Machinery Design for Construction Safety in Practice

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Abstract. Increasingly today more and more complex machinery are designed, produced or maintained. It causes that the requirements of machines operators in the scope of assurance protection are progressively higher. As a result new laws, standards and practices are introduced. These regulations concern all the machines which are placed into the EU market. In this paper the practical verification of construction design for safety is done on the example of shaping machines such as: loathes, milling machines, drilling machines and horizontal boring machines with the application of existing law. The investigated machines were offered for sale on Polish market by Internet.

Keywords: machinery design, safety design, Machinery Directives, harmonized norms, regulations.

1 Introduction

Modern technology has imposed profound need to use knowledge derived from different fields into machinery design. Both ergonomics and disciplines connected with technical or economic issues have become equally important. It follows from the fact that regardless of increasing technological advance of machinery there is still necessity to assure machinery and operators' safety [13, 14]. In order to fulfill this requirement, new principles involved in the machinery design have been introduced. In most cases they were due to safety requirements connected with the introduction of new materials and manufacturing techniques [15]. Furthermore, the machines need to be designed for using in more and more severe exploitation conditions. Their safety should be assured regardless of appearing of disturbances in working environment i.e. affects of humidity, environmental temperature changes, influence of chemical factors, corrosion, fluctuation and asymmetry of voltage [12, 13, 18]. Moreover, the meaning of the safety values, which relies on matching the operating obligations of the machine with the ability and physique characteristics of the operator, has also increased [15]. As the safety awareness and improved safety performance have grown, people become more concerned with economical, political and social effects of accidents and fatalities [5, 6, 8]. Therefore, safety of machinery has become risk based and relies on indicating the level of required protection. It appeared that dealing with the subject of machinery safety means to combine the problems of design, manufacturing and the use of machinery, systems of working and plant layout [15, 16].

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In the paper the issues of construction design for machinery safety are highlighted. The application of safeguarding requirements into practice is discussed on the basis of standards and legislation in force. The final part of the paper is devoted to the investigation of machines from assuring safety point of view. The research is conducted on the basis of shaping machines such as: loathes, milling machines, drilling machines and horizontal boring machines.

2 Fundamentals of Design for Safety

Increasingly today more and more laws, regulations and standards, which aim at ensuring an appropriate level of protection, are put into practice. It is expected from producers to provide machinery which guarantee protection to its operators. Thus, the designers should be aware that conditions or activities, which do not assure safety, are very often symptoms of abnormalities which should be predicted in the majority of accidents. Therefore, engineers engaged in safety issues should be motivated to cooperate with designers' teams in all the design stages of machinery design [3, 9, 21]. It is advisable that all the aspects of safety machinery usage should be taken into account on drawing board [2, 3, 7, 20, 21].

As the research results show [4, 19, 20], the effectiveness of producers' activities in the scope of safety decreases in the sequential stages of technical production preparation. Thus, the activities taken up in the conceptual design or early design stages have the greatest impact on final product safety as it is shown in figure 1.

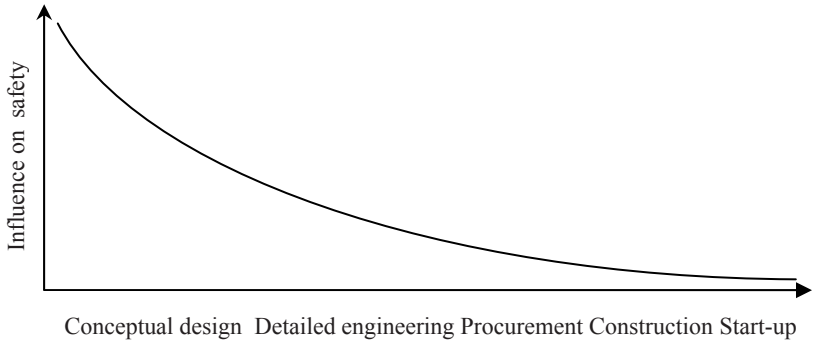

Fig. 1. Phrases of product design versus ability to influence safety (adapted from [20])

Furthermore, it is indicated that considering safety, which encompasses ergonomic, fire, health and environmental aspects, is very beneficial and necessary to companies from the financial point of view. It influences on the cost of implementing safety requirements in the next stages of life cycle of the machine [4]. It is depicted in figure 2.

