TECHNICAL REPORT

ISO/TR 20218-1

First edition
2018-08

Robotics — Safety design for industrial robot systems —

Part 1: End-effectors

Robotique — Conception de sécurité pour les systèmes de robots industriels —

Partie 1: Organe terminal effecteur

Reference number
ISO/TR 20218-1:2018(E)

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Foreword

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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).

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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*.

A list of all parts in the ISO 20218 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.

Introduction

This document applies to industrial robot systems as described in ISO 10218-2:2011 and ISO/TS 15066:2016.

This document provides guidance for end-effectors in robot systems, including collaborative applications where a robot system and operators share the same workspace. In such collaborative applications, the end-effector design is of major importance, particularly characteristics such as shapes, surfaces and application function (e.g. clamping forces, residual material generation, temperature).

A comprehensive risk assessment is required by ISO 10218-2:2011. This document provides additional guidance specific to end-effectors that can be helpful when performing the risk assessment in accordance with ISO 10218-2:2011.

Robotics — Safety design for industrial robot systems —

Part 1: End-effectors

1 Scope

This document provides guidance on safety measures for the design and integration of end-effectors used for robot systems. The integration includes the following:

— the manufacturing, design and integration of end-effectors;

— the necessary information for use.

This document provides additional safety guidance on the integration of robot systems, as described in ISO 10218-2:2011.

2 Normative references

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

ISO 10218-1:2011, *Robots and robotic devices — Safety requirements for industrial robots — Part 1: Robots*

ISO 10218-2:2011, *Robots and robotic devices — Safety requirements for industrial robots — Part 2: Robot systems and integration*

ISO 11593, *Manipulating industrial robots — Automatic end effector exchange systems — Vocabulary and presentation of characteristics*

ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction*

ISO 14539:2000, *Manipulating industrial robots — Object handling with grasp-type grippers — Vocabulary and presentation of characteristics*

ISO/TS 15066:2016, *Robots and robotic devices — Collaborative robots*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12100, ISO/TS 15066:2016, ISO 10218-1:2011, ISO 10218-2:2011, ISO 14539:2000, ISO 11593 and the following apply.

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

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

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

3.1
compliant
exhibiting deformation of material or mechanism when subjected to a force

EXAMPLE Compliant linkage, compliant surface.

Note 1 to entry: The reciprocal of compliant is stiff.

Note 2 to entry: Compliance is defined in ISO 8373:2012.

3.2
mechanical interface
end-effector (3.3) flange mounting surface at the end of the manipulator to which the end-effector is attached

[SOURCE: ISO 8373:2012, 3.10, modified — The words "end-effector flange" have been added at the start of the definition and the Note to entry has been deleted.]

3.3
end-effector
device specifically designed for attachment to the *mechanical interface* (3.2) to enable the robot to perform its task

EXAMPLE *Gripper* (3.4), welding gun, spray gun.

Note 1 to entry: In this document, the term refers to end-effectors in robot systems.

Note 2 to entry: End-effectors are sometimes known as end-of-arm tooling (EOAT).

[SOURCE: ISO 8373:2012, 3.11, modified — The words "nut runner" have been deleted from the Example and the Notes to entry have been added.]

3.4
gripper
end-effector (3.3) designed for grasping workpieces

Note 1 to entry: Grip, grasp, grasping and releasing are defined in ISO 14539:2000.

[SOURCE: ISO 8373:2012, 3.14, modified — The words "seizing and holding" have been replaced by "grasping workpieces" in the definition and the Note to entry has been added.]

3.5
fixture
device used to fixate an item as part of the handling or assembling process in a robot system, but not as an *end-effector* (3.3)

3.6
robot application
system comprising an industrial robot system [industrial robot, *end-effectors* (3.3), workpieces and any machinery, equipment, devices, external auxiliary axes or sensors supporting the robot performing its task] and any obstacle or object within the robot system workspace that has influence on the risk assessment of the workspace

[SOURCE: ISO 10218-1:2011, 3.11, modified — Adapted from definition for "industrial robot system".]

4 Risk assessment

4.1 General

This clause describes the actions and factors particularly relevant for the parts of a risk assessment that address end-effectors in a robot application. In accordance with ISO 10218-2:2011, 4.3.1, the risk assessment considers the risks for the entire robot application, including the robot, end-effector, workpieces and fixture(s), over its whole lifecycle.

According ISO 10218-2:2011, the initial risk is assessed on the assumption that no risk reduction measures have been applied. This includes modifications to existing robot applications.

Potential contact situations (both intended and unintended) and the expected accessibility of a person to interact with the end-effector(s) are considered.

The integrator consults with the user during the risk assessment and design of the workspace, in accordance with ISO 10218-2:2011, 4.4.2. The purpose of this consultation is to ensure that all reasonably foreseeable hazardous situations (task and hazard combinations) associated with the robot cell are identified, including indirect interactions (e.g. persons having no tasks associated with the system, but having exposure to hazards associated with the system). The integrator is responsible for coordinating this participation and for selecting the appropriate end-effector(s) based on the requirements of the application.

