ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 1986

Seria: GÓRNICTWO z. 143 Nr kol. 883

1st International Conference - Reliability and Durability
of Machines and Machinery Systems in Mining
1986 JUNE 16-18 SZCZYRK, POLAND

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ON RELIABILITY OF SAFETY IN MINING PROBLEMS

Summary. The paper deals with an approach to reliability of safety in mining problems. Mining, particularly underground and offshore one, taking into consideration its specific, is characterised by series of problems connected with exploitation of minerals concern safety problems. In connection with it they are solved more or less succesfully practicaly for years, but recently intensive development of theory and applied models of reliability of safety can be observed in Poland now.

In the paper an approach to definition of reliability of safety, review of applied models, safety systems elementary protective devices, gradation of failures, etc. are considered taking into account the concrete practice. Literature, dealing with the above problems is also given.

1. INTRODUCTION

Developing intensively in the sixties and seventies of our century, reliability theory lost its high developing speed at the begining of the eighties. It is due to the fact that simple adaption of formal mathematical models constructed previously in the scope of another discipline of sciences - first of all applied probability theory - has been exhausted. The number of scientists interested in the reliability theory decreased wheras new probabilistic models proposed by mathematicians and frequently obtained from the pure theoretical considerations, are usually sophisticated mathematical tools. Practical applications of those models are very often limited, due to the lack of connections with the practice. Some models have theoretical significance only, while others more complicated, and formulated in precise and sometimes difficult mathematical language are hard for engineers, practicians. However, problems of great worth for theory are those which came into being from the real practice. The problems of common thematical scope make new chapters in theory development. Such a group of problems is the reliability of the system: man - technical object which has been considered intensively for a dozen or so years. Such a group of problems is also the reliability of safety of systems, whose intensive development may be observed in Poland now.

Mining, particularly underground and offshore one, is such science for which safety problems are of great importance. Developing for centuries, mining has solved safety problems, more or less successfully on the base of practical solutions, partly on the base of theory. Meeting of the reliability theory with the theory of safety on the mining practice ground has taken place relatively not long ago[1], and due to the existing conditions has led to the rapid development of series empirical and theoretical studies. Several problems unsolved up till now have been taken into considerations and some have been solved successfully. On the other hand theoretical analysis and assessment of goodness of existing already exploitation solutions have been undertaken. Usually the obtained solutions are of practical use but their economical effectiveness both with that of the safety are hardly determinable.

The subject of consideration of this paper is the reliability of safety as it is understood in the mining. Reliability of safety of hoists, ventilation systems, dewatering systems, strata control (rock bursts, gas bursts, subsidence, methane emission, self - ignition of coal seams etc) in underground mines and comperatively rich set of problems in offshore mining - all these are abundant source of inspiration for investigation. It should be stated that the paper is an attempt at a certain recapitulation of research from this field (cf. [1-7]).

Several studies refer to narrow practical problems. There is a lack of papers which would synthesize obtained solutions in a nomenclature field, applied mathematical models or other problems.

2. RELIABILITY OF SAFETY

Reliability of object is its property to fulfil requirements set for it. Reliability of safety of an object is its resistance to such operation faults, which may result either in its destruction or the destruction of objects cooperating with it, environment hazard and human life losses (comp. [9]).

Therefore the term reliability of safety is a narrower term within the field of reliability. Term safety is, in turn, wider than reliability

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[1] Much earlier, for example, safety problems of building constructions in probabilistic sense have been considered.

of safety is important in determining operation faults of an object. If an object can impend over human health due to vibrations higher than addmissible for human body or emission of harmful radiation, but its operation is correct, everything is right from reliability of safety point of view. Never the less, such a problem is interesting when considering operation of the system: man - technical object.

The presented above designation of the reliability of safety is of the descriptive type and reliability measures used to describe this property are of objective character.

It seems an interesting proposition to consider additionally the so - called "regulation reliability of safety". According to it the regulation reliability of safety is property of object to fulfil safety regulations (requirements) which are connected with exploitation of the object.

