MODELLING OF RELIABILITY INDICATORS BY MEANS OF THE INTERFERENCE METHOD

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Abstract

The article describes the application of the simulation modeling of tasks of the interference theory of reliability (SSI - stress - strength interference reliability model) in the MATLAB programming language. It points to the possibility of creating your own purpose-built models designed to predict the evolution of the reliability of the technical system during the user's interactive activity. Reliability simulation by changing load and resistance parameters makes it possible to find acceptable reliability parameters.

Keywords: reliability, MATLAB programming, failure

1. Introduction

Systems simulation is currently one of the most progressive means to investigate the operation of complex systems, which can be applied to most technical problems showing the nature of service processes. Simulation modelling of processes nowadays forms the basis of scientific research in several scientific fields. Even though modelling methods and simulation tools were developed based on different scientific disciplines, knowledge and methods of system simulation can be transferred from one discipline to another and applied in several scientific fields. The theoretical basis for the management of such a specific area is the knowledge from various scientific disciplines, which enter the research process and thus enable the research of the given area.

From the research possibilities of the given methods, it follows that computer simulation and modeling of systems has a primary position, which allows us to:

- describe and express processes whose analytical solution we do not know,
- to simplify the solution of complex mathematical problems,
- shorten time-consuming experiments,
- carry out experiments of new projects,
- quickly and efficiently analyze changes and assess their consequences,
- examine many failure states and assess their variants.

It is most appropriate to use the following procedure to examine the systems defined in this way:

1. We will determine the properties of system elements and the relationships between them and the environment through analysis. We select and consider only those that are essential from the point of view of the function of the system and the objectives of the investigation. We will neglect the unimportant features of the system.
2. We will acquire specific knowledge of the necessary statistical characteristics (e.g. the reliability of machines and equipment, which allow us to express the probability of the occurrence of random failures - failure-free, their groups, subgroups and requirements for restoring their operability - repairability). In this way, we can express the basic states out of several possible ones in which the system element is located.
3. We will describe the system theoretically. We create an idea about the system of the so-called theoretical model. We assign the modeled system to a different system based on similarity, according to certain criteria - called a model, or computer model.
4. We transform the system or its subsystem into a computer simulation model that imitates the current idea of the simulated system and its movement by implementing a simulation program on the computer.
5. We will perform simulation experiments with the simulation model, which allow us to monitor the values of important parameters of the model, implement changes in the studied model and determine their effects on the function of the system.
6. Based on the evaluation of the simulation experiments, we will propose or implement changes in the investigated system

The inference theory of reliability originates from a concept based on the comparison of the mutual connection of the selected reliability quantity. It is understood and described by deterministic principles and is based on determining and respecting the values of reliability indicators [1]. The approaches described by the inference theory of reliability are based on the assumption that a failure or a failure function occurs when the resistance limit of the object is exceeded, i.e. ability to withstand stress. An element of a technical system can fulfil its function if it must be sufficiently resistant to all loads that may act on it. From the internal and external environment that influence such an element.

This is an assessment approach that is based on the deliberate oversizing of the object with the expression of the safety factor against failure (SF - safety factor) or safety level (SM - safety margin). If the stress R exceeds the strength value S of the element given by the structural design, a failure will occur.

$$SF = \frac{\bar{S}}{\bar{R}} \ or \ SF = \frac{Smin}{Rmax} \tag{1}$$

$$SM = \frac{S\,min - Rmax}{Smin} \tag{2}$$

Where:
SF – safety factor
SM – safety margin
L – stress
R – strength

Numerical values of the required or acceptable SF and SM depend on the technical department, type of product, consequences of the failure on safety, risks, etc. They are determined by standards and regulations.

The concept of stochastic description assumes that stress as well as resistance to failure are generally of a random nature with a certain law of distribution of the probability of occurrence. They can occur in a wide range of values, with the possibility of non-overlapping or interference.

For a better characteristic of resistance to failure, we can express reliability as follows:

$$SM = \frac{\bar{R}-\bar{L}}{(\delta_R^2+\delta_L^2)^{\frac{1}{2}}} \tag{3}$$

and LR (Loading roughness)

$$LR = \frac{\delta_L}{(\delta_R^2+\delta_L^2)^{\frac{1}{2}}} \tag{4}$$

The SM factor characterizes the relative distance between the mean stress and resistance values. The LR factor characterizes the impact of the standard deviation of stress on safety. The input values of stress L and strength R are random in nature. This can be obtained from an experimental measurement, or they are determined by other methods / e.g. by expert estimate/. The result is either a non-parametric distribution of the obtained data, which we can statistically process in the form of a histogram or convert it to a usable parametric distribution. Both cases provide us with the possibility of generating input quantities and assessing the occurrence of decisive events for the statistical expression of failure rate or failure-freeness of elements using the interference method.

