Advances in Robotics & Automation
ISSN: 2168-9695

Chinniah, Adv Robot Autom 2016, 5:1
DOI: 10.4172/2168-9695.1000139

Short Communication | Open Access

Robot Safety: Overview of Risk Assessment and Reduction

Chinniah Y*

Associate Professor, Department of Mathematics and Industrial Engineering, Polytechnique Montreal, University of Montreal, Canada

Abstract

Industrial robots are found increasingly in the workplace. They can cause severe and fatal injuries to workers during interventions such as maintenance, unjamming, adjustments and set-up. This paper summarises some of the causes of accidents linked to robots. It presents risk assessment as described in international standards as a method to make workplaces involving robots safe. The operating modes in terms of safety aspects and strategies around collaborative robots are also presented. A case study involving safety of an industrial robot used as auxiliary equipment to a horizontal injection molding machine is described. Risk analysis and risk reduction measures for the case study are then summarised.

Keywords: Collaborative robots; Risk reduction; Risk assessment

Introduction

In this paper, for simplicity, the term robot is used to for industrial robot system (i.e., industrial robot, end-effectors and any machinery equipment, devices, external auxiliary axes or sensors supporting the robot performing its tasks) as well as for collaborative robots. An industrial robot is defined as an automatically controlled, reprogrammable multi-purpose manipulator, programmable in 3 or more axes, which may be either fixed in place or mobile for use in industrial automation applications [1,2]. Industrial robots have several functions such as welding, material handling, loading and unloading and painting. They perform hazardous and repetitive tasks. Collaborative robots are purposely designed robots in direct cooperation with a human within a defined workspace. The human can perform tasks simultaneously during production operation. Robots can cause serious and fatal workplace accidents. This paper provides a brief overview of risk assessment and risk reduction strategies for industrial robots and collaborative robots. A case study involving safety of an industrial robot used as auxiliary equipment to a horizontal injection molding machine is described. Risk analysis and risk reduction measures for the case study are then summarised. The main hazards are presented as well as the general methods used to reduce risks.

Causes of Accidents Involving Industrial Robots

A study based on analysis of 32 accidents was carried out by Jiang et al. [3]. It showed that robot operators (72%), maintenance workers (19%) and programmers (9%) suffered various injuries. Examples of injuries were: pinch injuries (56%) occurring when a robot traps a worker between itself and an object and impact injuries (44%) occurring when a robot and worker collide. The causes of injuries included unexpected robot behavior, human errors (e.g., a second worker activating the robot when one worker is close to the robot) and unexpected software problems. The harm ranges from slight injuries with no loss time, to fatal injuries. In France, Charpentier et al. [4] 2012 analysed 31 accident reports which occurred during the 1997-2010 period. The study showed that operation activities accounted for the majority of accidents (20 cases) and that maintenance activities accounted for 11 cases. Fatal injuries (8 cases) and serious injuries (21 cases) were reported. The causes of injuries included safeguards being absent, improperly installed or bypassed because they are unsuited to the intended task. Access to the moving parts of the robot was prevented by fixed guards (6 cases) and by moveable guards (8 cases). In 5 cases, there was insufficient safeguarding (i.e., guards allowed access to hazards). In 5 cases there was guard rail or emergency stop. Problems with safeguards included: bypassing, unsuited to the situation, improper usage, not installed, temporarily disabled and in a degraded mode.

Risk Assessment

Risk linked to machinery is defined in ISO 12100 [5] *Safety of machinery-General principles for design-Risk assessment and risk reduction* as a combination of the severity of harm and the probability of occurrence of that harm. The advantages of machinery risk assessment are numerous: hazards are identified effectively and better risk reduction measures can be implemented, injuries and deaths are prevented, fines and criminal prosecution are avoided, regulatory compliance is ensured and productivity is increased. The hazard is the source the harm. Machines possess mechanical and electrical hazards, as well as those generated by heat, noise, vibration, radiation and dangerous chemical and biological substances. ISO 12100 specifies principles of machinery risk assessment and reduction. The standard describes risk assessment as two stages namely risk analysis and risk evaluation, as illustrated in Figure 1. Risk analysis consists of (i) Determining the limits of the machinery, (ii) Hazard identification and (iii) Estimating the risk. The risk estimation step, which is carried out for each identified hazard and hazardous situation, is important since its results will dictate risk evaluation and therefore the choice and prioritization of risk reduction methods.

