SAFETY DIAGNOSTIC IN MECHANICAL ENGINEERING

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Summary

This paper focuses on the problems related to risk analysis at the stage of design. Various methods, their advantages and position in calculation procedure have been presented on the basis of international standards. The final part of the paper concerns the application of technical diagnosis in risk evaluation operations. From this point of view the possibility of use if the proportional hazard models are presented.

Keywords: Vibroacoustic diagnostic, risk assessment, proportional hazard models

DIAGNOSTYKA BEZPIECZEŃSTWA W BUDOWIE MASZYN

Streszczenie

W pracy skupiono się na problemach związanych z zastosowaniem analizy ryzyka na etapie konstruowania. Na podstawie norm międzynarodowych zaprezentowano różne metody i ich zalety oraz miejsce w procedurze obliczeniowej. Część końcowa pracy zawiera analizę możliwości zastosowania diagnostyki technicznej w oszacowaniu ryzyka Z tego punktu widzenia zaprezentowano możliwość wykorzystania proporcjonalnych modeli zagrożeń.

Słowa kluczowe: Diagnostyka wibroakustyczna, oszacowanie ryzyka, proporcjonalne modele zagrożeń

1. INTRODUCTION

The analysis of the cost according to "life cycles" of machines and devices allows one to estimate, from economic point of view, the alternative solutions from both, the manufacturer's and the user's points of view, and above all from the point of view of social cost and damage to natural environment. The LCC (Life Cycle Costing) concept was adopted over thirty years ago in the US Defense Department. The broad presentation of the historical development of such an approach is found in [1], while putting stress on the differences and similarities of such an analysis in various countries.

The most important definition of LCC, which has been termed as Terotechnology in the UK, has been published in British Standard BS: 3811: "Terotechnology – A combination of management, financial, engineering and other practices applied to physical assets in pursuit of economic life cycle costs." For comparison, terotechnology in the Polish glossary of technical terms [2] is explained in the following way. "Terotechnology – a field of knowledge concerning rational operation and maintenance of means of production."

As regards international guidelines and regulations touching upon this issue, should be indicated: the ISO-9004-3 standard and the IEC 300-3 standard [3] that has published by IEC National Committees, worldwide organization for standardization comprising all national electrotechnical committees.

There standards particularly highlight the costs with the product's dependability, that describes the availability performance of product. The most important factors influencing the dependability are: safety, reliability and maintainability performance. Therefore the costs associated with these factors should be accounted for in life cycle cost models. As a basis to the presentation of the LCC method's problems an approach suggested in ISO-9004-3 standard has been adopted as a basis. It assumes that achievement of a required quality of safety depends on punctual completion of the operations, compliance with the conditions and taking into account both normal and special conditions of the operation and load.

Let us note that the standard does not recommend a particular method, although it sets out a range of possible approaches. It does specify, however, the items which should be included in a proper evaluation of a project, i.e.[3]:

- issues resulting from the necessity to meet the recipient's needs, among others, safety of

the product and its environmental compatibility;
- problems resulting from the adopted technical conditions and maintenance requirements, including these related to reliability, reparability and service capability (e.g. acceptable tolerances and comparison with the capacity of production process and description of minor damage);

All these operations are supposed to ensure quality in the process of defining technical conditions at the stage of design. The principal task is to determine area limits in order to obtain satisfactory solutions. Generally, solutions which minimize the risk of loss, including the risk of legal liability, are deemed satisfactory. It requires a proper identification of risk aspects and a guarantee of maximum safety of the use of the product, even if it is misused. Practically, it implies a procedure which allows:

a) identification of hazard related to all stages and conditions of use of the product, including installation, inspections and possible scrapping;
b) definition of risk resulting from hazard related to these operations;
c) evaluation of required safety level with respect to acceptable risk;
d) minimizing hazard by means of additional safety measures.

In other words, it has to be taken into account that the traditional evaluation method related to the quality of design must be reviewed. It concentrates mainly on the feasibility of punctual completion of the project, within budget limits and in compliance with specified functional tasks. First of all, according to the tendency of quality evaluation in project valuation all stages and phases of formation and existence of the object should be taken into account and then risk analysis should follow. At this stage of project development special attention should be paid to the problem of reduction of uncertainty of type and size of hazard. Therefore, the problems of hazard identification, including identification of the mechanism of hazard formation, determination of initial events and peak events initiating damage, should be treated extensively.

