The validation system for reliability and survivability of unique mechanical systems

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Abstract. We propose a concept of the validation system for the properties of reliability and survivability of unique mechanical systems, the failures of which can result in accidents. The system is based on the principles of self-organization and provides the opportunity to consider off-design impacts of any origin, errors in design and operation based on the use of appropriate rules formulated by experts. The principles of self-organization are implemented by a mechanism based on the rules that step-by-step formulate the necessary tasks, the required expert systems and computing units to solve them, as well as on the rules directly linking negative factors and neutralizing their properties.

1. Introduction

The design automation of unique mechanical systems, the reliability, survivability and safety of which is ensured only by the limits of strength and durability, requires special approaches due to the lack of analytical dependencies between the main criteria.

It is important to highlight that when considering such systems, we cannot eliminate the possible exposure to off-design loads of any origin, errors in design and operation. Then, decision-making enters the area of high uncertainty and requires the use of new methods and means of validating and ensuring the properties of reliability and survivability [1-4].

2. Methods

The aim of the present study is to develop a system for validating the properties of reliability and survivability of Unique Mechanical Systems (UMS’s) using the strength and resource criteria. The validation system is based on an approach linking a set of logical decision rules, a transdisciplinary model of the UMS technical state and the principles of self-organization [5-9]. The further development of this approach adopts ontological modeling technologies, production expert systems, a model-driven approach, and component development of software systems [10, 11].

3. Results

For the justified assignment of safety factors that provide for the correction of accepted hypotheses, imperfect design schemes, possible deviations in workmanship and operating conditions, we need additional empirical and expert knowledge which is difficult to incorporate into existing models. This knowledge is used in the form of rules that furnish opportunities to justify of the coefficients level, to
determine the likely degradation processes, their speed and damage caused by them, as well as methods and tools that ensure the reliability and survivability of UMS’s.

The self-organization principle of the validation system for the properties of reliability and survivability of UMS’s, ensuring that the system achieves the goals, is realized not by the control system, but due to the interaction of the system components with each other, initiated by the initial data. The interaction of components is based on the rules describing the relationship between the objectives of the study, the functions of components, and the information processed.

Figure 1 shows the self-organization mechanism of a system for validating the UMS properties. The work of the mechanism begins with the input of initial data reflecting the influencing factors and technical requirements for UMS’s, assembly units (AUs) and parts (Ps). Further, the components of the software system interact and perform their functions: self-organization of tasks (Stage 1, Knowledge Base 1 and Scheduler), analytical blocks (Stage 2, Knowledge Base 2, Scheduler, Computing Units and Expert Systems) and finding properties of the object in question (Stage 3, Knowledge Base 3 and all components).

The functioning of these components and ensuring the self-organization of tasks is carried out using the appropriate rules formulated by experts, both on the basis of generally accepted knowledge and the special knowledge that experts have. The rules are stored in the corresponding knowledge bases of expert systems and computing units.

**Fig.1.** Self-organization mechanism of the system for validating properties of unique mechanical systems (UMS’s): AU – assembly unit, P – part

The stage 2 (Figure 1) is followed by the automatic formation of the software system architecture
(Figure 2). The interaction between the components is provided by the Self-Organization Mechanism. The direct validation of properties of UMS’s, AUs and Ps is provided by Expert Systems (ES’s) and Computing Units (CUs) incorporated into analytical blocks.

Therefore, first, initial data is entered into the system through the user interface. Based on this data, the systems select rules to self-organize (create) tasks, the solution of which provides validation of the properties. Then, for the selected tasks, the appropriate rules (rules for choosing expert systems and computing units) help to choose an ES’s and CUs that can solve these tasks and which are combined into analytical blocks. Then, the analytical blocks self-organize (validate) the required properties of the object in question.

For example, we have a set of ES’s that help to solve various tasks and CUs that solve formalized problems. Now, depending on the aim and scientific and technical aspects of the problem under study, we choose ES’s and CUs to form analytical blocks to address the problem.

Fig.2. Architecture of the complex software system for validating properties of Unique Mechanic Systems (UMS’s)

4. Example
Initial data. Influencing factors. Mechanic (power) load – constant. Contact medium – weakly active liquid at temperature of Q°C.

