requirements for industrial robots intended for use in collaborative applications (formerly, the content of ISO/TS 15066);
- clarifying requirements for functional safety;
- adding requirements for cybersecurity to the extent that it applies to industrial robot safety.

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

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

42 Introduction

43 The ISO 10218 series has been created in recognition of the particular hazards that are
44 presented by robotics in an industrial environment. ISO This document addresses robots
45 as incomplete machines, while ISO 10218-2 addresses robots integrated into complete
46 machines (systems, applications, cells).

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

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

- 50 — robot manufacturers (small, medium and large enterprises);
- 51 — robot system/ application integrators (small, medium and large enterprises);
- 52 — health and safety bodies (regulators, accident prevention organisations, market
53 surveillance etc).

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

- 56 — robot system users/employers (small, medium and large enterprises);
- 57 — robot system users/employees (e.g. trade unions);
- 58 — service providers, e. g. for maintenance (small, medium and large enterprises);

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

61 Robots and the extent to which hazards, hazardous situations or hazardous events are
62 covered is indicated in the Scope of this ISO document.

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

67 In recognition of the variable nature of hazards with different uses of industrial robots, the
68 ISO 10218 series is divided into two parts. This document ISO provides requirements for
69 safety in the design and construction of the robot. Since safety in the application of
70 industrial robots is influenced by the design and application of the robot application,
71 ISO 10218-2 provides requirements for the safeguarding of operators during integration,
72 commissioning, functional testing, programming, operation and maintenance.

73 The ISO 10218 series deals with robotics in an industrial environment, which is comprised
74 of workplaces where the public is excluded and the people (operators) are working adults.
75 Other standards cover such topics as coordinate systems and axis motions, general
76 characteristics, performance criteria and related testing methods, terminology, and
77 mechanical interfaces.

78 For ease of reading this ISO document, the words “robot” and “robot system” refer to
79 “industrial robot” and “industrial robot system” as defined in this document.

80 This ISO document has been updated based on experience gained since the release of the
81 ISO 10218 series in 2011. This document remains aligned with the minimum requirements
82 of a harmonized type-C standard for robots in an industrial environment.

Where appropriate, ISO/TS 15066:2016 on the safety of collaborative robot systems, was added to the ISO 10218 series. Most of ISO/TS 15066 has been incorporated into ISO ISO/DIS 10218-2:2020), since human-robot collaboration relates to the application and not the robot alone. Safety functions that enable a collaborative task can be embedded in the robot or can be provided by a protective device, or a combination of the robot and a protective device.

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

Revisions include the following:

- category 2 stopping functions;
- cybersecurity;
- definitions and abbreviations;
- details within the information for use clause;
- functional safety requirements;
- hand-guided control (HGC) requirements;
- markings;
- mechanical strength and stability requirements;
- mode selection;
- power and force limiting (PFL) requirements to enable collaborative applications;
- power loss requirements;
- hand-guided controls (HGC) requirements;
- robot classification (Class I and Class II) for functional safety requirements;
- spaces (maximum, restricted) figures shown in Annex B;
- speed and separation monitoring (SSM) requirements to enable collaborative applications;
- test methodology to determine the maximum force per manipulator for Class I robots.

110 **Robotics – Safety requirements – Part 1: Industrial robots**

111 **1 Scope**

112 This ISO document specifies requirements for the inherently safe design, protective measures
113 and information for use of robots for an industrial environment.

114 This ISO document addresses the robot as an incomplete machine.

115 This ISO document is not applicable to the following uses and products:

- 116 — underwater;
- 117 — law enforcement;
- 118 — military (defence);
- 119 — airborne and space robots, including outer space;
- 120 — medical robots;
- 121 — healthcare robots;
- 122 — prosthetics and other aids for the physically impaired;
- 123 — service robots, which provide a service to a person and as such the public can have access;
- 124 — consumer products as this is household use to which the public can have access;
- 125 — lifting or transporting people;
- 126 — mobile platforms;
- 127 — tele-operated manipulators.

128 Note 1 Requirements for robot systems, integration, and applications are covered in ISO 10218-2.

129 Note 2 Additional hazards can be created by specific applications (e.g. welding, laser cutting,
130 machining). These system-related hazards need to be considered during robot system and robot
131 application design. See ISO 10218-2.

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

135 This document does not cover the hazards related to:

- 136 — severe conditions (e.g. extreme climates, freezer applications, strong magnetic fields)
137 outside of manufacturer's specification;
- 138 — underground use;

- 139 — specific hygienic requirements;
- 140 — use in nuclear environments;
- 141 — use in potentially explosive environments;
- 142 — use in environments with ionizing and non-ionizing radiation levels;
- 143 — hazardous ionizing and non-ionizing radiation;
- 144 — handling loads the nature of which can lead to dangerous situations (e.g. molten metals,
- 145 acids/bases, radiating materials);
- 146 — handling or lifting or transporting people;
- 147 — the public or non-working adults have access, i.e. service robots, consumer products.
- 148 Noise emission is generally not considered a significant hazard of the robot alone, and
- 149 consequently noise is excluded from the scope of this document.
- 150 This is not applicable to robots that were manufactured prior to its publication date.

