

SYSTEM METHODOLOGY OF RISK ASSESSMENT IN MACHINE TOOLS

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Abstract

The contribution deals with the problem of safety assurance in machinery in accordance with the requirements of the Directive 2006/42/EC of the European parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast), replacing the Directive 98/37/ES. The existing methods suitable for identification of hazards associated with machinery are reviewed. A new method of risk assessment in machine tools is presented, applying the system approach to hazard identification and to analysis and evaluation of risks associated with machinery, in accordance with the relevant Czech and EU legislation.

Further, the contribution discusses a suitable way of documenting the risk assessment process.

Keywords: *Risk analysis, Risk assessment, Risk management*

1. Introduction

In order to reduce the social costs induced by great number of injuries caused during work with machinery, a key component of engineering industry, many legal regulations of the European Community dealing with safety of machines and machinery binding both for producers and users continue to come into force. Directives of the Council, as a part of the European legislation, are obligatory for member countries of the EU and their objective is to harmonize the national legislations with the EC law. As the current development of science and technology is much faster than the legislation process, it is not possible to specify quite accurately and concretely the legal requirements on safety of individual products. That is why the institute of harmonized technical standards has been created and their fulfilment is regarded as fulfilment of the legal duty set by the technical-legal regulation related to the harmonized standard. In this environment, the suppliers of machinery must comply with ever-increasing and dynamically changing requirements and so continuous monitoring of the relevant legislation and standards is essential.

2. Duties of machinery manufacturers

In compliance with the Directive 2006/42/EC [7], the manufacturer of machinery or his authorized representative are obliged to provide assessment of risk with the aim to determine the requirements on their machinery as regards health protection and safety. The machinery must then be designed and constructed with respect to the results of risk assessment.

Through a repeated procedure of risk assessment and reduction, the manufacturer [7]:

- determines the limits of the machinery, including its intended use and any foreseeable misuse,
- identifies the hazards that can be generated by the machinery and the associated hazardous situations;
- estimates the risks, taking into consideration the severity of the possible injury or damage to health and the probability of its occurrence;
- evaluates the risks with the aim to determine whether it is necessary to reduce them in compliance with the objective of this Directive;

- eliminates the hazards or reduces the risks by applying protective measures in this order of priority:
 - eliminate or minimize the risks;
 - take the necessary protective measures in case of risks that cannot be eliminated;
 - inform the end user of the residual risks.

Risk assessment documentation must include:

- a list of the essential requirements on health protection and safety related to the machinery;
- the description of the protective measures taken to eliminate the identified hazards or to reduce risks and, when appropriate, the indication of the residual risks associated with the machinery.

The basic requirements of the 2006/42/EC Directive [7] are supported by ČSN EN ISO 12100-1/2004 [4]. This standard defines the terminology and methodology used to achieve safety of machinery. Technical principles that may help the designers to construct safe machinery are defined in ČSN EN ISO 12100-2/2004 [5]. General principles of risk assessment procedure in all phases of the life of machinery are described in ČSN EN 1050/2001 [6]. Information necessary for risk assessment and risk analysis must include:

- limit values of machinery;
- requirements for individual phases of the life cycle of machinery;
- technical drawings or other instruments describing the character of machinery;
- information on power supply;
- any known injuries and development of accident occurrence relevant to the machinery;
- any available information on damage to health.

3. Review of occupational accident occurrence in the Czech Republic

According to statistical data from 2005, trends of overall occupational accident occurrence and occupational fatalities in the Czech Republic were different. The values of occupational fatalities indicators significantly decreased compared to 2004, while the overall occupational accident occurrence showed slight increase [8]. In 2005, there were 82 042 cases of incapacity to work due to occupational accidents reported in the Czech Republic. These accidents resulted in 3,702 mil calendar days of incapacity to work in total. The average length of incapacity to work due to occupational accident was 45.13 calendar days, which means that 10 143 people were absent from work each day on average as a result of occupational accidents

164 fatal occupational accidents were reported in the Czech Republic in 2005, of which 48 occurred in the sector of processing industry.