The results of the risk assessment are documented in accordance with ISO 12100:2010, 5.1 and Clause 7.

4.2 Limits of the end-effector(s)

The limits of the end-effector(s) should be considered when determining the limits for the robot application as a whole (see ISO 10218-2:2011, 4.3.2). Some specific considerations for end-effectors can include, but are not limited to the following:

a) use limits (description of functions, intended use and reasonably foreseeable misuse):

— automatic or manual;

— hand-guiding;

— collaborative or non-collaborative;

b) space limits:

— end-effector changing station;

— movement of the end-effector and workpiece;

— variation in dimensions of the end-effector and workpieces;

c) time limits:

— expected life for end-effector or parts of the end-effector or the grasped tool;

— end-effector exchange system exchange time;

NOTE 1 Deviations in the end-effector exchange time can indicate a fault in the robot system or the end-effector exchange system.

d) other end-effector limits:

— acceptable workpiece shape/geometry;

— centre of gravity of workpiece(s);

— maximum/minimum payload;

— maximum/minimum grasping force (see ISO 14539:2000, 3.1.5);

— maximum/minimum suction of vacuum cup(s);

— maximum/minimum magnetic attraction properties;

— minimum friction between grasping surface (e.g. gripper fingers) and the workpiece;

— physical properties of workpiece, e.g. maximum/minimum size, compliance;

— maximum speed and/or acceleration;

— environmental data, e.g. maximum/minimum temperature.

4.3 Hazard identification

4.3.1 General

In accordance with ISO 10218-2:2011, Clause 4, the risk assessment should identify all hazards related to the intended use and the reasonably foreseeable misuse of the end-effector(s). End-effector hazards are identified by a task-based risk assessment (see ISO 10218-2:2011, 4.4). In consultation with the user, the integrator identifies all the tasks associated with the end-effector(s). These tasks could be associated with an operating mode. End-effector usage is identified. In accordance with ISO 12100, examples of factors which should be taken into consideration include but are not limited to the following:

a) transport;

b) assembly and installation or commissioning, e.g. process observation and monitoring;

c) setting, e.g. teaching and testing the robot program;

d) operation, e.g. routine operator intervention not requiring disassembly such as load/unload operations, operator intervention such as clearing jams or similar simple corrections;

e) cleaning or maintenance, e.g. extended interaction with operator such as an adaptive fixture for variable presentation of work piece or assembly;

f) fault-finding or troubleshooting;

g) dismantling or disabling.

An understanding of the interaction between end-effectors and other parts of the robot application is needed for hazard identification.

While hazards are similar for collaborative and non-collaborative applications, the exposure of the operator to these hazards can vary greatly. Consequently, the most relevant risks to consider can differ depending upon whether the end-effector is used in a collaborative application or whether it is solely operating in a non-collaborative environment.

4.3.2 Examples of hazards from end-effectors and workpieces

Examples of hazards that could be caused by end-effectors and workpieces include, but are not limited to, those shown in Annex D.

4.4 Risk estimation

Risk is defined in ISO 12100:2010 as the combination of the probability of harm and the severity of that harm. Annex A gives practical examples of risks associated with end-effectors.

Hazards associated with end-effectors and workpieces can be more or less severe than hazards associated with the motion of the robot. Depending on the estimation of the risks associated with the hazards of the end-effector and workpiece, safety functions used to control these hazards have a safety performance level (PL) or a safety integrity level (SIL) in accordance with ISO 10218-2:2011, 5.2.

The risk level also depends upon whether the application uses a type of collaborative operation as described in ISO 10218-2:2011, 5.11. The exposure of the operator is considered accordingly. The hazards are the same for collaborative and non-collaborative applications, although the exposure can vary greatly.

In accordance with ISO 12100, exposure is carefully considered for the design of the end-effector for both collaborative and non-collaborative applications.

NOTE 1 ISO/TR 14121-2 gives examples of risk estimation tools.

4.5 Risk evaluation

In accordance with ISO 12100, risk evaluation should be performed after risk estimation to verify whether risks have been adequately reduced.

4.6 Residual risks

In accordance with ISO 10218-2:2011, 7.1, information about identified residual risks is included in the information for use. See Clause 7.

5 Safety requirements and risk reduction

5.1 General

In accordance with ISO 10218-2:2011, end-effectors:

— are designed and constructed to comply with ISO 10218-2:2011, 5.3.10;

— comply with ISO 10218-2:2011, 5.2, for any safety-related control functions.

If intended for use in a power and force limited (PFL) collaborative application, a means to establish the threshold limit values is provided in ISO/TS 15066:2016, Annex A.

NOTE 1 Power and force limited robots and robot systems are described in ISO 10218-1:2011, 5.10.5, and ISO 10218-2:2011, 5.11.5.5. ISO/TS 15066:2016 contains additional information. The information contained in this clause provides detailed guidance for designers of generic end-effectors, integrators selecting end-effectors for robot applications as well as integrators designing end-effectors for specific robot applications.

NOTE 2 ISO 10218-2:2011 requires an end-effector to undergo a risk assessment for its specific application.

