Наведено результати розробки методу оцінки, прогнозування технічного стану функціонально-взаємопов'язаних і взаємодіючих підсистем (ФВВП) суднових складних технічних систем (СТС) при екстремальних умовах. Рішення поставленого завдання вимагало: розробити когнітивні імітаційні, нечіткі моделі оцінки та прогнозування технічного стану ФВВП СТС; розвинути метод інформаційного забезпечення підтримки прийняття рішень при пошуку причин відмов елементів суднових СТС

Ключові слова: складні технічні системи, ризик відмови, оцінка технічного стану, прогнозування технічного стану, когнітивні моделі

Приведены результаты разработки метода оценки, прогнозирования технического состояния функционально-взаимосвязанных и взаимодействующих подсистем (ФВВП) судовых сложных технических систем (СТС) при экстремальных условиях. Решение поставленной задачи потребовало: разработать когнитивные имитационные, нечеткие модели оценки и прогнозирования технического состояния ФВВП СТС; развить метод информационного обеспечения поддержки принятия решений при поиске причин отказов элементов судовых СТС

Ключевые слова: сложные технические системы, риск отказа, оценка технического состояния, прогнозирование технического состояния, когнитивные модели

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DEVISING A METHOD FOR THE ESTIMATION AND PREDICTION OF TECHNICAL CONDITION OF SHIP COMPLEX SYSTEMS

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1. Introduction

Elements and subsystems of ship complex technical systems (CTS) are functionally interconnected. They are operated under extreme technogenic and natural conditions [1]. The performance efficiency of ship CTS, the level of navigation safety and economic consequences are largely determined by the quality of diagnosis and prediction of the technical condition of subsystems and CTS as a whole, by their energy, material and physical and informational characteristics, by results of analysis of the estimation of risk of systems' failures [2]. Ineffective operation of at least one of the subsystems is reflected on the performance of other subsystems and leads to accidents when equipment is damaged and people may possibly die [3].

At present, estimation and prediction of technical condition of ship CTS do not entirely take into account the requirements of the International Convention for the Safety of Life at Sea SOLAS-74, positions of the International Code on the Control of Safety [4]. The applied methods do not consider the complexity and diversity of CTS FIIS in the estimation and prediction of their technical state [5].

In order to reduce emergencies and damages to equipment, it is relevant to devise new methods for the estimations of risk and prediction of the technical condition of ship CTS.

2. Literature review and problem statement

From the point of view of technical safety, quantitative assessments of the risk of CTS failures are a necessary and complex problem, which requires development and application of special mathematical apparatus. As follows from [6], the solution of applied problems of such type is frequently based on the methods of mathematical and statistical modeling, the method of analysis "tree of failures", etc. At present, among the methods for modeling the reliability, there is an advanced technology of the automated structural-logical simulation and calculation of reliability, safety of complex systems objects and processes, effectiveness and risk in the functioning of systems [7].

Reliability of ship CTS depends on a large number of factors, which characterize their design, conditions of production and operation. This leads to the fact that the processes of changing the technical condition and reliability have a random nature, and, when estimating and analyzing the indices of reliability, it is necessary to use the methods of probability theory. Paper [8] points to the prospects of using imitation modeling (IM) for the prediction of the CTS safety level in such cases. The known software packages CARA and RCM-Tool, developed by the Norwegian Scientific Research Institute of Marine Technologies MARINTEK, are the system for the automated construction of the CTS "tree of failures". But they do not make use of IM, for example, based on statistical tests, which significantly limits the possibility of their use, especially at the uncertainty of initial data that happens in the course of CTS operation. A promising method of IM for exploring the CTS reliability and predicting their technical condition is the cognitive imitation modeling (CIM) [9] that allows the consideration of a large number of probable alternatives. Taking into account the objectively existing uncertainty, incompleteness and fuzziness of information about the object, it is expedient to use an apparatus of fuzzy logic when devising a knowledge base and the output mechanisms of expert systems [10]. This will make it possible to objectively estimate technical condition and to make better substantiated decisions to control repairing operations of ship equipment. The fuzzy models for the estimation of the CTS failures risk, designed taking into account variation information about the estimation of failures risk at different scenarios, make it possible to explore the behavior models of systems under extreme scenarios at the minimization of time for the calculation. In this case, both the functional intercorrelation and the interaction of subsystems and elements are considered, as well as the quantitative and qualitative characteristics of information-energy interchange. The most effective tool for realization of procedure for the estimation and prediction of the CTS failures risk is the CIM in combination with fuzzy simulation, ensured by algorithms and methods, which adequately reflect peculiarities of the systems. However, at present, for the estimation and prediction of the CTS failures risk, this approach needs further development. This will make it possible to consider complexity and heterogeneity of CTS FIIS in the estimation and prediction of their technical condition, to support systems in the operational mode due to the timely flaw detection. It is necessary to devise new effective models for the solution of problems on diagnosis and prediction of the CTS behavior. In the course of solving the problems, related to improving reliability of operation of ship CTS, a more important role is played by the methods based on modern software for the diagnosis and prediction of such technical systems.

