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PRINCIPLES FOR RISK REDUCTION IN THE DESIGN OF MACHINERY

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Abstract. *This article describes the general principles that designers should use in the design of machinery, with the aim to reduce risk throughout its intended use. These principles for risk reduction examine different conceptual solutions for machine safety systems. The safety systems suggested in the article do not reduce the ability of the machinery to perform its intended function(s) during its life cycle, whereas the risk is sufficiently reduced. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. For the purpose of safe machine handling, the procedures for the elimination of hazards or the provision of sufficient risk reduction in the phase of the design of machinery have been given in this article.*

Key words: *risk, machinery, protective devices, guards*

INTRODUCTION

In order to reduce risk in the design phase, the designers must, first of all, perform risk assessment. Risk assessment begins by determining the limits of the machinery, taking into account all the stages of its life cycle. This means that the characteristics and performance of the machines in an integrated process (use limits, space limits, time limits and other limits) should be defined. For more details see [1].

After determining the limits of the machinery, the essential step in any risk assessment of the machinery is the systematic identification of reasonably foreseeable hazards (permanent hazards and those which can appear unexpectedly). Only when hazards have been identified can steps be taken to eliminate them or to reduce risks. To accomplish this hazard identification, it is necessary to identify the operations which need to be performed by the machinery and the tasks to be performed by persons in an interactive man-machine communication system. The designer shall identify hazards taking into account the following: human interaction during the whole life cycle of the machine, possible states of the machine, unintended behavior of the operator or reasonably foreseeable mis-

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use of the machine. All reasonably foreseeable hazards, hazardous situations or hazardous events associated with the various tasks shall then be identified. The examples of hazards, hazardous situations and hazardous events to assist in this process have been given in [1].

After hazard identification, risk estimation shall be carried out for each hazardous situation by determining the elements of risk. The risk associated with a particular hazardous situation depend on the severity of harm and the probability of occurrence of that harm. The severity can be estimated by taking into account the severity of injuries or damage to health (slight, serious or fatal injuries). The probability of occurrence of harm functionally depends on:

- Exposure of persons to the hazard,
- Occurrence of a hazardous event,
- The technical and human possibility of avoiding or limiting harm.

While analyzing the possibilities of risk reduction in the design of machinery, it is necessary to take into account the above mentioned facts, which imply certain factors. Factors to be taken into account when assessing the risk of exposure of persons to the hazard are, among others: the need for access to the hazard zone, the nature of access (e.g. manual feeding of materials), the time spent in the hazard zone, the number of persons requiring access, and the frequency of access.

Factors to be taken into account when estimating the occurrence of a hazardous event are: the reliability of the machine, accident and event history, as well as the history of damage to health.

Factors to be taken into account when estimating the technical and human possibility of avoiding or limiting harm are the following: different persons who can be exposed to the hazard(s), (e.g. skilled or unskilled individuals), the human ability to avoid or limit harm (e.g. reflex, agility, etc.), practical experience and knowledge (e.g. knowledge of the machinery, of similar machinery, or no experience).

After risk estimation has been completed, risk evaluation shall be carried out to determine if risk reduction is required in the design of the machinery. If the requirements for risk reduction are justified, then the appropriate protective measures shall be selected and applied, which will be the subject of another discussion.

Adequate risk reduction at the design stage of the machinery is achieved when: all the operating conditions and all intervention procedures have been considered, the hazards have been eliminated or risks reduced to the lowest practicable level, any new hazards introduced by the protective measures have been properly addressed, users are sufficiently informed and warned about the residual risks.

Protective measures to be taken to reduce risk in the design of the machinery are a combination of measures implemented by the designer and the user. Inherently safe design measures are better than those that have been implemented by the user and generally exhibit a better effect.

RISK REDUCTION IN THE DESIGN OF MACHINERY

The aim of the designer is to minimize the risk to the greatest extent possible, taking into account that it is necessary that the machine is safe and functioning at all stages of the life cycle. Achieving this goal can be possible if inherently safe design measures are applied.

Inherently safe design measures eliminate hazards or reduce the associated risks by a suitable choice of design features of the machine itself and/or interaction between the exposed persons and the machine. These measures are the first and the most important step in the process of reducing risk. This is because the inherent safeguarding cannot be separated from the machinery construction. On the other hand, other protective measures are rarely used or even not applied.