151 2 Normative references

- 152 The following documents are referred to in the text in such a way that some or all of their content
153 constitutes requirements of this document. For dated references, only the edition cited applies.
- 154 ISO 4413:2010, *Hydraulic fluid power — General rules and safety requirements for systems and*
155 *their components*
- 156 ISO 4414:2010, *Pneumatic fluid power — General rules and safety requirements for systems and*
157 *their components*
- 158 ISO 7010:2019, *Graphical symbols — Safety colours and safety signs — Registered safety signs*
- 159 ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk*
160 *reduction*
- 161 ISO 13732-1:2006, *Ergonomics of the thermal environment — Methods for the assessment of*
162 *human responses to contact with surfaces — Part 1: Hot surfaces*
- 163 ISO 13849-1:2015, *Safety of machinery — Safety-related parts of control systems — Part 1:*
164 *General principles for design*
- 165 ISO 13850:2015, *Safety of machinery — Emergency stop — Principles for design*
- 166 ISO 14118:2017, *Safety of machinery — Prevention of unexpected start-up*
- 167 ISO 14119:2013, *Safety of machinery — Interlocking devices associated with guards — Principles*
168 *for design and selection*

- 169 ISO 14120:2015, *Safety of machinery — Guards — General requirements for the design and*
 170 *construction of fixed and movable guards*
- 171 ISO 19353:2019, *Safety of machinery — Fire prevention and fire protection*
- 172 ISO 20607:2002, *Safety of machinery — Instruction handbook — General drafting principles*
- 173 ISO 20643:2005/AMD 1:2012, *Mechanical vibration — Hand-held and hand-guided machinery —*
 174 *Principles for evaluation of vibration emission*
- 175 IEC 60204-1:2016, *Safety of machinery — Electrical equipment of machines — Part 1: General*
 176 *requirements*
- 177 IEC 60947-5-8:2006, *Low-voltage switchgear and controlgear - Part 5-8: Control circuit devices*
 178 *and switching elements - Three-position enabling switches*
- 179 IEC 61310-1:2007, *Safety of machinery — Indication, marking and actuation — Part 1:*
 180 *Requirements for visual, acoustic and tactile signals*
- 181 IEC 61310-2:2007, *Safety of machinery — Indication, marking and actuation — Part 2:*
 182 *Requirements for marking*
- 183 IEC 61310-3:2007, *Safety of machinery — Indication, marking and actuation — Part 3:*
 184 *Requirements for locations and operation of actuators*
- 185 IEC 61508-2:2010, *Functional safety of electrical/electronic/ programmable electronic safety-*
 186 *related systems — Part 2: Requirements for electrical/ electronic/ programmable electronic safety-*
 187 *related systems*
- 188 IEC 62061:2015, *Safety of machinery — Functional safety of safety-related electrical, electronic*
 189 *and programmable electronic control systems*
- 190 IEC 62745:2017, *Safety of machinery — Requirements for cableless control systems of machinery*

191 **3 Terms, definitions and abbreviations**

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

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

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

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

198 **3.1 Terms and definitions**

199 **3.1.1 Robot, robot system, robot application, application**

200 **3.1.1.1**

201 **industrial environment**

202 workplace where the public is restricted from access or not reasonably expected to be present
 203 for the intended tasks and *robot application* (3.1.1.4)

204 Note 1 to entry: This includes manufacturing, laboratory, pharmaceutical, warehousing, logistics, and more.

205 3.1.1.2

206 industrial robot

207 robot

208 automatically controlled, reprogrammable multipurpose *manipulator(s)* (3.1.2.5), programmable
209 in three or more *axes* (3.1.2.1), which can be either fixed in place or fixed to a *mobile platform*
210 (3.1.2.8) for use in automation *applications* (3.1.1.6) in an *industrial environment* (3.1.1.1)

211 Note 1 to entry: The industrial robot includes:

- 212 — the *manipulator(s)* (3.1.2.5), including *robot actuators* (3.1.2.10) controlled by the robot control;
- 213 — the robot control;
- 214 — the means by which to teach or program the robot, including any communications interface (hardware
215 and software).

216 Note 2 to entry: Industrial robot includes any *auxiliary axes* (3.1.2.2) that are integrated into the kinematic
217 solution.

218 Note 3 to entry: The following are considered industrial robots:

- 219 — the manipulating portion(s) of mobile robots, where a mobile robot consists of a *mobile platform*
220 (3.1.2.8) with an integrated *manipulator* (3.1.2.5) or *robot* (3.1.1.2);
- 221 — robots with hand-guided controls (HGC);
- 222 — robots with power and force limited (PFL) functionality;
- 223 — robots with built-in speed and separation monitoring (SSM) functionality.

224 3.1.1.3

225 robot system

226 industrial robot system

227 machine comprising an *industrial robot* (3.1.1.2), *end-effector(s)* (3.1.2.3), and any *end-effector*
228 *sensors and equipment*) needed to support the intended task and a *task program* (3.1.4.2)

229 Note 1 to entry: Examples of equipment are vision systems, adhesive dispensing, weld control.

230 3.1.1.4

231 robot application

232 industrial robot application

233 machine comprising an *industrial robot system* (3.1.1.3), *workpieces, machinery and*
234 *equipment*) *application*

235 intended use and purpose of the *robot* (3.1.1.2) or *robot system* (3.1.1.3), i.e. the process, the
236 task(s)

237 EXAMPLE Manipulating, processing, machining, inspection, spot welding, painting, assembly,
238 palletizing.

239 3.1.1.5

240 collaborative application

241 *applications* (3.1.1.6) that implements one or more *collaborative task(s)* (3.1.1.8)

242 NOTE 1 to entry: *Collaborative applications* can include non-collaborative and *collaborative tasks*.

243 **3.1.1.6**
 244 **collaborative task**
 245 portion of the robot sequence where both the *robot application* (3.1.1.4) and *operator(s)* (3.1.7.2)
 246 are within the same *safeguarded space* (3.1.9.5)

247 **3.1.1.7**
 248 **industrial robot cell**
 249 **robot cell**
 250 one or more *robot applications* (3.1.1.4) including any object that has influence on the risk
 251 assessment of the intended use, associated *safeguarded space(s)* (3.1.9.5) and *safeguards*
 252 (3.1.10.2)

