INDUSTRY 4.0 STANDARDS CELL
ROBOTICS AND AUTONOMOUS SYSTEMS

September 2024

An increasing number of robots and autonomous vehicles work alongside operators.

But, what's new on the standardisation front?

What does the future hold in the field?

Would you like to find out which standards are of particular concern to your own activity?

With support from Federal Public Service Economy, Sirris initiated the Industry 4.0 Standards Cell, to inform Belgian businesses – essentially SMEs – of existing standards and pending publications.

The most pertinent standards in the field of robotics in industrial environments are coordinated by ISO, in particular via its technical committees ISO/TC 299 'Robotics' and ISO/TC 199 'Safety of machinery'. Standardization in the field of power-operated industrial trucks as AGV and AMR is developed by ISO/TC110 'Industrial Trucks'

This document provides an insight into currently applicable standards and their projected evolution

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1 Technical committees

Three technical committees are active in the field of robotics and autonomous systems in industrial environments :

1. The **ISO/TC 299** is active in the field of robotics for manufacturing, healthcare and consumers, excluding toys and military applications. The technical committee has links with: ISO/TC 199 Safety of machinery, ISO/TC 184 Automation systems and integration, ISO/TC 173 Assistive products, and ISO/IEC JTC 1/SC 35 User interfaces.

2. Within the **ISO/TC 199** committee, most ISO workgroups or ISO-IEC liaison groups intervene on aspects likely to impact the safety of collaborative robots: WG 5 works on general machine design principles and risk assessment, WG 6 intervenes on safe distances and ergonomic aspects, WG 8 works on secure control systems and WG 12 on man-machine interaction.

3. The **ISO/TC 110** is active in the field of power-operated industrial trucks, hand-operated industrial trucks (including sack trucks, hand carts, trailers), all types of wheels and castors excluding those with pneumatic tyres and rubber solid tyres for pneumatic tyre rims.

Robotics and autonomous systems standardisation activities dealt with by these 3 technical committees cover three fields:

1 Terminology

2 Robotics and autonomous systems application safety

3 Mechanical interfaces

The next chapters look at the standards developed for each area of standardisation activity.

2 Terminology

The standards **ISO 9787:2013** (Coordinate Systems and motion nomenclatures), **ISO 19649:2017** (Vocabulary for Mobile Robots), **ISO 8373:2012** (General terms and Definitions) and **ISO 14539:2000** (Manipulating industrial robots - Object handling with grasp-type grippers - Vocabulary and presentation of characteristics) define the terminology referenced in other standards. The same applies to **ISO 11593 : 2022** (Robots for industrial environments–Automatic end-effector exchange systems –Vocabulary and presentation of characteristics) which is currently being developed.

The **ISO 5053-1:2020** (Industrial trucks – Vocabulary) standard is crucial for establishing precise definitions of various types of industrial trucks, including AGVs and AMRs. This standard ensures that all stakeholders, from manufacturers to end-users, have a common understanding of these terms, which aids in applying the correct safety standards and properly assigning liability in the event of an accident or malfunction.
Accordingly with ISO 5350-1: 2020 :

"a driverless truck is a powered truck including any trailers, designed to travel automatically in which the safety of operation does not depend on an operator"
As you can see, the term safety is very relevant when it comes to define a driverless truck.

3 Robotics and autonomous systems application safety

Most standards relating to robotics are in line with standards pertaining to the safety of people and machines, such as **EN/ISO 13849-1** and **IEC/EN 62061**. However, the specificities of robotics and its applicability within industrial (and non-industrial) environments have led to the necessity to develop the following, more specific standards (for further information, we invite you to click on the hyperlinks in the document).

- Safety standard: ISO 10218-1,2:2024 (ISO/TC 299)
- Technical report: ISO/TR 20218-1:2018, Robotics - Safety design for industrial robot systems - Part 1: End-effectors (ISO/TC 299)
- Technical report: ISO/TR 20218-2 :2017, Robotics — Safety design for industrial robot systems — Part 2: Manual load/unload stations (ISO/TC 299)
- New work item proposal on ISO/TR 20218-3, Robotics – Guidance for the use of ISO 10218-2 (ed 2)
- Technical report: ISO/TR 21260 Safety of Machinery – Mechanical safety data for physical contacts between moving machinery and people (ISO/TC 199)
- Safety standard : ISO 3691-4:2023, Industrial trucks — Safety requirements and verification — Part 4: Driverless industrial trucks and their systems (ISO/TC110)

4 Mechanical interfaces

The standards **ISO 9409-1:2004** (Manipulating industrial robots – Mechanical interfaces – Part 1: Plates) and **ISO 9409-2:2002** Manipulating industrial robots-Mechanical interfaces – Part 2: Shafts) define the main dimensions, designation and marking of circular plates and cylindrical projection shafts as mechanical interfaces. They are designed to ensure interchangeability and orientation of manually assembled terminals. They define no other requirements pertaining to the terminal coupling mechanism. They contain no indication of the payload capacity, since the appropriate interface can be selected according to the application and the robot's payload capacity.