Inherently safe design measures include factors related to the geometric form and physical aspects of the machine. The geometric form of machinery is designed to maximize direct visibility of the working areas and hazard zones from the control position. All the designed components with sharp edges and corners should be out of reach as they could cause injury, see [2].

The physical aspects of the machine include the following:

- Limiting the activated force to a sufficiently low value so that the activated part does not generate a mechanical hazard,
- Limiting the mass and/or velocity of the movable elements, and their kinetic energy,
- Limiting the emission of noise and vibration at the source,
- Limiting radiation emissions, including, for example, avoiding the use of hazardous radiation sources, limiting the power of radiation to the lowest level sufficient for the proper functioning of the machine, designing the source so that the beam is concentrated on the target, increasing the distance between the source and the operator or providing more remote operation of the machinery, see [3].

Machines shall be designed so that they have sufficient stability to allow them to be used safely in their specified conditions of use. Factors to be taken into account include: weight distribution, the dynamic forces during machine operation, vibration, external forces among others. Safety of the machinery shall be considered in all phases of the life cycle of the machine, including handling, travelling, installation, use, dismantling, disabling and waste disposal.

In addition to all the characteristics of the machine, during the design stage, it is necessary to pay attention to the ergonomic principles so as to reduce the mental or physical stress of, and strain on, the operator. These principles are considered when allocating the functions to be performed by the operator and the machine respectively, depending on the degree of automation. All of the elements of the operator–machine interface, such as signaling, controls or data display elements should be designed to promote clear and unambiguous interaction between the operator and the machine, see [4].

The designers should pay special attention to the following ergonomic aspects in the design stage of the machine:

- Avoid stressful postures and movements during the use of the machine (e.g. provide the facilities to adjust the machine to suit the various operators).
- Design hand-held and mobile machines that are operated easily, taking into account the soft start operating devices, and the anatomy of the hands, arms and legs.
- Limit noise, vibration and thermal effects such as extreme temperatures.
- Avoid making connections between the operator's working rhythm and automatic succession of cycles.
- Provide local lighting on or in the machine for the illumination of the working area, setting up and adjusting the work piece.

- Locate and mark manual controls so as to make them clearly visible and identifiable, making them safe to operate without hesitation or loss of time and without ambiguity so that they can be safely operated without hesitation or loss of time and without ambiguity (e.g. a standard layout of controls usually reduces the possibility of error when an operator changes from a machine to another one of similar type or operation).

Machine controls shall be arranged so that their layout, movements and resistance to operation are compatible with their function, taking into account ergonomic principles. Constraints due to the necessary or foreseeable use of personal protective equipment (e.g. footwear, gloves) should also be taken into consideration.

In order to reduce risk, it is necessary to choose, design and implement a visual display so that it fits the parameters and characteristics of human perception. All the information on the display must be identified and interpreted conveniently so that the operator could see them from the operating position. Where possible, control devices and devices for position control shall be placed so that the operator is able to observe the work area or hazard danger from a safe position.

Risk can be significantly reduced through mechanization or automation of loading (feeding)/unloading (removal) operations. This is accomplished by installing robots, handling devices, transfer-mechanisms and the like.

Mechanized equipment for automated feeding and removing objects from processing zones have positive effects in preventing accidents caused by machine operators, but they can also be a source of danger during fault removal. For these reasons, it is necessary to ensure that the use of these devices does not introduce additional risks, such as trapping or crushing between the devices and parts of the machine or work piece/materials being processed. If these hazards cannot be prevented, suitable safeguards shall be provided.

Whenever an inherently safe design measure does not make it possible to either completely remove hazards or to sufficiently reduce risks, guards and protective devices should be used. Different types of guards and protective devices may operate independently or with emergency stop equipment. Guards can be machine housing, shell, cover, curtains, and so on. Depending on their construction, safeguards can be fixed guards, movable guards, interlocking guards with or without guard locking, see [6].

Certain safeguards may be used to provide protection for more than one hazard. For example, a fixed guard may prevent access to a zone of danger where a mechanical hazard is present, but it is also used to reduce noise levels and prevent the spread of toxic substances produced by machines.

The selection of safeguards should be based on the individual risk assessment for a specific machine. Where access to the hazard zone is not required during normal operation, the guards should be one of the following: fixed guards, guards with or without guard locking, self-closing guards, or pressure sensitive protective equipment. However, where access to the hazard zone is required during normal operation of the machinery, safeguards should be: interlocking guards with or without guard locking, light curtains, pressure-sensitive mats, adjustable guards, self-closing guards and two-hand control devices, see [6].