253 **3.1.2 Sub-assemblies and components of robots, robot systems and robot applications**

254 **3.1.2.1**
 255 **axis**
 256 actuated mechanical joint (e.g. rotating about a pivot, linear) that provides at least one degree of
 257 freedom

258 **3.1.2.2**
 259 **auxiliary axis**
 260 *axis* (3.1.2.1) that is not physically part of the *manipulator* (3.1.2.5) and is controlled by the *robot*
 261 (3.1.1.2)

262 Note 1 to entry: Controlled means that there is feedback signal(s) to enable closed loop control by the *robot*.

263 **3.1.2.3**
 264 **end-effector**
 265 device specifically designed for attachment to the *mechanical interface* (3.1.2.7) to enable the
 266 *robot* (3.1.1.2) to perform its task

267 EXAMPLE: Gripper, welding gun, spray gun.

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

269 **3.1.2.4**
 270 **gripper**
 271 *end-effector* (3.1.2.3) designed for seizing and holding workpieces

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

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

275 **3.1.2.5**
 276 **manipulator**
 277 mechanism consisting of an arrangement of segments, jointed or sliding relative to one another

278 NOTE 1 to entry: A *manipulator* (3.1.2.5) includes *robot actuators* (3.1.2.10).

279 **3.1.2.6**
 280 **mass per manipulator (M)**

281 mass of all moving parts of the *robot* (3.1.1.2)

282 **3.1.2.7**

283 **mechanical interface**

284 mounting surface at the end of the *manipulator* (3.1.2.5) to which the *end-effector* (3.1.2.3) is
285 attached

286 **3.1.2.8**

287 **mobile platform**

288 assembly of the components which enables locomotion and provides the structure by which to
289 affix a *manipulator* (3.1.2.5)

290 **3.1.2.9**

291 **payload**

292 mass of all that is attached to the *manipulator* (3.1.2.5), including the *end-effector* (3.1.2.3) and
293 workpiece

294 Note 1 to entry: The payload can be, but is not limited to, the payload attached to the *mechanical interface*
295 (3.1.2.7) of the *robot* (3.1.1.2).

296 **3.1.2.10**

297 **robot actuator**

298 powered mechanism that converts energy to effect motion

299 NOTE 1 to entry: Energy can be electrical, hydraulic, pneumatic or more.

300 **3.1.2.11**

301 **tool centre point**

302 **TCP**

303 point defined for a given *robot application* (3.1.1.4) with regard to the *mechanical interface*
304 (3.1.2.7) coordinate system.

305 Note 1 to entry: The TCP setting defines the location of the TCP relative to the *mechanical interface*.

306 **3.1.3 Controls-related**

307 **3.1.3.1**

308 **control station**

309 enclosure which contains one or more control devices intended to activate or deactivate functions

310 Note 1 to entry: The *control station* can be fixed in place (e.g. control panel) or can be movable (*teach*
311 *pendant* or *pendant* (3.1.3.2) which can be referred to as a portable control station).

312 **3.1.3.2**

313 **teach pendant**

314 **pendant**

315 portable hand-held *control station* (3.1.3.1) linked to the *robot* (3.1.1.2) with which a *robot* can be
316 programmed, moved or actuated

317 **3.1.3.3**
 318 **direct control**
 319 state of the system or portions of the system in which operation is only effected from the *control*
 320 *station* (3.1.3.1) or *teach pendant* (3.1.3.2) of the individual machine(s) or portions of the
 321 machine(s)

322 **3.1.3.4**
 323 **single-point-of-control**
 324 ability to operate the *robot* (3.1.1.2) such that initiation of motion is only possible from one source
 325 of control and cannot be overridden from another initiation source

326 **3.1.3.5**
 327 **singularity**
 328 occurrence whenever the rank of the Jacobian matrix becomes less than full rank

329 NOTE to entry: Mathematically, in a singular configuration, the joint velocity in joint space can become
 330 infinite to maintain Cartesian velocity. In actual operation, motions defined in Cartesian space that pass
 331 near singularities can produce high axis speeds. These high speeds can be unexpected to an *operator*
 332 (3.1.7.2).

333 [SOURCE: ISO 10218-1:2011, 3.21]

334 **3.1.3.6**
 335 **span-of-control**
 336 predetermined portion of a *robot cell* (3.1.1.9) or machine that is under control of a specific device
 337 for a safety function (3.1.8.1)

338 Note 1 to entry: Span-of-control can apply to a component part, a portion of a machine, an incomplete
 339 machine, i.e. a *robot* (3.1.1.2), or a machine within the *robot cell* (3.1.1.9).

340 **3.1.3.7**
 341 **simultaneous motion**
 342 motion of two or more *robots* (3.1.1.2) at the same time under the control of a single *control*
 343 *station* (3.1.3.1), which can be coordinated or can be synchronous

344 Note 1 to entry: A *teach pendant* (3.1.3.2) is an example of a single *control station* (3.1.3.1).

345 **3.1.3.8**
 346 **mode**
 347 **operating mode**
 348 characterization of the way and the extent to which the *operator* (3.1.7.2) intervenes in the
 349 control equipment

350 Note 1 to entry: In the context of this standard, mode refers to the control state of the *robot* (3.1.1.2), e.g.
 351 *automatic mode* (3.1.3.10), *manual mode* (3.1.3.9).

352 **3.1.3.9**
 353 **manual mode**
 354 control state that allows for the *direct control* (3.1.3.3)

355 Note 1 to entry: Sometimes referred to as teach mode where program points and *robot* (3.1.1.2) attributes
 356 are set.