Various sources of hazards exist during the life cycle of the robot [1]. Risk assessment is required for example, for the design, integration, installation, testing, verification, operation, maintenance and training. An important step is to identify the hazard, hazardous situation, hazardous event and possible harm. There are different hazards, namely mechanical, electrical, thermal, noise, vibration, radiation,

***Corresponding author:** Chinniah Y, Associate Professor, Department of Mathematics and Industrial Engineering, Polytechnique Montreal, University of Montreal, Canada, Tel: 514 340 4711; E-mail: yuvin.chinniah@polymtl.ca

Received December 21, 2015; **Accepted** January 28, 2016; **Published** January 30, 2016

Citation: Chinniah Y (2016) Robot Safety: Overview of Risk Assessment and Reduction. Adv Robot Autom 5: 139. doi: 10.4172/2168-9695.1000139

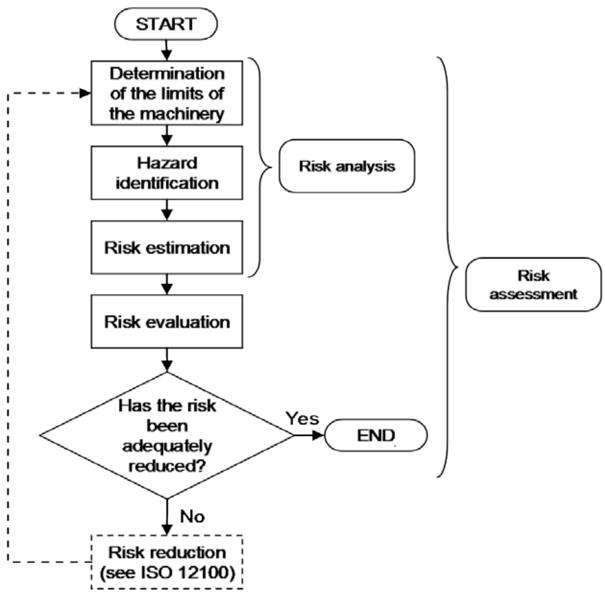

Figure 1: Simplified management of risk based on ISO 12100.

material or substance, ergonomic, associated with the environment in which the machine or the robot is used. The hazardous situation is the circumstance in which a person is exposed to at least one hazard and often the consequence of performing a task on the machine or the robot. The hazardous event can have many causes which are often technical in nature or by human actions. In Annex A of ISO 10218-1 [1], a list of significant hazards for robots and robot systems is provided.

Risk estimation tools

ISO 12100 provides guidelines on how to estimate risk and what parameters to use. This international standard mentions that the risk associated with a particular hazardous situation depends on the following two main elements: (a) The severity of harm; and (b) The probability of occurrence of that harm. The probability of harm is a function of (1) The exposure of person(s) To the hazard, (2) The occurrence of a hazardous event, (3) The technical and human possibilities of avoiding or limiting the harm. The standard also provides guidance on how to estimate all those parameters, as summarised in Table 1. Moreover, an ISO technical report has been published where several examples of risk estimation tools are given [6]. The ISO report provides practical guidance on conducting risk assessment for machinery.

Risk reduction

Designers are required to carry out risk assessments as well as risk reduction, i.e., to implement protective measures. Standards such as ISO 12100 [5], ANSI B11-TR3 [7] presents the 3 step approach for risk reduction, namely (i) Inherent safe design measures (hazard elimination), (ii) Safeguarding and complementary protective measures (fixed guards, movable guards with interlocks, safety devices) and (iii) Information for use (safe working practices for the use of the machinery, warning of residual risks, recommended personal protective equipment).

The residual risk is then managed by the user, based on the information for use provided by the designer. The protective measures implemented by the user include (i) Organization of safe working procedures such as lockout, supervision, permit-to work, (ii) Provision and use of additional safeguards required due to a specific process not foreseen by the designer in the intended use of the machine, (iii) Use of personal protective equipment, (iv) Training and so on. To ensure robot safety, manufacturers and users apply the 3 step method detailed in ISO 12100. Specific risk reduction strategies are given in ISO 10218-1 [1].

In Annex F of ISO 10218-1 [1], the means of verification of the safety requirements and measures for robot manufacturers are listed. The methods listed are: (a) Visual inspection, (b) Practical tests, (c) Measurement, (d) Observation during operation, (e) Review of application specific schematics, circuit diagrams and design material, (f) Review of task-based risk assessment and (g) Review of specifications and information for use.