3. The aim and tasks of the study

The work is aimed at creating and exploring a method for the estimation and prediction of the technical state of FIIS of ship CTS under extreme technogenic and natural conditions. This will make it possible to improve reliability of the ship CTS operation.

To achieve the set aim of present work, the following tasks were to be solved:

– to devise cognitive imitation and fuzzy models for the estimation and prediction of the CTS FIIS technical condition;

– to design a model for a decision making support when detecting the reasons for failures of the FIIS elements of ship CTS;

– to develop the method of information provision of decision making support when searching for the reasons of failures in the FIIS elements of ship CTS.

4. Method for the estimation and prediction of the FIIS technical condition of ship CTS

An estimation of failures risk as a comprehensive index of CTS reliability and the remote мonitoring, diagnosis and prediction (RMDP) system includes a multistage estimation of failures risk in different interconnected magnitudes. Energy-substance-information (ESI) may be considered to represent such magnitudes. Estimation is carried out based on statistical and expert data taking into account the operating conditions of the systems' elements. The procedure for the construction of scenario of CTS behavior in the course of emergency is an iterative process. In accordance with the proposed method, the sequence of quantitative assessment and of the prediction of FIIS failures risk of ship CTS includes the stages:

– determining FIIS of ship CTS in the hierarchy and topology of the systems with regard to the utilized ESI resource;

– the estimation of failures risk of the systems' elements of the damaged components of the systems; the prediction of failures risk of the elements of the systems from the damaged CTS components;

– decision making support (DMS) in the search for the reasons of failures in the elements of ship CTS.

Underlying the method for the estimation and prediction of technical condition of FIIS of ship CTS is the CIM technique for the estimation of risk in the functioning of systems in combination with the fuzzy simulation that makes it possible to realize description of the equipment condition, formalized with a different degree, taking into account the evolution of systems over time.

4. 1. Realization of the method based on the CIM estimations and the prediction of failures risk of ship CTS

Cognitive model is represented in the form of functional graph

$$F_P\langle G,X,F,Q\rangle, \quad (1)$$

where G=<V, E>, G-digit directed graph: $V=\{v_i\}$, i=1, 2,..., k is the set of vertices of cognitive map; $V=\{e_{ij}\}$ is the set of arcs, which connect vertices v_i and v_j; $X=\{x_i\}$ is the set of parameters of vertices; $F=f\{v_i, v_j, e_{ij}\}$ is the function of connection between the vertices; Q is the parameter space of the vertices.

When devising cognitive model (1), its part is built according to the statistical data on the object, another part is based on the expert and theoretical data processing. The CIM stages include:

– study of the cause-effect relations (paths and cycles of cognitive model) of CTS FIIS taking into account the utilized ESI resource;

– analysis of the structure of the model, which reflects the mechanism of functioning of the examined CTS;

– study of the possible development of the processes in the system by pulse modeling;

– estimation of probabilities of the losses of working ability, damages and risk of failures in CTS.

When constructing CIM, we consider the type of the transferred ESI resource from an element-source to the element-receiver. In order to evaluate probabilities of the loss of working ability, damage and risk of failures in the CTS elements, CIM applies damaging simulating pulses (DSP) $1-\mathrm{imp}_k(t),\ k\in\{1,2,3,\ldots,l\}$ with amplitude $m_{\mathrm{imp}_k}(t)$ for the discrete time moments [4]. DSP is the array of values, which determine the type of CIM's element (interrelation). In addition, DSP is the degree of damage of the element (interrelation) of the model, which is in the range from 0 (element (interrelation) is operational) to 1 (element (interrelation) is not operational). 0 corresponds to the state of the element (interrelation), if DSP does not pass through element (interrelation), and 1 if DSP passes through the element (interrelation). Pulse vector for V, E

$$\mathrm{imp}_{i(ij)}(t)=(x_1,x_2,\ldots x_{V(E)}), \qquad (2)$$

where $x_1, x_2,\ldots,x_{V(E)}$ are the states of the elements (interrelations).