- 357 **3.1.3.10**
 358 **automatic mode**
 359 control state that allows executing programmed tasks
- 360 **3.1.4 Program-related**
- 361 **3.1.4.1**
 362 **control program**
 363 inherent set of instructions which defines the capabilities, actions, and responses of a *robot*
 364 (3.1.1.2)
- 365 Note 1 to entry: This type of program is fixed and usually not modified by the *user* (3.1.7.3).
- 366 **3.1.4.2**
 367 **task program** (*noun*)
 368 set of instructions for motion and auxiliary functions and program control flow that define the
 369 specific intended task of the *robot system* (3.1.1.3)
- 370 Note 1 to entry: This type of program is generated during *integration* (3.1.7.1) or by the *user* (3.1.7.3).
- 371 Note 2 to entry: The *task program* (3.1.4.2) can include functions of other machinery within the *robot*
 372 *application* (3.1.1.4).
- 373 **3.1.4.3**
 374 **teach**
 375 **task programming** (*verb*)
 376 programming of the task performed manually positioning of the *manipulator* (3.1.2.5), or by using
 377 a *teach pendant* (3.1.3.2) to move the *robot* (3.1.1.2) through positions, or by using a *teach*
 378 *pendant* to program without causing motion, or by using an external device for off-line
 379 programming
- 380 Note 1 to entry: Manually positioning can be referred to as "lead-through teaching".
- 381 **3.1.4.4**
 382 **program verification** (*noun*)
 383 execution of a *task program* (3.1.4.2) for confirming the *robot* (3.1.1.2) path and process
 384 performance
- 385 Note 1 to entry: *Verification* (3.1.11.2) can include the total path traced by the *tool centre point (TCP)*
 386 (3.1.2.11) during the execution of a *task program* (3.1.4.2) or a segment of the path. The instructions can
 387 be executed in a single instruction or continuous instruction sequence. *Verification* is used in new
 388 *applications* (3.1.1.6) and in fine-tuning/editing existing *applications*.
- 389 **3.1.5 Power-related**
- 390 **3.1.5.1**
 391 **drive power**
 392 energy source or sources enabling the *robot actuators* (3.1.2.10) to apply force or torque
- 393 **3.1.5.2**
 394 **energy source**

395 electrical, mechanical, hydraulic, pneumatic, chemical, thermal, potential, kinetic or other type of
396 source that is capable to supply power

397 **3.1.6 Hazard-related**

398 **3.1.6.1**

399 **hazard**

400 potential source of harm

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

404 Note 2 to entry: The hazard envisaged by this definition either

405 — is permanently present during the intended use of the machine (for example, motion of hazardous
406 moving elements, electric arc during a welding phase, unhealthy posture, noise emission, high
407 temperature), or

408 — can appear unexpectedly (for example, explosion, crushing hazard as a consequence of an
409 unintended/unexpected start-up, ejection as a consequence of a breakage, fall as a consequence
410 of acceleration/deceleration).

411 [SOURCE: ISO 12100:2010, 3.6, modified by deletion of NOTE 3]

412 **3.1.6.2**

413 **hazardous motion**

414 movement that can cause personal physical injury or damage to health

415 **3.1.6.3**

416 **hazardous situation**

417 circumstance in which a person is exposed to at least one *hazard* (3.1.6.1)

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

419 [SOURCE: ISO 12100:2010, 3.10.]

420 **3.1.7 Roles**

421 **3.1.7.1**

422 **integration**

423 act of combining a *robot* (3.1.1.2) other equipment or another machine including additional *robot*
424 *systems* (3.1.1.3) and *robot applications* (3.1.1.4) to form a *robot cell* (3.1.1.9) capable of
425 performing useful work

426 Note 1 to entry: This act of machine building can include the requirements for the installation of the
427 machinery and equipment associated with the *applications* (3.1.1.6).

428 **3.1.7.2**

429 **operator**

430 person or persons using, operating, adjusting, maintaining, cleaning, repairing, troubleshooting,
431 transporting, commissioning and disassembling a *robot* (3.1.1.2), *robot system* (3.1.1.3), or *robot*
432 *cell* (3.1.1.9)

433 Note 1 to entry: This definition includes person or persons that can be expected at or near machinery, even
434 if not performing a task associated with the specific machine or portion of a machine.

435 **3.1.7.3**

436 **user**

437 entity that uses *robot applications* (3.1.1.4) and *robot cell* (3.1.1.9) and is responsible for the
438 *operator(s)* (3.1.7.2) associated with the *robot applications* and *robot cells*

439 **3.1.8 Functional safety-related**

440 **3.1.8.1**

441 **safety function**

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

443 [SOURCE: ISO 12100:2010]

444 **3.1.8.2**

445 **emergency stop function**

446 function which is intended to avert arising or reduce existing *hazards* (3.1.6.1) to persons, damage
447 to machinery or to work in progress, and be initiated by a single human action

448 Note 1 to entry: ISO 13850 gives detailed provisions.

449 [SOURCE: ISO 12100:2010, 3.40]

450 **3.1.8.3**

451 **protective stop**

452 automatic interruption of operation that causes a cessation and prevention of motion which
453 retains the information of the state of the *robot* (3.1.1.2), including its program, to facilitate a
454 restart

455 **3.1.8.4**

456 **monitored standstill**

457 safety-rated monitored stop

458 *safety function* (3.1.8.1) that monitors the position after the *robot* (3.1.1.2) has stopped while
459 drive power is active

460 **3.1.8.5**

461 **monitored-speed**

462 *safety function* (3.1.8.1) that limits the speed to a configured value

463 **3.1.8.6**

464 **reduced-speed**

465 *safety function* (3.1.8.1) that limits the speed to be no greater than 250 mm/s .