Selected sources of occupational accidents resulting in incapacity to work longer than 3 days:

- Material, loads, objects – 38.6% of cases
- Working areas – 28.4% of cases
- Equipment and tools – 9.5% of cases
- Machines – 8.3% of cases

Selected sources of fatal occupational accidents:

- Working area – 18.3% of cases
- Material, load, objects – 17.2% of cases
- Elevators and transporters – 4.1% of cases
- Machines – 3.6% of cases
- Electricity – 3.0% of cases

Selected causes of occupational accidents:

- Incorrectly or insufficiently estimated risk – 57.8% of cases
- Loss of control over machines – 47.2% of cases

- Insufficient personal qualifications – 31.8% of cases
 - Slipping, tripping, fall of persons – 7.6% of cases
 - Movement of body under or with physical load – 12.6% of cases
 - Breaking, snapping, material destruction – 4.9% of cases
 - Overfill, overturn, evaporation, emissions – 3.2% of cases
 - Defective or unfavourable state of the source of injury – 1.7% of cases
 - Application of dangerous work methods – 1.5% of cases
 - Endangering by other persons – 1.9% of cases
- (individual causes overlap, therefore the sum is not 100%)

The above listed causes of occupational accidents advert to key significance of thorough risk assessment for development of a virtually safe machine. It is mainly the stages of identification and analysis of hazards and evaluation of risks associated with these hazards that are crucial for precise risk assessment. The current legislation and standardization specify the general procedure of the risk assessment process, not describing the method of realization of its individual stages. Besides, identification and analysis of hazards and estimation of their risk is done subjectively. For some types of machinery, manufacturers may use the type C standard containing a list of serious hazards; however, it usually does not comply with the current requirement on identification of hazards during the whole life cycle of the machinery. Therefore, the problem of risk assessment lies in the absence of methodology for hazard analysis and risk estimation that would increase the objectiveness of the results and support the fulfilment of all current legal requirements.

4. Methods of hazard analysis and risk evaluation

A number of simple or more complex methods of hazard analysis and risk estimation are available (Checklist, Safety Review, Fault Tree Analysis, Event Tree Analysis, Failure Mode and Effect Analysis, Hazard Operation Process, Human Reliability Analysis, Preliminary Hazard Analysis, What - If Analysis, Meta-Quality Deployment etc.) [3]. Each of these methods has been developed for specific conditions of different cases of their application and therefore can not be used universally. The following methods may be more or less applied in the process of risk estimation in machinery:

- Checklist – in hazard analysis, checklist is for example the list of serious hazards presented in type C standard of the specific machinery.
- Failure Mode and Effect Analysis – a part of this method dealing with system analysis may be used during hazard analysis of machinery.
- What - If Analysis – when analyzing the hazards in machinery, we can apply this method for identification of hazards connected with the activity of operating personnel.
- Method Organised for a Systematic Analysis of Risk – when analyzing the hazards in machinery it is also convenient to see the equipment as a set of subsystems with interactive relations.
- Meta-Quality Deployment – when analyzing the hazards in machinery it is suitable to apply system approach to analysis of potential failures and their causes.

It turned out that a new methodology is needed for successful realization of risk assessment process in machine tools that would integrate the advantages of the above-listed methods and would apply system approach to the solution of this fundamental process.

5. System methodology of risk assessment

The following sections present the newly-developed system methodology for assessment of risks and determination of necessary preventive measures.

5.1 Planning of risk analysis and assessment

Risk analysis planning is a task of strategic management of an enterprise. The policy of risk perception must be clarified on the level of top management. The strategic risk management must provide determination and approval of limits of risk levels for evaluation of their seriousness, categories of probability of risk occurrence and tables of risk significance. Besides, it is necessary to gather information on the current state of the art of science and technology, solutions of safety risks in comparable products, information on previous occurrences of risks (i.e. accident occurrence) in similar equipment and to prepare the risk estimation graph.