A generalized Harrington function of desirability is used for the ranking of the estimations of failures risk of the CTS elements (interrelations) [16]: 0–0,2 – the risk level is estimated to be minimum, the consequences of emergency are minimal, not affecting the CTS operation essentially; 0,2–0,37 – the risk level is estimated to be permissible, the consequences of emergency are insignificant, allowing the CTS operation without essential repair; 0,37–0,63 – the risk level is estimated to be maximum, the consequences of emergency are considerable, but allowing the CTS operation upon conducting repair work; 0,63–1 – the risk level is estimated to be critical, the consequences of emergency are catastrophic, not allowing the CTS operation at all. A qualitative condition of the subsystems and their elements, included in CTS, when estimating the probabilities of the loss of working ability is expressed by the functional of states

$$Q=\left[P_{V.n},P_{V.i},v_i,v_j,H_m^v(t),K_{V.i}\right], \qquad (3)$$

where $P_{V.n}$ is the nominal probability of the loss of working ability of the systems' elements; $P_{V.i}$ is the current probability of the loss of working ability of the systems' elements; $H_m^v(t)$ is the transfer coefficient of the change in the DSP amplitude, passing through the CIM's vertices; $K_{V.i}$ is the coefficient of degree of damage in the CTS element.

A qualitative state of the interrelation between the CTS subsystems and their elements is expressed by the functional of states

$$E_Z=\left[P_{En},P_{Ei},e_{ij},H_m^e(t),K_{Ei}\right], \qquad (4)$$

where $P_{E.n}$ is the nominal probability of the loss of working ability of interrelation; $P_{E.i}$ is the current probability of the loss of working ability of interrelation; e_{ij} is the type of ESI resource; $H_m^e(t)$ is the transfer coefficient of the change in the DSP amplitude, passing through the interconnections of the CTS elements; K_{Ei} is the coefficient of degree of the damage of interrelation.

DSP is generated in the conditionally assigned damaged vertex (edge) of CIM, it moves towards the subsequent vertices (edges), consecutively rendering inoperable interconnected elements of the systems.

As the object of modeling, we selected CTS – ship power plant (SPP). A typical structure of SPP is FIIS that transform the energy of fuel into mechanical, electrical, thermal power and transport it to consumers. A directed graph of the examined oil subsystem of SPP is depicted in Fig. 1

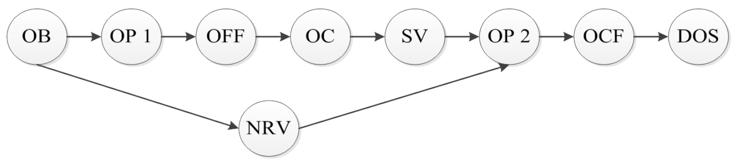

Fig. 1. Directed graph of SPP oil subsystem (OB – oil bath, OP1 – the first oil pump, OFF – oil fine filter, OC – oil cooler, SV – safety valve, MN2 OP2 – the second oil pump, OCF – oil coarse filter, DOS – diesel oil system, NRV– non-return valve)

A simulation of the damaging pulses action on the system was performed based on the German distributive of the Debian GNU/Linux 8.0 (stable) operating system. Realization of the model's basic algorithm is conducted by the means of high-level Python programming language, initial data on the models are represented in the JSON format, the results are in the form of protocols in the CSV format and of diagrams in the DOT language of the graphviz system. We used the Vim editor as IDE. The automation of the system's performance was accomplished based on the GNU make tools, visualization – with the aid of the graphviz software package. The data representation files formats (CSV/JSON) are universal, platform– and language-independent; they are easily processed by most software tools for data serialization and are undemanding to computational resources and data transfer channels.

The process of simulation is organized as follows (Fig. 2): initial model is assigned in the form of a file in the JSON format; the Python program processes the model, generating an array of tables in the CSV format and diagrams in the DOT format.

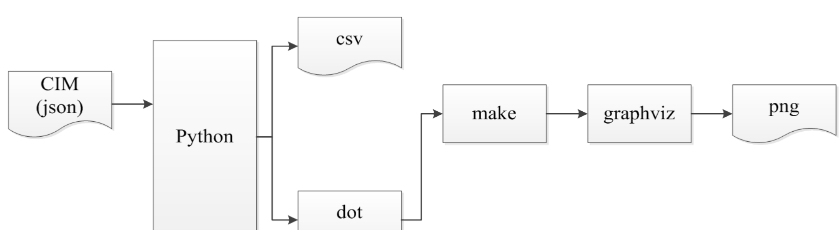

Fig. 2. Simulation process of vitality in the Debian GNU/Linux environment

The make utility processes the DOT-files with the aid of the graphviz program, which results in the creation of the array of graphic diagrams of state of the system in the png format. An analysis of the obtained results is carried out by Calc Libre Office.

