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Research Article

Robotics and Health and Safety at Work

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ABSTRACT

The paper provides an analysis of the main changes due to robotic disruption in the workplace. In particular, the article focuses on the health and safety at work taking account the EU regulatory framework as well as the international technical safety standards. The study carried out by the authors reveals that the legislator is unable to specify the wide range of mechanisms due to the impossibility of keeping up with the pace of creation of new machines (industrial and collaborative robots). Therefore, the ISO standards are a cornerstone in order to understand the prevention duties of all parties (manufacturer, integrator) directly involved in the adoption of safety measures. However, the research identifies some weaknesses and proposes an approach that takes into account not only the technical aspects but also the ergonomic principle and psycho-social aspects.

Keywords: Robot; Disruption; Legal framework; Technical standards; Health and safety; Workplace

INTRODUCTION

Robotic disruption and its implications in the company

It is a well-accepted fact that robotics has the potential to transform people's lives and society as a whole. Since Leonardo da Vinci designed the first humanoid robot in 1495 or George Devol created the first industrial robot revolutionizing assembly lines in 1948, the development of robotics has been unstoppable. Its impact will be increasing, as the interactions between robots and people multiply (Fundación Telefónica, 2019).

According to Rifkin [1], the impact of robotics can lead to a progressive reduction of human labour, although there is no consensus on the effects this will have on employment and our future labour markets (between 9-54% of jobs threatened according to the Opinion of the European Economic and Social Committee on Artificial Intelligence: anticipating its impact on employment to ensure a fair transition 2018/C 440/01) [2]. A clear example of these issues is the Chinese mobile phone factory Changying Precision Technology which used to be run by 650 employees, but now just 60 people get the job done, while robots take care of the rest and the human workforce will drop further to 20 employees who will be in charge of managing and maintaining this robotic machinery. As a counterweight, some experts say that robotic applications will lead to the emergence of skilled labour with its correlative salary improvement and the emergence of new jobs (including managers of autonomous vehicle traffic or teleoperated agriculture systems). Many questions arise as a result of the use of this new technology: Will our working model be able to cope with digital disruption? How should the benefits of robotics be distributed? Will universal basic income cease to be optional and become compulsory? Should we build technologically responsible companies? These are questions that, far from being science fiction, await answers.

The incidence of robotics is a tangible reality in sectors such as the automotive, transportation or cleaning industries. In fact, some job descriptions already reflect the changes that the tasks have gone through, specifically in relation to robots. For example, in the automotive sector, the job positions like electromechanical automation program and paint robot technician or automatic polishing machine and robot technician, sometimes, indicate the training period that the worker needs in order to adapt.

The first challenge is to determine what we mean by "robot". According to the Encyclopaedia Britannica, a robot is "any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner." Merriam-Webster defines robot as "a machine that resembles a human being and performs several complex human acts (such as walking or speaking)", a "device that

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automatically performs complicated, often repetitive tasks "and "a mechanism guided by automatic controls". The robots adopt multiple forms ranging from the industrial, collaborative, welfare, medical robots, wearable technology and drones (Unmanned Aerial Vehicle and Autonomous Underwater Vehicle) to the forms linked to artificial intelligence like the autonomous vehicles.

ROBOTIC TECHNOLOGY AS A SOURCE OF RISK AND IMPROVEMENT OF WORKING CONDITIONS

One of the main advantages associated with robotics is to improve the working conditions of employees by avoiding exposure to hazardous work or allowing them to perform less repetitive tasks. Thus, in France the Decree No 2012-639 of 4 May 2012, relating to the risks of exposure to asbestos, states that robotization reduces the exposure time of workers to asbestos. In the aerospace, defence, security and nuclear industries, but also in the logistics, maintenance and inspection sectors, autonomous robots are useful to replace workers who carry out unhealthy, tedious or unsafe work, thus avoiding exposing people to dangerous substances and conditions, and reducing physical, ergonomic and psycho-social risks. Some electricity companies, such as the Spanish company Iberdrola, have used a system to detect faults and failures in their high voltage line network [3]. This drone equipped with view cameras and temperature chambers is capable of detecting faults in the high voltage system, emitting the signal live and leaving a record on a hard disk. In this way the service to the consumers is improved and inspection and maintenance tasks do not need to be carried out so frequently by workers who have to do their work under pressure. Similarly, a prototype of the same company inspects wind turbines. Some of these drones can be used for confined spaces, to explore them and see the dangers that are found and even take measurements of gases or other chemical agents in these spaces. At the same time, in the automotive sector, painting with a spray gun using robots allows workers to avoid contamination, the painted surface is more uniform, less paint is lost, less retouching is necessary, and there is less waste.

