Computer technologies of dynamic and logical-probabilistic modelling for calculations of engineering systems

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Abstract. The article deals with the issues of using modern Russian software in the tasks of modelling the processes of functioning of engineering systems and assessing the risks associated with them. Techniques for performing numerical calculations are demonstrated on the example of a pipeline with a "leak before break". The conclusion is made about the expediency of using CAD SimInTech and PC ARBITR in educational work with students of MSU CE.

1 Introduction

The analysis of the processes and safety of the functioning of engineering systems, including building structures, is an urgent problem from both scientific and practical points of view [1].

The requirements for the reliability of building structures and the general principles of risk assessment in the design of buildings and structures are contained in the standards [2, 3].

Computer modelling makes it possible to investigate and predict the states of structurally complex systems at various stages of the life cycle [4-6, 8, 10,11].

Important tasks are connected both with the study of the dynamics of various technical systems and with the assessment of their risk.

The purpose of this work is the joint application of computer technologies of dynamic and logical-probabilistic modelling for the calculation of technical systems.

2 Methods

The following software packages served as research tools in this work:
1. CAD SimInTech is a software platform for developing mathematical models, control algorithms, control interfaces and automatic code generation for programmable controllers [7].
2. PC ARBITR (PC ASM SZMA) is a software package for automated structural-logical modelling and calculation of the reliability and safety of systems [9].

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CAD SimInTech solves the problems of modelling objects of the military-industrial complex and defence industry, energy facilities, nuclear facilities, oil and gas facilities, aerospace facilities, transport facilities and others.

The ARBITR software package is designed for automated mathematical modelling and calculation of the probabilistic characteristics of reliability [12] and safety (technical risk [13], the likelihood of emergencies and accidents due to element failures) of structurally complex systems of hazardous production facilities, objects of use nuclear energy, building facilities and other technical and information systems [14, 15].

To demonstrate some of the functionality of the presented software systems a typical structural element is considered - a pipeline with a high stored energy.

The simulation of the process of coolant flow in the pipeline is implemented using the HS thermal-hydraulic code, which is one of the modules of the SimInTech dynamic simulation environment. Using the HS code, a model of a pipeline with a "leak before break" was developed.

Operational experience and computational and experimental studies show that for pipelines with high stored energy, made of tough steel and having high resistance to unstable crack growth, the probability of hypothetical guillotine failure is extremely small even under heavy emergency loads. Instantaneous catastrophic failure is always preceded by stable subcritical crack growth. This circumstance makes it possible either to detect a crack during periodic monitoring of the metal long before it becomes a through one, or to detect a leak by a leak control system before a through crack through which the coolant flows out could reach a critical length. As a result, it becomes possible to timely detect a defective pipe section, carry out subsequent repair or replacement of the pipe, thereby eliminating a sudden rupture of the pipeline. This is the concept of “leak before break” [16].

The logical-probabilistic model of pipeline operability was built using the method of functional integrity diagrams [10].

3 Results

In the first numerical experiment, simulation of the dynamic process of formation of a coolant leak in a pipeline was performed. Figure 1 shows the hydraulic diagram of the pipeline, made in the graphical editor SimInTech [8]. A pipeline branch, including a valve and having an outlet to the external environment, is introduced into the scheme for modelling a through crack in the pipeline, through which the coolant leaks. In the calculation model the following dimensions for the pipe are accepted: diameter – 250 mm, wall thickness – 10 mm, length – 10 m. The simulation of the coolant flow in the pipeline was performed with the following initial data:
- coolant flow at the outlet Pipe 1 – 100 kg/s;
- coolant pressure at the inlet Pipe 3 – 1E7 Pa;
- coolant temperature at the inlet Pipe 3 – 100°C;
- external environment with pressure 1E5 Pa and temperature 20°C;
- gate valve with 5% opening degree.
Fig. 1. Hydraulic diagram of the pipeline.

Figures 2, 3 and 4 show graphs of the parameters of the dynamic process, simulating the guillotine opening of the valve, for the coolant flow rate, pressure, and temperature, respectively.

Fig. 2. Coolant flow rate in the pipeline.
Fig. 3. Coolant pressure in the pipeline.

Fig. 4. Coolant temperature in the pipeline.
The flow rate of the coolant in Pipe 2 equal to 286 kg/s characterizes the scale of leakage of the coolant from the pipeline at a steady pressure 1E7 Pa.

In the second numerical experiment, a risk assessment for a pipeline with a coolant leak was performed. Figure 5 shows the functional integrity diagram for the logical-probabilistic model of the pipeline, made in the graphic editor of the PC ARBITR [10].

![Functional integrity diagram of the pipeline.](image)

Fig. 5. Functional integrity diagram of the pipeline.

On Figure 5 the functional vertices 1, 2, 3 and 6 are associated with possible events (conditions) and the probabilities of their implementation. Fictitious vertex 7 is used for the logical addition of conditions 1 and 6. The results of the calculations are the probabilities of possible consequences of emergency events $P(y_4)=9.99\times10^{-10}$ and $P(y_5)=9.99\times10^{-8}$, as well as the weighted average damage equal to 0.5994.

4 Discussion

The considered modelling technology based on Dynamic Simulation Environment SimInTech can be successfully applied to structurally complex engineering systems [8]. The process is shown on the example of simulation of the dynamics of one of the small steam turbine plants. A step-by-step description of the development of a sensor model, an actuator and regulators for a complex model is also given using the example of level regulators in heaters, in a deaerator and in the main condenser.

The presented technology of using logical-probabilistic modelling based on PC ARBITR can be extended to structurally complex engineering systems [17]. The results of the development and examples of the application of a logically deterministic method for modelling and determining the reliable and probabilistic consequences of emergency situations in structurally complex systems of hazardous production facilities are presented. The initial data are: a block diagram of the system's operability, probabilistic parameters of the reliability of elements, criteria for the implementation of its main functions and parameters of an emergency. Based on these data, the developed logically deterministic modelling method makes it possible to determine the reliable consequences of emerging emergencies, as well as their influence on the change in the probabilistic characteristics of the system stability properties (reliability, survivability and safety), the effectiveness and risk of their operation.
5 Conclusions

The computer technologies for dynamic and logical-probabilistic modelling of structurally complex engineering systems presented in the paper use Russian software: CAD SimInTech and PC ARBITR. They have found application in various industries, including construction. Great potential exists for the use of these software tools for educational purposes when teaching several disciplines to students of MSUCE. From the point of view of carrying out scientific research, developing new products and performing expert assessments, the considered software is also promising.

Of note is the availability of software technical support from developers.

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