The use of the JSON format makes it possible to flexibly assign structure and configuration of the existing equipment. One of the advantages of working with the JSON format is in the fact that full specification of the system (numerical characteristics of nodes, configuration and the graph of inter-node connections) can be assigned in the uniform file in the universal format. In this case, a JSON-file can be edited both manually and by the automated tools of collection and processing of information. The scenarios of the diagnosing pulses passing through the system are represented both in the graphic form and in the form of CSV-scripts (together with the calculation data). In this case, both a separate file of the protocol of step-by-step pulse advancing and the summary CSV-file with a general set of protocols and the calculation of numerical characteristics of the failures risks for different configurations of the system are generated.

The CSV-file contains a numerical value of the pulse in each of the nodes at each moment of discrete time. Files with the indication of the calculated characteristics by each of the CTS nodes are generated separately. The obtained CSV-files might be used both in the analytical software (tabular editors – Libre Office, Microsoft Office Excel, more sophisticated systems of visualization – gnuplot, R, Seaborn) and in the decision making support systems for the automated processing and evaluating the risks (for example, systems that employ sklearn, Dataiku Data Science Studio, etc). Because of the use of combination of the JSON/CSV/DOT formats, the system makes it possible to work with the CTS configuration and analysis in two planes – visual and automated, as well as with their combination. The file of configuration is edited manually in the visual method at the stage of creating a system's model. A preliminary analysis of characteristics can be controlled visually – according to the diagrams of pulse advancing. Automatic methods make use of CSV-files for numerical analysis of the system's characteristics, making and analyzing decisions.

4. 2. Implementation of the method based on the fuzzy model of estimation and prediction of failures risk of ship CTS

Fuzzy-probabilistic submodels employ probabilistic fuzzy rules of Takagi-Sugeno of zero order [11].

Failures risk of the examined CTS can be presented in the form

$$R=\{<P_i,Y_i,q_i>\},\ i=1,2,...,N, \tag{5}$$

where P_i is the probability of failure risk of the CTS element; Y_i is the damage from the consequences of risky event; q_i is the weight of the i-th risk, established for each risk in the range of 0...1 provided the conditions are satisfied

$$\sum_{j=1}^{n_i} q_{ji}=1(i=1,\overline{N})\ \text{and}\ \sum_{i=1}^{N} q_i=1.$$

A total quantitative evaluation of CTS failures risk taking into account the estimations of failures risk the of subsystems is determined

$$R=\sum_{i=1}^{N} R_i\cdot q_i, \tag{6}$$

where R_i is the quantitative estimation of the i-th type of risk.

A fuzzy subset for the output variable with the function of belonging can be presented in the form

$$\mu_\Sigma(Y_R)=\mu_{x_i}(Y_{R_i,q_i})=\max_{Y_R}[\mu_{xP_i}(Y_R),\mu_{xY_i}(Y_R),\mu_{xq_i}(Y_R)], \tag{7}$$

where $\mu_\Sigma(Y_R)$ is the resulting fuzzy subset for the output variable of the estimation of risks of failures (Y_R); $\mu_{xi}(Y_R,q_i)$ is the fuzzy set, included in the subset $\mu_\Sigma(Y_R)$; $\mu_{xPi}(Y_R)$ is the fuzzy set of probabilities of failure in subsystems and the CTS elements; $\mu_{xYi}(Y_R)$ is the fuzzy set of damages to subsystems and the CTS elements and the RMDP system; $\mu_{xqi}(Y_R)$ is the fuzzy set of weights of risks of failure in the CTS subsystems and elements and the RMDP system.

Construction of the devised fuzzy models for the estimation of risks of failures in the subsystems and elements on the example of SPP was conducted with the aid of the Matlab software package, graphic means and tools of the Matlab extension package – Fuzzy Logic Toolbox. In the studies we used function of Gaussian distribution as the function of belonging, realized in the Matlab in the form gaussmf for assigning smooth symmetrical functions of belonging. At the stage of fuzzification, the input variables are assigned of the fuzzy models for the estimation of failures risk in the form of probabilities of failure and damage from the consequences of risky events of the SPP elements.

4. 3. Decision making support in the search for the reasons of failures in the ship CTS elements

Underlying the DMS method in the search for reasons of failures of the FIIS elements of ship CTS are the criteria, defined by normative documentation, expert estimations. They include:

– maximum probability of the loss of working ability;

– minimum damage from the failure of the subsystems' elements;

– maximum estimation of consequences of the occurrence of risk of failures;

– maximum duration of operation of elements of the CTS subsystems.

For DMS related to the estimation of FIIS failures risk of ship CTS based on a priori and a posteriori data, as well as in the search for the failed elements of the systems for the purposes of improving efficiency of their performance, we propose a method, based on the dynamic Bayesian networks of confidence (DBNC) [12]. The set problem is solved by using a constant system of interrogation of all elements of the system at its different levels over specific period of time. Construction and examination of DBNC on the probability of losing working ability, estimations of failures risk of the FIIS elements of CTS is implemented with the use of the GiNIe software package [13].

