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Manipulating industrial robots — Safety

Robots manipulateurs industriels — Sécurité

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Foreword

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

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

International Standard ISO 10218 was prepared by Technical Committee ISO/TC 184, *Industrial automation systems and integration*, Sub-Committee SC 2, *Robots for manufacturing environment*.

Annex A of this International Standard is for information only.

Introduction

This International Standard has been created in recognition of the particular hazards which exist in manufacturing automation systems incorporating manipulating industrial robots.

Hazards are well recognized but the sources of the hazards are frequently unique to a particular robot system. The number and types of hazards are directly related to the nature of the automation process and the complexity of the installation.

The risks associated with these hazards vary with the type of robot used and its application and the way in which it is installed, programmed, operated, and maintained.

In recognition of the variable nature of hazards with application of industrial robots, this International Standard provides guidance for the assurance of safety in design and construction of robots. Since safety in the application of industrial robots is influenced by the design and application of the particular robot system, a supplementary, though equally important, purpose is to provide guidelines for the safeguarding of personnel during installation, functional testing, programming, operation, maintenance, and repair of robots and robot systems.

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Manipulating industrial robots — Safety

1 Scope

This International Standard provides guidance on the safety considerations for the design, construction, programming, operation, use, repair, and maintenance of manipulating industrial robots and robot systems as defined in clause 3. It does not apply to other types of robots although the safety principles established in this International Standard may be utilized for these other types.

NOTE: For the purpose of this International Standard, the term "robot" means manipulating industrial robot.

For systems comprising multiple robots and/or associated material handling equipment or mobile robots, this International Standard may be used for the robot system portion of the equipment.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 204-1: —[1], *Electrical equipment of industrial machines – Part 1: General requirements.*

ISO 6385: 1981, *Ergonomic principles of the design of work systems.*

ISO/TR 8373: 1988, *Manipulating industrial robots - Vocabulary.*

ISO 9946: 1991, *Manipulating industrial robots - Presentation of characteristics.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 General terms

3.1.1 person: Any individual.

3.1.2 personnel: Persons specifically employed and trained in the use and care of a robot system.

3.2 Specific terms

NOTE : The terms which are referenced to ISO/TR 8373 are those which have been duplicated from that document.

3.2.1 arm [primary axes]: An interconnected set of links and powered joints comprising members of the longitudinal shape which supports, positions, and orientates a wrist and/or end effector.
[ISO/TR 8373:1988, 3.2]

3.2.2 automatic mode: The operating mode in which the robot control system can operate in accordance with the task program.
[ISO/TR 8373:1988, 5.3.8.1]

3.2.3 enabling device: A manually operated device intended to allow robot motion only while the device is held in a predetermined position.

3.2.4 guard: A machine component specifically used to provide protection by means of a physical barrier. Depending on its construction, a guard may be called casting, cover screen, fence, door, enclosing guard, barrier, etc.

3.2.5 hazard: A situation that may give rise to an injury or damage to health.

3.2.6 hazardous condition/motion: Any condition/motion of the robot or robot system that can cause injury to persons.

3.2.7 hold-to-run control: A control which allows movements exclusively during the manual actuation of that control and that causes these movements to stop as soon as it is released.

3.2.8 interlock (for safeguarding): An arrangement that interconnects guard(s) or device(s) with the robot control and/or power system of the robot and its associated equipment.

3.2.9 local control: A state of the robot in which it is operated from the control panel at the robot system installation or teach pendant.

3.2.10 lockout/tagout: The placement of a lock and/or tag on the energy isolating device (e.g. disconnecting means) in the 'OFF' or 'OPEN' position indicating that the energy isolating device or the equipment being controlled shall not be operated until the removal of the lock/tag.

3.2.11 manipulating industrial robot: An automatically controlled, reprogrammable, multi-purpose, manipulative machine with several degrees of freedom, which may be either fixed in place or mobile for use in industrial automation applications.

NOTE: The following is an explanation of terms used in the above definition:
- reprogrammable: whose programmed motions or auxiliary functions may be changed without physical alterations;
- multi-purpose: can be adapted to different applications with physical alterations;
- physical alteration means alteration of the mechanical structure or control system except for changing programming cassettes, ROMs, etc.