The safety requirements in Annex F of ISO 10218-1 [1], include : (i) General requirements (e.g., fixed and moveable guards), (ii) Actuating controls (e.g., status, indicator light, pendant), (iii) Safety-related control (hardware and software), (iv) Robot stopping functions (e.g., protective stop functions, emergency stop functions), (v) Reduced speed control, (vi) Operational modes, (vii) Pendant controls, (viii) Control of simultaneous motions, (ix) Collaborative operation requirements, (x) Singularity protection, (xi) Axis limiting, (xii) Movement without drive power, and (xiii) Provisions for lifting and electrical connectors.

ISO 13849 [8] and IEC 62061 [9] provide the design principles of safety control systems for machinery. The safety-related parts of control systems for robots need to be reliable. Reliable safety control systems incorporate redundant architectures, use well tried safety components, include fault monitoring principles and use basic safety principles. The control systems are resistant to random and systematic failures. Usually, reliable safety controls will be difficult to bypass or to modify. Examples of well-tried safety components and basic safety principles are: (i) Using safety position switches (not ordinary limit switches) with forced opening of their contacts and mounted positively to monitor position of moveable guards; (ii) Preventing modification to the program when electronic programmable systems are used to control safety functions. Safety PLCs restrict such changes and also possess a redundant internal architecture; (iii) Use mechanically linked safety relays (not ordinary relays); (iv) Use safety light curtains (not optical sensors); (v) Separating safety control and operation control and hence decreasing the likelihood that unwanted modifications by mechanics, electricians, and programmers are made to safety control system; (vi) Protecting safety position switches and safety devices from harsh environment which could degrade them and result in premature wear and damage.

ISO 10218 [10] sets performance requirements as being a performance level d with structure category 3 [8]. ISO 10218 [10] also mentions compliance with SIL 2 with a single fault tolerance in the hardware [9].

The speed of the robot end effector must be controllable at selectable speeds and under reduced speed control, it means a speed less than or equal to 250 mm/s. Enabling devices (pendant or teaching control) has 3 positions. When the operator continuously holds the centre-enabled position, the device allows robot motion but under reduced speed control. When the pendant has no cables, the loss of communication results in a protective stop of the robot.

Collaborative Robots

Collaborative robots are purposely designed robots in direct

Parameters	ISO 12100 Reference	Factors to be taken into consideration when estimating the parameter as given by ISO 12100
Severity of harm	5.5.2.2	Severity of injuries or damage to health (e.g., slight, serious, or death) and the extent of harm (e.g., one or several persons)
Probability of occurrence of harm	5.5.2.1	Exposure of person(s) to the hazard, the occurrence of a hazardous event, and the technical and human possibilities to avoid or limit the harm.
Frequency of exposure to the hazard	5.5.2.3.1	Need for access to the hazard zone (e.g., for normal operation, correction of malfunction, maintenance or repair); nature of access (e.g., manual feeding of materials); time spent in the hazard zone; and number of persons requiring access and frequency of access.
Duration of exposure to the hazard	5.5.2.3.1	
Probability of occurrence of hazardous event	5.5.2.3.2	Reliability and other statistical data; accident history; history of damage to health; and risk comparison
Possibility of avoiding or limiting harm	5.5.2.3.3	Different persons who can be exposed to the hazard(s), (e.g., skilled, or unskilled); how quickly the hazardous situation could lead to harm (e.g., suddenly, quickly, or slowly); any awareness of risk (e.g., by general information, information for use, by direct observation, or through warning signs and indicating devices on the machinery; the human ability of avoiding or limiting harm (e.g., reflex, agility, possibility of escape); and practical experience and knowledge, (e.g., of the machinery, of similar machinery, or absence of experience).

Table 1: Summary of risk estimation parameters defined in ISO 12100.