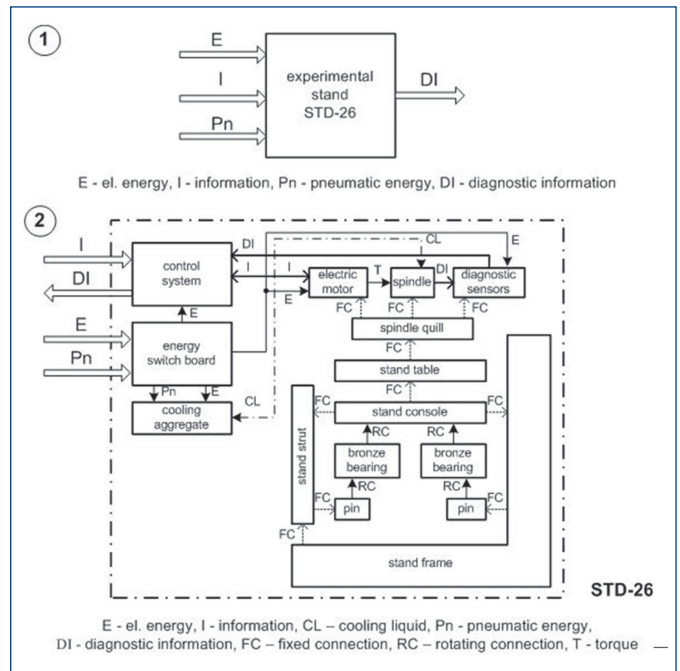


Figure 1. Example of a block diagram of machinery

5.2 System analysis of machinery

System analysis [1] of machinery is based on creation of its block diagram on suitable level of resolution (Fig. 1), which shows all relevant interactions between its individual elements (subsystems). In the following step, this block diagram together with the ČSN EN ISO 12100-1/2400 [4] standard are used for determination of all relevant hazards associated with the machine and the main dangerous areas of the analyzed machine are marked out.

5.3 Determination of limit values of machinery

Limit values represent the limit possibilities of the machine or staff:

Limits of use specify the intended use including various operational states of the machine, phases of use and various intervention processes during operation. Any reasonably foreseeable misuse should be also taken into consideration.

Spatial limits include range of movements, space for installation and maintenance of the machine, man-machine interface and machine-power supply interface.

Time limits include the expected service life of the machine, considering its intended use, and components used (i.e. tools, wear of parts, electrical components).

5.4 Identification of hazards

Identification of hazards in machinery is performed in accordance with the Czech technical standards ČSN EN 1050 [6], ČSN EN ISO 12100-1 [4] and ČSN EN ISO 12100-2 [5] for the whole life cycle of the machine, which includes:

- Construction activities
- Transport activities
- Assembly, installation, putting into operation
- Setting up, staff training/programming and/or change of process
- Operational activities
- Cleaning and maintenance activities
- Troubleshooting
- Taking out of service and dismantling, disposal

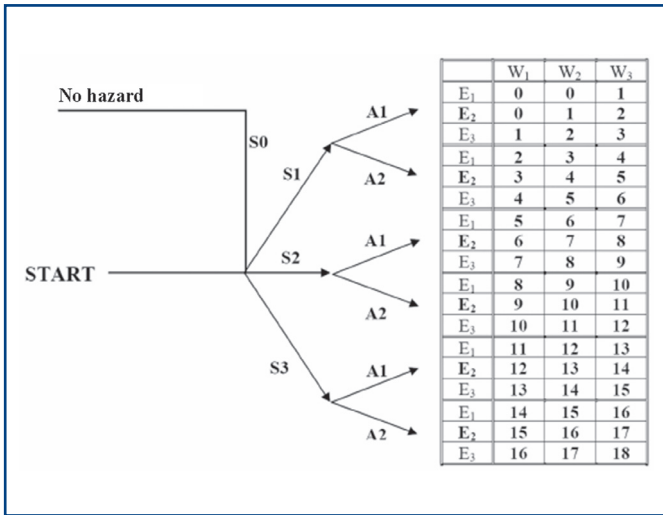


Figure 2. Example of risk estimation graph

5.5 Risk estimation

It is convenient to estimate the level of risk with the use of risk estimation graph (Fig.2.) for all identified significant hazards from the "List of significant hazards". If the hazards arise at more places within the machinery, it is necessary to perform the estimation of risk for all places of their occurrence in separate forms. The first estimation of risks is carried out for the case when no preventive risk-reducing measures are applied.