2. RISK EVALUATION PROGRAM

It is advisable to draw up a risk evaluation program in relation to complex systems or systems with a particular hypothetical hazard. In accordance with the suggestion in IEC 300-3-X draft standard, such a program should make it possible to identify hazard as well as risk evaluation and management. (Fig. 1). The principal element of this program is risk identification, which is the condition for proper definition of acceptable hazard values as well as for detection and interpretation of relationships and dependency between individual events. At the same time, it enables evaluation of the occurrence of undesirable events and size of hypothetical damage. This, in turn, makes it possible to determine conditions under which critical risk values may be reached or exceeded. According to the guidelines set out in CEI/IEC 300-3-9 standard [3], the abovementioned operations should be performed in a determined order and enable implantation of risk analysis process in the form of iterative algorithm (Fig. 2). First of all, it is noted that the aim and scope of operations should be formulated, in a manner which allows further adjustment as the results are being obtained. It concurs in particular a description of cause-result relationships implied by the structures of the analyzed system, determination of external and internal influences and assumptions adopted in connection with the conditions of implementation of functional operations.

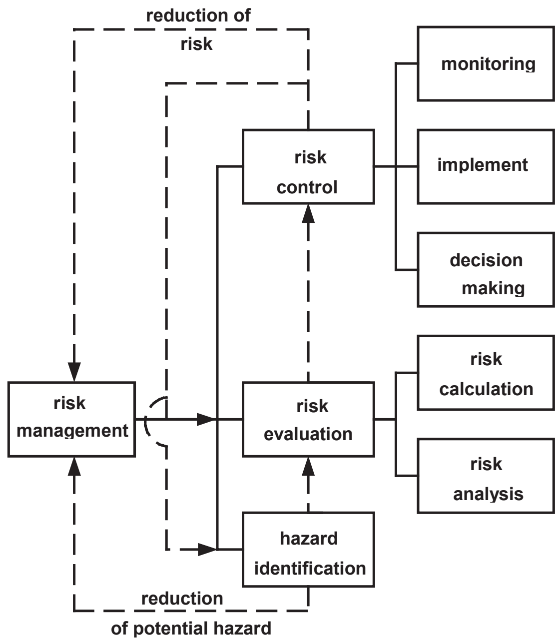

Fig. 1 Elements of risk evaluation and risk management program

Such an approach makes it possible to analyze the principal problem, i.e. hazard identification and analysis of the consequences of the occurrence of undesirable events. Only the implementation of the analyses and risk evaluation with respect to the occurrence of an undesirable event will enable calculation of the size of risk and, following a proper verification of results, preparation of final report [4].

Let us note that the key problem in the implementation of risk analysis process is evaluation of potential hazard, including a hypothetical process of becoming damaged and possible damage. This implies a necessity to determine the method and scope of operations eliminating or reducing hazard. It also implies, depending on the obtained result, continuation of risk calculation; or, if hazard or the consequences are negligible, termination of analysis.

In order to obtain a correct solution to a task formulated in such a way, it is necessary to make the right choice of the method of the analysis. The most frequent criterion of choice is determination - depending on the project development and availability of useful information - the aim of the research, type and degree of complexity of the analyzed system; size of potential hazard, including a hypothetical hazard to life and health, possibility of environmental damage or possible economic loss. When the aim of the analyses is to determine the critical risk level, additionally non-material damage is analyzed, in particular the loss of market position, lower confidence in other products of the company and the influence on the risk acceptance level.