Modes of operation of collaborative robots	Description	Comments on safety aspects
Stopped state monitoring or safety-rated monitored stop	Robot stops when worker enters the collaborative workspace. This space can be a scanned area. It continues to monitor until the worker leaves. It then resumes working, i.e. automatic operation when the worker leaves the collaborative workspace	Although it is called a collaborative workspace, it resembles a safeguarded robot inside a cage which stops when the worker enters the cage. One difference is that the robot automatically resumes work when the worker leaves. It is more like cooperation than collaboration. One example is a manual loading station.
Speed and separation monitoring	Robot slows down when worker comes near. Robot may stop if worker gets closer. Robot motion is allowed only when the separation distance is above a minimum separation distance. Different technologies can be used to detect the operator's position with respect to the robot (laser scanners, safety mats, vision-based systems).	The robot maintains a determined speed and separation barrier between itself and the worker. The relative speed of the worker and the robot is considered for minimum distance requirements. One example is worker replenishes parts. Safety control systems need to be reliable.
Hand guiding or gesture assistance robots	Worker is in direct contact with robot. Worker guides and trains robot. The robot assists the worker in tasks in which a force has to be exerted. The robot relieves the worker in that the force is exerted by the robot and not the worker. The robot motion is allowed only through direct input of the operator.	The hand guiding part is close to the end effector and consists of an enabling device and an emergency stop. A safety-rated monitored speed is used. This is collaboration between the robot and the worker.
Power and force limiting	Power and force of robot are limited. When the robot makes contact with a human being or any object with a certain force value, it stops immediately.	It is an inherent design and control of the robot. The robot knows the required amounts of force to pick up a load and to move it. When it recognizes an increase in torque or force required for movement, such as in a collision, the robot arm safely stops. Sensors at joints and output side of gearing are used. Control system is safety rated (fault tolerant). Robots are made of light material, have low inertia and no sharp or blunt edges. However, the worker who collaborates with the robot is not likely to accept being hit (although with little contact force) repeatedly.

Table 2: Operating modes for collaborative robots.

cooperation with a human within a defined workspace. The human can perform tasks simultaneously during production operation [1]. Table 2 presents the four operating modes for such robots. Collaborative robots are presented by their manufacturers as tools to empower operators in plants. The operators are responsible for training and supervising robots. There is an increase in quality of products and in overall productivity. In the long run, collaborative robots are expected to replace operators dealing with highly repetitive tasks. Some manufacturers specifically aim at small and medium sized enterprises (SMEs) which traditionally have not been heavily involved with the use of robots. By building relatively inexpensive robots that do require technical staff to program, robot manufacturers aim at automation in businesses and competition with low-wage manufacturing. In general, collaborative robots have user-friendly features that allow them to be taught, thus eliminating the need for sophisticated programming. The operator shows the robot the operation needed by grabbing the arm and guiding it to the object to be handled. They recognize with their vision system the object and the operator uses a simple set of menus to tell the robot what sequence of tasks to take.

Table 3 presents some of the collaborative robots on the market [11]. The use of collaborative robots can lead to musculoskeletal disorders for hand guiding stress due to the robot, loss of expertise and skills, dependence on technology to perform tasks, fear of loss of job and reduced autonomy. The absence of guards or physical barriers increases the need for thorough risk assessment and adequate design of safety control systems. The risks associated with the robots need to be considered as well as the products or process the robots are involved with.

Case Study from Quebec

On OSHA website, a fatal accident involving a robot and a plastic injection machine is described. On May 13th 2007, in US, an employee in the plastic sector was troubleshooting a robotic arm used to remove CD jewel cases from an injection molding machine, when the arm cycled and struck the employee. He suffered blunt force trauma to his head and ribs. He was transported to the hospital, where he died two weeks later. As seen by this example, robots often interact with other machinery and risk assessment has to include the robot and as well as the immediate environment. To illustrate the risk assessment and reduction process, a case study is described in this section. The

Robot name (year introduced and cost where available)	Single arm or Dual arm	Number of axis	Weight of robot in kg	Load capacity kg/arm	Speed m/s	Design feature and applications
Baxter (2012, 22K to 40 K USD)	Single or dual arm	6 or 7 axis per arm	75	2.3	0.6	Series elastic actuators providing flex joints; Human like; Repetitive tasks; Camera sensors for human detection
Dexter dot (2013, over 100K USD)	Dual arm	15 axis including two 7 axis arms connected to rotating torso	NA	5 to 20	High speed	Precision of traditional robots for process and assembly; High repeatability
Kuka (2013)	Single arm	7 axis arm	23	NA	NA	Power and force sensing; Force guided assembly
Universal robot (UR) (2009, 34 K USD)	Single arm	6 axis	18 for UR5	5 or 10	1.0	Power and force limiting; Very repetitive task,; Easy to use and set up
ABB	Dual arm	14 axis	NA	NA	NA	Small part assembly operation in electronics sector; Camera sensors for parts location

Table 3: Comparison among collaborative robots.

