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RISK-OF-INJURY ANALYSIS IN THE "OPERATOR-MEANS OF WORK" SYSTEM

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Abstract. *The subject of this paper is risk of injuries in the use of the means of work that have gone all the way from the manual work to automation. In the "operator-means of work" system, both objective risk depending on the objective causes of injuries and subjective risk depending on the operator himself play an important role. Complex interactions between these two kinds of risk have been defined. A parameter of the relative hazard intensity concerning mechanical injuries caused by the movable parts of the means of work was also given. In addition to the relative hazard intensity, the worker's exposure to the hazard arising from the means of work has also been taken into account in the analysis of risk. On the basis of the hazard intensity parameter, exposure to the hazard and the ratio of the endangered individuals to the total number of the individuals present in the affected environment, another parameter denoting the level of risk was defined.*

Kay words: *risk of injuries, "operator-means of work" system, hazard intensity, exposure to risk*

1. INTRODUCTION

In the "operator–means of work" system, automation has mostly contributed to the changed design of the crankshaft which is the active part of the means of work. This resulted in the ever-increasing removal of the operator from the dangerous working zones created by technological processes. When non-automatic machines are concerned, risk of injuries has increasingly become lower owing to the adequate systems of built-in protection which made the hazard zones inaccessible.

The link between the operator and the automated machine is a computer, therefore, there is no risk of mechanical injuries. In this case, however, some other forms of risk, like radiation, noise, vibration etc., become increased involving not only the operator but also all the individuals within the technological environmental. The more sophisticated

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the means of work are, the greater their negative effects become involving a greater number of individuals within a certain production system environment when an accident takes place.

Some of the complex and insufficiently investigated issues concerning risk are:

– causes and mechanisms of the occurrence of risk
– level and structure of risk in the working environment
– exposure to risk
– nature of risk and it's disposition in space and time
– realizability of risk
– reoccurrence of risk
– risk management, etc.

While working, man is among other things, bound to notice, detect, perceive, identify and estimate risk; he is also bound to assume a certain behavior as an adequate response to the hazardous event. Within the "operator – means of work" system, there are both objective and subjective risks. Objective risk associated primarily with the workplace, working environment or machine is caused by the objective factors. Subjective risk, on the other hand, is dependent on the individual's capabilities, his ability to learn, recognize, discover, identify and estimate objective risk (hazard) and his ability to respond to it in an adequate way; it is also dependent on his psycho-physical limitations (disability) etc.

The operator's inability to perceive objective risk and to make an adequate response to it results in cumulative risk, both objective and subjective, depending on him. Thus accumulated risk is frequently concretized into an accident. The operator's ability, on the other hand, to perceive objective risk and to respond adequately to it thereby avoiding the danger mitigates the detrimental effects of objective risk.

The structure of subjective risk is different, however. Within this structure, the occasional dominance of different factors has been noticed: lower degrees of the operator's abilities, bad health, loss of motivation, harmful habits and concepts, inadequate knowledge or skill etc. Risk is therefore increased owing to all those factors that reduce or degrade the operator's capabilities (alcohol, fatigue, biological and social motives, etc.).

2. CONCEPT (DEFINITION) OF RISK

Risk is defined as the probability that a certain unwanted event will take place as a result of some other event. In addition to this definition, there have been different attempts to define risk. It is thus defined as the likelihood of loss, the likelihood of injury, or uncertain to resulting from the unwanted event, etc. Generally, the concept of risk denotes danger or likelihood of some unwanted event whose effects are either material damage or endangering of human health and life.

However, if viewed within the domain of production technologies and the "operator – means of work" system, risk serves as a specific indicator of how reliable the system's performance is, namely, how safe the individuals are while operating the technological system. The very existence and operation of a certain technical or technological system in the environment that is either directly or indirectly related to it.

The total risk arising from the technical or technological system can be expressed as:

$$R_u = \prod_{i=1}^{i=n} R_{pi} \tag{1}$$

where: R_{pi} - is a partial parameter denoting the i - th risk.

All the while it must be borne in mind that the technological systems within the production processes are operated by man. These systems involve relatively great amounts of the kinetic and potential energies as well as the ever increasing rates of the movable mechanism motions. This has an adverse effect on the operator's safety since the level of the hazard and therefore, risk is increased. Another consideration refers to the relatively narrow or limited space in which everything takes place.