But robotics also appears as a new source of safety hazards in the workplace. Precisely, in relation to injuries caused to workers by conventional robots, there are some court decisions both in Spain and abroad. Thus, the Judgement of the Spanish Supreme Court of 20-1-2010 (RJ 2010/3110), which corrects the ruling of the appealed judgement considering that there was no recklessness by the worker entering the risk zone and proceeding to perform a series of operations within the robot's scope at his own risk. There has been a concurrence of guilt as damage arises, on the one hand, from breaches of security regulations attributable to the company, but also from the behaviour of the victim himself, who, with the intention of repairing the damage, enters the risk zone and proceeds on his own to perform a series of operations within the scope of the robot. The enamelling line lacked of devices and measures that prevented the access of workers in these mobile and aggressive areas in a sudden and unexpected way and the robot arm lacked a mechanism to prevent the restart of the movement automatically once stopped for any reason, that is, the machine lacked of a safety device, which stopped the machine definitively when the arm stopped due to a fault in the bricks laying, so that it would be necessary to reactivate the movement of the control panel once the difficulty was solved. Likewise, the Judgement of the High Court of Justice of Galicia of 29-4-2011 (AS 2011\1768), analyses the injuries to a worker by entrapment caused by a robot, in particular, multiple injuries caused by a robot and concludes that the robot lacked protective devices against entrapment or blows caused by movements in the welding table whereas no reference is made to the risks of the said machine in the company's risk assessment (...).

In France, the Criminal Court of the Supreme Court, in its ruling, 30-9-2003, No 02-87666, condemned the director of a packaging and supervision manufacturing plant after the death of a worker who was crushed between the fixed part of a mould and the mobile part of the robot connected to a hydraulic press. There are other cases in this country worth mentioning such as the Supreme Court Judgement, in its Civil Appeal, 16-9-2003, No 01-21192, about an employer who had an employee working in a robotic manufacturing line without taking the safety measures required.

The news on a robot killing a worker in a Volkswagen plant in Germany in 2015 had a significant impact on media. The technician was a young external contractor who was installing the robot along with a colleague when he was hit in the chest by the robot which crushed him against a metal plate. It is not clear if the determining cause of the accident was a machine or human error.

The idea of responsibility and control of technological development is the basis on which the technological development we are facing must be based upon. Responsibility is essential in the future scientific development. Hans Jonas [4], in his work "The Imperative of Responsibility", tried to deal with the moral repercussions of the unprecedented technological capacity of humanity and its fundamental idea is summarised in the "responsibility imperative": "act in such a way that the effects of your action do not destroy the possibility of future life." We will have to face new technical challenges such as intelligent humanoid robots or new forms of artificial intelligence capable of self-learning and we must proceed with those challenges by evaluating and reducing their potential risks. The European Parliament Resolution of 16 February 2017 with recommendations to the Commission on Civil Law Rules on Robotics is proof of this. It establishes as a general principle that "a gradualist, pragmatic and cautious approach (...) for the Union (...) so as to ensure that we do not stifle innovation". Research activities in the field of robotics must be carried out in accordance with the precautionary principle, anticipating the possible impacts of their results on safety and adopting the necessary precautions, depending on the level of protection, while at the same time progress is promoted for the benefit of society and the environment. At the current development stage of different types of robots, the issue of "civil liability for damage caused by robots" is fundamental and must also be analyzed and addressed by the European Union. It states that "creating a specific legal status for robots in the long run, so that at least the most sophisticated autonomous robots could be established as having the status of electronic persons responsible for making good any damage they may cause, and possibly applying electronic personality to cases where robots make autonomous decisions or otherwise interact with third parties independently."