5.6 Proposal of risk-reducing measures

This step is performed in accordance with the requirements of ČSN EN ISO 12100-1 (iteration method). First, the built-in design measures are proposed, followed by safeguard measures reducing the risks, and information for users is provided. Each proposal of a measure must include a detailed written description of the risk reduction method.

5.7 Estimation of residual risk

After every proposal of a risk-reducing measure, the residual risk must be estimated (see 6.5).

5.8 Risk evaluation

Each of the estimated risks must be evaluated and classified as acceptable or unacceptable. It is necessary to bear in mind that total elimination of risk is not possible. If the level of risk is not acceptable, further risk-reducing measures must be proposed (see 6.6).

5.9 Information on residual risks

The hazards, whose risk can not be totally eliminated through construction and safeguard measures, must be listed in information on residual risks.

6. Documentation of the risk assessment process

The output of the risk assessment process in accordance with the proposed system methodology is the following documentation:

- Information on limit values of the machinery
- Block diagram of the machinery (Fig. 1)
- List of relevant hazards (Tab. 1)
- List of dangerous areas
- Analysis of significant hazards (Tab. 2)
- List of significant hazards (Tab. 3)
- Estimations of risks of serious hazards (in separate forms – Tab. 5)
- List of measures built in machine design (Tab. 4)
- List of applied safeguards and additional protective measures (Tab. 6)
- List of safety warnings on the machine (Tab. 7)
- List of warnings in the instruction manual (Tab. 8)
- List of further measures that were taken (Tab. 9)
- Protocol on risk evaluation
- Information on residual risks

7. Conclusions

The proposed system methodology of risk assessment objectifies to a great extent the identification of hazards and estimation of risks. At the same time, it supports realization of risk analysis in all phases of life cycle of a machine. Working with the block diagram showing interactions between individual subsystems and elements, the methodology increases transparency of the whole risk evaluation process, thus enabling even the persons not directly involved in the machinery development to perform risk evaluation on high-level professional level.

Name of component	Position of the component in the system	Type of hazard according to ČSN EN 1050
belt drive for spindle actuation	left motor area	mechanical hazard, hazard generated by noise, rupture during operation
etc.		

Table 1. Documentation of sources of relevant hazards in machinery

ANALYSIS OF SIGNIFICANT HAZARDS				Machine: experimental stand
During transport, assembly and installation				Model: STD 21
No.	Phase of life cycle	Type of hazard according to EN 1050		Description of hazardous event:
		brief description	ID	
1.1	Unloading of stand, lifting of stand,	inconvenient position, overstrain, fall, overthrow, crushing	8.1, 18, 23, 27.1, 27.2, 27.3, 27.6	During lifting there is a risk of fall or overthrow of the stand if the gravity centre is not known or is not respected. In case of unfavourable construction the workers may also suffer overstrain or inconvenient position.
etc.				

Table 2. Documentation of analysis of significant hazards

LIST OF SIGNIFICANT HAZARDS							Machine:			
Date:	Responsible:					Model:				
No. of hazard according to EN 1050	HAZARD	zrušena ČSN EN 292					HAZARDOUS SITUATIONS	Corresponding B type standard	Relevant articles of C type standard	Total number of hazards
		Part 2 - A1:1995	Part 1 t. 1991	Part 2 t. 1991	ČSN EN ISO 12100-1:2003	ČSN EN ISO 12100-2:2003				
Hazards, hazardous situations and hazardous events										
1	Mechanical hazards caused by:									
1.1	Crushing hazard	1.3	4.2.1	4.2.1						
1.2	Shearing hazard	1.3	4.2.1	4.2.1	4.2.2	4.2.1	5.2.1	5.3.2.6		
etc.										

Table 3. Documentation of the list of serious hazards

Description of measures built in design	Hazards treated
Machinery is equipped with fittings that enable its connection with standard manipulation devices.	1.1-1
etc.	