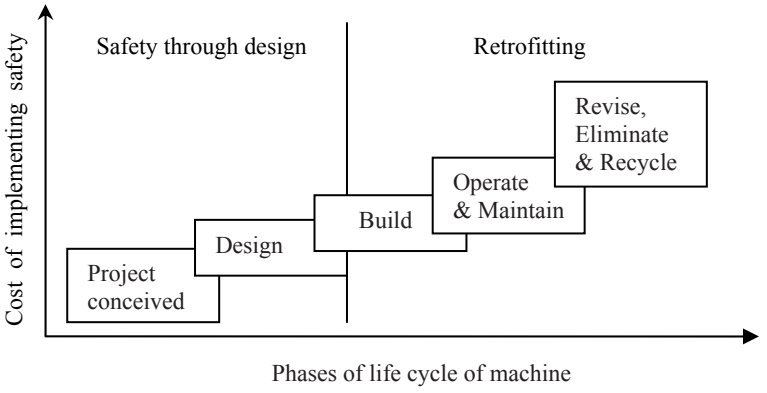

Fig. 2. Safety requirements and its costs (adapted from [4])

The more extended investigation was carried out by the Institute for Safety through Design (ISTD). They noticed that treating safety as forethought enables to reduce operating costs. The other benefits of addressing safety in the conceptual design and early stages of design are the following:

- improved productivity,
- avoidance of expensive retrofitting to correct design shortcomings,
- significant reductions in injuries, illnesses, environmental damage and attendant costs [7].

Moreover, it is noticed [16] that eliminating the hazard provides better results to safety improvement than reducing the hazard or giving personal protective equipment to workers. Manuele [10] proposed a list of activities influencing safety in the order of decreasing priority and effectiveness:

- design to eliminate or avoid the hazard,
- design to reduce the hazard,
- incorporate safety devices after the fact,
- provide warning devices,
- institute training and operating procedures.

The similar safety activities suggested Andres [1] and they are as follows:

- eliminate the hazard,
- provide engineering controls,
- warn,
- train,
- provide personal protective equipment.

In order to ensure that all safety aspects are taken into account in the process of designing machinery, Ridley and Pearce [16] proposed a pro-forma procedure. It comprises the following four stages:

1. Design hazard identification and elimination.
2. Risk assessment of residual hazards.

3. Risk reduction through provision of safeguards.
4. Warning to users of any remaining residual operating risks.

The implementation of the suggested strategy requires knowledge of the machine use from the designer and also manufacturer who have to establish recommendations how to operate and maintain the machine. All the possible to foresee uses of machine should be also considered by them. As it can be noticed the safety aspects involved in each stage of the machine life should be considered during the design process. Design assessments of the risks should be made as the design of the machine develops.

3 Machinery Safety Design in EU Regulations

There is a variety of guidelines to machinery safety legislation. As well as the moral obligation to avoid harming anyone can be differentiated, there are also laws that require machines to be safe. In the EU the major impact on safety has the Directive of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast) called Machinery Directive (2006/42/EC). According to this Directive machine manufacturers or their authorized representatives within the EU, must ensure that the machine is consistent with its requirements in the scope of health and safety relating to the design and construction of machinery. Such aspects as principles of safety integration, materials and products, lightening, design of machinery to facilitate its handling, ergonomics, operating positions, seating, control systems, protection against mechanical and other hazards, required characteristics of guards and protective devices, maintenance and information are taken into account. In order to conform that the machine is in accordance with this Directive a technical file is prepared, CE marking is affixed and a Declaration of Conformity is signed before the machine is placed on the EU market. During exploitation of machines, users have to ensure that they use, inspect and maintain machines in accordance with the manufacturer's instructions. Furthermore, any modification of machines can be treated as manufacture of a new machine if the risk assessment requires revision. The need to revise a risk assessment arises if modification concerns a change in the machine's function or its limits (e.g. position, speed, size). Therefore, the company, which modifies a machine, needs to realize that in such situations a need of issuing a Declaration of Conformity and CE marking appears [17].