466 **3.1.8.7**

467 **soft axis and space limiting**

468 **soft limit**

469 *safety function(s)* (3.1.8.1) with monitored limit(s) placed on the range of motion of the *robot*
470 (3.1.1.2)

- 471 **3.1.8.8**
 472 **safety function input**
 473 input signal having a specified safety-related performance
- 474 **3.1.8.9**
 475 **safety function output**
 476 output signal having a specified safety-related performance
- 477 **3.1.9 Spaces, zones and distances**
- 478 **3.1.9.1**
 479 **maximum space**
 480 space that can be reached by the moving parts of the *robot* (3.1.1.2)
- 481 Note 1 to entry: In the context of ISO this document, maximum space applies to the *robot* (3.1.1.2). See
 482 Annex B, Figure B.2 for a figure of the *robot* space.
- 483 Note 2 to entry: In the context of ISO 10218-2, maximum space applies to either the *robot system* (3.1.1.3)
 484 or *robot application* (3.1.1.4). See Annex B, Figures B.1 and B.3 for figures of spaces.
- 485 Note 3 to entry: In the context of *mobile platforms* (3.1.2.8), maximum space is indeterminate.
- 486 **3.1.9.2**
 487 **operating space**
 488 portion of the *restricted space* (3.1.9.3) that is used while performing all motions commanded by
 489 the *task program* (3.1.4.2)
- 490 Note 1 to entry: In the context of ISO this document, operating space applies to the *robot* (3.1.1.2).
- 491 **3.1.9.3**
 492 **restricted space**
 493 portion of the *maximum space* (3.1.9.1) reduced by *limiting devices* (3.1.9.4)
- 494 Note 1 to entry: When the restricted space refers to the *robot system* (3.1.1.3), this includes the space
 495 reached by the *end-effector* (3.1.2.3), see ISO 10218-2.
- 496 Note 2 to entry: When the restricted space refers to the *robot application* (3.1.1.4), this includes the space
 497 reached by the *end-effector* (3.1.2.3) and workpiece(s), see ISO 10218-2.
- 498 **3.1.9.4**
 499 **limiting device**
 500 means that reduce the range of motion of the *maximum space* (3.1.9.1), resulting in the *restricted*
 501 *space* (3.1.9.3)
- 502 Note 1 to entry: ISO 12100:2010, 3.28.8 has a broader definition of a limiting device, which encompasses
 503 more than motion. In ISO 12100, it is a device that prevents a machine or hazardous machine condition(s)
 504 from exceeding a designed limit (such as space limit, pressure limit, load moment limit, etc.).
- 505 Note 2 to entry: Limiting device(s) can be fulfilled by *safety function(s)* (3.1.8.1), e.g. *soft axis and space*
 506 *limiting* (3.1.8.7). See *soft axis and space limiting* and *safeguard* (3.1.10.2).
- 507 **3.1.9.5**
 508 **safeguarded space**

509 space where *safeguards* (3.1.10.2) are active or where the perimeter safeguard provides
510 protection

511 Note 1 to entry: This sometimes refers to the space within perimeter safeguarding.

512 Note 2 to entry: The *safeguarded space* can change dynamically.

513 **3.1.9.6**

514 **hazard zone**

515 any space within and/or around machinery in which a person can be exposed to a *hazard* (3.1.6.1)

516 [SOURCE: ISO 12100:2010, 3.11]

517 **3.1.9.7**

518 **task zone**

519 any predetermined space within and/or around the *robot system* (3.1.1.3) in which personnel can
520 perform a specified activity

521 **3.1.9.8**

522 **detection zone**

523 zone within which a specified test piece is detected by *sensitive protective equipment* (3.1.10.5)

524 Note 1 to entry: The detection zone can be a point, line, plane or a space.

525 Note 2 to entry: Adapted from IEC 61496-1:2004, definition 3.4.

526 [SOURCE: ISO 13855:2010, 3.1.8, modified by addition of “sensitive” before “protective
527 equipment” and adding “or a space to NOTE 1 to entry.]

528 **3.1.9.9**

529 **hazard zone**

530 any space within and/or around machinery in which a person can be exposed to a *hazard* (3.1.6.1)

531 [SOURCE: ISO 12100:2010, 3.11]

532 **3.1.9.10**

533 **task zone**

534 any predetermined space within and/or around the *robot application* (3.1.1.4) in which *operators*
535 (3.1.7.2) can perform a specified activity

536 **3.1.9.11**

537 **separation distance**

538 shortest permissible distance between any moving hazardous part of the *robot application*
539 (3.1.1.4) and any *operator* (3.1.7.2)

540 Note 1 to entry: This value can be fixed or variable.

3.1.10 Risk reduction measures

3.1.10.1

protective measure:

measure intended to achieve risk reduction, implemented:

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

— by the *user* (3.1.7.3) (organization: safe working procedures, supervision, permit-to-work systems; provision and use of additional *safeguards* (3.1.10.2); use of personal protective equipment; training).

[SOURCE: ISO 12100:2010, 3.19]

3.1.10.2

safeguarding

protective measure using *safeguards* (3.1.10.2) to protect persons from the *hazards* (3.1.6.1) which cannot reasonably be eliminated or risks which cannot be sufficiently reduced by inherently safe design measures

[SOURCE: ISO 12100, 3.21]

3.1.10.3

safeguard

guards or *protective devices* (3.1.10.4)

Note 1 to entry: *Protective devices* (3.1.10.4) include a broad range of means by which to reduce or control risks, for example:

— interlocking devices for guards,

— *sensitive protective equipment (SPE)* (3.1.10.5),

— *safety function* (3.1.8.1), e.g. *limiting devices* (3.1.9.4) provided by *soft axis and space limiting* (3.1.8.7),

— *limiting devices* (3.1.9.4),

— limited movement control device.