The objective function of the estimation of working ability of the CTS elements and the RMDP system by means of DBNC takes the form

$$F(P_b)=\{G,M\}, \tag{8}$$

where G is the acyclic directed graph of the network; M is the set of the SPP elements, which compose DBNC.

Vertices of the graph are CTS FIIS, which are determined with regard to the hierarchy of network

$$v=\left\{v_i^j\middle|\overline{1,n},j=\overline{1,m}\right\}, \tag{9}$$

where v is the designation of CTS element; i is the number of block in the network; n is the number of blocks in the network; j is the number of level in the network; m is the number of levels in the network.

A structure of the examined DBNC of the SPP oil subsystem is represented in Fig. 3.

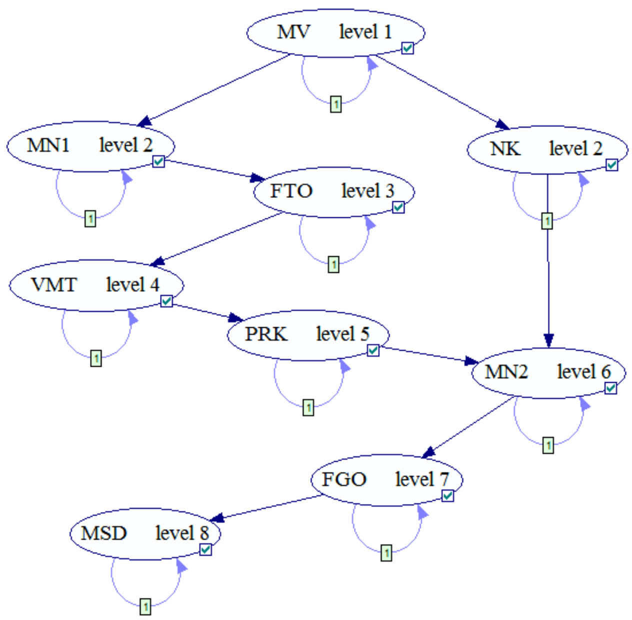

Fig. 3. Structure of DBNC of the SPP oil subsystem (FTO – oil fine filter, MN1 – the first oil pump, FGO – oil coarse filter, MV – oil bath, VMT – water oil heat exchanger, MN2 – the second oil pump, NK – non-return valve, PRK – safety valve, MSD – diesel oil system)

It is accepted that the probabilities of losing working ability in the prediction of working ability of the SPP elements SPP change in accordance with the exponential distribution law with the use of logistic regression, which contributes to the prediction of probability of occurrence of a certain event by the values of set of attributes.

A realization of the DMS model is implemented in accordance with the algorithm for the estimation of failures risk of such subsystems. It consists in the construction of CTS DBNC with the use of databases (Fig. 4).

A sample of the required data set is formed in the data analysis for each particular script of failure. Obtained data are interpreted and processed with the aid of blocks of knowledge acquisition, DMS and control over rules. Then the bases of knowledge, data and rules are updated and modified. An analysis of possible recommended decisions is run based on the updated information and the selection of preferable alternatives from the general collection of solutions is conducted, upon completion of which a decision regarding the elimination of reasons for failures is made.

In order to identify possible reason for the failure of oil subsystem, we carried out research in accordance with the search technique for the failure in its performance, given in Fig. 5.

In the assumption that failure F_i has probability of occurrence p_i and criticality index S_i, the efficiency of DSE diagnosis can be determined by formula [14]

$$DSE = \frac{\sum_{D_F} S_i p_i}{\sum_{F} S_i p_i}, \qquad (10)$$

where F is the set of possible failures, obtained as a result of analysis of types and consequences of failures [14]; D_F is the set of diagnosed failures (subset F); $\sum_{D_F} S_i p_i$ is the sum of products of criticality indices and probability of failure of the SPP elements; $\sum_F S_i p_i$ is the sum of products of criticality indices and probability of failure of the set of elements of the SPP oil subsystem.

Criticality index of the S_i-th failure is calculated by formula:

$$S_i = FR \cdot CF \cdot SF \cdot SDF, \qquad (11)$$

where FR is the rate of failures (number of failures per 1 hour); CF is the cost coefficient, which takes integer values in the range from 1 to 3 (low, medium, high) and determined by expenditures for the required maintenance, losses from possible idle time; SF is the danger coefficient, which takes integer values in the range from 1 to 3 (low, medium, high); SDF is the coefficient of secondary damages, which takes integer values in the range from 1 to 3 (low, medium, high).

Using dependence (10), it is possible to estimate the effectiveness of the performed diagnosis of the examined CTS subsystem CTS.