Hazard	Hazardous situation	Hazardous event	Possible harm
Movement of the arm of the robot in the direction of the worker	Worker in close proximity to the arm	Struck by the arm. Trapped against a mechanical part	Fractures, death
Movement of the gripper or other retention device in the direction of the worker	Worker in close proximity to the gripper or other retention device	Struck or pinched by the gripper or other retention device Trapped against a mechanical part	Fractures, punctures, crushing injuries, death
Stored energy -high pressure (pneumatic) at the end effector	Worker doing maintenance activities on parts of the robot	Release of stored energy and struck by moving part High pressure jets	Fractures, puncture wounds, crushing injuries
Electricity (press)	Worker in close proximity to live parts-intervening on panel-troubleshooting	Contact with live parts or with parts accidentally becoming live due to a short circuit or insulation problem	Electrocution, electrical shock
Projected object from robot	Worker in the path of the projected object	Struck by projected object after a failure of fixtures, grippers or other mechanical parts retention device	Fracture, bruises, death
Closing movement the mold of the press	Worker in close proximity to the mold or inside the molding area	Struck by the mold Trapped and crushed inside the molding area	Fractures, crushed to death
High temperature of molten plastic	Worker in close proximity to the nozzle of the injection unit and inside the molding area	Splashed with hot molten plastic following a technical problem or human error	Serious burns
Stored energy -high pressure (hydraulic or pneumatic) on the mould closing system and/or inside the mold	Worker doing maintenance activities on parts of the press and/or robot	Release of stored energy and struck by moving part High pressure jets	Fractures, puncture wounds, necrosis, crushing injuries
Projected object found inside of mold	Worker in the path of the projected object	Struck by projected object (parts of the broken mold or forgotten tools) from the closing mold	Fracture, bruises, death
Gravity	Worker climbs on the press	Loss of balance and fall from height due to slippery parts or detective/poor access	Fractures, death (head injuries)

Table 4: Hazard identification for press and robot system without considering existing risk reduction measures.

case study involves a 6 axis robot in Quebec used to unload products on a large automated horizontal plastic injection molding machine. The company specializes in manufacturing electrical components which also contain some plastic parts. At the end of each injection cycle, the mold area of the plastic injection machine opens. The arm of the robot then reaches into the mold area and with specialised end effectors delicately picks up simultaneously several small plastic parts directly from the mold. The arm of the robot enters the mold area from the operator side (i.e., the front where the control panel of the press is located). The robot then rotates and places the plastic parts on a conveyor found on its side which transports the parts through an opening in the guard surrounding the robot (i.e., a cage) for quality inspections. There is a second conveyor found in the mold area which collects remaining unused plastic parts.

The molding area of the injection molding press is a hazardous zone due to both the closing mold and the moving robot. The original moveable guard protecting the operator side of the injection molding machine had to be removed by the company when the robot was integrated to the press since it prevented the robot from reaching into the molding area. Table 4 presents the hazards linked to the robot and press. Workers perform set-up, adjustments, unjamming, and maintenance activities in or around the mold area. They are exposed to several hazards. An operator could enter the molding area following a jam or a mechanic for troubleshooting or adjustments of the press and/or of the robot. On several occasions, it was observed that the workers had their back facing the robot (i.e., they were working with their arms inside the mold area and they could not see the robot). In Table 4, the corresponding hazardous situations, hazardous events and possible harm for each identified hazard are given. As described in ISO 12100, the hazard identification phase is carried out without considering risk reduction measures in place. This approach enables to better evaluate existing risk reduction methods and, if needed, to improve or change existing risk reduction methods.

After hazard identification as described in Table 4, risk estimation is needed for each hazard. A risk estimation tool can be used (e.g., a risk graph or a risk matrix). Based on the severity of harm and the probability of harm, a risk index is obtained for each hazard, followed by risk evaluation. Risk reduction strategies are then implemented and risk reduction measures need to be evaluated to ensure that the acceptable level of risk is reached and that no new hazards have been introduced (e.g., a sharp edge on the guard).

For conciseness, only the main risk reduction measures for the case study are described here. The guard and openings in the guard need to be at a safe height and size. Standards exist to calculate the dimensions of guards. The doors of the guard surrounding the robot and mold area (i.e., cage) were interlocked such that no movement of the robot and of the press was allowed when the doors were opened and a worker entered the hazardous zone.

Reliable safety control systems incorporate redundant architectures, use well tried safety components and include fault monitoring principles. They are resistant to random and systematic failures. Usually, reliable safety controls will be difficult to bypass or to modify. Safety control system need to be designed following basic safety principles and well-tried safety components. ISO 13849 [8] and IEC 62061 [9] provide the design principles of safety control systems for machinery.