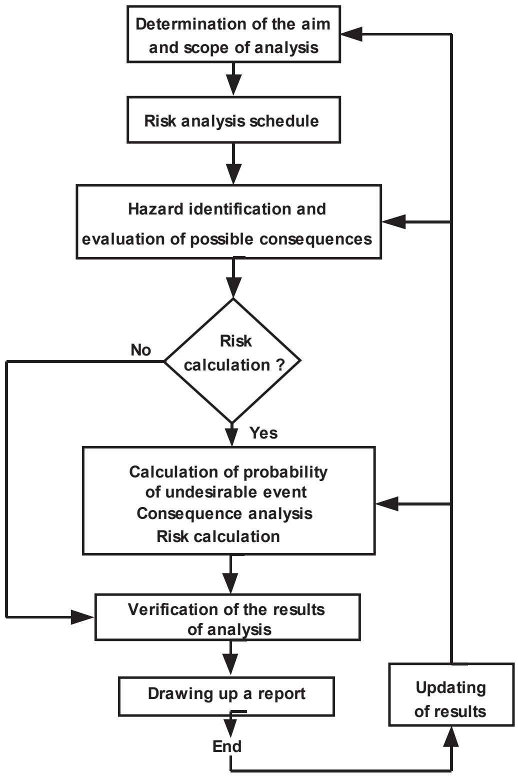

Fig. 2 Risk analysis algorithm recommended by the standard

Among a series of methods, which are drawn up in the form of international standards and often recommended by certain regulations to be applied in risk analysis, from constructor's viewpoint the most important one is HAZOP (Hazard and Operability Study). It is a modification of FMEA method (failure mode and effect analysis). The method, originally drawn up and developed for the purposes of chemical industry, is being more and more widely applied in other branches of technology. In practice, the application of this approach implies a systematic analysis of system operation as well as identification and definition of hazard, including hazard unpredictable in normal operation and possible operational problems. Since the information we have in the construction process is not complete and unreliable, and due to the fact that certain decisions are taken in the conditions of uncertainty as far as the method and intensity of the processes of degradation and wear are concerned, such analyses may prove particularly useful.

The important factor here is reduction of uncertainty of evaluation of changes in technical condition as well as the increase of influence on the size of damage, including the process of damaging. To become more familiar with these issues, let us consider a problem of application of methods and means of technical diagnosis.

3. APPLICATION OF DIAGNOSTIC METHODS

As regards the fields that strive to predict the safety levels for a specific product which operates in a defined environment, we should consider the possibility of using the diagnostic methods. Diagnosis enables supervision and rational control of the course of operating processes.

As regards the human engineering systems, it is the medical, psychological and social diagnosis that should be applied, while with regard to the natural environment, we should, generally speaking, apply the ecological diagnosis [5]. All these types of diagnosis should ensure the description of the current status, the explanation of the reasons of such a status and the time horizon for emergence the next step status with a defined probability. The statuses can be indicated while using numerical quantification for security purposes, and specified levels of risks of loss can be assigned to them.

In general, in the implementation of any production process with a determined level of quality and effectiveness of production, there is always an assumption of process parameters being maintained. At the same time, the abovementioned parameters are load parameters and their occurrence may cause damage.

From the relationship of load and damage there result various types of damage and necessity of development and proper choice of obtaining and analysis of diagnostic information. For instance, distribution of load depends both on external factors and on the sensitivity of an object to internal disturbance.

In order to reduce occurrence of failure, we should, at the stage of design, identify the factors whose occurrence or modification in course of operation could cause changes in the technical condition of the object thus leading to the inefficiency of operation and, subsequently, causing failure.

Such a procedure allows us to determine the method of finding out diagnostically important information and to establish signal parameters of significant diagnostic usefulness.

Attention to the problems connected with measuring, data transmission, elimination of disturbances and error estimation will, on the one hand, allow us to estimate the diagnostic ability of the analyzed variant of the project. On the other hand, it will allow us to determine methods and means of diagnostic system with respect to formulated aims of the diagnosis and access to the information a priori concerning a possible course of failure, nature and course of the process of becoming damaged, size and range of damage and anticipated loss.

Referring to the definition of risk as presented by Kuhlmann [6], who defines risk as an anticipated value of potential loss, and with reference to the model of the occurrence of damage and potential course of events, an exemplary model of risk evaluation, according to Roland and Moriarty [7] can be presented as follows:

$$P(S_{t_n}) = \\ = \sum_i \sum_j \sum_k P(I_i) P(C_j I_i) P(L_k / C_j) P(S_{t_n} / L_k) \quad (1)$$

where:

n - kind of loss

$P(S_{t_n})$ - probability of cost S_{t_n} per one exposure unit

$P(I_i)$ - probability of the occurrence of I_i initiating event

$P(C_j/I_j)$ - conditional probability of the occurrence of C_j damage provided I_j occurs

$P(L_k/C_j)$ - conditional probability of the occurrence of L_k loss provided C_j occurs

$P(S_{t_n} / L_k)$ - conditional probability of the occurrence of S_{t_n} cost provided L_k occurs

The global size of risk can be then determined as an anticipated cost of loss taking into account all periods of exposure:

$$\bar{r} = \sum_m \sum_n P(S_{t_{n,m}}) \cdot S_{t_{n,m}} \quad (2)$$

m - possible periods of exposure

n - different types of loss

$S_{t_{n,m}}$ - cost as a value of discrete random variable

Formula (1) indicates a possible modification, which can take into consideration the type of random variables (discrete, continuous), degree of dependence or independence of individual variables, distribution of the probability of random variables or stochastic processes. In general, risk quantity calculated in result of such a procedure can be used as a measure for hypothetical loss in the procedure of establishment of the limiting value of a diagnostic parameter.