The instruction manual is an important factor in reducing risk that could not be eliminated at the design stage. The information given in the manual is intended for professional and/or non-professional users and should contain all the necessary guidelines for

safe and proper use of equipment. Taking these in consideration, the users shall be reminded of the residual risks.

Information for use should include the following information about the machine: transport, assembly installation, commissioning, use of the machine (setting, training, work process, cleaning, fault finding, failures and maintenance), dismantling, disabling and waste disposal. Instructions printed directly onto the machine should be durable and remain legible throughout the expected lifespan of the machine. Signs or written warnings indicating only 'Danger' shall not be used. Markings, signs and written warnings should be easily understandable and unambiguous. Easily understood signs (pictograms) shall be used primarily for written warnings.

REQUIREMENTS FOR THE DESIGN AND CONSTRUCTION OF GUARDS

Guards shall be designed to be suitable for the intended use, taking into account mechanical and other hazards. These safety systems shall provide minimum possible interference with activities during machine operation.

Guards must meet certain requirements, including the following:

- be of robust construction,
- not to give rise to any additional hazard,
- not be easy to bypass or render non-operational,
- be located at an adequate distance from the danger zone,
- cause minimum obstruction to the view of the production process,
- enable intervention during fault removal and maintenance.

In order to select and design the appropriate type of guard for a particular machine, it is important to assess the risks of different hazards in the machines, see [1].

In the design and application of guards, it is necessary to properly consider the foreseeable aspects of the machine environment and operation throughout the foreseeable life of the machine. Inadequate consideration of these aspects can lead to unsafe or inoperable machinery. This in turn can lead the persons operating the machine to defeat the guards, thus exposing them to even greater risk.

To minimize access to danger zones, where applicable, guards and machinery shall be designed so as to enable routine adjustments, lubrication and maintenance to be carried out without opening or removing the guards.

In case the access within the guarded area is required, it should be free and unobstructed. These are the examples of reasons for access to the danger zone:

- Loading and unloading,
- Tool changing and setting,
- Measurement, gauging and sampling,
- Process observation,
- Maintenance and repair,
- Lubrication,
- Removal of waste material (e.g. scrap, swarf, spillage, etc.),
- Obstruction removal,
- Cleaning and hygiene.

For a better understanding of a given problem, there are some examples of possible risks and risk removal by installing safety systems immediately at the design stage of the machines.

In the first example, where there is a foreseeable risk of the ejection of parts (e.g. broken tools or the object being processed) from the machine, the guard should be designed and constructed from appropriate materials so as to contain those hazardous broken parts. Take tool breakage during grinding for example. In this case, guards around the grinding tools shall be designed so as to prevent uncontrolled chipping of the broken tools. For more details see [5].

In the second example, where there is a foreseeable risk of emission from hazardous substances from the machine (e.g. coolant, vapors, gases, swarf, sparks, hot or molten material, dust), the guard shall be designed to contain these and enable extraction of hazardous substances from the working environment without harm to human health. If a guard is a part of an extraction system in the working environment, this function shall be considered in the design, the selection of materials, construction and positioning of the guard. In the third example , where there is a requirement to reduce machine noise, guards shall be designed and constructed so as to enable the required noise reduction and provide protection against other hazards arising from the machine. Guards acting as acoustic enclosures shall have adequately sealed joints to reduce the emission of noise. When necessary, the materials that reduce noise and vibration should be chosen. This can be achieved through isolation (putting acoustic obstacles in the noise passage) and/or absorption (covering guards by suitable materials that absorb noise) or a combination of both.

In the fourth example, where there is a foreseeable risk of exposure to hazardous radiation, guards shall be designed and the appropriate materials should be selected to protect people from the hazard. One of the examples is the use of darkened glazing to prevent weldflash. For particular uses, such as welding or the use of lasers, the materials which provide protection against hazardous radiation should be used.

SELECTION OF TYPES OF GUARDS

If the risk assessment determines the need for guards as part of the machine, they must be selected according to the scheme given in the Figure 1.

Figure 1 provides the guidelines for the appropriate selection of guards in an emergency caused by the moving parts of machinery, see [7].