5.2 Risk reduction measures

5.2.1 Shape and surfaces

End-effector and fixture designs can incorporate design measures that reduce sharp edges to reduce human contact forces or pressures (e.g. using smooth and compliant surfaces). End-effector mass can be as low as practicable to minimize the forces or pressures associated with a transient contact (e.g. minimizing momentum and kinetic energy). Padding and cushioning materials, as well as deformable components, can reduce impact energy transfer.

Risk reduction measures are taken to minimize risks posed by sharp edges and prevent motion where edges can result in unacceptable contact force(s) or pressure(s). Protective measures, such as increasing edge radius, increasing surface area, modifying edge profiles (e.g. chamfer), or using different surface materials, can be implemented. ISO/TS 15066:2016 provides further information on collaborative robot applications.

The end-effector can also be designed to provide protection from hazards associated with the workpiece(s).

5.2.2 Protective devices and safety-related functions

Protective devices and safety-related control systems built into, or associated directly with, the end-effector can be used in some robot applications to reduce risk. Protective devices and safety control systems can be, but are not limited to, the following:

a) force sensing (e.g. enhanced force sensing that is more sensitive than force sensing of the robot arm):

   — measurement of applied forces on the surface(s) of the end-effector and corresponding monitoring of the end-effector and/or robot as a safety function;

b) end-effector path planning:

— if certain orientations of the gripper result in crush points and/or sharp edges being present (e.g. a screw pointing towards a hole into which the robot screws it), robot movement in that direction can be minimized and movement speed can be decreased to reduce risks; safety-rated soft axis and space limiting functions can be used to monitor robot motion and end-effector orientation and poses;

NOTE 1 ISO 13854 contains information about the minimum gaps to avoid crushing of parts of the human body.

c) grip force:

— where the maximum grip force of the end-effector exceeds the risk assessment safety limits, the grip force applied by the end-effector is reduced and monitored not to exceed acceptable levels in accordance with ISO/TS 15066:2016;

d) speed monitoring:

— the robot speed for which the gripper is intended to be used is considered in the design of the gripper;

— guidance is provided in ISO/TS 15066:2016 for collaborative applications;

— if the end-effector movement is controlled separately from the robot, the stop monitoring is considered in addition to the robot system stopping;

e) presence sensing:

— a sensor (e.g. proximity, motion, image) can be used to detect a workpiece that has the potential to initiate a sequence that could cause an injury to the operator;

— to reduce risk associated with contact to the moving end-effector during collaborative operation, sensing means can be used to e.g. disable end-effector actuation when it is being touched or when the operator is within a detection zone around the end-effector;

— these devices comply with the applicable parts of IEC 61496; integration of these devices is in accordance with ISO 10218-2:2011, 5.2;

f) compliant link (e.g. a pliable link between the robot mechanical flange and the end-effector):

— compliant linkages and mechanisms in the gripper can absorb energy of contact; the transferred force, motion, or energy achieved through compliant links are dissipated in a manner that reduces the risk and does not introduce new risks;

— a sensor or safety function can be used to initiate a protective stop;

— for PFL robot applications, the effective force for initiating a protective stop is in accordance with ISO/TS 15066:2016, 5.5.5;

NOTE 2 Collision protection devices, energy absorbing materials, springs can be used.

— the force or torque which an end-effector can apply to the environment can be limited, e.g. by mechanical couplings that yield when a certain force or torque level is reached;

g) functional safety requirements:

— functional safety requirements in accordance with ISO 13849-1 are derived through the risk reduction process;

— end-effector safety-related functions are designed in accordance with ISO 10218-2:2011, 5.2;

NOTE 3 Safety-related functions of the end-effector can be provided by either the robot or the end-effector.

h) emergency stop:

— in accordance with ISO 10218-2:2011, the emergency stop functions for the end-effector and for the robot upon which it is mounted are in the same span of control;

— in accordance with ISO 13850, the actuation of this function stops or controls all hazards associated with the robot and the end-effector as a minimum;

— IEC 60204-1 specifies the requirements about emergency stop categories;

— in the event of additional risks due to hazards in the remainder of the application, the risk assessment can require that these be stopped or controlled as well by the same function.

5.2.3 Robot application design

Design changes to the robot application can be made to achieve adequate risk reduction. Design factors that can be considered include, but are not limited to the following:

a) clearances between end-effector/fixture/workpiece and any obstructions (e.g. posts, building columns) during normal and manual operation;

b) obstacles (e.g. posts, carts, or other robot application objects) or foreign objects (such as an automated guided vehicle passing by) and how they relate to robot system operation;

c) robot system and robot application boundaries and entry/exit locations.

5.2.4 Risk reduction measures implemented by the user

In accordance with ISO 12100:2010, Figure 2, organizational measures include the development and use of safe working procedures, supervision, permit to work system, use of personal protective equipment (PPE) and training for the equipment, machinery, change management of the robot application (e.g. by use of safety user profile, password, checksums and other measures).

5.3 Safety-related control system performance

When 5.2.2 is applied, it is in accordance with ISO 10218-2:2011, 5.2, which includes provisions for the performance of safety-related control systems.