The requirements of the Machinery Directive in the aspects of safety and work hygiene are rather general. Thus, in accordance with so called "New Approach Directives of the European Union", detailed technical solutions are included in European harmonized standards. The structure of the European standards for the Safety of machinery is shown in Table 1.

As it can be seen three types of safety machinery standards are differentiated. The categorization into one of these groups depends on the subject of the standard. These EN standards are adopted by member countries of the European standards bodies as a national wide with the prefix preceding "EN". In a case of conflicting with any national standard, it must be withdraw to keep a common standard applied across Europe.

Table 1. European standards for safety of machinery

Type of standard	Scope	Examples
Type A	Basic safety standards	EN/ISO 12100-1, EN/ISO 12100-2 EN/ISO 14121-1 EN 614-1, EN 614-12
Type B	Generic safety standards	
Type B1	Safety aspects	EN/ISO 13857 EN 349 EN 999
Type B2	Safeguards	EN 574 EN 1088 EN 1760-1, EN 1760-2, EN 1760-3
Type C	Machine safety standards	EN 201 EN 289 EN 692

The Machinery Directive (2006/42/EC) is enforced on the territory of Poland by the Regulation of Ministry of Economy on fundamental requirements for machinery published in Dziennik Ustaw No. 199, item 1228 of 21 October 2008. It is obligatory from 29 December 2009. Before this time, so for machines produced in years 2003-2009, the Directive 98/37/EC of the European Parliament and of the Council of 22 June 1998 on the approximation of the laws of the Member States relating to machinery is in forced by Dziennik Ustaw No. 91, item 858 of 10 April 2003. The comparison of the revised Machinery Directive 2006/42/EC with the old Machinery Directive 98/37/EC shows that it does not cause any revolutionary changes. It combines the achievements of the Machinery Directive as far as free circulation and safety of machinery are concerned. Nevertheless, the scope of the new one is extended (e.g. inclusion of construction-site hoists and cartridge-operated fixing). The most important changes cover requirements relating to:

– risk assessment,
– risks associated with machinery serving fixed landings extended by construction site hoists and slow-moving lifts,
– noise and vibration emissions,
– application of certain guidelines used to mobile machinery or machinery for lifting to all machinery presenting the risk concerned [11].

In the case of machines produced before 1 January 2003 the mandatory regulation is the Directive 2009/104/EC of the European Parliament and of the Council of 16 September 2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work (second individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). It is introduced into Polish law by the Regulation of Ministry of Economy of 30 October 2002 with changes in 30 September 2003 (Dziennik Ustaw No. 191, item 1596 of 18 November 2002 and No. 178, item 1745 of 16 October 2003).

4 Investigation of Machinery Design for Construction Safety

4.1 Research Objectives and Methods

The purpose of this study was to determine construction design practices in accordance with safety standards in force. For this purpose, three primary activities were undertaken: a literature review, a review of European standards containing references to machinery design and a survey of machines and their salesmen. The researchers took an attempt to assess sales' knowledge about fundamental or minimal requirements for machinery resulting from the adoption of the Machinery Directive 2006/42/EC, 98/37/EC or 2009/104/EC, respectively. They considered viability of demands to be related to the introduction of machines into market. They also asked their respondents about their attitude to the design-for-safety concept.