Fig. 1 shows an example of it: survival function of mining hoisting ropcs for wear measure defined as percentage decrease of laod - carrying cross-sectional area or 5-6 rope lay lenght. According to the Polish regulations [12] it can be 20% or 15%.

It is easy to notice that assessement of regulation reliability of safety of an object may be at the very most as good as regulations actually in force.

Here wide scope of empirical and theoretical investigations come into being:

- reliability of safety determination of an object of a given type,
- (as the result of the above) rational formulation of safety regulations of exploitation of an object.

This is a way to determine reliability of safety and formulation of the regulations so to say "from the beginning" (new class of an object). The most frequently the determination of regulations of safety is obligatory. In such case, there is new investigation field: empirical and theoretical verification of existing regulations. As the result of it may be necessary to change or supplement regulations actually in force.

Realisation of these studies is difficult not only because of penetrating and frequently wide empirical and theoretical investigations but also because of the fact that reliability of safety is in cristalisation stage. Other difficulties will be mentioned in further part of the paper.

3. CATASTROPHIC FAILURE

As it was stated, reliability of safety concerns determined group of operation faults of an object. Saying it precisely - group of determined consequences of their appearance.

The centrel term is here a catastrophic failure. It is, from the mathematical point of view, a random event of determined consequences of particular type. These consequences, e.i. probable damage of object, devastation of environment, occurrence of accidents among staff or failure of cooperating objects, distinguish all failures of heavy economical consequences - long breaks in realisation of important production processes, for instance.

Next feature of catastrophic failure is that it belongs to rare events. The above observation has determined repercussion. In exploitation investigations carried out to determine, e.i. probability of occurence of catastrophic failure, possessing of appropriate number of observations is necessary for statistic reasons. This means investigation of a proper number of objects of particular class in appropriate lenght of time,which is not always possible on account of many reasons (financial barrier, non existence of required number of objects etc).

Let us notice further that it does not make sense to consider reliability of safety for all objects. Practically, reliability of safety usually concerns systems.

Looking at consequences of catastrophic failure occurrence, two events are possible:

- catastrophic failure means the end of the object life,
- catastrophic failure does not mean the end of the object life.

In the second case, taking into consideration that they are rare events, catastrophic failures during the life of an object occur in small number or they do not occur at all. Time of catastrophic failure clearing is long in comparision to other repair times of an object and is characterised by different distribution function or the same on but of different parameters.

It should be stated that is easier to determine what is or what is not catastrophic failure for a particular object than to give precise definition of catastrophic failure.

4. EXPLOITATION PROCESS AND RELIABILITY OF SAFETY

An exploitation process of an object e.g. process of the change of its properties in time, depends on:

- object properties shaped in the process of its designing and production,
- applied method of exploitation,
- properties of environment - conditions of exploitation of an object.

Manifested in the exploitation process reliability of safety of object depends on the above mentioned factors.

Let us consider this problem a little wider.

4.1. Danger events; watching systems

Let us consider N-element system for which reliability of safety considerations make senses.Let us assume that reliability structure of system is known and that failure of each element of the system and the very system is defined. Generally part of failures can be defined 1-0 type (up - down), part - parametrically. In this second case it is assumend that there is a given set Z of technical and exploitation parameters and a failure is defined as parameter value exceeding its limited values.

For each failure which can appear in the system a probabilistic measure - conditional probability of catastrophic failure can be defined P_{ki}, $P_{ki} \in [0,1]$

$$P_{ki} = P(K/U_i), \qquad i \in H \tag{1}$$

where:

K - castrophic failure,

U_i - i - tn failure in the system,

H - set of all possible failures in the system, may be ascribed.

Obviously an event $P_{ki} = 1$ is the castrophic failure.

Let us assume a certain probability level $P_k = \beta$, β near zero.

Ech event j for which relationship

$$1 > P_{kj} = P(K/U_j) \geqslant \beta; \qquad j \in \mathcal{B}, \quad \mathcal{B} < H \tag{2}$$

appears will be called a danger failure. Therefore symbol $\mathcal{B}$ means a set of all possible danger failures of the system.