[Source: ISO 12100, 3.26, modified — Note 1 to entry has been added.]

3.1.10.4

protective device

safeguards (3.1.10.2) other than a guard

Note 1 to entry: Examples of types of protective devices are provided in 3.28.1 to 3.28.9 of ISO 12100:2010.

[SOURCE: ISO 12100:2010, 3.18, modified — Note 1 to entry has been adapted.]

3.1.10.5

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

578 [SOURCE: ISO 12100:2010, 3.28.5, modified — Note 1 to entry has been deleted.]

579 3.1.11 Verification and validation

580 3.1.11.1

581 validation

582 confirmation, through the provision of objective evidence, that the requirements for a specific
583 intended use or *application* (3.1.1.6) have been fulfilled

584 Note 1 to entry: Validation determines if the specification accomplishes what was intended, e.g. that a
585 specified limit is acceptable for its purpose. Validation includes functional testing.

586 [SOURCE: ISO 9000:2015, 3.8.13, modified — Note 1 to entry has been added.]

587 3.1.11.2

588 verification

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

591 Note 1 to entry: Verification determines if the design meets its specification, e.g. through review,
592 measurement, analysis, or inspection.

593 [SOURCE: ISO 9000:2015, 3.8.12, modified — Note 1 to entry has been added.]

594 3.2 Abbreviated terms

Abbreviated term	Term	
3P	3-position <3-position <i>enabling device</i> >	5.2.9.1, 5.5.3.2, 5.5.3.3, Annex C, Annex G
Cat	Category	5.3.3, Annex C, Table D.1
Class	Classification	5.1.17, Table 1, 5.2.8.2.2, 5.2.9.1, 5.3.3, 5.7.1, 5.9.1, h), 7.5.12.7, Annex C, Table C.1, Annex E, Annex G
EMC	Electromagnetic Compatibility	5.3.7, Annex G
EMI	Electromagnetic Interference	5.3.7, Annex A, Annex G
F _{MPM}	Force maximum per manipulator	5.1.17.c), Table 1, Annex E
HFT	Hardware Fault Tolerance	5.3.3, 7.5.12.1, Annex C, Table D.1, Annex G
HGC	Hand-Guided Control	Introduction, 3.1.1.2, 5.2.9.1, 5.5.1.2, 5.10.2, Annex C, Annex G
M	Total mass of moving parts of the manipulator	5.1.17, Table 1
m _L	Effective mass of the payload for the robot application (specified maximum payload of the application)	5.1.17, Table 1

Abbreviated term	Term	
m_M	Effective mass of the moving parts of the manipulator	5.1.17, Table 1
m_R	Effective mass of the robot system as a function of robot posture and motion with specified maximum payload $m_R = \frac{M}{2} + m_L$	5.1.17, Table 1
n_{op}	mean Number of annual OPerations	Annex D
PFH_D	average Probability of dangerous Failure per Hour	5.3.3, 7.5.12, Table D.1
PFL	power and force limiting	Introduction, 3.1.1.2, 5.2.9.1, 5.4.3.3, 5.10.2, 5.10.4, Annex C, Annex G
PL	performance level	5.3.3, Annex C
PLa	Performance Level a	Annex C, Table C.2
PLb	Performance Level b	Annex C
PLc	Performance Level c	Annex C, Table C.2
PLd	Performance Level d	5.3.3, Annex C, Annex D, Annex G
PLe	Performance Level e	5.3.3, Annex C
SIL	Safety Integrity Level	5.3.3, 7.5.12.1, Annex C, Annex D
SIL 1	Safety Integrity Level 1	Annex C
SIL 2	Safety Integrity Level 2	5.3.3, Annex C, Annex G
SSM	Speed and Separation Monitoring	Annex C
SPE	Sensitive Protective Equipment	3.1.10.2, 3.1.10.5, Annex C
TCP	tool centre point	3.1.2.11, 3.1.4.4, 5.1.9, 5.1.14, 5.1.16, 5.1.17, 5.5.2.1, 5.5.2.2, 7.5.3.d), 7.5.12.2, Annex G

4 Risk Assessment

A robot manufacturer 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 robots.

For robot system, robot application and robot cell requirements, see ISO 10218-2:2021.

5 Design and protective measures

5.1 Robot design

5.1.1 General

The robot shall be designed in accordance with the principles of ISO 12100 for identified hazards.

For protective measures concerning information, see Clause 7.

Note See IEC 60812 and other similar standards for information about failure mode effects analysis.

5.1.2 Materials, mechanical strength and mechanical design

5.1.2.1 General

Robots shall be designed and constructed to prevent hazardous situation(s) which result from failure due to fatigue and wear. Design and construction shall take into account the lifecycle of the intended use (e.g. transportation, installation, operating conditions and maintenance in accordance with the information for use).

5.1.2.2 Materials

Materials used to build the robot shall;

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

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

5.1.2.3 Mechanical strength

The robot shall be designed and constructed to:

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

Tests shall be performed at the maximum speed. If simultaneous motion can be programmed, the tests shall be done using the least favourable conditions.

5.1.2.4 Mechanical design

Robots shall be designed and constructed so that exposed sharp edges, sharp corners, and hazardous projections are reduced as far as reasonably practicable. Mechanisms that enable motion shall be installed or mounted inside the robot frame 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 in accordance with 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 or the guard. Movable guards shall be interlocked with the hazardous movements in such a way that the hazardous machine functions cease before they can be reached.

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

5.1.3 Handling, lifting and transportation

Hazards due to sudden movements or instability such that tipping and falling-over during transport, lifting and handling of the robot or its component parts, shall be prevented as long as they are handled in accordance with the instructions for use.