The study was done on the example of shaping machines such as: loathes, milling machines, drilling machines and horizontal boring machines. All the investigated machines were offered for sale on Polish market by Internet. As a small, pilot-level effort, the study was intended to be the starting point for a more comprehensive research project which would encompass more types of machines in the whole European market.

For the purpose of this research, the machines were analyzed in two groups. The division was done on the basis of their origin (the EU countries and others). Moreover, a new approach how to assess construction of machinery for the sake of safety was applied. It was considered on the basis of five groups of tasks distinguished by the authors, which are as follows:

- safety of technology and machinery exploitation,
- safety of work process,
- safety of work space,
- safety of information, signal and control elements,
- safety of work environment.

Each group of the tasks was analyzed with the application of a checklist prepared on the basis of the Regulation of Ministry of Economy or Regulation of Ministry of Economy, Labour and Social Politics on fundamental requirements for machinery (Dziennik Ustaw No. 199, item 1228 of 21 October 2008 and No. 91, item 858 of 10 April 2003) or minimal requirements for machinery (Dziennik Ustaw No. 191, item 1596 of 18 November 2002 and No. 178, item 1745 of 16 October 2003). Following these regulations, only machines which fulfill the provisions should be placed on the market and/or put into service.

4.2 Results and Discussion

If it is required that the machines, which are launched or sold in the EU market, should conform the provisions of the appropriate Directive, not only the manufacturers or their authorized representatives should be aware of this fact but also second hand suppliers. They should know it to be able to provide correct and full information to potential buyers. The results of the research show that of the 42 respondents interviewed, 35 (83%) were judged to be knowledgeable of the overall concept. When

they were asked in details it revealed that only 27 (77%) knew the answer. On the basis of this data two groups of suppliers can be distinguished. The first one, who offered a great number of machines which were previously used, knew what conditions should be fulfilled to exploit the machine in industry. The second group wanted to sell a single product which in most cases was exported by their own or was applied for their own use in the past. They had a slight idea about the problem and it was difficult for them to determine if the machine which they offer should fulfill the minimal or fundamental requirements. In many cases they did not have a full documentation concerning introduction of the machine into use. Moreover, the technical documentation was not translated into national language for two machines. Additionally, when all the respondents asked, "What is your attitude to design-for-safety concept?", 40% of them were negative (Fig. 3).

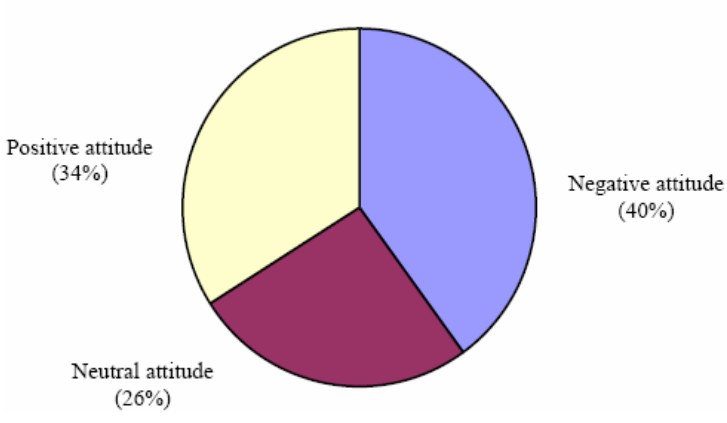

Fig. 3. Attitude to design-for-safety concept

They perceived it as making trouble in using cheap second hand machines, particularly, those which were placed on the market and/or put into service after 1 January 2003 from non-European countries (e.g. China, Russia or South Korea). However, many suppliers had a positive attitude (34%) and only 26% had no opinion about it.

Although legislation forcing the adoption of the Machine Directives (2006/42/EC, 98/37/EC or 2009/104/EC) is restricted by Polish regulations, in some aspects construction design for safety is not always fulfilled in practice. This phenomenon is particularly visible when offers for sale on Polish market by Internet are analyzed. In Table 2 there are shown the results of survey of machines which were offered and/or put into service before 2003.