[ISO/TR 8373:1988, 2.3]

1) To be published. (Revision of IEC 204-1:1981.)

3.2.12 manual mode: The operating mode in which the robot can be operated by, for example, pushbutton or joystick and that excludes automatic operation.

3.2.13 maximum space: The space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end effector and the workpiece (see figure 1).

3.2.14 (teach) pendant: A hand held unit linked to the control system with which the robot can be programmed (or moved).
[ISO/TR 8373:1988, 5.8]

3.2.15 presence sensing device: A device that has a sensing field or space which will detect any intrusion into that field or space.

NOTE: Presence sensing devices include but are not limited to light screens, electromagnetic fields, pressure sensitive devices, ultrasonic and infrared devices, and image processing systems.

3.2.16 programmer: A competent person designated to prepare the task program.
[ISO/TR 8373:1988, 2.9]

3.2.17 reduced speed: A single selectable velocity provided by the robot supplier which automatically restricts the robot velocity to one intended to allow sufficient time for persons either to withdraw from hazardous motions or to stop the robot.

3.2.18 restricted space: The portion of the maximum space that is restricted by limiting devices that establish limits that will not be exceeded in the event of any foreseeable failure of the robot system (see figure 1).

NOTE: The maximum distance that the robot can travel after the limiting device is actuated is considered the basis for defining the restricted space.
[ISO/TR 8373:1988, 4.5.3]

3.2.19 risk: A combination of the probability of injury occurring and the degree of the injury.

3.2.20 robot system: A robot system includes:
- the robot (hardware and software) consisting of the manipulator whether mobile or not, power supply, and control system;
- the end effector(s);
- any equipment, devices, or sensors required for the robot to perform its tasks;
- any communication interface that is operating and monitoring the robot, equipment, or sensors, as far as these peripheral devices are supervised by the robot control system.

[ISO/TR 8373:1988, 2.6]

3.2.21 safe working procedure: A specified procedure intended to reduce the possibility of injury while performing an assigned task.

3.2.22 safeguard: A guard or device designated to protect persons from a hazardous point or area.

3.2.23 safeguarded space: The space determined by the safeguards (see figure 1).

NOTE: The safeguarded space includes the restricted space.

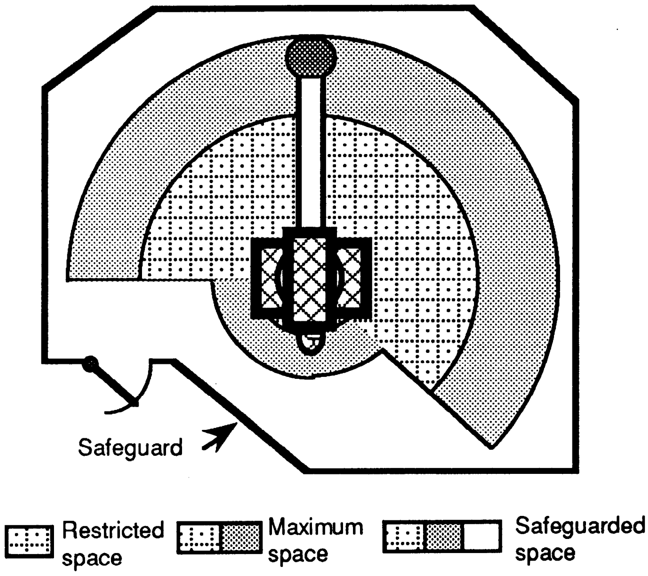

Figure 1 – Example of restricted space and safeguarded space

3.2.24 safeguarding: Methods for protection of person(s) using guards, devices, and safe working procedures.

3.2.25 trouble shooting [fault finding]: The act of methodically determining the reason that a robot system has failed to perform the task or function as intended.

4 General considerations

4.1 General

It is recognized that the operational characteristics of robots can be significantly different from those of other machines and equipment. Robots are capable of high energy movements through a large volume beyond the base of robots. The pattern and initiation of movement of the robot arm are difficult to predict and can vary because of variables in product and environmental conditions.

Some maintenance and programming personnel are at times required to be within the restricted space while power is available to the machine actuators. The restricted space of the robot can overlap a portion of the restricted space of other robots or work zones of other industrial machines and related equipment. This can give rise to hazards of impact, trapping, or flying objects released by the gripper.