One or more of the following measures shall be provided for lifting and shall be adequate for handling the anticipated load:

- appropriate design;
- additional support elements;
- adequate packaging.

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

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

For robots and any part of the robot intended to be handled separately whose weight does not exceed 23 kg and are designed for handling by one person, instructions for safe transport, lifting and handling may be sufficient.

Note See EN 1005-2 for manual handling of machinery and components parts of machinery.

5.1.4 Packaging

The robot, and any part of the robot intended to be handled separately, shall be packaged or designed to ensure handling without injury and storage without robot damage.

5.1.5 Stability

Robots shall be stable for installation, operation, use, disassembly and dismantling such that tipping and falling-over are prevented by specified mounting to affix the robot and its components (e.g. manipulator, control panel, teach pendant) securely.

5.1.6 Temperature and fire risks

The design of the robot shall be such that the temperatures of accessible surfaces are in accordance with the ISO 13732 series.

Where there is a risk of fire or overheating, the design principles of ISO 19353 shall be applied.

5.1.7 Special equipment

Special equipment and accessories to enable the robot to be adjusted, maintained and used safely shall be supplied or made available.

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

678 5.1.8 Position holding

679 If the loss of power can lead to a hazard due to gravity affecting the manipulator, the robot shall
680 have a means for maintaining robot position without drive power (e.g. brakes, pins, or other
681 technology).

682 If required for safety,

683 — position holding shall use appropriate design margins in accordance with 5.1.2; and

684 — a method shall be provided for testing the position holding means if failure of the position
685 holding means can cause a hazardous situation, e.g. unexpected movement of the
686 manipulator.

687 Note 1 See 5.3.4 for failure or fault detection when position holding is provided by a safety function.

688 Note 2 See 5.1.10 about power loss or change.

689 5.1.9 Auxiliary axis (axes)

690 Auxiliary axis (axes) is an optional capability.

691 Position holding means provided with auxiliary axis (axes) shall comply with 5.1.8.

692 An auxiliary axis can be part of the robot's overall kinematic solution, allowing for coordination
693 with the manipulator kinematics.

694 When the auxiliary axis motion affects the TCP speed in reduced-speed manual mode, the
695 requirements of reduced-speed (5.5.2.1) shall apply to the auxiliary axis (axes).

696 When a monitored-speed safety function is provided with the robot, this safety function (see
697 5.5.2.2) shall also be provided for the auxiliary axis (axes).

698 Axis limiting shall be provided in accordance with 5.7 when the auxiliary axis (axes) is included
699 in the three axes of greatest (largest) displacement motions.

700 5.1.10 Power loss or change

701 Loss or change of electrical, hydraulic or pneumatic power to the robot shall not result in a
702 hazardous situation.

703 Re-initiation of power shall not lead to

704 — any hazardous movement(s); or

705 — a change of parameters.

706 The robot shall comply with ISO 14118 to prevent unexpected start-up.

707 Note See IEC 60204-1 for electrical power supply requirements. See ISO 4413 for hydraulics and
708 ISO 4414 for pneumatics requirements.

709 5.1.11 Component malfunction

710 Robot components shall be designed, constructed, secured, or contained in accordance with 5.1.2,
711 so that risks caused by breaking or loosening, or releasing, including those related to stored
712 energy, are reduced to an acceptable level.

713 5.1.12 Hazardous energy

714 Stored energy shall not cause hazardous situation(s). A means shall be provided to prevent
715 uncontrolled or hazardous release of stored energy. If the hazardous energy is potential (e.g.

spring balancer, gas balancer), the robot shall have means to secure it in a position which can be either the energized or de-energized position.

The robot shall be fitted with means to isolate it from all energy supply sources. This means shall be capable of being locked or secured.

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

A label shall be affixed to identify the stored energy hazard.

Where robot axes can move due to gravity, means shall be applied either to prevent axis motion or to ensure that resulting motions can be initiated and result in a de-energized position in a controlled way. Safety function(s) for position holding (see 5.1.8) may be provided to prevent uncontrolled or hazardous release of release stored energy.

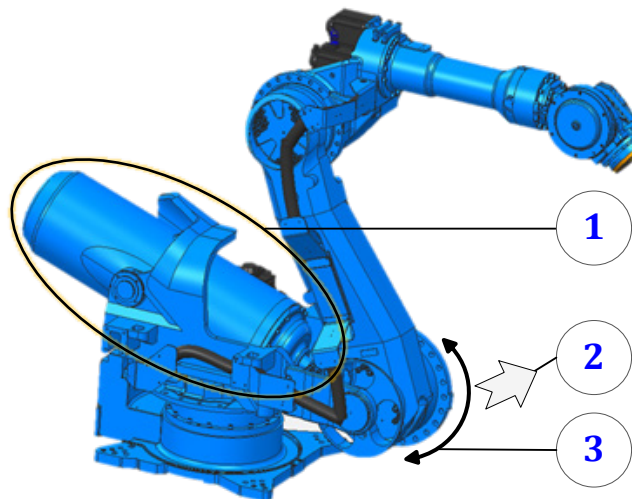
Note 1 Hazardous energy can take many forms, e.g. kinetic, gravity, electrical, pneumatic, hydraulic, thermal, chemical. The sources of these energies can sometimes be readily identified. However, often the sources are hidden or not obvious, e.g. accumulators, capacitors, batteries, springs, counterbalances, flywheels, heat as an outcome due to friction or other reactions.

Note 2 Energy saving capabilities, e.g., energy recovery or regeneration locally at the robot or back to the local mains electrical supply, can be a source of stored energy.

Note 3 This document does not cover hazards associated with nuclear, potential explosive environments, and radiation. See Scope 1.

Note 4 Preventing axis movement can be provided by securely fixing with bolts, holding brackets with sufficient design margin, etc.