As it can be seen the greatest amount of discrepancies between the construction of the investigated machines and the minimal requirements was for the first and fourth aspects of safety. As far as technology and machinery exploitation are concerned, lack of guards and application of materials not resistant to corrosion occurred. In the case of the requirements for information, signal and control elements such differences were distinguished as lack of warnings on the machinery, buttons without hollows and improper colour of control elements (white). The other problems concerned work

Table 2. Assurance of construction safety by minimal requirements

Aspect of safety	EU countries (n=12)	Non-EU countries (n=8)
1. Technology and machinery exploitation	42%	50%
2. Work process	92%	88%
3. Work space	92%	75%
4. Information, signal and control elements	67%	50%
5. Work environment	75%	75%

environment (no extractor), work space (no protection of the operator and the other workers against hot shavings) and work process (no supporting elements).

In Table 3 there is presented data concerning assurance of construction safety of the machinery in accordance with fundamental requirements.

Table 3. Assurance of construction safety by fundamental requirements

Aspect of safety	EU countries (n=11)	Non-EU countries (n=11)
1. Technology and machinery exploitation	54%	45%
2. Work process	45%	36%
3. Work space	90%	72%
4. Information, signal and control elements	100%	100%
5. Work environment	81%	72%

The results of the study showed that it is very difficult to assure safety work process. The investigated machinery was not supplied with all the special equipment and accessories necessary to adjust, maintain and use it safely. The lack of them was justified by wearing them up and on the other hand, the possibility of purchasing new one (e.g. back centre or rotary backstay). The second aspect, which was far from the desired, was technology and machinery exploitation. Considering it, the particular attention was paid to guards and protective devices. The necessary steps were not taken to prevent accidents as they were in impropriate condition (e.g. it was possible to open them without using tools) or were not fixed. The another problem occurred in the case of assuring safety from work environment point of view. The machines were not supplied with appropriate lighting for internal parts requiring inspection, adjustment and maintenance. In some cases it did not have an integral lighting suitable for the operations. It was also possible to find the machinery with no adjustment of space for shavings.

The analysis of the machinery offered for sale by Internet allowed to indicate the weakness points of their construction in comparison to the present legal requirements. The data showed that the problem of fulfilling fundamental requirements is more difficult as these guidelines are more precise. However, it must be emphasized that

the condition of machines from construction safety point of view, which were placed on the market and/or put into service after 2003, is significantly better than those from earlier time but still not satisfying. The attention must be paid to the fact that almost half of the investigated machines, which should be in accordance with the provisions of the Machinery Directive, did not have a Declaration of Conformity and CE marking. They should be adjusted to these requirements before being put into market and in service.

5 Conclusions

As safety has become a matter of valuable importance in machinery design, the number of safeguarding requirements has been enlarged. New regulations which ensure that the manufacturer is responsible for any damage or harm caused by a defective product have appeared. The best examples of them are EU Directives. Such provisions provide the best practices how to support conformity with local and national regulations and contribute to fulfillment of the demands of the operator and the employer. Moreover, they provide the basis for the design procedures.

On the basis of the Directives enforced in Polish law by Regulation of Ministry of Economy on fundamental requirements for machinery and Regulation of Ministry of Economy, Labour and Social Politics on minimal requirements for machinery the investigation concerning design for construction safety was carried out. The results of it indicated that a significant discrepancy between the legal requirements and the state of second hand machines can be noticed, particularly, in the case of those produced 20 years ago in EU and non-EU countries. Unfortunately, such products are still available on the market. On the other hand, the machinery, which was launched after 2003 into EU countries, seems to fulfill some of essential health and safety requirements. However, the use up of particular elements of construction does not allow to apply for EC declaration of conformity of the machinery and CE marking without being adjusted.

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