Each parameter ψ_h; $h \in M$; $M < Z$, of the value exceeding the allowable interval means the occurence of event from the $\mathcal{B}$ set, will be called a "significant parameter". Therefore M means a set of all possible significant parameters of system.

Let us notice that having the set M and the set $\mathcal{B}$ "importance" gradation of significant parameters from the reliability of safety may be introduced.

We can say that significant parameter ψ_h is "more important" than significant parameter ψ_l if

$$P_{kh} > P_{kl}; \qquad h, l \in M \tag{3}$$

There is a rule that in systems for which reliability of safety considerations make sense, significant parameters for which probability exceeding allowable intervals has appropriate "hight" value in the life of an object, are constantly watched by diagnostic subsystems.

In man - technical object systems, values of significant parameters shown by appropriate indicators are information for controlling the system for current exploitation decisions making among the other things - decisions concerning counteracting of probable hazards as a result of exceeding particular significant value parametr outside its allowable interval.

In many modern systems, where only it is possible, an operator is replaced by automatically controlled systems. To avoid appearance of catastrophic failure or saying precisely, to diminish probability of occurrance of failure of such type, special safety systems (safety circuits, protective devices) are constructed.

According to needs and possibilities (financial, technical etc) various constructions can be used, from the simplest, i.e, constructions switching off the system when a danger event occurs, to automatic controlling systems.

As an example of a safety system a safety circuit used in mining hoisting installation may be considered. An ideological diagram of it and its cooperation with the rest of assemblies of hoist and operator is shown in fig. 2. It is a system which consists of a certain number of sensors - receptors which react when an event exceeding limited values appears - signal S. Such signal causes sending by safety circuit two signals: to the brake subsystem (signals V) in order to brake the rope drum (friction wheel) - signal Y, and to the power transmission assembly (signals I) in order to make the driving moment drop to zero - signal X.

It is worth noticing that gradation of significant parameters has its practical sense in the constructional solution applied in the considered safety circuit. Anyway if the limited value is exceeded by a certain, specified by Polish Mining Regulations, [12] group of parameters, the hoist is stopped in any moment of transportation cycle. An analogical situation, in turn, concerning parameters of lesser "importance" makes it impossible to start a new transportation cycle after the cycle is finished. Rationalization of the circuit which relies on the application of wider range of consequences of circuit actions has just been proposed [1].

The most important receptor characteristic is its reliability R_1 described by conditional probability of an event: if the danger of a failure occurs than receptors act correctly sending the signal to the safety circuit. Receptors as functional or structural reduandancy are also applied. As the reserve the hot one is only used (usually the same elements) because the overswitching of elements can not be done.

Correct receptor action does not guarantee the stopping the hoist. Fig. ? shows the ways of receptors' signals and the minimal set Q of hoist assemblies which have to act correctly when danger failure occurs in order to stop the hoist.

Analysing information shown by fig. 2, one can divide danger failures with regard to the place of their occurance and possible consequences. Such division may be as fallows:

- the "basic danger failures" which include failures of all such elements of system which make the counteraction of the safety circuit impossible (here: the stopping the rope carrier),
- the failures when values of significant parameters are exceeded over allowable intervals - "danger failures of I-st order",
- "danger failures of II-nd order", failures of direct receptors which react on occurrence of failures of the I-st order,
- controll fault caused by an operator[2].

To the above division value intervals of probability P_k may be ascribed and thus

- if the basic danger failure appears then catastrophic failure occurs with the probability near 1,
- if the danger failur of II-nd order appears than probability of catastrophic failure occurence is close to β.

Usually relation:

$$1 > P^{(b)} \geq P^{(I)} \geq P^{(II)} \geq \beta$$

where: $P^{(I)}$, $P^{(II)}$, $P^{(b)}$ - probability of catastrophic failure occurance as the result of appearance of danger failure of - appropriately - I order, II order, basic, takes place.

It is worth noticing that the considered safety systems belong to so-called watching systems, counteracting - diminishing probability of the occurrence of catastrophic failures.