In accordance with ISO 12100, risk estimation is needed to determine the performance level required (PLr) of the safety functions applied to a specific robot system. Safety-related control systems (electric, electronic, hydraulic, pneumatic and software) comply with ISO 10218-2:2011, 5.2.2 or 5.2.3.

5.4 Gripper end-effectors

5.4.1 General

Robot end-effectors often include gripping mechanisms designed to hold workpieces. In general, there are two gripping principles with advantages and disadvantages, namely mechanical actuation (e.g. grasping or clamping) and non-mechanical actuation (e.g. vacuum cups and magnetic grippers). The choice of principle and the mechanical design should be suitable for the specific application in accordance with ISO 10218-2:2011, 4.1.4. The design and installation of end-effectors are in accordance with ISO 10218-2:2011, 5.3.10.

When selecting or designing a gripper for a specific application, the features and functions of the end-effector can be a part of the risk-reduction measure(s). These gripper features and functions include, but are not limited to the following:

a) manual move or release function for use without power, to free entrapped fingers or other body parts;

NOTE 1 Power includes, but is not limited to, electrical, pneumatic, hydraulic, kinetic, or stored energies.

b) persistent gripping function under loss of power, to prevent a heavy workpiece from falling out;

c) minimization of gripping forces needed to achieve adequate grasping of an object instead of maximum force available;

d) the requirements of ISO/TS 15066:2016, 5.5.5, apply to contact between gripper/grasped workpieces and an operator;

e) application design measures in which crush hazards are eliminated (e.g. safety-rated force limits while the robot is positioning the gripper, inhibiting gripper closure if the gripper is not in the grip location, sufficient clearance for an operator's fingers not to be crushed when the gripper closes).

NOTE 2 Examples of gripper designs and their safety performance are given in Annex B.

NOTE 3 The table in Annex C gives guidance on the specific aspects of a gripper risk assessment.

5.4.2 Grasp-type grippers

Workpieces can be secured in grasp-type grippers, typically either by a form closure grasp or by force closure grasp (see ISO 14539:2000, 3.2.1.2 and 3.2.1.3). In the former case, the grasping surfaces geometrically trap the workpiece in place. The latter case holds the workpiece through friction generated by the grasping force between the workpiece and grasping surfaces.

Some grippers can have a physical capability of actuating with forces that are significantly higher than the forces they are normally configured to provide. Systems that control gripping forces can have either a fixed or adjustable force setting. If a fault in the gripper control system can result in an unacceptable risk in the robot application, then a safety-related function prevents forces exceeding the safety threshold. The safety function complies with ISO 10218-2:2011, 5.2.

If forces are adjustable, the interface is designed such that setting and adjusting can be performed to consistent values. Verification of settings (e.g. by use of a checksum indication) and protection against unauthorized changes (e.g. by use of password) can be necessary.

With the use of pin grippers for grasping of workpiece by penetrating the surface with pins, needles and hooks, the sharpness of the penetrators is a consideration.

5.4.3 Vacuum grippers

Loss of the workpiece is a concern with vacuum grippers.

If the loss of vacuum can result in a risk, the following can be considered to reduce risks:

a) redundant or diverse vacuum systems (each branch capable of holding the workpiece in place);

b) safety-related control and generation of vacuum with an appropriate PL;

c) warning signals (audio/visual) when power is lost and vacuum holding a workpiece is only maintained for a limited time (i.e. several seconds to a few minutes).

Safety related control functions comply with ISO 10218-2:2011, 5.2.

5.4.4 Magnet grippers

Loss or release of the workpiece(s) due to a loss of power or a change of the magnetic field can be a concern with magnet grippers. The influences of the magnetic fields are considerations in the selection and use of magnet grippers.

If the loss of or release of the workpiece(s) can result in a risk, the following can be considered to reduce risks:

a) diverse or redundant magnetic systems (each branch capable of holding the workpiece in place);

b) safety-related control and generation of magnetic field with an appropriate PL;

c) warning signals (audio/visual) when power is lost and holding a workpiece is only maintained for a limited time (i.e. several seconds to a few minutes).

The activation/deactivation of the magnet gripper can be safely monitored in accordance with ISO 10218-2:2011, 5.2.

5.5 Application-specific end-effectors

5.5.1 General

There are application specific end-effectors where the end-effector performs a task onto a workpiece or its environment and does not manipulate by grasping (see 5.4). When an operator is exposed to hazards created by the end-effector's applications, the end-effector is designed so the hazardous attributes of its operations are reduced to an adequate level.

5.5.2 Examples of applications

Application examples include, but are not limited to:

a) joining/assembly/adhesive/inspection (e.g. welding, laser, sensing, measuring, pressure, gluing, sealing, riveting);

b) fastening (e.g. torque gun);

c) material removal/cutting/trimming/grinding/polishing/deburring/sanding (e.g. laser, blade, water-jet, drilling);

d) dispensing/spraying/coating (e.g. hot glue, paint, mould injection, foundry);

e) use of technologies with emissions (e.g. laser, water cutting, radiation, ultrasonic).