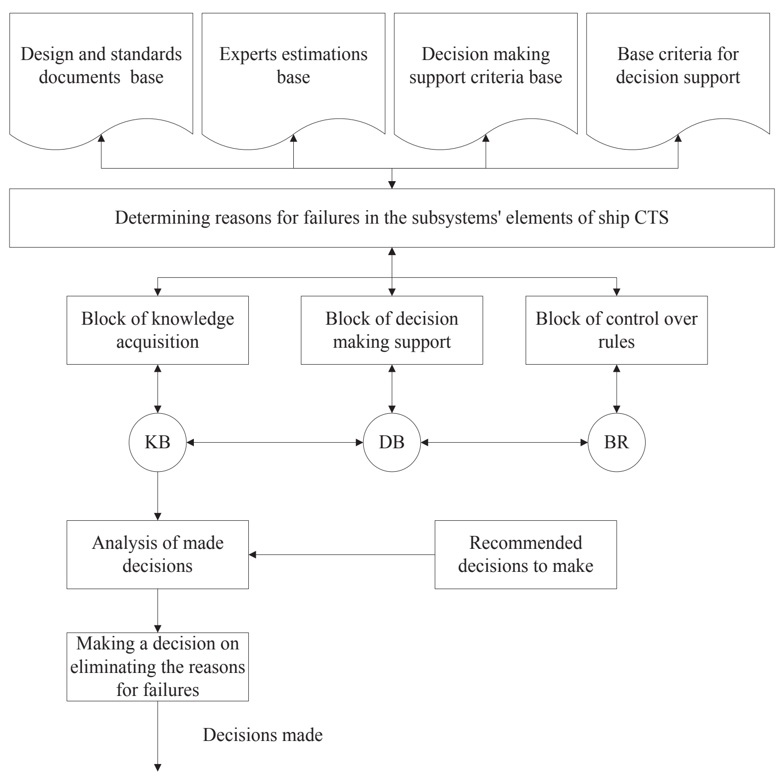

Fig. 4. Structural scheme of DMS in the search for reasons of failures according to the estimation of failures risk of ship CTS

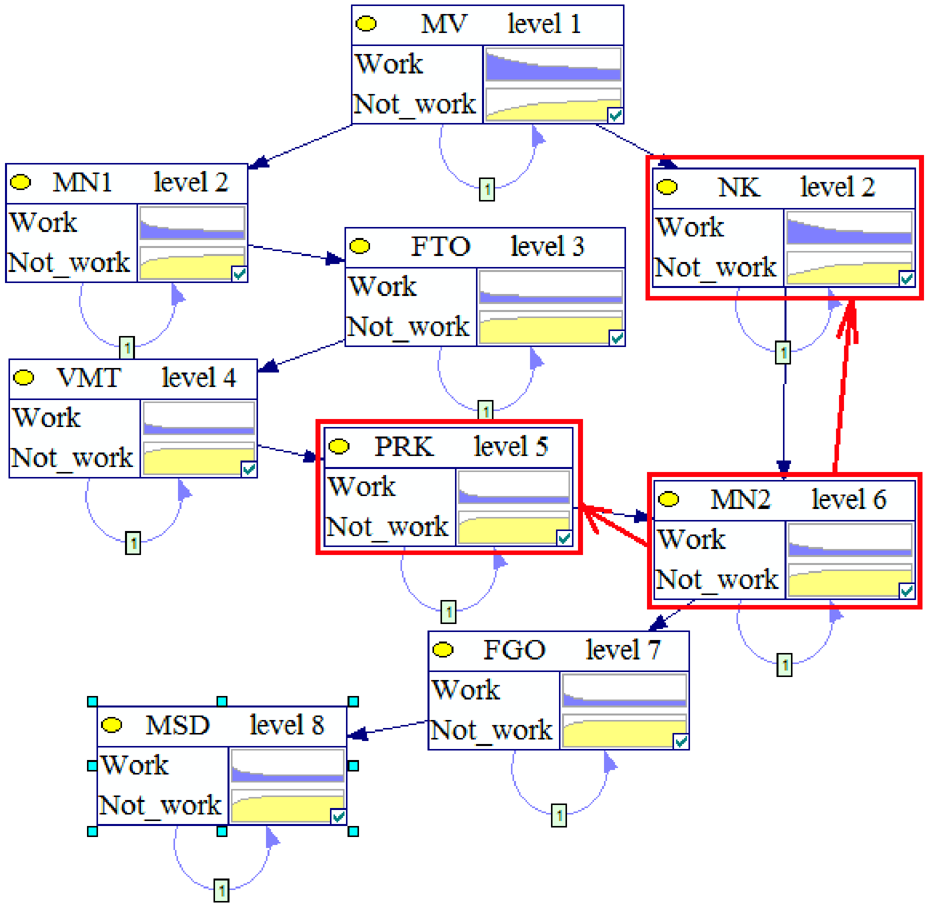

Fig. 5. Search technique for the reason of failure in the oil subsystem

5. Results of research into devised method

For the simplification of mathematical description, a generalized SPP model is devised at the level of SPP subsystems, mechanisms and devices. If the detailed study of the SPP model is necessary, the model can be complemented by separate models (directed graphs) of the SPP subsystems. In this case, the designed principle of modeling is valid.