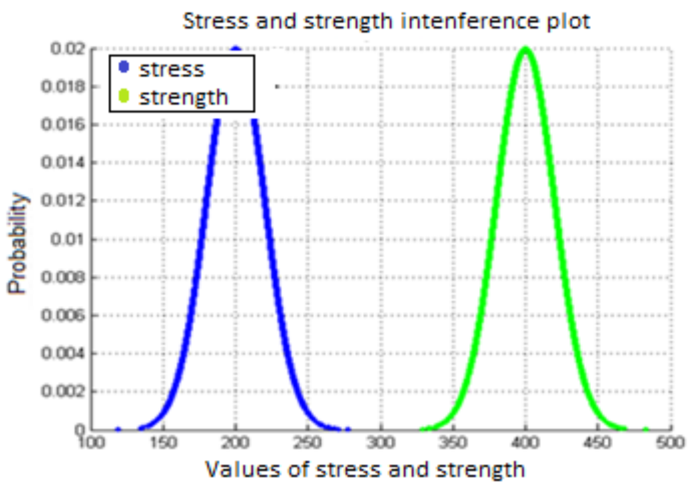

Figure 1: *Deterministic concept of load and resistance simulation*

2. Possibilities of reliability simulation

The simulation in figure 1 presents a situation that occurs very often, especially when applying high values of coefficients with small variances of R and L. Stress and resistance are very far from each other with medium values, they have a small variance, a low LR value and a high SM value. If it is possible to influence the variances and standard deviations of stress and resistance quantities and to move the mean values of both quantities as far as possible from each other, these quantities cannot interfere with each other, and then there is a high probability that the object will not fail during its entire life. Since the quantities R and L do not interfere with each other, the element is reliable. If there is a situation where the distributions of stress and resistance overlap, there is mutual interference and thus the possibility of a malfunction - the system thus becomes unstable, and a malfunction may occur. The SM and LR factors enable a deterministic analysis of the mutual interference of stress and strength and the possibility of failure. The interference theory of reliability is based on the analysis of regularities and properties of two random variables that characterize the elementary properties of reliability, as a distribution function. We will call the distribution function of the random variable X the real function of the real variable F(x) defined by the relation:

$$F(x) = P(X < x) = P(X \in (-\infty, x)) \text{ for any } x \in R. \quad (5)$$

The distribution function has the following properties:
1. for each $x \in R$: $0 \le F(x) \le 1$,
2. for each $x1, x2 \in R$: if $x1 < x2$, then $F(x1) \le F(x2)$
3. $\lim_{x\to-\infty} F(x) = 0$, $\lim_{x\to\infty} F(x) = 1$

Both the stress and the resistance are random variables, characterized by quantities or random processes. The mechanical structure Mk, which is subjected to operational load at the time, will be reliable if the operational stress L with a certain probability does not exceed the resistance R (bearing capacity, permissible stress, etc.). Quantities characterizing operational stress (load) and resistance (bearing capacity) of the structure can be expressed by probability densities and distribution functions. Let $f_L(L)$ denote the probability density for the stress random variable L and $f_S(R)$ the probability density for the fault resistance random variable S. Let's denote the distribution function for the random stress variable L by $F_L(L)$ and $F_R(R)$ the distribution function for the random variable S against failure. The quantities L and R are random, and we assume that they have a specific probability distribution law (continuous or discrete). They can influence each other (interfere) [3,4].