Note 5 Figure 1 shows an example of stored energy in a spring balancer. A hazardous situation can occur when a motor is removed, even though the energy supply to the robot is isolated. Upon release, the unexpected motion of the robot due to the energy in the spring balancer can cause injury, e.g. crushing, entrapment.



Key

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

Figure 1: Example of stored energy in a spring balancer

5.1.13 Electrical, pneumatic and hydraulic parts

The electrical parts shall be in accordance with the relevant requirements of IEC 60204-1.

748 The pneumatic equipment shall be in accordance with the relevant requirements of ISO 4414.

749 The hydraulic equipment shall be in accordance with the relevant requirements of ISO 4413.

750 Note 1 For requirements related to specific sub-assemblies and components, see relevant IEC or
751 ISO standards, e.g. IEC 60269, IEC 60947, ISO 13850.

752 Electrical, hydraulic and pneumatic connectors shall be selected to prevent erroneous connection
753 when this can lead to a hazardous situation. Where this is not practicable, connectors shall be
754 labelled to lessen the likelihood of erroneous connection(s).

755 Note 2 See IEC 60204-1, 13.4.5 for requirements for plug-socket combinations.

756 Electrical, hydraulic and pneumatic connectors that can cause a hazard if they are separated or if
757 they break away, shall be designed and implemented to prevent unintended separation.

758 **5.1.14 Tool centre point (TCP) setting**

759 If a TCP setting is needed for a safety function, it shall be possible for a TCP setting to be entered
760 in accordance with 5.3.5.

761 Failure to enter the TCP setting shall result in a warning of the need for entry of a value. Upon
762 manual reset of the warning, the program may continue. After the manual reset of the warning,
763 subsequent warnings are not required.

764 The range of acceptable values shall be limited.

765 EXAMPLE: If the robot has a TCP monitored-speed safety function, a TCP offset setting can be
766 needed.

767 Note 1 TCP settings are the dimensional values that define the location of the TCP relative to the
768 mechanical interface to enable the TCP to be controlled; e.g. speed, pose.

769 Note 2 If the robot and auxiliary axes are being operated in coordination with one another, each
770 individual axis can move at different speeds and this includes the auxiliary axis.

771 **5.1.15 Payload setting**

772 If a payload setting is needed for a safety function, it shall be possible for a payload setting to be
773 entered in accordance with 5.3.5.

774 Failure to enter the payload shall result in a warning of the need for entry of a value. Upon manual
775 reset of the warning, the program may continue. After the manual reset of the warning,
776 subsequent warnings are not required.

777 The range of acceptable values shall be limited.

778 **5.1.16 Cybersecurity**

779 A cybersecurity assessment of the robot shall be carried out. If the assessment has identified that
780 a threat can result in (safety) risk(s), measures to support cybersecurity shall be provided. These
781 measures shall include the means to prevent unauthorized access to the robot, its hardware,
782 software, configuration data and the industrial robot application program.

783 The means to prevent unauthorized access can include providing the following:

- 784 — ability to disable access to communications ports, e.g. TCP/UDP port;
- 785 — ability to change the TCP/UDP port number, e.g. logical connection;
- 786 — authenticated protection of the safety configuration;

787 — ability to change the default usernames and passwords;

788 — use of encrypted and authenticated protocols.

789 Note 1 For further information, see ISO/TR 22100-4:2018.

790 Note 2 For information and requirements about security of industrial automation and control systems,
791 see IEC 62443 series and IEC TR 63074:2019.

792 5.1.17 Robot class

793 Robots shall be classified as either Class I or Class II. Classification as a Class I robot shall be
794 determined in accordance with Table 1, by the maximum capability of the manipulator without
795 being limited by robot control or safety functions, based on the following values:

796 a) maximum achievable speed of the TCP;

797 b) total mass of moving parts of the manipulator (M);

798 c) maximum achievable force per manipulator (F_{MPM}) in accordance with the test methodology
799 in Annex E.

800 Note 1 Maximum speed M , and F_{MPM} are not used for determining risk or suitability for use in
801 collaborative application (see ISO 10218-2). These are factors solely used in determining if a robot is a
802 Class I robot.

803 The total mass of moving parts of the manipulator (M) shall be determined by measurement of
804 the weight of the moveable parts of the manipulator without its fixed base. When the manipulator
805 is intended to be used in applications where the base moves, the total mass of the manipulator
806 (with the base and its fastenings) shall be provided.

807 Note 2 Applications where the base moves can include mounting the manipulator (including its base)
808 to a mobile platform, track, gantry, etc.

809 Robots may be classified as a Class II robot without performing testing in accordance with
810 Annex E. In this case, the robot shall meet the requirements of Class II robots including the
811 functional safety requirements in accordance with 5.3.

812 **Table 1: Robot class**

Robot Class	Total mass per manipulator (M) [kg]	Maximum force* per manipulator (F_{MPM}) [N]	Maximum speed [mm/s]
I	10 kg and under	50 and under	250 mm/s and under
II	Over 10 kg	Over 50	Over 250 mm/s

NOTES:
 M is the total mass of the moving parts of the manipulator.
 See Annex E for M test methodology.
 If multiple manipulators are provided, M is per manipulator.
 See reference [65] FP 0317 (Mainz Study) for derivation of the 50 N maximum force per manipulator value (F_{MPM}).
 * Maximum force is with a manipulator minimum contact area of 0.5cm² [65].
 Reference [65] FP 0317 (Mainz Study): the third quartile of the 29 body parts that were considered (except head and neck) study FP 0317 shows that forces of around 50N are below pain onset independent of pressure (except needles and knives). Therefore, the 50 N limit can be applied as a general borderline between robot class I and II.

813