5.5.3 Risk reduction

5.5.3.1 General

Additional design methods (see 4.3 and 5.3) include, but are not limited to the following:

a) contain the hazards (e.g. guarding, shields);

b) locate hazards so that they are not accessible by the operator;

c) use a disable function that depends on the orientation of the end-effector;

d) reduce collaborative workspace when hazards exist (e.g. zones, use safety-rated orientation functions of the robot);

e) distinguish areas where unexpected hazardous processes may occur;

f) alert operator before and during the hazardous process, which includes residual time after the process has ended (e.g. warning symbols, illuminated signs, audio signals);

g) use of sequencing based on conditions (e.g. temperature range, retracted blade) instead of timers;

h) design a layout with suitable access when using additional PPE (e.g. hearing protection, eye protection, welding masks, heat-resistant gloves);

i) inspection tools such as ultrasonic inspection and camera systems;

j) indications are used to warn the operator of hot surfaces (e.g. warning symbols, illuminated signs or audio signals).

For safety-related functions, see 5.3.

5.5.3.2 Weld applications

End-effectors for any welding applications are designed such that the welding wire feeders do not unintentionally forward the welding wire with the risk of hitting the eyes of an operator. Examples of ways to achieve such a design include, but are not limited to, using a disable function that depends of the orientation of the end-effector or using orientation functions of the robot.

NOTE Welding applications typically strongly encourage either PPE or curtains to protect the operator against welding light and splatters.

5.6 End-effectors for hand-guiding robots

5.6.1 General

Devices for hand-guiding are intended to provide direct operator input to effect robot motion in accordance with the hand-guiding type of collaborative operation (see ISO 10218-2:2011, 5.11.5.3, and ISO/TS 15066:2016, 5.5.3). This type of hand-guiding device has at least the following:

a) emergency stop device with appropriate span of control to cover all relevant hazards;

b) enabling device with appropriate span of control to apply to all relevant hazards;

c) input device to effect robot motion, e.g. a joystick or other control.

For many applications, it could be necessary to provide additional control features to accomplish the productive task. If the hand-guiding application involves moving loads in a gripper, the hand-guiding device could provide the means to open and close the gripper.

5.6.2 Risk reduction

Specific risks associated with hand-guiding applications are the exposure to the moving robot system and workpieces, exposure to hanging loads and the possibility of non-ergonomic postures and associated physical strain. Mitigating measures associated with the location and the functionality of the overall hand-guiding device can include:

a) choosing the best location considering the need for a full view of the application, minimizing exposure to moving workpieces, and an ergonomically favourable posture for the operator: possibilities include mounting on the end-effector structure, mounting at a fixed station, or providing as a mobile device carried by the operator;

b) safety functions to interlock or monitor functions such as gripper closing and opening with information on the positioning of the end-effector; this can prevent inadvertent release of the load in a hazardous position;

c) limiting the speed, acceleration and deceleration of moving parts of the robot system and the workpiece;

d) limiting the forces and torques in the actuation of moving parts of the robot system and workpiece;

e) ensuring that loss of power does not lead to loss of load, unexpected motion, or other hazards.

The presentation of the controls on the hand-guiding device and their implementation as part of the robot are key to the realization of risk reduction measures for the hand-guiding type of collaborative operation.

5.7 End-effector exchange systems (tool changers)

If a robot system can initiate motion without the end-effector attached, then the risk assessment considers this scenario. The likelihood of movement without the end-effector attached should not lead to unacceptable risk.

Where several robots use the same type of end-effector exchange system, only intentional combinations of robots and end-effectors are possible.

The possibility of incorrect end-effector selection (e.g. detect the correct end-effector, monitor the end-effector stand/end-effector exchange system) should be considered and, where practicable, the robot system is able to detect such a scenario and prevent continued operation until the correct selection is made.

Unintended release of the end-effector is prevented (e.g. release only occurs in a docking station) in accordance with ISO 10218-2:2011, 5.10.9.

NOTE 1 ISO 11593 provides vocabulary for automatic end-effector exchange systems.

NOTE 2 Requirements for the design of end-effector exchange (tool changing) systems are given in ISO 10218-2:2011, 5.10.9.

6 Verification and validation

ISO 10218-2:2011, Clause 6, and ISO/TS 15066:2016, Clause 6, specify requirements for verification and validation.

7 Information for use

7.1 General

ISO 10218-2:2011, Clause 7, and ISO/TS 15066:2016, Clause 7, specify requirements for information for use.

Information for use of end-effectors is provided by the integrator of the end-effector solution for the target application.

Information for use contains all information and instructions necessary to ensure safe and correct use of the system, including end-effectors, and provides information and warnings to the user about any residual risks. Exposure is carefully considered, in accordance with ISO 12100, for the design of the end-effector(s) for both collaborative and non-collaborative applications. Information for use from component machine manufacturers is also to be included.