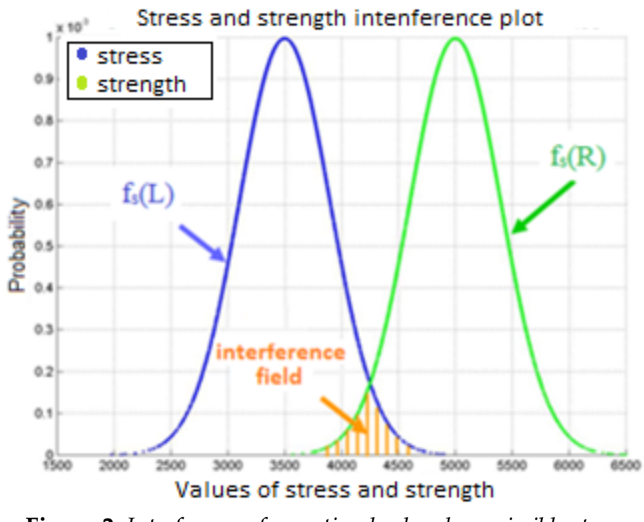

Figure 2: *Interference of operating load and permissible stress*

The simulation model of load probability density and resistance must follow the following steps:
1. Determining the appropriate number of simulations.
2. To analyze the input data of the distribution parameters of the probability density functions of the operating load and the resistance of the assessed system element.
3. Determine input parameters of histograms or probability distributions.
4. Generate the level of operational load and resistance.
5. Statistically process a set of values in the form of values of probability density functions and distribution functions.
6. Graphically display the courses of probability density functions and distribution functions.

Statistically process the generated data into the form of values of probability density functions and distribution functions, and by plotting them we get an idea of their interference.

Calculate

- probability of failure PF = n / N,
- probability of reliability PR = 1 - PF

7. Determine the minimum value of the resistance function and the maximum value of the load function, i.e. the interference interval of the generated values.
8. Graphically show the mutual dependence of L and R values.
9. Calculate the size of the area under the graph line.
10. Determine the resulting of reliability.

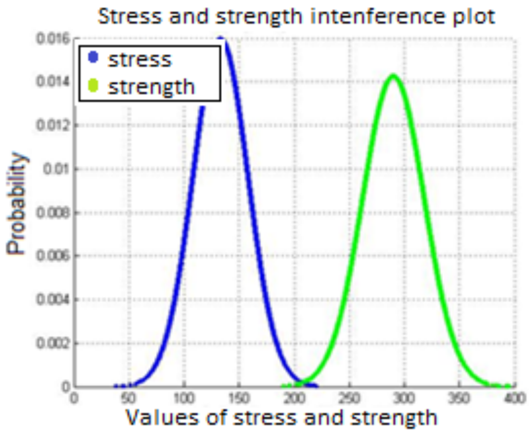

Figure 3: *Load and resistance probability density distribution functions*

The boundary between the failure and reliability areas is given by the condition R≥L and is expressed by a red line.

Basic conditions for SSI reliability modeling:

- The parameters for stress and force are statistically independent.
- Dynamic parameters for loading forces and stress are described by the Poisson distribution.
- Random strength degradation is described by a distribution.
- Random strength degradation and deterministic loading force.

Stress L and strength R are time-dependent random variables. The load values may have the character of an increasing gradient, while the resistance tends to decrease due to external factors dependent on the environment.

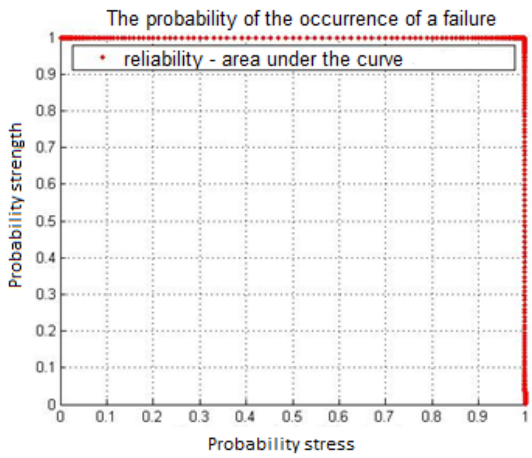

Figure 4: *Graphic representation the probability of failure*

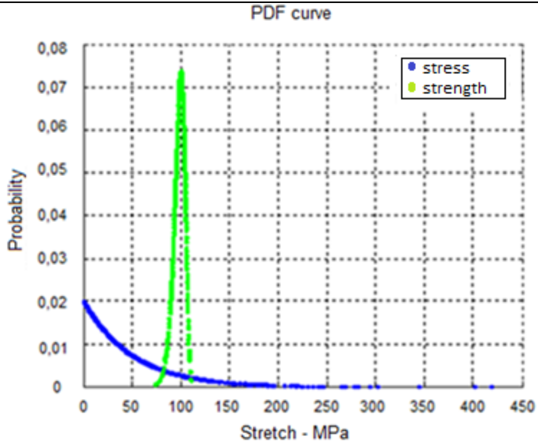

Figure 5: *PDF curve*

The MATLAB simulation language and its graphics make it possible to create interactive programs, the environment of which allows the user to dialogically change the parameters of the distributions and to judge what load and resistance values are acceptable for the structural design application [5]. The program in the basic window offers the option of choosing the number of simulations, the type of load distribution and the resistance of the element under investigation and the distribution parameters. If, from the input data used, the simulation results indicate that the required fault-free parameters do not meet, the simulations can be carried out by changing the parameters until an acceptable level of interference is reached.