When the kinetic energy gets out of the operator's control, it is transmitted to the environment there by endangering not only the operator himself but also the environment as a whole. The intensity of risk depends on both the subjective and objective hazards or risks. To what extent the risk will be concretized and what effects (injuries and accidents) it will have depends on the operator's exposure to the risk and the rate of the machine operation.

Therefore, safety in the "operator–means of work" operating system depends on the objective risk level and the subjective risk level, namely, on the operator's subjective abilities to cope and operate under the conditions of the working environment, exposure to risk and the rate of the machine operation, i.e. on the coordination between the operator's pace of work and the rate of the system's operation within the working environment.

3. Safety and Productivity

Starting from the conceptual definition of safety as the absence of the hazard or risk of unwanted events, injuries and accidents, and productivity as an indicator of production, it is necessary to analyse their causal connection. This results from the fact that, in terms of safety, a certain system can only be observed and analysed on the basis of it's performance including productivity when industrial production systems on all the levels are concerned.

When the operator's safety is concerned, i.e. when his physical being is endangered by the means of work in the production process and when there is a likelihood of injuries or accidents, the increase of productivity is dependent on the level of automation in the means of work. This has a positive effect on the operator's safety, i.e. the reduction of risk since the more automated the means of work are, the more removed from the dangerous zones the operator is.

Both the operator and the machines as a source of the necessary energy take part in the part in the present-day production technologies and produce certain products. Since the power of the machines is much greater, it is clear that productivity is directly proportional to the ratio of the operator's to the machine's share in the process of production. Consequently, the smaller the share of the human work in the process of production of each unit, the greater the productivity. It is, therefore, natural that along with man's continual efforts to produce more of the quality products, there goes an effort to use less of the human work.

4. ANALYSIS OF THE "OPERATOR – MEANS OF WORK" SYSTEM

Regardless of what system is being observed (processing, technological or industrial; with one or more operators interacting with one or more physical objects ranging from the simple tools like the hammer, the lever etc. to the present-day sophisticated processing systems like the NC-machine, the CNC-machine, the flexible processing cells etc.), the basic consideration is to examine the system that consists of two basically different parts:

– a man or a group of men, and
– physical objects.

These two entities make up a system with a certain purpose – industrial manufacture of goods. The usual term "man-machine" has been replaced by the term "operator-means of work" in this paper. The reason for this is that man` s activities take place within the production processes and the "machine" is a narrow term excluding the manual hammering, for example.

The "operator-means of work" systems are both various and numerous. In spite of that, they all share some common characteristics:

– with a view to realizing his aim, the man–operator makes use of an adequate tool (means of work) i.e. the adequate physical component of the system (the hammer, the lathe, the milling machine, the press, the flexible cell, etc.) , and
– the interaction and communication are always established between the operator and the physical component of the system.

Therefore, Figure 1 shows a diagram of the "operator-means of work" system together with the interactions existing in it.

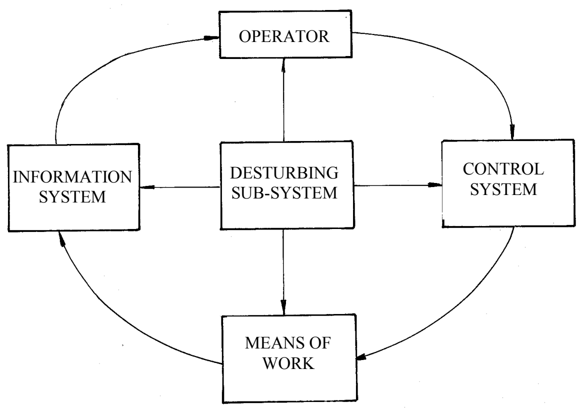

Fig. 1. Diagram of the "operator means of work" system

In terms of the types and the range of activities and engagements, the interactions among the above-mentioned components of the "operator-means of work" system are dependent on the degree of mechanization and automation in the system` s physical components. The possible variations include:

1. Non-mechanized and non-automated means of work. This variation involves the purposeful treatment of the material where the operator receives and processes additional information during the production process, makes decisions and controls the subsequent treatment of the material.
2. Mechanized although non-automated system. This variation involves the increasing participation of the means of work in the treatment of the material whereas the material treatment process is exclusively man-controlled.
3. Partially automated system. The operator`s physical engagement in the material treatment process is negligible and his control of the process reduced since almost the entire treatment of the material and some of the process control functions have been taken over by the means of work.
4. Automated system. In this case, the operator is excluded from both the material treatment and control processes. His role and engagement are essentially different since he has been removed from the production part of the working environment.