THE EU REGULATORY FRAMEWORK FOR ROBOTICS SAFETY

Directive 89/391/EC, of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work, known by all as a Framework Directive on Health and Safety at Work, contains minimum legislation on Health and Safety at Work [5], which protects all workers in the European Union, including those working with robots. The employer's generic safety duty includes the whole set of instrumental obligations (risk assessment, planning of preventive activity, training and information on risks and preventive measures, etc.) also applicable to automated work environments.

The specific Directives of development do not directly address the risks and preventive measures associated with robotics. Only Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, includes preventive measures that, in principle, could be transferred to this type of technology. These are the essential health and safety requirements within general scope that are then completed with more specific safety measures for certain types of machines.

However, it should be remembered that, in general, a robot is partly completed machinery, but cannot perform a specific application by itself (Guide for the application of Directive 2006/42, July 2017) [6]. The partly completed machinery or robot is only intended to be incorporated into, or assembled with other machinery, or other partly completed machinery or equipment, thereby forming machinery to which the Machinery Directive applies (art. 2 g) of Directive 2006/42) [7]. Precisely, the manufacturer of the final product takes the necessary measures so that the robot can develop its specific application safely with the assembly. In practice, only a robot that works independently provided with a final effector and a control system that can develop a specific application, is a complete machinery according to the provisions of the Machinery Directive (Guide for the application of Directive 2006/42, July 2017) [8].

In the Statement of Legal Reasons of Directive 2006/42, it is said that although this EU regulation does not apply to partly completed machinery in their entirety, it is important that the free movement of such machinery be guaranteed by means of a specific procedure set out in article 13 of the Machinery Directive. The manufacturer of partly completed machinery or his authorised representative shall, before placing it on the market, ensure that: a) The relevant technical documentation, Part B of Directive 2006/42 is prepared; b) assembly instructions of the Directive are prepared, including the indications that must be complied with to enable the correct assembly on the final machinery so that health and safety are not compromised; c) a declaration of incorporation, part 1, Section B of the aforementioned Directive has been drawn up. The assembly instructions and the declaration of incorporation shall accompany the partly completed machinery until it is incorporated into the final machinery and shall then form part of the technical file for that machinery [9].

In relation to the relevant technical documentation, it must show which requirements of Directive 2006/42 have been applied and complied with [10]. The construction file is part of the technical documentation and must integrate, first of all, the overall drawing of the partly completed machinery and the drawings of the control circuits and the full detailed drawings, accompanied by any calculation notes, test results, certificates, etc., required to check the conformity of the partly completed machinery with the applied essential health and safety requirements. Secondly, the construction file must include the risk assessment documentation, showing the procedure followed and including: i) A list of the essential health and safety requirements applied and fulfilled; ii) The description of the protective measures implemented to eliminate identified hazards or to reduce risks and, where appropriate, the indication of the residual risks; iii) The standards and other technical specifications used, indicating the essential health and safety requirements covered by these standards; iv) Any technical report that reflects the results of the tests carried out by the manufacturer, or by a body chosen by the manufacturer or his authorized representative; v) A copy of the instructions for assembling the partly completed machinery. For series manufacture, the technical documentation must include the internal measures that will be implemented to ensure that the partly completed machinery remains in conformity with the essential health and safety requirements applied. The manufacturer must carry out the necessary research and tests on components, fittings or the partly completed machinery to determine whether by its design or construction, it is capable of being assembled and used safely. In particular, the relevant reports and results shall be included in the technical file. The relevant technical documentation must be available for at least 10 years following the date of manufacture of the partly completed machinery or, in the case of series manufacture, of the last unit produced, and on request presented to the competent authorities of the Member States on request.

What is clear is that the legislator is unable to specify the wide range of mechanisms due to the impossibility of keeping up with the pace of creation of new machines, and therefore the generic norms or security debt are applied in all cases. A clear example of this is the damage that a worker suffered resulting from being trapped by a robot in a Spanish case. In the legal argumentation of the final Judgement, it is explained that the adequate security measures were omitted since there was no adequate warning, coordination and communication systems available to the worker, which was obligatory given the characteristics of the work, as well as the absence of risk assessment (Judgement of the High Court of Justice of Galicia 28-11-2009, JUR\2009\144698).