Our hitherto considerations concern systems which "take care" of their subsystems watching values of significant parameters. As it was stated previously, exploitation process of an object depends on properties of its environment as well. Any significant change of exploitation conditions may be a reason of catastrophic failure occurrence. In the underground mining and offshore one, careful observation of environment is of very high importance in order to avoid catastrophic failures of not only whole machinery systems but whole mines sometimes or platforms or exploitation ships. Special watching safety systems measuring significant parameters constantly have been used for years.

In the underground mining quantity of emitted methane or water from the rock, temperature of seams, basic parameters of mine air are measured

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2) Operator is "receptor" too, but of a special type. Assessment of his operation is considered in the paper [2].

with determined frequency or continuously. The task of such systems is to give information to undertake appropriate prevention measures of switch on automatically additional dewatering pumps, fans, airconditioners etc. In the offshore mining safety systems are connected additionally with prediction systems which predict the future values of significant parameters.

4.2. Availability (standby) systems

Other class of safety systems are emergency (standby) systems often called availability systems. These systems counteract the results of catastrophic failures. In underground mining, for instance, medical first aid systems, fire brigades, mobile rescue winders and special rescue systems to liberate miners trapped by collapsed rock are systems of that type.

Units used in flood standby systems,used in nuclear power plants [11], military units and many other belong to the considered class of safety systems.

Their basic parameter is probability of accomplishing of determined tasks in stipulated period of time.

The theory of standby systems is well developed in comparision with the theory of watching safety systems.

4.3. Elementary safety systems, operation models

The general theory of watching safety systems is not formulated yet. Problems from their scope lie in common field of the diagnostic theory and the reliability theory. Great number of elementary safety watching systems used in practice have not been assessed from the reliability of safety point of view. When such investigations have been carried out [1, 4, 6] the coincidence problem in renewal processes has been formulated for the first time (comp. [6]).

Majority of elementary safety watching systems act in such short time that it may be assumed they act in a discrete way. Hot reserve as a protective unit is frequently used. The main problem is to find explicite form of reliability characteristics of a system when both reliability of components and system structure are known. Theory of discrete random processes is applied to describe exploitation processes of the considered systems. Sometimes it is enough if probabilities of system states are known [4], sometimes richer reliability description is needed and in spite of seeming simplicity of problem, sulutions appear non - trite and interesting from the theoretical and practical points of view [6, 10]. It should be added that the lack of clearly formulated theory of stochastic chains, dafferent than the Markov ones has been feeled in distict way.

5. REMARKS

The aim of the above paper has been to present a recapitulation of papers which have appeared recently and which concern reliability of safety in mining. Two main problems have been omitted:

- reliability of safety of object operator,
- reliability of safety of information systems.

Certain particular problems connected with the above have been presented in papers [2, 8].

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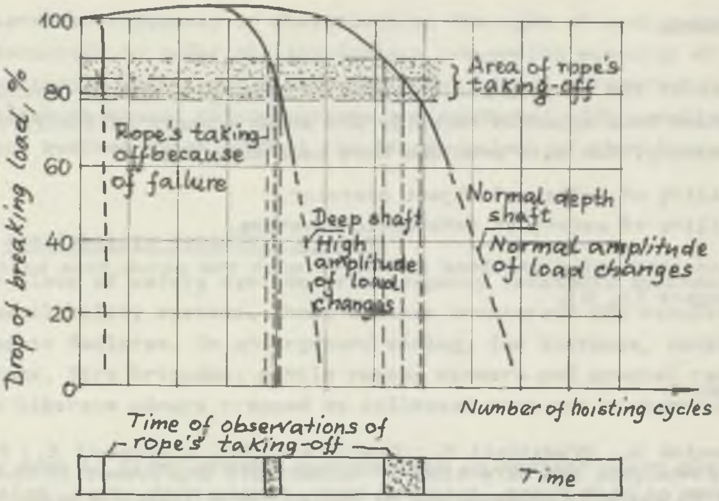