The ranking of results of the studies of the estimation of failures risk for the vertices of the CIM directed graph of the SPP oil subsystem is given in Fig. 6. The estimation of failures risk of the subsystem was conducted for two arrays of values with the highest probability of failures. It follows from the results of calculations of the structural damages of the subsystem's elements that the most vulnerable element of the SPP subsystem is the oil fine filter (risk of failure – 0,44). The less vulnerable element of SPP is the diesel oil system (0,02).

In the course of the conducted research by simulation, we obtained a three-dimensional visualization of the surface of fuzzy model for the estimation of failures risk in the SPP oil subsystem (Fig. 7). The devised model is used for the formalization of representation of criteria of failures risk of the examined object. It makes it possible to obtain the prediction of failures risk in the elements of the CTS subsystem under extreme perturbing impacts on them.

When simulating SPP DBNC for the different values of probability (risk) of the failure of input element, we determined the values of failures risk of the functionally – interconnected and interacting elements of the oil subsystem over 20000 hours of the SPP operation (Fig. 8). It follows from the results of conducted research that with an increase in the risk of failure of the subsystem's input element from 0.09 to 0.2, the values of failures risk of all subsidiary, subordinate elements of SPP DBNC grow.

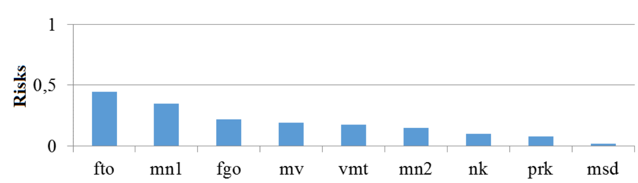

Fig. 6. Ranking of results of evaluating failures risk in the SPP oil subsystem (fto – oil fine filter, mn1 – the first oil pump, fgo – oil coarse filter, mv – oil bath, vmt – water-oil heat exchanger, mn2 – the second oil pump, nk – non-return valve, prk – safety valve, msd – diesel oil system)

A target purpose of applying DBNC for the estimation of both the probability of losing working ability and the risk of failures in the elements of the CTS subsystems is a posteriori conclusion. A posteriori conclusion is based on the techniques for data analysis, which are obtained as a result of using DBNC. Simulation by a priori and a posteriori data determined the elements of the SPP oil subsystem, exerting the largest influence on the diesel working ability and the work of entire system over different time intervals. It is established that this element includes the safety valve (Fig. 9).

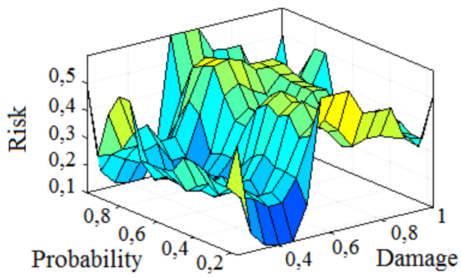

Fig. 7. Three-dimensional visualization of the surface of fuzzy model for the estimation of failures risk of the SPP oil subsystem

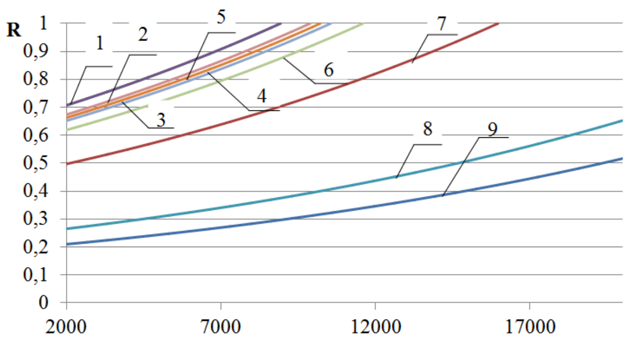

Fig. 8. Risk of failure in the elements of the oil subsystem with the risk of failure of the element at the system input 0,26 (1 – water–oil heat exchanger, 2 – oil fine filter, 3 – oil coarse filter, 4 –safety valve, 5 – the second oil pump, 6 – diesel oil system, 7 – the first oil pump, 8 – non-return valve, 9 – oil bath)

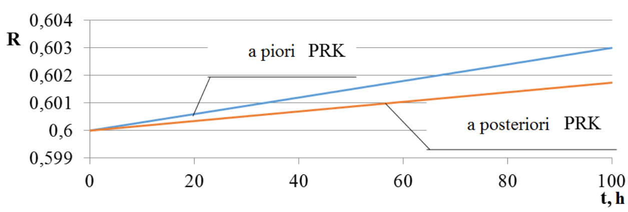

Fig. 9. A priori and a posteriori estimations of the risk of failure in the safety valve of the oil subsystem when the information on failures is received.