As a complement to the EU regulations, it is possible to identify national experiences of interest in this matter. In this way, the British Standards Institute (BSI) has developed the Guide (BS 8611:2016) to eliminate or reduce the risks associated with robots to an acceptable level giving guidelines for safe design, protective measures, taking into consideration not only the physical risks but also the ethical implications. The aforementioned guide is aimed at industrial, welfare and medical robots. The French Ministry of Labour, in 2017, published the Guide for the prevention of risks in the case of collaborative robots.

Some European countries are including robotics in their national programs and try to promote safe and flexible cooperation between robots and operators to achieve higher productivity [11-15]. For example, in Germany, the Federal Institute for Occupational Safety and Health (BAuA) organizes annual seminars on the topic "cooperation between humans and robots". In addition, the Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA), in cooperation with the University of Mainz, has prepared a scientific study to establish power and/or strength limit values that a person's body can take without being harmed. In the study a number of parts of the body and the head are analyzed taking into account whether the contact is quasi-static or transient.

THE TECHNICAL SAFETY STANDARDS OF INDUSTRIAL ROBOTICS

The Directive 2006/42 defines only the essential health and safety requirements of general application, supplemented by a number of more specific requirements for certain categories of machinery. The situation described is more devastating when taking into account the security measures planned for partly completed machinery where robots seem to fit in [16]. Probably because legislators do not deal with the new challenges of artificial intelligence, the technical standards have been used to deal with this robotic wave for some years. There is a dissociation between the form and the content of the law. The right becomes a minimum right, the rules set guidelines or high protection objectives. However, the integration of material contents has been extracted from its action framework. That is, the prevention standard requires the adoption of adequate preventive measures without specifying the specific content of the aforementioned measures.

If, as Luhmann [17] pointed out, risk "is a form of present description of the future," there is no doubt that we will have to face the risks that arise from this growing reality. Unlike our ancestors, "it is not possible to separate the order from the chaos, nor to question that innovation is, above all, the result of an unstable reality". It will therefore be necessary to continue on this path and provide it with safe regulatory frameworks that should be the result of the greatest possible technical consensus, which, in all likelihood, will progressively lead to what has been called "the world government of experts".

The Statement of Legal Reasons of Directive 2006/42 refers to the technical standards when it says that in order to help manufacturers to prove conformity to these essential requirements, and to allow inspection of conformity to the essential requirements, it is desirable to have standards that are harmonised at Community level for the prevention of risks arising out of the design and construction of machinery. These standards are drawn up by private-law bodies and should retain their non-binding status.

At this point, we must refer to the technical standards that exist in the field of robotics and hazards at the workplace and that have been developed by the International Organization for Standardization (ISO). In particular, ISO 10218-1 and ISO 10218-2 [18] and Technical Specification ISO/TS 15066:2016. Recently, the International Organization for Standardization has changed its standardization committee "Robots and robotic devices", from being a subcommittee under the domain of industrial automation (ISO TC 184), to an independent technical commission, ISO TC 299.

ISO 8373-2012 and ISO 10218-1 define the industrial robot as a programmable manipulator in three or more multipurpose axes, automatically controlled, reprogrammable and multifunctional, programmable in three or more axes, which can be fixed or mobile and which is used in automated industrial applications. On the other hand, ISO 10218-1 and ISO 10218-2 set the safety requirements for industrial robots [19]; the first of the standards oriented towards safety in the design and construction of the robot and the second focused on the guidelines for the safety of personnel during the integration of the robot, its installation, testing, programming, operation, maintenance and repair.

The technical specification ISO/TS 15066:2016 [20] is a complement and support for the previous ISO standards and, in particular, it deals with the applications with collaborative robots, defines more specifically those operating modes and their corresponding safety measures. A collaborative robot is one designed to interact directly with a human being within a collaborative workspace. It should be noted that the technical specification is of immediate application, but the objective is that it is later transformed and published as an international standard once feedback has been obtained from users.

In relation to this issue, it should be noted that work is being done jointly by the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO) in a new proposal of standard ISO 21260 on "Safety of machinery. Mechanical safety data for physical contacts between moving machinery or moving parts of machinery and persons."