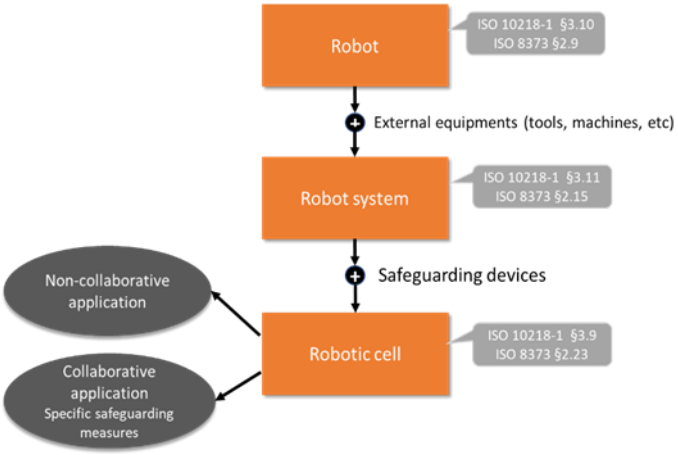
Safety standard: ISO 10218-1,2:2024 (ISO/TC 299)

Since 2011, the collaborative operation of industrial robots is described via the standards ISO 10218-1:2011 (focusing on quasi-machine design) and ISO 10218-2:2011 (focusing on robot system integration and use).
These 2 standards provide presumption of conformity with the 2006/42/EC Machinery Directive[1].
Published in 2 parts (Figure 1 Hierarchy of industrial robots), these documents describe the safety requirements that must be taken into account by robot manufacturers and system integrators.

PRINCIPAL DEFINITIONS ASSOCIATED WITH ROBOTICS

Robot

According to the ISO 10218-1 standard, it is a programmable handling arm designed for multiple applications. It moves in at least three directions and can be fixed or mobile. When a robot is used in an industrial environment, it is referred to as an industrial robot. A robot is not considered as a machine in its own right, but as a quasi-machine, when it is sold with neither tools nor dedicated application.



Robot system

According to the ISO 10218-1 standard, it is a robot completed by all external equipment (tools, external axes, machines, etc.), which enable it to accomplish its task. A robot system is therefore a machine, as per the 2006/42/EC directive definition.

Robotic cell

According to the ISO 10218-2 standard, it is one or several robotic systems completed by adequate preventive measures. The implementation of a robotic cell requires a clear definition of the maximum space needed for the robotic system's operation, of the shared space (also referred to as collaborative workspace) and the controlled space (perimeter protection).

Physical assistance robot

Robot used to provide the operator with physical assistance. In the case of a manually controlled industrial robot arm, it is considered as a collaborative industrial robot and must satisfy requirements pertaining to machine safety.

Figure 1: Hierarchy of industrial robots

[1] On 29 June 2023, the new European Machinery Regulation (2023/1230) was published, replacing the Machinery Directive (2006/42/EC) and coming into force on 20 January 2027.

Part 1 of the 10218 standard deals with requirements pertaining to the **'naked' robot** (i.e. without tools) and is important **for robot manufacturers**. This is a Type C technical standard, which covers industrial robots only. However, the safety principles established by this standard can be used for other types of robots. The standard deals with the most crucial aspects of robot safety, namely the performance of the safety-related control system, the stop function, speed control and the limitation of the robot's handling area.

Part 2 deals with global robotic **system safety requirements** and is **useful to system integrators**. ISO 10218-2 describes the basic hazards and hazardous situations associated with these systems, and provides requirements for eliminating or reducing the risks associated with these hazards.

Based on the experience gained since the publication of the first edition, and in order to adjust the safety requirements, the 10218 series of standards has been undergoing a **fundamental revision** for almost five years. The texts submitted to ISO and CEN in April 2024 have been approved and will be published shortly. This revision has several important objectives:

- **Maintaining the status of harmonised standards**: This status is crucial for the European Union. Although not essential for two-thirds of the world, the majority of robot manufacturers and many integrators prefer it to be preserved. Integrators are responsible for equipping robots with their tools and integrating them (physical, electrical and/or control) into a specific work environment, enabling robots to become complete machines and carry the CE mark.
- **Correction of errors and incorporation of technological advances**: The standard aims to eliminate existing errors while incorporating recent scientific and technological advances.
- **Clarification of requirements for collaborative applications**: the terms 'collaborative robot' and 'collaborative operation' are no longer used. Only the application can be developed, verified and validated as a collaborative application. The requirements for collaborative applications have been clarified to make them easier to understand and implement.
- **Definition of flexible functional safety criteria:** The aim is to enable safety to be adapted according to the different levels of risk associated with the various applications.