Fig. 1. Depedence between the ropes life and the number of hoisting cycles

Rys. 1. Zależność między trwałością liny i liczbą wyciągów

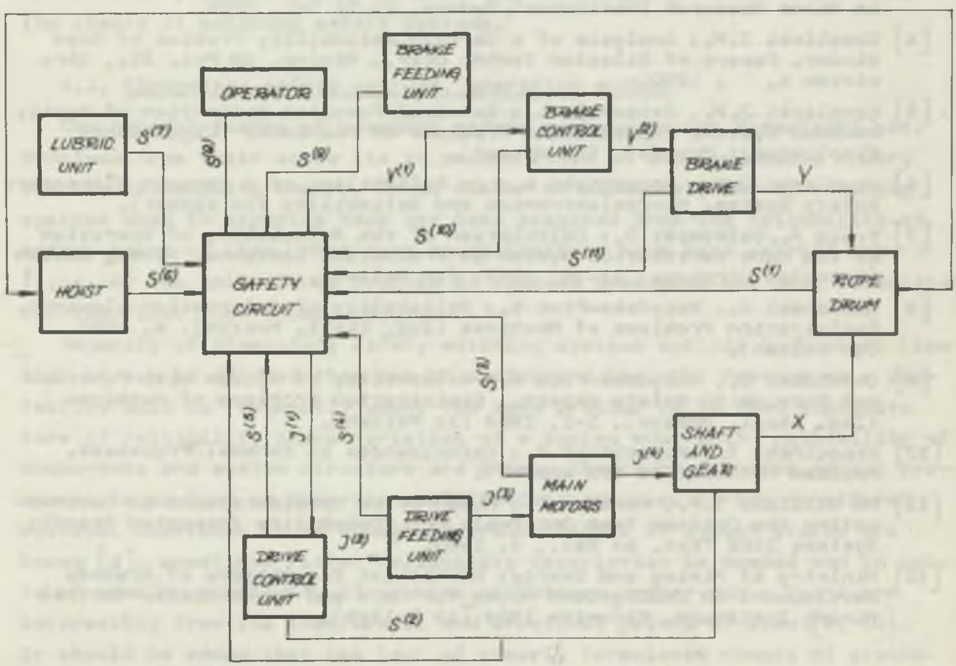

Fig. 2. Safety circuit diagram of mining hoisting installation

Rys. 2. Schemat obwodu bezpieczeństwa górniczego urządzenie wyciągowego

O NIEZAWODNOŚCI BEZPIECZEŃSTWA W PROBLEMATYCE GÓRNICZEJ

S t r e s z c z e n i e

Praca traktuje o podejściu do zagadnień niezawodności bezpieczeństwa w problematyce górniczej. Górnictwo, szczególnie podziemne, ze względu na swą specyfikę charakteryzuje się między innymi tym, że szereg problemów związanych z eksploatacją kopalin dotyczy zagadnień bezpieczeństwa. Od kilku lat w Polsce daje się zauważyć intensywny rozwój teorii niezawodności bezpieczeństwa.

W referacie prezentuje się sposób podejścia do zagadnień definicji niezawodności bezpieczeństwa, stosowanych modeli probabilistycznych, systemów bezpieczeństwa, elementarnych systemów zabezpieczających, gradacji uszkodzeń itp. sformułowanych dla potrzeb praktyki górniczej. Pracę uzupełnia literatura, która traktuje o omawianych zagadnieniach.

О НАДЁЖНОСТИ БЕЗОПАСНОСТИ В ГОРНОЙ ПРОБЛЕМАТИКЕ

Р е з ю м е

В работе говорится о подходе к вопроcу надёжности безопасности в горной проблематике. Горное дело, особенно подземное, с точки зрения своей специфики характеризуется, в частности, тем, что целый ряд проблем, связанных с эксплуатацией ископаемых, касается вопросов безопасности. В течение нескольких последних лет в Польше интенсивно развивается теория надёжности безопасности.

В реферате представляется способ подхода к проблемам: дефиниции надёжности безопасности: применяемых вероятных моделей; систем безопасности; элементарных систем, гарантирующих безопасность; градации дефектов и т.п., - сформулированным для нужд горной практики. Работа дополняется литературой, обсуждающей представляемые проблемы.