It is useful to bear in mind some pieces of evidence from Reference [2] about the operator's physical and mental engagement during work with universal, special and automated machines. These are given in Table 1 and expressed in terms of the relative parameters:

P_u - physical engagement parameter while the operator is using universal machines,
P_s - physical engagement parameter while the operator is using special machines,
P_a - physical engagement parameter while the operator is using automated machines,
M_u – mental engagement parameter while the operator is using universal machines,
M_s – mental engagement parameter while the operator is using special machines
M_a – mental engagement parameter while the operator is using automated machines.

Table 1.

MACHINE	OPERATOR'S PHYSICAL ENGAGEMENT PARAMETER (P_i)	OPERATOR'S MENTAL ENGAGEMENT PARAMETER (M_i)
Universal	$P_u = (0{,}8 \div 1{,}0)$	$M_u = (0{,}0 \div 0{,}2)$
Special	$P_s = (0{,}2 \div 0{,}8)$	$M_s = (0{,}2 \div 0{,}8)$
Automated	$P_a = (0{,}0 \div 0{,}2)$	$M_a = (0{,}8 \div 1{,}0)$

The operator's reliability in the "operator–means of work" system is an additional problem. The operator is regarded as a machine. His characteristics are expressed in terms of parameters: therefore, his reliability is determined in the same way as the reliability of the means of work. The operator has become an element in the system in which his role is equalized to that of the machine or any other technical object. He has become like a robot.

Contrary to that, experts (sociologists, psychologists, culturologists, etc.) engaged in the study of human characteristics, relations and behavior in organized systems use some other unquantifiable parameters, like individual traits and feelings, pointing out that an individual goes through different phases showing both pleasure and dissatisfaction, cheerfulness and dejection, love and hate, tolerance and aggressiveness etc. This indicates the fact that must by no means be overlooked or minimized, namely, that development of the means of labor and automation can have detrimental effects on humans. Indeed, owing to unnatural working conditions created by increased automation, man's reliability decreases although reliability of the technical component in the "operator–means of work" system is increased.

5. Degree of hazard in the use of the means of work

Causes and forms of injuries and threats to the operator's integrity have changed together with changes in:

– the means of work and production technologies,
– the working environment (it's contents, structure and organization),
– the social and organizational systems in the fields of economy, social
– relations, legislation etc., and
– the state of the biosphere.

It is possible to structure and analyse each of the stated general causes of the hazard so that they can be described in terms of the parameters and defined in terms of the partial degrees of the hazard. The means of work, for example, are of special interest since they are the things that both enable the technological process and represent a source of the hazard; the partial degree of the hazard arising from the means of work can therefore be expressed as:

$$H_{pd} = f\,(M_{h,}\,;\,P_{h,}\,;\,C_{h,}\,;\,M_{h,}\,;\,CO_h\,) \tag{2}$$

where:

H_{pd} - the partial degree of the hazard,
M_h - the mechanical hazards arising from the movable parts of the means of work (e.g. injuries of the hand when it happens to be within the press working area during the material treatment, etc.),
$P_{h,}$ - the hazards arising from the physical objects that are formed during the production cycle and that have an immediate effect on the human organism (e.g. the presence of dust that has a mechanical effect on the respiratory system organs at the workplace, etc.),
$C_{h,}$ - chemical hazards arising from the means of work (e.g. the technological process is a source of the hazardous materials causing different chemical processes in the human organism),
E_h - power hazards (electric power, thermal energy, etc.), and
CO_h-combination of hazards.

Risk of injuries arising from the movable parts of the means of work participating in the treatment depends on the amount of the kinetic energy contained in these elements. Risk of injuries therefore depends, among other things, on the velocity and mass of the movable parts. Consequently, hazard intensity can be expressed in terms of the parameter denoting the synchronized operation paces of both the worker and the means of work.