In many cases the technical condition of an element can be quite easily defined. This may result from the earlier operational analyses as regards resistance to errors, and above all the "ability to inspect" an object. In many cases such an approach calls for use of devices which will be able to assess the condition of selected, critical parts," from the outside". This is connected with the need for planning the connection points for the measuring devices, setting the measurement points and potentially feeding the measurement wires outside an object or to a selected point in which the measurement and analysis module can be used. In another, more developed variant, the approach leads to installation of the measurement-and-analysis devices directly on a given object, or in fact application of a diagnostic-and-prognostic system. Each subsequent step means additional manufacturing and operational cost. A systematic diagnostic analysis should eventually decide which diagnostic strategy would be adopted.

For instance, in a statistical method of decision making as presented by Birger [8], in addition to the determination of loss at failure, also the cost of unnecessary repair and the probability of the occurrence of 'fit' and 'unfit' state should be defined. Only then the relationship which allows us to define reliability quotient can be established and in the next stage, we can define, the limiting value of the diagnosis parameter:

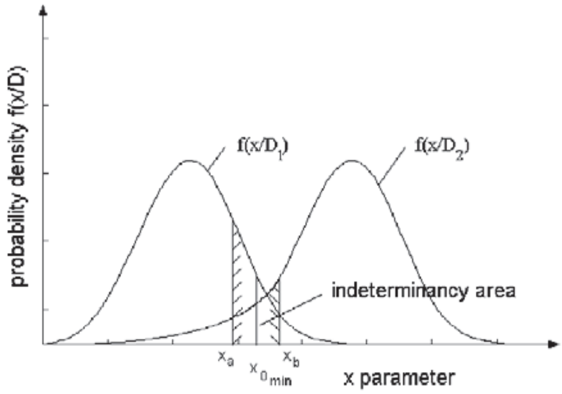

Fig. 3 An example of establishment of the limiting value

$$\bar{r} = R_{11} P_1 \int_0^{x_a} f(x/D_1)\mathrm{d}x + R_{12} P_1 \int_{x_b}^{+\infty} f(x/D_1)\mathrm{d}x + \\ + R_{21} P_2 \int_0^{x_a} f(x/D_2)\mathrm{d}x + R_{22} P_2 \int_{x_b}^{+\infty} f(x/D_2)\mathrm{d}x + \quad (3) \\ + R_0 \int_{x_b}^{x_b} \left[P_1 f(x/D_1) + P_2 f(x/D_2) \right] \mathrm{d}x$$

where:

R_{11}, R_{22} - costs borne in order to obtain information and perform operations connected with making the right decision (timely repair - avoidance of repair in the state of operational efficiency),

R_{21} - costs related to the occurrence of failure, established on the basis of formula (2),
R_{12} - cost of unnecessary repair,
P_1, P_2 - probability of the object being in D_1 state of efficient operation or D_2 state of inefficiency of operation,
R_0 - cost of uncertainty related to the occurrence of error of the model and random nature of signal.

The optimal maintenance performance in connection with system condition monitoring is concentrated on suitable rules for replacement system comprising of items. The more interested problems of optimal degradation process control of a critical unit as a kind of technical diagnostics do not possess a standard solution. The solution in term of the optimum scheduling procedures has an insufficient connection to the physical degradation processes experienced under external loads.

Therefore, the important task is to create and to apply such operational models that take into account the degradation processes with an adequate stochastic description of the damage processes.

The simplest statistical distribution that can be used is the exponential distribution. At this time in the literature [9, 10, 11] are discussed the exponential regression models, there are the combination of an exponential systematic component and exponentially distributed errors (covariates). At first let to present some problems of using this models.

While the value of the covariate, z , does not change over time and assuming y = ln (*t*), v^* = ln *v* the exponential model of the survival time may be expressed as follows:

$$y = \beta_0 + \beta_1 z + \sigma v^* \tag{4}$$

On this way, survival time is determined by systematic and error component (the *v* part) By choosing the value of the shape parameter σ we can determine the form of hazard function. In the publication [9] it is shown that the error component distribution is exponential when the value of shape parameter is equally to one and the hazard function is:

$$h(t,z,\beta) = e^{-(\beta_0+\beta_1 z)} \tag{5}$$

In this case the hazard function does not depend on time and the probability of failure is constant as long the subject has been followed.