(see also https://committee.iso.org/sites/tc299/home/projects/ongoing/iso-10218-1.html)

Both parts of the standard are more detailed and extensive, almost two to two-and-a-half times longer. On the one hand, numerous new requirements have been added to bring them into line with the fundamental health and safety requirements of the Machinery Regulation. Secondly, since human-robot collaboration relates to the application and not just the robot, most of ISO/TS 15066 has been incorporated into Part 2. The safety functions that enable a collaborative task may be part of the robot and/or provided by a protective device. Part 2 also incorporates ISO/TR 20218-1 and -2, providing additional information and guidance for the safety design of manual grippers and loading and unloading points in robotic systems.

A brief overview of the numerous topics and requirements discussed as part of the overhaul is provided below :

– **Robot design**

Part 1 of the standard defines two classes of robots: Class I includes robots equipped with a manipulator with a maximum total mass of 10 kg, a force of 50 N and a speed of 250 mm/s. All models exceeding these values belong to Class II. Class I robots are subject to much less stringent requirements in terms of safety functions. For example, they are not required to have a programming terminal with a three-position activation device (3PE).

The new requirements concern the following points :

- Mechanical strength and materials used: the designer must minimise sharp angles, edges and protruding elements, while taking into consideration wear, fatigue and toxicity of materials.
- Safety when handling, storing, transporting and packing robots and their components.
- The sizing of the braking system. There must be a means of testing the braking system, which may be a procedure
- Temperature limitation of accessible surfaces (see ISO 13732) and Fire protection (see ISO 19353). If the risk cannot be completely eliminated by design, functional safety will be required.
- The use of electrical, pneumatic and hydraulic energy. These requirements concern the means of separating the robot, the terminal and the robotic application from any source of hazardous energy, but also situations involving the loss or change of energy, as well as behaviour in the event of component failure or malfunction - particularly where the loss of energy may lead to risks associated with unexpected movements of the manipulator (the moving part of the robot to which the tool is attached) due to gravity.
- Tool Center Point (TCP) setting, load-dependent safety adjustments, as well as the special equipment needed to ensure safety during setting, maintenance and use.

– **A new approach to functional safety**

- Given the diversity of industrial robot applications, it is impossible to foresee all possible risks and hazardous situations. In addition, each application may present different levels of risk depending on its design and context of use, which can lead to varying requirements for the performance of safety functions, sometimes in contradiction with current standards.
- The revision of the standard does not impose a single PLr performance level for security functions. It is essential to base this level on a risk assessment in accordance with ISO 12100. Normative Annex C defines the domains, thresholds and other parameters to be used to reduce significant risks. It specifies the necessary safety functions, the triggering events and the expected results, i.e. the reaction of the safety elements in the event of an error. Some safety functions are mandatory while others are conditional or optional.

- Although the risk parameters are predefined, users of the standard have the freedom to choose the risk estimation method. This approach enables the required performance of the control's safety elements to be specified in a harmonised and verifiable way, guaranteeing consistent results for similar applications.

- **Security features for collaborative applications**

  - The notion of 'collaborative operation' and other similar terms have been removed from both documents. Experts agree that there is no such thing as a 'collaborative robot', 'collaborative mode' or 'collaborative speed'.

  - For safe collaborative applications, standards now focus on three distinct safety functions: manual guidance, distance and speed control, and force and pressure limitation. The fourth function, 'safe stop monitoring', has been omitted, since it is also required for non-collaborative applications.

- **Cyber security**

If the cyber security assessment reveals that unauthorised access to the control system poses safety risks, appropriate protective measures must be put in place. The first part presents a list of appropriate measures to be implemented by the robot manufacturer. For further information and requirements, reference is made to the IEC 62443 series of standards on IT security for industrial automation systems. In principle, it is considered plausible that safety level 2 of IEC 62443 applies to control elements that can have a negative impact on safety (such as starting, stopping, changing safety settings, etc.), while level 1 applies to other elements.

- **Control and operating modes**

The operating modes and corresponding safety requirements are described more clearly in both standards. Certain requirements have been added for the control of robot functions:

  - Only one control station may be active at any one time (including remote control stations).

  - Robots must have at least two operating modes: manual operation (programming) and automatic operation (program execution). Manual operation at high speed is optional.

  - The active mode must be monitored by a safety system.

  - Selection of the operating mode is not considered a safety function, only its activation. This avoids the risks associated with selecting the wrong operating mode. In part 1, there is a graphic that explains the concept

  - Any portable control station (pendant, console, smartphone, tablet, etc.) capable of triggering movements or other potentially dangerous situations must have an emergency stop function complying with standard ISO 13850, and a three-level enable button.