If (V_m) is the velocity of the observed part of the means of work and (V_o) the velocity of those parts of the operator's body that are coordinated with the operation of the means of work, then

$$\Delta V = V_m - V_o \tag{3}$$

Introducing the velocity quotient:

$$K_v = \frac{\Delta V}{V_o} = \frac{V_m}{V_o} - 1 \tag{4}$$

linear dependence between parameter (K_v) and operation velocity of the observed part of the means of work is obtained.

The operator's velocity is an individual trait; consequently, if ($Vo_{\min}$) is the slowest operator's velocity, and ($Vo_{\max}$) the fastest operator's velocity, then the graphic illustration of expression (4) gives the shaded area in Figure 2 which is the area of the parameter (K_v) possible values dependent on the operation velocity in the observed part of the means of work.

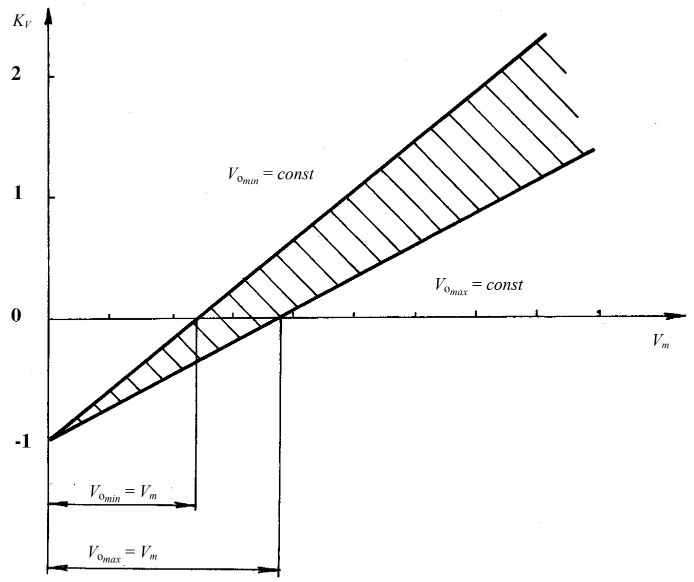

Fig. 2. Dependence, $K_v = f(V_m)$

An analysis of expression (4) gives the velocity quotient values within: $K_v \in (-1 \div \infty)$

In order to avoid an area of negative values, the relation:

$$a = 2 + K_v = 1 + \frac{V_m}{V_o} \tag{5}$$

is introduced and the relative intensity parameter denoting the hazard of mechanical injuries arising from the movable parts of the means of work can be expressed as:

$$I_V = \frac{1}{n_e} \sum_{i=1}^{i=n_e} \left(1 - \frac{1}{a_i}\right) \tag{6}$$

where: n_e – number of the movable parts of the means of work likely to cause injuries.

The law of the relative intensity change involving the fastest and the slowest operator which was defined by expression (6) and illustrated in Figure 3 gives the shaded area of the hazard intensity possible values depending on the velocity of the movable parts of the means of work.

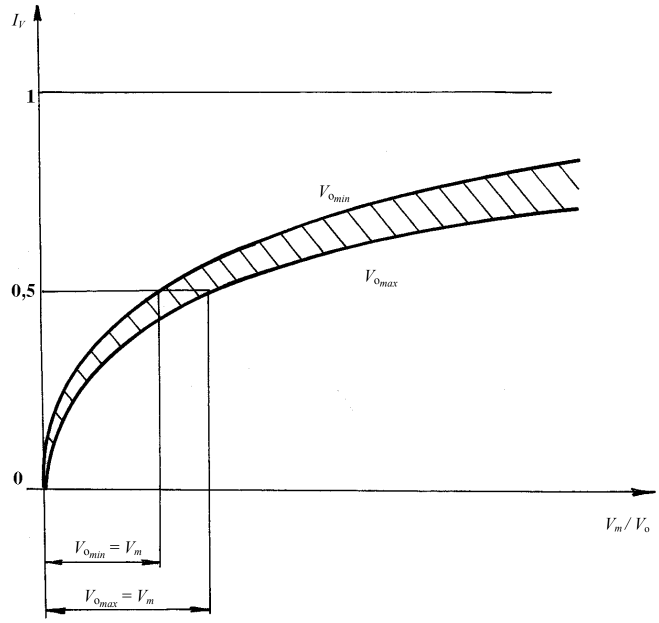

Fig. 3. Relative hazard intensity dependence on velocities; $I_v = f(V_m / V_o)$

In addition to velocity, the amount of the kinetic energy is influenced by the mass of the element as well. Therefore, if an element of the least mass within the system under observation is taken, the relative intensity parameter denoting the hazard of the movable parts mass (*M*) can be expressed as:

$$I_M = 1 - \frac{M_{\min}}{M} \tag{7}$$

Therefore, the relative intensity parameter denoting the hazard of all the movable parts of the system is:

$$I_h = I_{Vi} \cdot I_{Mi} \tag{8}$$

Subsequently, the general form of the hazard intensity for a complex system is:

$$I_h = \frac{1}{n_e} \sum_{i=1}^{i=n_e} I_{Vi} \cdot I_{Mi} \tag{9}$$

Exposure to the possible effects of the hazard. Risk of injuries is also dependent on the time of the operator's exposure within the hazardous area.

The parameter of exposure for a single work – day is:

$$E_t = \frac{t_{ei}}{24} \tag{10}$$

or, for several work – days:

$$E_t = \frac{1}{24 \cdot n_d} \sum_{i=1}^{i=n_d} t_{ei} \tag{11}$$

where:

t_{ei} – time of exposure to the hazard expressed in hours during the i - th day (24 -hours),
n_d – number of the work – days when the operator is exposed to the hazard.

By introducing the parameter:

$$f_N = \frac{N_{ei}}{N_t} \tag{12}$$

where:

N_{ei} –number of the endangered individuals within the observed area where the impact of the hazard is felt in the case of failure of a certain production system, and
N_t – total number of individuals within the observed area where the impact of the system failure is felt,

it is possible to define the parameter expressing the level of risk:

$$R_N = I_h \cdot E_t \cdot f_N \tag{13}$$

where:

I_h – relative intensity parameter denoting the hazard arising from the movable parts of the means of work,
E_t – exposure to the possible action of the hazard,
f_N – parameter denoting the ratio of the endangered individuals to the individuals present within the hazardous area.

6. Conclusion

On the basis of the previous analysis the following conclusions can be drawn:

The effect of production processes on risk is a complex subject; therefore, it is not possible to make a generalized and universal model expressing the risk level. The problem of modern man's protection against risk in the industrial working environment has turned into the problem of protecting his own integrity within the living environment.

Since the emergence of the machine, the production process has gone through three phases in the development of the "operator – means of work" system: in the beginning, the machine provided help during the production process; then, man started operating the crankshaft; and finally, he became the machine monitor.

Owing to the development of electronics and microprocessor – based information technology contained in automated production systems and robots, protection of the operator's physical integrity in the working environment has become almost complete. The operator is increasingly being removed from the hazardous zones of direct material treatment owing to automated means of work and technological processes. Direct mechanical injuries arising from the movable parts of the means of work have thus become less likely or even eliminated. Age – old demands for the operator's physical protection have thus been met.

This, however, resulted in reduction of the operator's movement functions together with prolongation of the static load and nervous and emotional tension. This means that far more serious problems have emerged giving rise to numerous psychological disorders and diseases and affecting great numbers of people within a certain area regardless of their relation to the production system.

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ANALIZA RIZIKA OD POVREĐIVANJA U SISTEMU "ČOVEK – SREDSTVA RADA"

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U radu se analizira rizik od povređivanja pri korišćenju sredstava rada koja su se vremenom usavršavala od manufakturne proizvodnje do automatizacije. Zapaženo je da u posmatranom sistemu "čovek-sredstva rada" važnu ulogu ima objektivni rizik, koji zavisi od objektivnih faktora kao uzročnika povređivanja, i subjektivni rizik koji zavisi od čoveka. Definisani su kompleksni odnosi između ova dva rizika i njihova interakcija. Dat je parametar relativnog intenziteta opasnosti mehaničkog povređivanja od pokretnih delova sredstava rada. Pored relativnog intenzieta opasnosti, za analizu rizika, uzeta je u obzir i eksponiranost radnika dejstvu opasnosti od sredstava rada. Na osnovu parametara: intenziteta opoasnosti, eksponiranosti dejstvu opasnosti i odnosa broja ugroženih sa ukupnim brojem prisutnih u ugroženom prostoru definisan je parametar koji izražava nivo rizika.

Ključne reči: *rizik povređivanja, sistem "čovek-sredstva rada", intenzitet opasnosti, eksponiranost riziku*