For no constant hazard function is to assume that the shape parameter is not equal to one.

On this way the survival time has a Weibull distribution and the hazard function equation is:

$$h(t,z,\beta,\alpha) = \frac{\alpha t^{\alpha-1}}{e^{(\beta_0+\beta_1 z)^{\alpha}}} \tag{6}$$

where: $\alpha = \dfrac{1}{\sigma}$;

The hazard function change in (6) must be monotonic, the function increases if α > 1 and decreases if α < 1. In certain applied settings this type of hazard function will be still not suitable. For diagnosis aim the model must describe the error component distribution that determine the basic underlying distribution of survival time and must additionally characterize the impact of systematic components on the distribution changes of survival time. In general one needs to specify the hazard functions as a function of time and covariates (systematic components):

$$h(t,z,\beta) = h_0(t) r(z,\beta) \tag{7}$$

where:

$h_0(t)$ – characterizes the changes of the hazard function as a function of survival time.

$r(z,\beta)$ – characterizes the changes of the hazard function as a function of subject covariates.

The model (7) was proposed by Cox [10] with suggestion to use:

$$r(z,\beta) e^{z\beta} \tag{8}$$

With this parameterization the equation (7) is:

$$h(t,z,\beta) = h_0(t)\exp[z\beta] \tag{9}$$

The Cox model is referred to the proportional hazards model to the fact that in (9) the hazard functions are related multiplicatively and their ratio is constant over survival time.

In general the influence of a covariate on the hazard function is expressed by the covariate parameters. For example the mathematical formula for the Weibull proportional hazard model at time *t* is:

$$h(t,z,\beta,\alpha) = \\ = \frac{\alpha}{\eta}\left(\frac{t}{\eta}\right)^{\alpha-1} \exp[\beta_1 z_1(t) + \cdots + \beta_p z_p(t)] \tag{10}$$

where η is the scale parameter, α is the shape parameter, $\beta_1 \ldots \beta_z$ are the covariate parameters and t refers to working age.

An important use of model containing a single covariate. Using the link function in term of the natural log transformation one has possibility to analyze the proportional hazard model as the log – hazard function:

$$g(t,z,\beta) = \ln(h_0(t)) + z\beta \tag{11}$$

For a change from $z = a$ to $z = b$ the difference in the log hazard function is:

$$g(t,a,\beta) - g(t,b,\beta) = (a-b)\beta \tag{12}$$

It means, that baseline hazard function is subtracts itself out and the difference (12) does not depend on time.

In general, as shown in [11] as the covariate we may consider the condition of operation like load or temperature, the corrosion level and many other factors – even of a binary nature. The multiplicative shape of the hazard function makes easy to show the impact of the covariates in terms of the logistic vector on the hazard function and survival function.

On the other hand the function of $h_0(t)$ the hazard function changes during the operating time. Now suppose that due to diagnostic procedure some additional information becomes available. As is shown in [12] the inherent variability of the basic random variable can be use to estimate the posterior distribution by Bayesian updating:

$$f''(t) = \frac{f\left(B/_t\right) f'(t)}{\int_{-\infty}^{\infty} f\left(B/_t\right) f'(t) dt} \qquad (10)$$

This distribution with updated parameters can be used in a probabilistic analysis and design of product for a desire level of reliability and safety.

CONCLUSIONS

Using a diagnostic system results in possibility of setting a policy limit which responds to some economic objective, like the minimizing the total cost of failure and maintenance, maximizing physical asset availability or achieving a particular performance measure such a target ratio of planned to breakdown maintenance.

The analysis should fulfill the following postulates:

- account for all the essential features of a system,
- enable comprehensive assessment of diagnostic aspects of alternative solutions that will support mutual comparison. of these elements,
- indicate these elements which from diagnostic point of view are weakest and in what extent, so as to set the priorities for their elimination,
- the overall evaluation of the diagnostic aspects of a given solution must enable its inclusion among other quality parameters, so as to enable the selection of a compromise solution.

Generally the Life Cycle Cost Method needs to be integrated with the reliability design process by taking into account the cost of useful diagnostic information.

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