The most important criteria for the selection of guards are the following:

- The probability of injuries;
- The hazards present in the machine;
- Temporal and spatial involvement of workers in the vicinity of the machine.

There is the possibility of combining different types of guards at one machine. For example, if a machine has several danger zones and access is required to one of them during the operating phase, the guards can consist of a fixed guard combined with an interlocking movable guard.

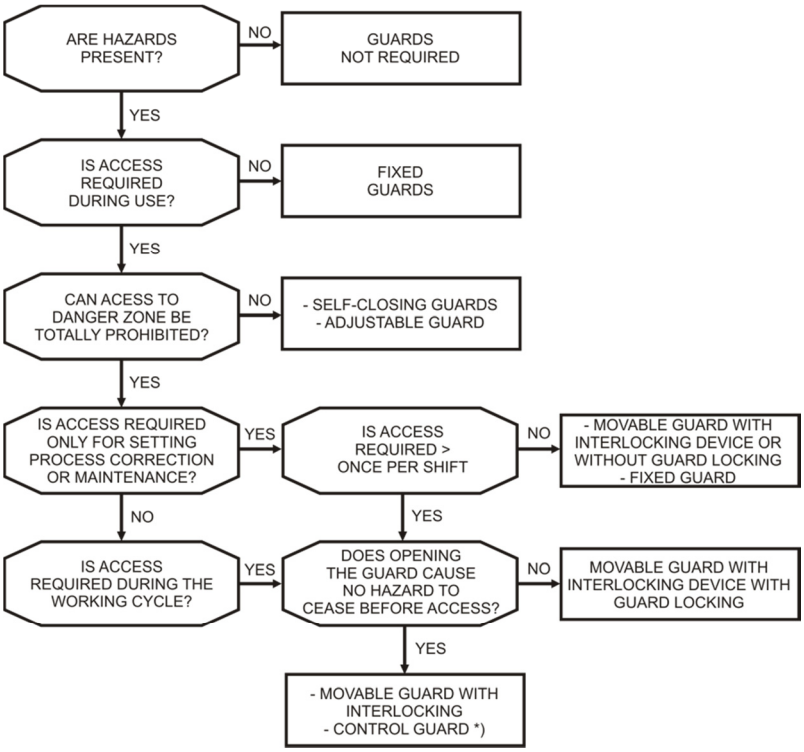

Fig. 1 Selection of types of guards

CONCLUSION

In the design stage of the machinery, the task of the designer is to identify and keep a record of hazards, hazardous situations and events throughout the life cycle of the machine. All hazards should be recorded even though the risk associated with them seems sufficiently reduced by suggested safeguards. Otherwise, undocumented risk may be the cause of injury.

When selecting a guard in the design of machinery, the most appropriate guard would be the one that reduces risk. The simplest solution is a fixed guard that is used in cases where access to the hazard zone is not required during normal operation. However, if there is a need for more frequent access to the danger zone, this requires the use of alternative protective measures (e.g. a movable guard with locking or light curtains). The machinery must be designed so that the safety system within the machine provides protection for the operator, and ensures the safety of the personnel that perform the set-up, training, the change of operation, fault finding, cleaning or maintenance, without limiting the exercise of the functions for which the machine is designed. All functions of the machine must be identified, while hazardous situations during machine operation and potential risks should be reduced immediately in the design stage.

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PRINCIPI SMANJENJA RIZIKA U FAZI PROJEKTOVANJA MAŠINA

U radu se daju opšti principi koje projektanti treba da koriste u fazi projektovanja mašine, kako bi se smanjio njen rizik pri korišćenju u predviđenoj upotrebi. Datim principima za smanjenje rizika razmatarju se različita koncepcijska rešenja sistema bezbednosti mašina. Predloženi sistemi zaštite ne umanjuju sposobnost mašine da obavlja svoju predviđenu funkciju/e u toku svog životnog ciklusa, dok je rizik adekvatno smanjen. Dati principi su zasnovani na saznanjima i iskustvu koji proističu iz analize incidenata, nezgoda i rizika koje mašina sa sobom nosi. U cilju bezbednog opsluživanja mašina dati su postupci za eliminisanje opasnosti, odnosno odredbe za dovoljno smanjenje rizika u fazi projektovanja mašine.

Ključne reči: *rizik, mašina, zaštitni uređaji, zaštita*