Well-tried safety component and basic safety principles used in the press-robot system were safety position switches (not ordinary limit switches) with forced opening of their contacts and mounted positively. Those safety switches monitored the position of moveable guards which are gates of the cage. Moreover, the safety position switches were protected from harsh environment which could degrade them and result in premature wear and damage. However, several safety principles were not implemented in the press-robot system. For example, a safety principle is to separate safety functions or controls and operation controls. Separating safety control and operation control decreases the likelihood that unwanted modifications by mechanics, electricians, and programmers are made to safety control system. In our case, there was no such separation. Safety functions were achieved using the same programmable logic controllers (PLCs) for the press and that of the robot used for operational control. No safety PLCs was used. Safety PLCs prevent modification to the program, when electronic programmable systems are used to control safety functions. Safety PLCs also possess a redundant and fault tolerant internal architectures (e.g., different compilers). Software is also programmed and tested using stringent rules (e.g., V cycle). In fact, the safety control system for the press-robot system was not designed with regards to their performance levels or PL (i.e., probability of dangerous failures per hour). Redundancy, monitoring and reliability principles are used to calculate the PLs. The PL calculations involve input, logic and output elements of the circuit. In our example, the inputs were the safety switches, the logic were standard PLCs and the outputs are hydraulic valves and electrical contractors. No PLs calculations were done in the press-robot system.

One important design feature on machinery includes the control mode for interventions such as maintenance, setup, when safeguards are bypassed i.e., worker being in the hazardous zone. ISO 12100 and the machinery directive mention that the safety of the operator is achieved using a specific control mode which simultaneously satisfies 4 conditions. The first condition is that the specific control mode disables all other control modes in the machinery to ensure that another worker does not restart the equipment. The second condition is that the specific control mode, permits operation of the hazardous elements only by continuous actuation of an enabling device, a two hand control device or a hold-to-run device. This ensures that the worker has full control of the hazard. The third condition is that the specific control mode permits operation of the hazardous elements only in reduced risk conditions (e.g., reduced speed, reduced power/force, step-by-step using a limited movement control device). The objective behind this condition is to limit the severity of harm, increase the possibility of avoidance of harm by anticipating it and having enough time to react accordingly. The fourth condition of the specific control mode is that it prevents any operation of hazardous functions by voluntary or involuntary action on the machine's sensors. In the press-robot system, a worker can set up the robot using a pendant while being inside the cage, close to the robot which then moves at a reduced speed of 250 mm/s.

Conclusions

The number of industrial and collaborative robots is expected to increase significantly in many industrial sectors. Occupational health and safety risk management by manufacturers and users of robots is important to ensure safe and efficient workplaces. This paper provides a brief overview of risk assessment and risk reduction strategies for industrial robots and collaborative robots. A case study involving safety of an industrial robot used as auxiliary equipment to a horizontal injection molding machine is described. Risk analysis and risk reduction measures for the case study are then summarised. The main hazards are presented as well as the general methods used to reduce risks.

References

1. ISO 10218-1 (2011) Robots and robotic devices. Safety requirements for industrial robots. Part 1. Robots. International Organization for Standardization.
2. CAN/CSA-Z434-14 (2011) Industrial robots and robot systems (Adopted ISO 10218-1 (1st edn.), 2011-07-01, with Canadian deviations and ISO 10218-2:2011 (1st edn.), 2011-07-01, with Canadian deviations.
3. Jiang BC, Gainer (1987) A cause and effect analysis of robot accidents. Journal of Occupational Accidents 9: 27-45.
4. Charpentier P, Sghaier A (2012) Industrial robotic: Accident analysis and human-robot coactivity. SIAS Conference.
5. ISO 12100 (2010) Safety of Machinery - General Principles for Design - Risk Assessment and Risk Reduction. International Organization for Standardization.
6. ISO/TR 14121-2 (2012) Safety of machinery - Risk assessment - Part 2: Practical guidance and examples of methods. International Organization for Standardization.
7. ANSI B11-TR3 (2000) Risk Assessment and Risk Reduction - A Guide to Estimate, Evaluate and Reduce Risk Associated with Machine Tools. American National Standards Institute.
8. ISO 13849-1 (2006) Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design. International Organization for Standardization.
9. IEC 62061 (2012) Safety of machinery - functional safety of safety-related electrical, electronic and programmable electronic control systems. International Electrotechnical Commission.
10. ISO 10218-2 (2011) Robots and robotic devices. Safety requirements for industrial robots - Part 2: Robot systems and integration. International Organization for Standardization.
11. Tanya A (2013) Robotic Industries Association (RIA), The end of separation: Man and robot as collaborative coworkers on the factory floor. Robotics online.