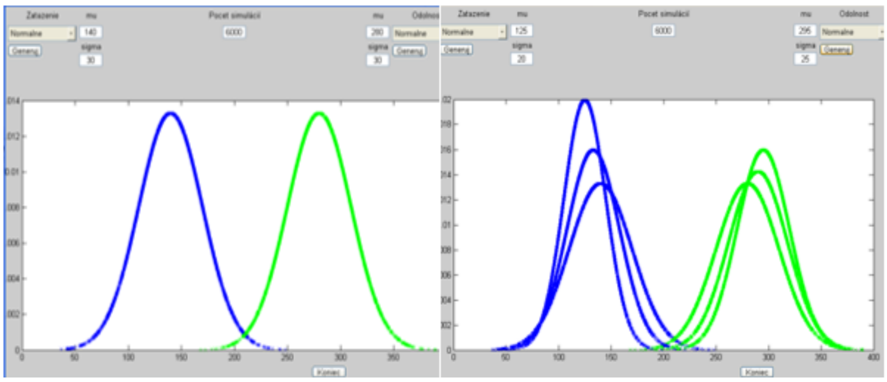

Figure 6: *Analysis of the impact of changes in stress and strength parameters*

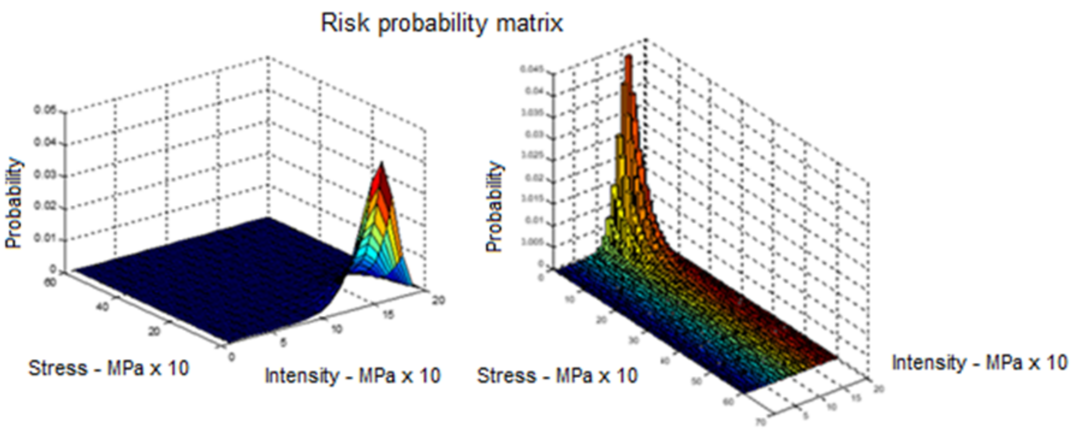

Figure 7: *Analysis 3D model*

3. Conclusion

The interference stress-strength reliability assessment model is a model for predicting the probability of failure for various engineering systems. For an objective modeling result, it is necessary to have known probability distributions of stress and strength available. Failure or failure is defined as the ratio of stress > strength. If both stress and strength distributions are acceptable, the simulation provides an analytical solution that provides an accurate result. The technical perfection of all means of computer simulation and modelling often does not allow the creation of a suitable simulation model and its correct application without deep knowledge of the nature of the investigated phenomena or systems [6,7]. The quality of the system determination depends on the solver of the model and the obtained input data necessary for its determination. A simulation model or any forecast is a very complex process. A complex part of the methodology, requiring good knowledge of the simulation process, is the processing of algorithms for individual events and program events. Nevertheless, let's know even the most complex algorithm is created from simple algorithms. Such a simulation model makes it possible to eliminate the imperfections of calculation methods.

It uses the results for few measurements of experimental methods in an appropriate way, can apply the results to determine the reliability of elements of diverse systems and determine the interference of different probability density distributions of randomly variable functions of operational loads and resistances.

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