The type of robot, its application, and its relationship to other industrial machines and related equipment will influence the design and the selection of the safeguarding methods. These need to be suitable for the work being done and permit, where necessary, teach programming, setting, maintenance, program verification, and trouble shooting operations to be carried out safely. Many installations will require close approach for such work.

The chosen methods should be appropriate for the hazards associated with the robot installation. Before designing or selecting appropriate safeguarding methods, it will be necessary to identify the hazards and to assess the associated risks.

Technical measures for the prevention of accidents are based upon two fundamental principles:

- the absence of persons in the safeguarded space during automatic operation;
- the elimination of hazards or at least their reduction during interventions (e.g. teaching, program verification) in the safeguarded space.

The observance of these principles involves several actions:

- the creation of a safeguarded space and a restricted space;
- a design of the robot system such as to allow the maximum number of tasks to be performed from outside the safeguarded space;
- provision of compensatory means of safety in case of interventions within the safeguarded space.

4.2 Safety analysis

To carry out a safety analysis, it is necessary to

- define the required tasks for the foreseeable applications including an evaluation of the need for access or close approach,
- Identify the sources of hazards including the fault and failure modes associated with each task (see 4.2.1),
- evaluate and assess the risks (see 4.2.2),
- consider safety strategies which minimize the risks to an acceptable level (see 4.2.3),
- select the safeguarding methods consistent with the required task and the acceptable level of risks (see 7.3, 7.4, and 7.5), and
- assess the achieved levels of safety integrity for the safety and ensure that these levels are acceptable (see 4.2.3).

4.2.1 Sources of hazards

Hazards can arise from the robot system itself, from its association with other equipment, or from interaction of persons with the robot system. Examples of sources of hazards are (but are not limited to)

a) failures or faults of
   1) protective means (e.g. devices, circuits, components) including removal or disassembly;
   2) power sources or means of distribution;
   3) control circuits, devices, or components;
b) moving mechanical components causing trapping or crushing
   1) individually (by themselves);
   2) in conjunction with other parts of the robot system or other equipment in the work area;
c) stored energy
   1) in moving parts;
   2) in electrical or fluidic power components;
d) power sources
   1) electrical;
   2) hydraulic;
   3) pneumatic;
e) hazardous atmospheres, materials, or conditions:
   1) explosive or combustible;
   2) corrosive or aggressive;
   3) radioactive;
   4) extreme high or low temperature;
f) noise (acoustical);
g) interferences:
   1) electromagnetic, electrostatic, radio frequencies;
   2) vibration, shock;
h) human errors in
   1) design, development, and construction including ergonomic considerations;
   2) installation and commissioning including access, lighting, and noise;
   3) functional testing;
   4) application and use;
   5) programming and program verification;
   6) set-up including work handling/holding and tooling;
   7) trouble shooting and maintenance;
   8) safe working procedures;
i) moving, handling, or replacing of the robot system or associated components.

4.2.2 Risk assessment

The size, capacity, and speed of robots vary greatly. In addition, there are many different potential applications for robots. Consequently, there will be different hazards and different levels of risk. The risks during the installation, programming, operation, use, trouble shooting, and maintenance of the robot system shall be assessed.

Particular attention should be paid to the need for close approach to the robot when power is available at the machine actuators. The need for close approach is recognized in some exceptional circumstances and shall be provided for in the design and application of appropriate safeguards. Attention should be paid to the fact that the final position of the robot after an emergency stop cannot be adequately determined owing to the kinetic energy involved.

4.2.3 Safety strategy for selection of safety measures

Safety measures are a combination of the measures incorporated at the design stage and those measures required to be implemented by the user.

The design and development of the robot system shall be the first consideration while still maintaining an acceptable level of performance. Where this is not possible, safeguarding shall be considered in such a manner that the flexibility of the robot system in its application is retained. Safeguarding includes the use of safeguards, awareness means, and safe working procedures (see 7.3, 7.4, and 7.5).

5 General design requirements

5.1 Failure to safety

The robot system shall be designed, constructed, and implemented so that in case of a foreseeable failure of any single component, whether electrical, electronic, mechanical, pneumatic, or hydraulic, safety functions are not affected or when they are, the robot system is left in a safe condition. Safety functions include but are not limited to

- limiting range of motion,
- emergency and safety stopping,
- reduced speed, and
- safeguard interlocking.