7.2 Instructions

When end-effectors are implemented in a specific robot system, the instructions for use can include the following information where appropriate:

a) if the end-effectors have movable parts, or places where fingers could be trapped, how to escape from a clamped condition, both with and without power (e.g. electrical, pneumatic, hydraulic, kinetic);

b) if the end-effectors are designed to be touched under intended operation and, if so, the expected frequency of contact for which it is designed;

c) recommendations on how to restart the robot system after a stop if special actions are needed for the end-effector (e.g. if a workpiece is removed manually);

d) if the safety of the worker is affected by the operating path of the robot system (e.g. collaborative applications) then the degree of freedom to re-program the path can be protected by passwords, etc.;

e) guidance on which contact surfaces and orientations during robot movement are considered most appropriate and which contact surfaces and orientations during robot movement are considered less appropriate (see force sensing in 5.2.2);

EXAMPLE One side of an end-effector can be equipped with padding and a recommendation can therefore be to orient that padding in the direction of robot movement.

f) how much the robot application can be changed or adjusted (e.g. gripper positioning and/or workpiece) without affecting the risk assessment: any changes outside the specifications would require reassessing whether new hazards are present or if risk has increased significantly;

g) recommend protective measures, if any, which may include but are not limited to the following:

— recommend robot features and functions, if any;

— recommend maximum robot speed, if any;

— recommend maximum frequency of contacts, if any.

h) if power losses (electric, pneumatic, or hydraulic) can cause workpieces to fall out of the end-effector(s);

i) identify which functions are safety-related, if any;

j) identify whether functions are inherently safe or safe by control, or a combination;

k) how faults in non-safety-rated functions in the end-effector(s) can change severity of contacts (e.g. increased gripping force);

l) state worst case forces for inherently safe grippers;

m) provide tolerances for both nominal forces and safety-rated force settings for safety-rated grip force control systems;

n) provide other methods to reduce severity of contacts, if any.

Annex A
(informative)

Practical examples for end-effector risk assessment

A.1 General

Three practical examples that relate to end-effectors are given below.

— **Example 1:** Application where the operator passes a workpiece to the robot using a gripper. The gripper is closing while the operator is holding the workpiece and the probability of clamping the fingers of the operator is therefore high. A low risk would therefore require a low severity of a clamped finger.

— **Example 2:** Application where the robot is working next to the operator, but where they do not handle the same workpieces. Here it is less likely that the operator has his fingers near the gripper while it is closing and the probability of clamping the fingers of the operator is therefore lower than in Example 1.

— **Example 3:** Same scenario as in Example 2, but this time a fault occurs in the gripper control system that causes the gripper to use forces ten times higher than nominal. The probability of clamping a finger while a fault occurs is negligible.

A.2 Example of safety-rated monitored stop

The person can enter the robot cell, when robot cell is in a safety-rated monitored stop condition. If the end-effector can lose the workpiece, the workpiece could be repositioned to be lower before the guard locking unlocks to allow a person to enter the robot cell. This example is shown in Figure A.1.

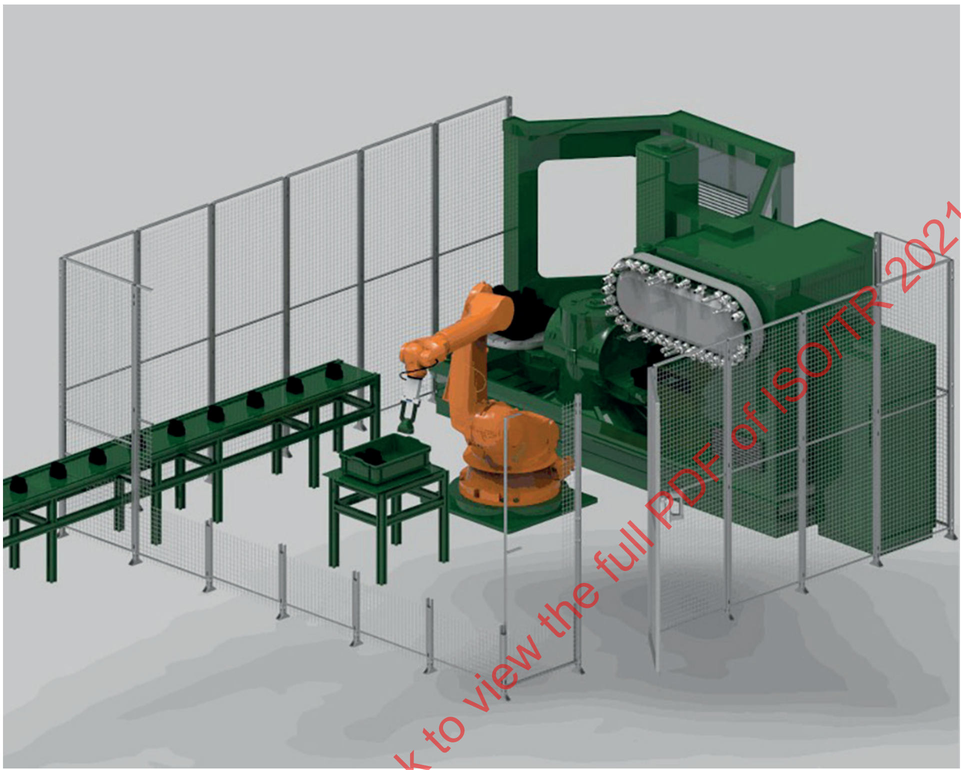
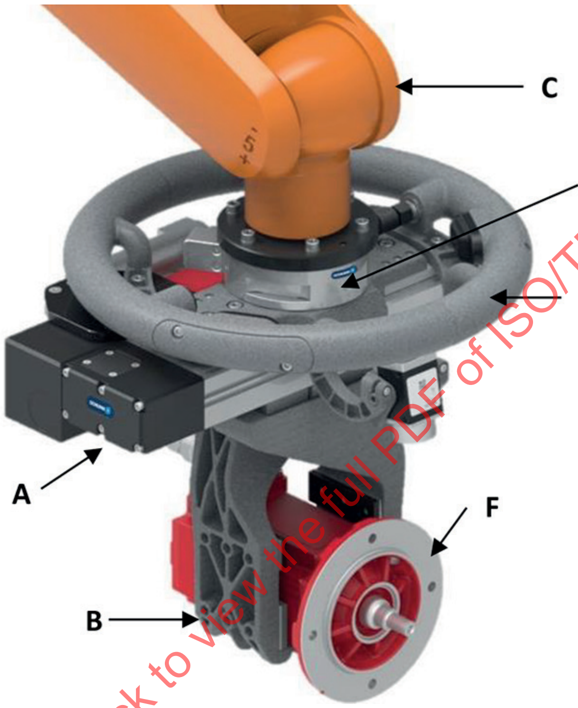