THE GENERAL PRINCIPLES

Before examining the technical content included in the ISO standards, a set of general principles can be deduced from the reading of these standards. First of all, the principle of willingness of the technical provisions contained in the ISO standards. Secondly, the ISO standards are basically aimed at preventing physical damage to workers as a result of contact with robots. Thirdly, the evolution of the technique will operate as a criterion to be taken into account to determine the application of the standards.

The principle of willingness of the technical provisions and the presumption of conformity

The ISO standards are private standards whose compliance is optional. This is a key principle accepted by all. This is so because they are regulations of a principle of willingness approved by bodies that do not have regulatory authority. However, this does not mean that it has no legal effect. Quite the opposite. The degree of legal effectiveness of the technical standard will be determined by the type of call made by the legal norm to the technical provision. In this sense, the Machinery Directive indicates that machinery manufactured in conformity with a harmonised standard, the references to which have been published in the Official Journal of the European Union, shall be presumed to comply with the essential health and safety requirements covered by that harmonized standard (art. 7 of Directive 2006/42).

This means that the aforementioned ISO standards have been developed to provide a tool to comply with the essential requirements of Directive 2006/42. Once these technical standards are quoted in the Official Journal of the European Union under this Directive and are implemented as national standards in at least one Member State, compliance will mean presuming compliance with the specific essential requirements of this directive. In particular, reference is made to these rules in the Communication by the Commission in the framework of the implementation of Directive 2006/42/EC of the European Parliament and of the Council, on machinery and amending Directive 95/16/EC (Publication of titles and references of harmonised standards under Union harmonisation legislation) (OJ C 92 of 9.3.2018) [21-23].

The approach aimed at preventing workers' physical injuries

The reading of the ISO standards warns that they focus their attention on the physical risks that can be derived from the use of robots in the company. Although the technical standards list hazards belonging to a different category (including crushing, cutting, electric shock, burn, fatigue, unhealthy positions), the technical content of the technical standards is basically focused on the worker safety. In addition, the ISO standards do not include solutions for the moral dilemmas in the case of collaborative robots. For example, how to programme a driverless car in the case of accident: to kill an old man or a group of young people.

However, preventive measures should not be limited to the reduction of mechanical risks due to the possible collision between robot and person within the shared space, but also a multidisciplinary approach that takes into account not only the technical aspects but also the ergonomic principle and psycho-social aspects [24]. Following this integrative approach, the risks of musculoskeletal disorders due to the possible imposition of work rhythms by the robot on the person and psycho-social risks should be evaluated as a consequence of the robot's continuous presence around the person, the mental load caused by the robot, fear of contact with the robot or stress caused by a repeated number of contacts between the robot and the person. Involuntary contact during collaboration between a person and a robot, although it may be considered physically harmless, may not be tolerable under certain conditions.

Indeed, although the impacts of robotics on health and safety at work reduce physical risks, they generate new working conditions in which new stressors appear. The empirical studies show the increase of the levels of stress in those workers who develop their activity in highly automated contexts. Some processes of robotization might lead to a greater isolation for the worker to some extent when in their department or section there is a smaller presence of human workers or they experience a non-stop monitoring because the virtual worker also controls how the work is performed by the human worker. In the same way, workers' breaks in highly automated work processes must be strictly respected. If appropriate strategies are not established and evaluated, these factors can lead to new professional diseases. All this suggests that a proactive approach is needed to assess and manage the risks associated with the presence of robotics in the workplace as well as new training, responsibility and technical level of the workers.

The state of the art as assumption of compliance with ISO standards

The ISO standards set the safety and health requirements that must accompany the use of robots from the level of technology and experience existing at the time of the design and manufacture of the robots. The introduction of ISO 10218-1 [18] points out that this standard does not apply to previously manufactured robots. On the other hand, the Technical Specification ISO TS 15066, in its first section, indicates that it does not apply to collaborative applications manufactured before the entry into force of this standard, which was in 2016. It is worth remembering at this point that the first version of ISO 10218-1 was released in 2011 and that it was modified in February 2014. Similarly, the first version of ISO 10218-2 was approved in 2011 and subsequently underwent changes in September 2016.

In this way, the principle of non-retroactivity of legal rules is also applied in the framework of technical standards as the security requirements that are incorporated into the ISO standards are applicable upon the entry into force of the regulation and its compliance is not required at an earlier stage [25]. Consequently, if an accident occurs in the workplace due to the use of robots, the safety conditions which must be verified are those that were specified in the technical regulations in force at the time of the manufacture of the robots.