The requirements of IEC 204-1 regarding control functions in case of failure shall apply.

5.2 Electrical equipment

The application of the electrical equipment of the robot and robot system shall be in accordance with IEC 204-1.

5.3 Power supply

The power supply and grounding (protective earth) requirements shall be in accordance with the manufacturer's specifications.

5.4 Isolation of power sources

Each robot system shall have means to isolate each of its power sources. These means shall be located in such a way that no person will be exposed to hazards and they shall have a lockout/tagout capability. (For requirements of electrical supply disconnecting devices, see IEC 204-1.)

6 Design and construction of the robot

6.1 General

The robot manufacturer shall design and construct robots in accordance with the principles described in this clause and clause 5.

6.2 Ergonomic aspects

Application of ergonomic measures and data contributes to improvement of the safety level by making task completion easier and by decreasing the number of human errors during interventions (e.g. repairing, maintenance, checking, programming, operating). The following requirements apply.

— Design of robot elements, on which human intervention is intended, shall take into account human characteristics such as size, posture, strength, and movements (see ISO 6385).
— Human-machine interfaces (including operating and programming devices, signalling units such as portable control devices, control panels, computer terminals, and software-driven features from application programs) shall be designed and arranged to minimize difficulty for the individual user.
— Pertinent information shall be provided such as clearly indicating robot working modes and displaying the reason for unprogrammed robot stops.

6.3 Mechanical aspects

6.3.1 General

Whenever practicable, hazards arising from the moving parts of the robot shall be eliminated in the initial design. If they cannot be eliminated, then suitable safeguards shall be incorporated as part of the design, and if this is not practicable, provision shall be made for safeguards to be incorporated at a later stage.

6.3.2 Limitation of range of motion

The design of the robot shall not prevent the provisions of means for limiting the range of motion of the primary axes. When a method of limiting the range of motion is required by the designed use, it shall comply with one of the following.

— Mechanical stops may be provided. These should be adjustable and shall be capable of stopping the robot at any adjusted position when it is carrying its rated load at maximum velocity.
— Alternative methods of limiting the range of motion may be provided only if they are designed, constructed, and installed to achieve the same level of safety as the mechanical stops. This may include using the robot controller and limit switches according to IEC 204-1.

6.3.3 Covers and enclosures

Electrical, hydraulic, etc. equipment which constitute a hazard shall be provided with fixed covers or enclosures. Access shall not be required during operation of the robot. Removal of the fixed covers and enclosures shall require the use of a tool.

6.3.4 Transportation

For the purposes of transportation, hooks, eye-bolts, etc. shall be provided when required. They shall be located so that if they are used properly, unintended movement during transportation is prevented. The shipping weight should also be marked on the robot.

6.3.5 Mounting provisions

Means shall be provided for securely mounting the robot to provide stable operation during all designed operating conditions.

6.4 Control aspects

6.4.1 Panel arrangement

Actuating control devices shall be arranged, identified, and protected against unintended or accidental operation in accordance with IEC 204-1.

6.4.2 Emergency stop

Manually operated emergency stop devices shall be in accordance with IEC 204-1. Each robot shall have provisions to connect external emergency stop devices, safeguards, or interlocks to the emergency stop circuit.

It shall be necessary to reset manually the emergency stop circuit before any robot motion may be initiated. The resetting of the emergency stop circuit by itself shall not initiate any motion. Where an emergency stop or power fault causes the loss of critical logic or memory states, a reset sequence of the logic or memory shall be necessary before operation may be initiated.

6.4.3 Safety stop

When a safety stop circuit is provided, each robot shall have provisions to connect safeguards and interlocks to this circuit. It shall be necessary to reset the power to the machine actuators before any robot motion may be initiated. The resetting of the power to the machine actuators by itself shall not initiate any operation (see IEC 204-1: —, 9.2.2, category 1).

6.4.4 Electrical connectors

Electrical connectors used on robots which can cause hazardous motion when mismatched shall be keyed or labelled. Electrical connectors which could cause hazardous motion of the robot if they are separated or if they break away shall be designed and constructed so as to guard against unintended separation.