Figure A.1 — Safety-rated monitored stop example

A.3 Example of hand-guiding collaboration

Figure A.2 shows an application example for a hand-guiding collaborative operation. The gripper grasps the workpiece in an area where the gripper is separated from a person. The person who guides the gripper presses the two enabling devices in the hand-guiding wheel for operation. The safety function of the enabling devices achieves performance level PLd in accordance with ISO 13849-1, while performing as two 3-position enabling devices.



Key

A gripper

B gripper fingers

C robot

D force-torque sensor

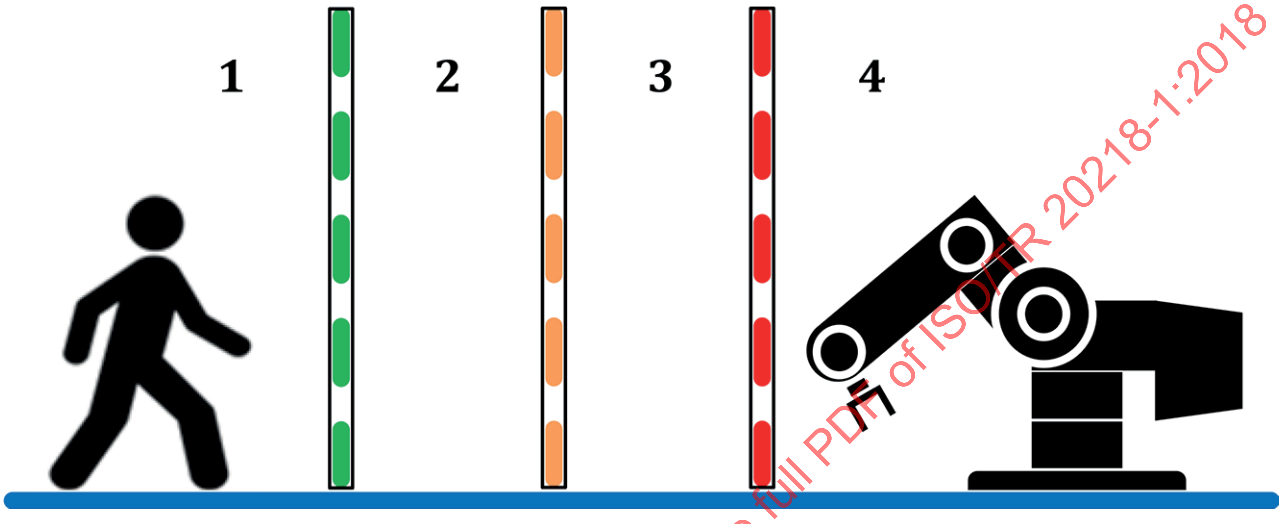
E hand-guiding wheel, with 3-position enabling device

F workpiece

Figure A.2 — Hand-guiding example

A.4 Example of zone-oriented speed reduction

Zone-oriented speed reduction is a safety concept shown in Figure A.3, based on the distance between robot system and a person. The intrusion towards the robot system is monitored by sensitive protective equipment. The robot cell is in safe state when a person reaches the closest hazard zone, e.g. the robot system including the end-effector. One example of how the end-effector could be in a safe state is when the end-effector has “safe operating stop” or similar capability, as described in IEC 61800-5-2.



Key

1 Zone 1

2 Zone 2

3 Zone 3

4 Zone 4: contains the robot system including the end-effector

Figure A.3 — Speed reduction due to zone monitoring example

A.5 Example of a power and force limited collaborative application

Figure A.4 shows an application where a person can touch the workpiece or gripper. The gripper is safely limited if the forces and pressures could be higher than the values of ISO/TS 15066:2016, Annex A. If the forces and pressures are under these values, the performance level required (PLr) of the gripper safety functions is derived from risk estimation during the risk reduction process.