However, it is particularly interesting that these regulations do not include transitory provisions that set a period of adaptation to the new safety requirements for robots manufactured prior to the publication of ISO standards [26]. At this point, it is important to remember that the employers must adopt the necessary measures to protect the health and safety of their workers, including activities to prevent hazards in the workplace, information and training, as well as the establishment of an organization and means necessary according to general principles of prevention, among them, adapting to technical progress (art. 6.2 of Directive 89/391).

SAFETY REQUIREMENTS

To understand hazards in the workplace associated with robotics and their correlative safety measures, a distinction must be made between the robot that is the manufacturer's task and is detailed in ISO 10218-1, and the robot system or cell which are analyzed in the ISO 10218-2 standard. This second part refers to the integration that is the action of combining a robot with other equipment or machines (including additional robots) to form a system capable of developing useful work. The ISO 10218-2 standard defines the integrator as the entity that designs, provides, manufactures or assembles robot systems or integrated manufacturing systems and is responsible for the security strategy, including security measures, interfaces and interconnections of the control system. The integrator can be a manufacturer, assembler, engineer or user.

The safety measures addressed to the manufacturer

The safe design of the robot: The ISO standards of industrial robotics are responsible for setting specific requirements but refer to the general technical regulations relating to machines. It is said that the robot must be designed according to the principles of ISO 12100 "Safety of machinery - General principles for design - Risk assessment and risk reduction."

The robots must be designed and built in such a way that there is no danger (loss of power or change of energy) for the workers. However, if there is a risk that is not dealt with by the design, other protective measures have to be implemented to reduce these hazards. Special attention is given in technical regulations to the stop functions of the robot. Thus, every robot is required to have a safety stop function and an independent emergency stop function. Abnormal situations, such as the case of component failures, are also subject to the ISO 10218-1 standard. For situations such as the one described, the robot parts must be designed in such a way that the hazards are minimized.

Likewise, the ISO standard analysed states that the requirements specified in the standard are minimum to ensure the safety of the robot. The ISO standard literally states that "many additional features can be added to the robot to improve its safety" (ISO 10218-1).

The manufacturer's instructions: The manufacturer's instructions are a key tool where the operation of the control system related to the safety of the robot and any other installed equipment must be clearly explained. In this sense, the ISO standard indicates that the manufacturer must provide the marks (for example, signs, symbols) and the instruction material (operating and maintenance manuals) according to ISO 12100 (Safety of machinery - General principles for design -Risk assessment and risk reduction) and IEC 60204-1 (Safety of machinery - Electrical equipment of machines).

Each robot must come with an instruction manual or an appropriate medium containing, in addition to the name of the company, complete address and the necessary contact information of the manufacturer and, if necessary, the authorized supplier or authorized representative, the instructions for a safe operation, configuration and maintenance, including safe work practices and the necessary training for robot operators to reach the level of skill necessary for handling, a guide on the means for releasing people trapped inside or by the machine; recommendations for staff training on how to react in emergencies or anomalies; information on unprotected risks due to the intended use of the robot, among other items.

The safety measures in the integration stage of the robot in the company

The ISO 10218-2 standard describes the sequence that must be carried out in the integration stage of the robot in the company, indicating that hazards must first be identified, then evaluating the risks associated with the robot system and then applying the fundamental principles to reduce risks.

The hazard identification stage is very important considering the variable nature of the risks of use of this technology. While ISO standards identify some of the hazards of using robots, they warn that the sources of these hazards are usually unique to a particular robot system. The number and type of risks are directly related to the nature of the automation process and the complexity of the installation. In short, the dangers vary with the type of robot used and its function, as well as with the way it is installed, programmed, operated and maintained.