6.4.5 Pendant

When a pendant is provided, the following design requirements shall apply.

a) The pendant shall be designed in accordance with known ergonomic principles (see 6.2) so that it can be reliably used while it is being carried.
b) As long as the pendant is being used in the safeguarded space, it shall not be possible to switch the robot to automatic operation.

c) The pendant shall have an emergency stop device.
d) A pendant intended to initiate robot motion by personnel who are within the safeguarded space shall be provided with hold-to-run control device(s).
e) The robot control shall be designed so that when the robot is placed under pendant control, all robot motion shall only be initiated from the pendant.
f) All motion of the robot that is initiated from the pendant shall be at no greater than the reduced speed. What constitutes an acceptable reduced speed will depend on the forces exerted by the robot and the use of the robot (e.g. layout of installation). The reduced speed should not exceed 250 mm/s as measured at the mechanical interface.

Exceptions to f): When a speed greater than the reduced speed is required (e.g. for verification of a task program), it shall require a deliberate action by the operator (e.g. with a key switch) to select this method of operation. Robot motion shall only be initiated by the use of hold-to-run control device(s) and an enabling device while personnel is inside the safeguarded space (see 6.4.6).

6.4.6 Enabling device

When an enabling device is provided as part of the robot system, it shall be designed to allow robot motion or other functions in one position only. In any other position, hazardous motion or functions shall be stopped safely. Operation of the device by itself shall not initiate hazardous motion or functions.

When an enabling device is required (e.g. for robot motion at a speed greater than reduced speed), it shall be connected to the safety stop or another stop circuit with an equivalent level of safety.

The enabling device may be deactivated by design when either
— there are no persons within the safeguarded space, or
— the robot motion is not greater than the reduced speed.

The enabling device may be part of the pendant or may be a separate device.

6.5 Provisions for robots with arm-moving programming

For robots which are programmed by manually leading the arm, provisions shall be made to switch the power off safely during programming and counterbalancing where required.

6.6 Provisions for emergency movement

Means shall be provided for the movement of robot axes for emergency purposes. These means are for example:

a) with power off:
   — relief valves to depressurize systems under pressure;
   — manual release of power-actuated brakes provided that weight-balancing exists;
b) with power on:
   — manual control facilities of power-piloted valves/ drives;
   — control facilities to start counter motions.

6.7 Power sources

Robots shall be designed and constructed so that any loss, restoration, or variation in the power sources will not result in hazardous motion of the robot.

6.8 Stored energy

Means shall be provided for the controlled release of stored energy. This energy source may be in the form of (but is not limited to) fluid pressure accumulators, capacitors, springs, counter balances, and flywheels. An appropriate label shall be affixed to each stored energy source.

6.9 Interference(s)

The design and construction of the robot shall incorporate good engineering practices to minimize the effects of interference(s) which can affect safety. These can include electromagnetic interference (EMI), electrostatic discharge (ESD), radio frequency interference (RFI), heat, light, vibration, etc.

NOTE: The provisions for interference requirements and testing are found in IEC 204-1.

6.10 Facilities for selection of operating conditions

Facilities shall be provided to ensure unambiguous selection of operating conditions. These facilities shall also indicate the selected operating condition. The selection of different operating conditions shall not in itself cause robot motion or start other functions.

When the protection of safeguards is suspended by the selection of the operating condition (e.g. for set-up, teaching, program verification), this should only be possible when the facilities for selecting the operating conditions are secured (e.g. key selection). Automatic (normal) operation shall be prevented during suspension of the safeguards and robot motion shall be at reduced speed [see 6.4.5 f) for exception].

6.11 Requirements for documentation

For requirements for documentation supplied by the robot manufacturer, see 10.1.

7 Design and safeguarding of the robot system

7.1 General

The robot system manufacturer/supplier shall design and construct robot systems in accordance with the principles described in this clause and clause 5.

7.2 Design

7.2.1 General

The robot system shall be designed in accordance with the manufacturer's specifications so that personnel who operate, program, and maintain the system can be appropriately safeguarded. All environmental conditions shall be evaluated to ensure compatibility of the robot and the robot system with the anticipated operational conditions. These conditions include, but are not limited to, explosive mixtures, corrosive conditions, humidity, dust, temperature, electromagnetic interference (EMI), radio frequency interference (RFI), and vibration.