Sources :
https://committee.iso.org/sites/tc299/home/projects/ongoing/iso-10218-1.html
https://committee.iso.org/sites/tc299/home/projects/ongoing/iso-10218-2.html

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Technical report: ISO/TR 20218-1:2018, Robotics - Safety design for industrial robot systems - Part 1: End-effectors (ISO/TC 299)

This document is designed for use with the 10218 standard.
This document is a type B standard as indicated in its ISO 12100 standard.
The aim of this document is to describe the best safety practice with regard to end-effectors (end-of-arm-tooling, or EOAT). The industrial robot per se can execute no task; it must be integrated within a global robotic system, including the end-effectors that handle the part and execute the task. Certain end-effectors are adapted to collaborative man-robot work and others are not - the risks they present are too high. This document examines a vast range of different end-effectors, gives examples of potential dangers associated with end-effectors and provides advice on how to reduce risks associated with end-effectors.
This document is useful to robotised system integrators, as well as suppliers of end-effectors and tool changers. The final users of industrial robots can also find useful information to ensure the safety of their workers around end-effectors in the document.

Technical report: ISO/TR 20218-2 :2017, Robotics — Safety design for industrial robot systems — Part 2: Manual load/unload stations (ISO/TC 299)

This document is designed for use with the 10218 standard.
ISO/TR 20218-2:2017 aims at solving difficulties likely to occur when industrial robot safety requirements conflict with safety requirements pertaining to ergonomics. For example, a safety requirement for traditional (protected) industrial robot systems consists in enclosing the robotised cell within a peripheral screen of a height of 1,400mm.
But what happens when an employee must interact with the robotised system, either to load or unload? From an ergonomic viewpoint, it is not reasonable to expect that the entrance or exit be raised to a height of 1,400mm. How can the individuals involved solve or minimise these two distinct but associated risk sources (robotised system vs. ergonomic risk)? The present ISO TR document has been elaborated in an aim to answer this question.
This document is of particular use to robotised system integrators and users.

New work item proposal : Technical report ISO/TR 20218-3, Robotics – Guidance for the use of ISO 10218-2 (ed 2)

To complement the new editions of ISO 10218-1 and -2, ISO/TC 299/WG3 has proposed the development of a technical report **ISO /TR 20218-3 "Robotics – Guidance for the use of ISO 10218-2 (ed 2)"**. The purpose of the proposed technical report is to provide guidance to integrators on how to use the new ISO 10218-2 (ed 2) while highlighting what is new and different in the standard compared to the previous edition.
The circulation of the approval draft (DTR) is expected by January 2026 with publication planned for August 2026.

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Technical report: ISO/TR 21260 Safety of Machinery – Mechanical safety data for physical contacts between moving machinery and people (ISO/TC 199)

There are several applications in which robot-to-person contact is necessary. For any person involved in risk assessment and control, the question of awareness of what force level can be tolerated by operators remains topical. In 2012, **ISO/TC 199** launched work aimed at drafting a new ISO 21260 standard to help designers of machines of all types to apply the first level of control hierarchy, i.e. intrinsically safe design.
The document will specify force and power limits for physical contact between the machine or machine parts and people, caused by machine or machine part movement, within the context of its intended use or of any predictable inappropriate use. This document will only define threshold values to avoid damage caused by physical contact. It will not deal with thermal or electrical effects, which all require more in-depth study.
The WG 12 Man-machine interactions workgroup specific to this subject was created in 2016.
Late April 2020, difficulties on reaching a consensus on the document's contents led the workgroup to abandon the ISO/DIS 21260:2018 'Safety of machinery – Mechanical safety data for physical contacts between moving machinery or moving parts of machinery and persons' project and to initiate a new ISO/TR 21260 project (technical report, non-prescriptive) by using the (informative) contents of the ISO/DIS 21260:2018 standard as a basis. The technical report is still in development.

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Safety standard : ISO 3691-4:2023, Industrial trucks — Safety requirements and verification — Part 4: Driverless industrial trucks and their systems (ISO/TC110)

Until recently, there was no C-Type standard available for AGVs and similar systems. However, due to the rapid development of emerging technologies in the field of automated vehicles, the ISO 3691-4 standard was released in 2020 to address this gap, with reviewed version published in 2023 and harmonized in 2024. This standard has replaced the EN 1525:1997 and refers to other common standards, such as ISO 12100, ISO 13849, and ISO 13850. It is now considered the primary international standard for AGVs and AMRs. The ISO 3691-4 outlines three critical aspects of AGV/AMR safety that must be considered for safe operation, including defining the different zones in which the truck operates and interacts with humans, identifying associated hazards and risks, and ensuring proper implementation of safety systems. The last version takes into consideration virtual bumper technology, hybrid (i.e. manual and automatic) mode trucks, performance level versus category, further specified clearances and guarding for specific zones.

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