The risk assessment should include the other machinery and equipment associated with the robot system that is not directly controlled by the robot controller, the zone configurations, the protections and the scope of the control. If the risk assessment shows that the remaining risk is not acceptable, the integrator should check whether the user can make the necessary contribution to risk reduction through additional measures, such as: 1) Special training of employees; 2) Providing usual (written) instructions. Information regarding the use of the integrated robot system must include, for example, bad uses and reasonably foreseeable prohibited practices, personal protective equipment that needs to be used and their necessary training; 3) Personal protective equipment (for example, goggles, protective footwear, appropriate clothing); and, 4) Attaching operating instructions relative to the additional operating mode. The ISO standard states that protection measures and devices must meet the requirements of ISO 12100 "Safety of machinery - General principles for design Risk assessment and risk reduction" and ISO Standard 14120 "Safety of machinery - Guards - General requirements for the design and construction of fixed and movable guards."

The fundamental principles for reducing risks are: a) The elimination of hazards through design or reduction by replacement; b) Prevent the operators from coming into contact with the hazards or controlling the danger by reaching a safety state before the operator comes into contact with the hazard; and, c) Reduction of risk during the intervention (for example, command).

The need for special preventive measures for collaborative robotics

The security requirements for collaborative robotics have been developed within the framework of Technical Specification ISO/TS 15066. These contents are incorporated in part and are complemented in the review made of the two ISO standards related to industrial robots (ISO 10218-1 and ISO 10218-2).

The justification of the special rule for this typology of robotics is explained by the fact that due to the potential reduction of the spatial separation between the human and the robot in the cooperative space, physical contact between the employee and the robot can occur during operation. While in traditional robot systems, risk reduction is typically achieved through the security measures that separate the operator from the robot system, in the case of collaborative operation, risk reduction is mainly driven by the design and application of the robot system and the collaborative workspace [18]. Protection measures must be provided to ensure worker safety at all times.

The additional requirements in the design stage in the case of collaborative robots basically refer to the fact that they must provide a visual indicator when the robot is operating in cooperation. Likewise, the robot must maintain a certain speed and safety distance from the worker.

In the technical standard, collaboration between robot and worker is authorized only for previously defined tasks; the collaboration space must be clearly defined, for example by identification on the ground, signs, etc. If several people are found in the collaboration zone, they must be protected by individual protection elements.

Special attention is given to the risk assessment which the integrator must carry out in this case considering the totality of the cooperative task and workspace, including, at least: i) the characteristics of the robot (for example, load, speed, strength, power); (ii) the dangers of the terminal element, including the piece of work (for example, an ergonomic design, sharp edges, protrusions, work with the tool changer); (iii) the scheme of the robot system; (iv) the location of the operator with respect to the proximity to the robot arm (e.g., avoid work under the robot); (v) the location of the operator and path with respect to the positioning of parts, the orientation of structures (for example, the accessories, the building stands, walls) and the location of the dangers in the Assembly line; vi) design accessories, operation and location of brackets, other associated hazards; (vii) the design and location of any robot guiding device controlled manually (for example, accessibility, ergonomics, etc.); (viii) the specific hazards of the application (for example, temperature, removal of parts, welding sparks); (ix) the limitations caused by the use of necessary personal protective equipment; (x) environmental issues (e.g., chemicals, radiation, etc.); and xi) operating criteria of the associated safety functions. It is also advisable that the worker participates in the process of risk assessment and design of the workspace.

The risk reduction should consider the means by which the possible contact between the employee and the robot system does not result in harm to the worker. This objective is achieved through different measures: i) Identifying the conditions in which such contact would occur; ii) Assessing the potential risk of such contacts; iii) Specifying the robot system and the collaborative space so that such contact is infrequent and avoidable; and, iv) Applying risk reduction measures that maintain contact situations below the limit values.

Finally, we must point out that the technical specification is also the first standard that provides detailed data on pain thresholds for different parts of the body. These values are the basis to perform the application with a power and strength limitation.

CONCLUSIONS

The first conclusion is that it would be necessary to pay more attention to the psychosocial risks. As we have mentioned, the technical standards focus exclusively on physical damages caused by the robot. However, the employee may suffer from stress due to the presence of robot in the workplace. Secondly, it would be useful to prepare new technical standards on the autonomous decisions of collaborative robots. The ISO standards may include how to address the situations of moral dilemmas. For example, how a driveless car should be programmed when the robot should choose from two possible accidents: to kill an old man or a group of young people. Finally, we recommend creating a record of robots in order to share information between all users on accidents, technical failures, etc.

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