NOTE 1 ISO 13849-1 contains information about functional safety as well as the terminology related to functional safety.

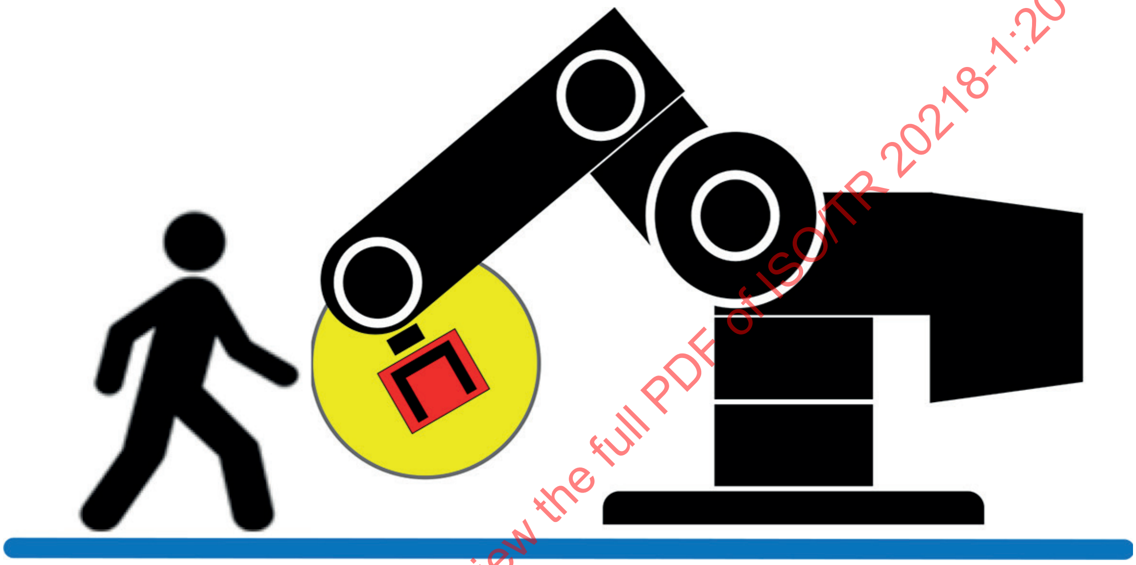


Figure A.4 — Force and pressure limiting of the gripper

Annex B
(informative)

Examples of gripper designs and their safety performance

B.1 General

Grippers that are capable of forces and pressures higher than those identified in ISO/TS 15066:2016, Annex A, could require the use of a safety-rated limiting function adequately reduce risks, though other protective measures could achieve the same level of risk reduction.

For the other types of collaborative operation, a safety-rated monitored stop is required in accordance with ISO/TS 15066:2016. For non-collaborative applications, the requirements for any safety functions are determined by the risk assessment in accordance with ISO 10218-1:2011 and ISO 10218-2:2011.

A "safe operating stop" or similar is provided in accordance with IEC 61800-5-2, which can be realized with, for example, redundant sensors and a safety controller.

B.2 Electric gripper

Electric grippers can have an internal or an external controller and motor control. In both cases, forces and pressures higher than ISO/TS 15066:2016, Annex A, are safely limited in case of a power and force limited collaborative application. For the other types of collaborative operation, a protective stop occurs in accordance with ISO/TS 15066:2016. For non-collaborative applications, the need for any gripper safety functions are determined in the risk assessment in accordance with ISO 12100 and ISO 10218-2:2011.

Annex C
(informative)

Examples of hazards, their potential origins and consequences

Table C.1 — Examples of hazards, their potential origins and consequences

Type or group	Examples of hazards	
	Origin	**Potential consequences**
Mechanical	— cable related issues (e.g. snags, breaks, whipping) — grasp failure — broken sensors — failure in mechanical flange adapter or end-effector exchange (tool changing) system — end-effector wear — end-effector design not suitable for the workpiece variability	— crushing hazards between end-effector and robot manipulator, workpieces fixtures or other objects in robot cell — falling workpieces or parts of the robot system — unintended or unexpected release of workpiece — grasp failure, not grasping or dropping of the workpiece — pinch points between end-effector and robot, workpieces, fixtures or other objects in work cell
Energy sources (e.g. electrical, pneumatic, or hydraulic, sensors)	— loss of power — power off commands — incorrect design and use of emergency & protective stop — release of stored energy — underestimated power requirements — directed energy sources as part of a process end-effector (e.g. laser, water jet, electrical arc) — sensor (e.g. non-eye-safe lasers) — loss of pressure — broken power cables or hoses (e.g. electrical, pneumatic, hydraulic)	— falling workpieces or parts of the robot system — unintended or unexpected release of workpiece — hazardous release of stored energy in end-effector — ejected workpiece at rest or in motion due to grasp failure — unintended or unexpected release of end-effector from the end-effector exchange system
Electrical	— live end-effector surface — overheating — exposed electrical conductors/live end-effector surface	— shock from contact — skin burn