Structural, Constructive and Technical Requirements for the Part. Technical requirements in accordance with the Terms of Reference. The Part must withstand workloads at a given temperature. The Part’s Resource – G hours (G is some variable denoting the number of hours). Survivability
factor – «leak before destruction». Ensure limited performance and safety of the Part under conditions of unacceptable damage and its possible detection by instrumental and organoleptic methods.

The structure of the rules from Knowledge Base 1 (Figure 1) of self-organization of Tasks incorporated into the expert system and forming a set of tasks, the solution of which will ensure the self-organization of the properties of the Part:

Left-hand part of the rule – Initial data; Right-hand part – Tasks.

Examples of rules: IF mechanical Loads are continuous THEN Tasks assess strain-stress state AND justify the choice of the Part’s material AND justify the safety factors, bearing capacity and resource AND assess the strength and bearing capacity, etc.; IF Exposure to a contact working medium THEN Objectives identify possible degradation processes taking into account mechanical impact and determine the rate of degradation processes AND determine the type of damage parameters AND calculate the resource, etc.

The structure of the rules from Knowledge Base 2 (Figure 1) of the self-organization of Analytical Blocks: The left-hand side of the rule is Task; The right-hand part is Analytical Blocks.

Example of the rule: IF Task complies with Rule 1 THEN corresponding ES’s and CUs.

The structure of the rules from Knowledge Base 3 (Figure 1) of the self-organization of the Part’s properties based on Expert Systems (ES’s) and Computing Units (CUs) incorporated into the analytical blocks: The left-hand side – influencing factors; The right-hand side – necessary actions and properties.

Examples of the rules for the ES validating the computational scheme: IF Part has a shape $\Phi_i$ from \{\$\Phi_1$, $\Phi_2$, …, $\Phi_n$\} THEN computational scheme for the flat stress-strain state is accepted. CUs for the VAT calculation. Computational models correspond to the computational scheme. ES’s for the preliminary choice of the part’s material. IF loads are static AND access to assessment of the technical state is impeded AND operating temperature AND contact medium is weakly active THEN steel is low-alloy AND heat-resistant AND mechanical, physical, chemical properties. Computing unit. Calculation of the stress intensity factors, safety factors, etc. ES’s for detecting possible degradation process and its rate, type and damage parameters. IF long-term design and beyond design constant tensile stresses AND compliance and non-compliance of the contact medium with the technical requirements THEN degradation processes DP_1, DP_2, …, DP_K AND damages Dam_1, Dam_2, …, Dam_M are possible. Computing unit. Вычислительный модуль. Calculation of the rate of degradation processes under design and beyond design factors.

The obtained constructive properties of the Part. Material – low-alloy heat-resistant steel. Safety factor for yield strength – 1.6; Resource – 20,000 hours; $K_i < K_c > 90$ MPa m$^{1/2}$; possible damage: pitting, cracks perpendicular to maximum tensile stresses, cracks that cause depressurization before they become critical, or become visually detectable with a margin of 1.3 to the critical size of the crack.

5. Conclusion
The system for validating the properties of reliability and survivability is self-organizing due to the mechanism for identifying tasks, expert systems, and computing units that ensure their solution.

The mechanism consists of three stages. At the first stage, the initial data, including the requirements for the created object, are compared with the tasks in which they are used to validate the properties satisfying the requirements. At the second stage, to solve the identified problems, the corresponding expert systems and computing units using this data are selected. At the third stage, expert systems and computing units solve tasks based on the corresponding knowledge bases in the automatic mode.

The system delivers validation of the properties of reliability and survivability of UMS’s due to the self-organization mechanism, which includes alternative intelligent (expert) and computing systems that provide specified functions based on the rules formulated by experts and to some extent consistent with the adopted development system for UMS’s. The system architecture includes a set of
components that provide both functional and information support for the process of self-organization of properties.

The logical and computational tasks in the example are presented in a simplified form. However, we can provide their detailed description if necessary. Experts participate in solving tasks during formulation of the rules of knowledge bases (off-line) and online.

The developed mechanism and architecture of an integrated software system are based on logical rules (products) that form the basis of production expert systems. The self-organization of the system and its subsequent use in automatic validation of the properties of UMS is provided without a specific control system that requires high costs for ensuring its reliability and development.

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