If after 20000 hours of operation, the subsystem MN2 is in operational condition, then an inspection is performed to check the working ability of the subsystems PRK, NK, interconnected with the MN2 working ability.

After technical maintenance of the MN2 subsystem, DBNC carries out the recalculation of estimations of failures risk in the subsystems. Because PRK directly influences MN2 and displays the risk of failure (0,6). Consequently, it is necessary to testing this subsystem. Failure of PRK will be the probabilistic reason for the failure in the MN2 subsystem. After technical maintenance of PRK, the updated data on the technical condition of the subsystem will enter DBNC and the recalculation of the estimation of failures risk in the subsystems will follow. If, after technical maintenance of the MN2 and PRK subsystems, as well as the recalculation of the estimation of failures risk for these systems, the risk value of failure remains unacceptably high, then it is necessary to test the NK subsystem, whose value of failure is (0,24).

Subsequently, the search is carried out for the next subsystems in the structure of the search technique for the reasons of failures in the subsystems, whose estimation of failures risk is maximum. The testing of all subsystems is carried out and of all subsystems connected with them at other levels of the DBNC technique. Data in DBNC are updated at each stage of the performed actions.

6. Discussion of results of exploring the estimation of failures risk of the ship CTS subsystems

It follows from the obtained results of the studies that the highest increase in the summary level of failures risk in the subsystems and elements of CTS is observed at the values of probability of losing working ability in the range 0,455...1. At the values of damage, for example, for SPP equal to 0,234 and probability of losing working ability equal to 0,5, the risk value of failure reached 0,157.

The devised fuzzy models for the estimation of failures risk in CTS make it possible to explore the models of systems under extreme scenarios at the minimization of time for the calculation.

The research into the imitation and fuzzy models for the estimation of risk of failure when operating FIIS of ship CTS revealed the following. A relatively small number of elements of subsystems generate a large number of possible variants of development of extreme situation with the damage experienced by any of the elements.

When complementing the models with the indices of real criticality and spatial arrangement of subsystems, the scales of models grow by several times. Upscaling the examined subsystems leads to further increase in the states of subsystems.

As a result of examining the DMS model for improving the performance efficiency of the diagnosed FIIS of ship CTS, we determined the degree of influence of each element of the system on the probability of losing working ability and failures risk of the system.

From a retrospective analysis of results of the studies when simulating SPP, we revealed those elements, which influence working ability of the system. When exploring emergencies, running analysis of incidents in CTS, the central objective is the identification of the reason for emergency.

The research conducted make it possible to obtain algorithmic and methodical provision for making justified decisions at the stage of SPP operation SPP with regard to the impact of random actions. The applied search algorithm for failures in the SPP system provides for:

– finding critical, in the technical sense, subsystems at all levels of the SPP system whose servicing must be carried out without delay;

– the optimization of time needed for the search for failures.

The use of the devised method and the DMS model when searching for the reasons for failures in the elements of diagnosed FIIS of ship CTS make it possible:

– to control the values of failures risk in the elements of the system when the information on failures in the subsystems is received;

– to predict risk value of failures in the system's elements for the purpose of selecting the strategy for its restoration;

– to support decision making when searching for the reasons of failures in the system's elements;

– to ensure economic effect through the increase in the systems' working life cycle and reduction of the expenditures for their repair while maintaining the assigned level of their reliability.

7. Conclusions

A place in the hierarchy and topology of the FIIS elements of ship CTS is defined based on the characteristics of the energy, material and information resources used by the systems in the devised method for the estimation and prediction of technical condition of CTS.

The most vulnerable elements of FIIS of ship CTS are found with regard to their weight values in the systems, obtained by cognitive imitation and fuzzy simulation.

The CTS elements, prone to failures, are determined by their advance detection by modeling the processes of decision making support in the search for reasons of failures.

The strategy of restoring the FIIS elements of ship CTS with decision making support when searching for the reasons of their failures is based on the prediction of change in the probability of losing working ability and risk of failures of the elements.

The obtained results provide a solution for the formulated substantiated tasks of applied-scientific problem – devising a method for the estimation and prediction of technical condition of FIIS of ship CTS under conditions of unpredictable extreme and technogenic impacts.

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