Table 4. List of measures built in machine design

BUT, FME UVSR - VCAM (RCMT) Prague		RISK ESTIMATION FORM responsible: Ing. Petr Blecha, Ph.D.		machine: stand STD 21 date: 1. 4. 2007	
No. of hazard according to ČSN EN 1050:	ID	Hazard identification according to ČSN EN 1050: 1. Mechanical hazards			
1.1	1	Crushing hazard			
Phase of life cycle:	transport, assembly, installation	Danger zone:		immediate environment of stand	
Exposed persons:	transporter, uninvolved person	Operational state:		stand not working	
Description of hazardous situation/event:	Threat of crushing during manipulation with the stand. The worker's body could be crushed by the self-weight of the stand.				
Initial risk	Seriousness of possible health damage:	S3 - death		Size of risk	14
	Frequency and length of threat:	A1 - seldom to occasional			
	Possibility of avoiding the hazard:	E3 - hardly possible			
	Probability of hazardous event occurrence:	W2 - medium			
STEP 1: Measures built in design (according to ČSN EN ISO 12100-1:2004)					
Description of measure:	Stand STD 21 is equipped with fittings that enable its connection with standard manipulation devices.				
Reduced risk after measure	Seriousness of possible health damage:	S3 - death		Size of risk	13
	Frequency and length of threat:	A1 - seldom to occasional			
	Possibility of avoiding the hazard:	E3 - hardly possible			
	Probability of hazardous event occurrence:	W1 - little			
STEP 2: Safeguards and additional protective measures (according to ČSN EN ISO 12100-1:2004)					
Description of measure:	Effective safeguards do not exist.				
STEP 3: Information for use (according to ČSN EN ISO 12100-1:2004)					
Description of measure:	Stand STD 21 is provided with a label indicating stand weight. Safety notice on the stand: "Activate and operate the stand according to the instruction manual!" Warning in the instruction manual: "When manipulating with the stand, behave with caution to prevent injury caused by self-weight of the stand!" etc.				
Residual risk	Seriousness of possible health damage:	S2 - serious injury (persistent effects)		Size of risk	6
	Frequency and length of threat:	A1 - seldom to occasional			
	Possibility of avoiding the hazard:	E2 - possible at certain conditions			
	Probability of hazardous event occurrence:	W1 - little			
VALIDATION:	Measures are sufficient:	Ing. František Bradáč, Ph.D.		date: 1. 4. 2007	

Table 5. Form for estimation of risk associated with serious hazard

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References

1. MAREK, J. How to go further in designing methodology of machine tools? In: *Proceedings of AEDS 2006 Workshop*. University of West Bohemia, Plzeň, 2006, pp. 81–88. ISBN 80-7043-490-2.

Type of safeguard or additional safety measure	Hazards treated
Instruction to use personal protective equipment (working boots with reinforced toe).	1.1-2
etc.	

Table 6. List of applied safeguards and additional safety measures

Formulation of safety notice on the machine	Hazards treated
Activate and operate the stand according to the instruction manual!	1.1-1, 23-1, 27.1.1-1,
etc.	

Table 7. List of safety notices on the machine

Formulation of notice	Hazards treated
"To protect feet from injury due to falling objects or tripping, use working boots with reinforced toe!"	1.1-1, 1.6-1, 1.6-2
etc.	

Table 8. List of warnings in the instructions manual

Measure taken	Hazards treated
Machinery is provided with a safety notice (label) indicating its weight.	1.1-1
etc.	

Table 9. List of further measures taken

- MAREK, J. Management of risk at design of machining centres. In: *Proceedings of Machine Tools, Automation and Robotics in Mechanical Engineering*. ČVUT Praha, 2004, pp. 91–98. ISBN 80-903421-2-4.
- PALEČEK, M. et al. *Procedures and Methods of Risk Analyses and Evaluation for the purposes of Act No. 353/ 1999 Coll. on prevention of major accidents*. VÚBP Praha, 2000.
- ČSN EN ISO 12100-1/2004. *Safety of machinery – Basic concepts, general principles for design – Part 1: Basic terminology, methodology*.
- ČSN EN ISO 12100-2/2004. *Safety of machinery – Basic concepts, general principles for design – Part 2: Technical principles*.
- ČSN EN 1050/2001. *Safety of machinery – Principles of risk assessment*.
- Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast) (Text with EEA relevance). EU Official report L157/24 CZ.
- Industrial accident rate in the Czech Republic in 2005*. Document of the Czech Statistical Office.