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STRUCTURING OF THE MAIN DIRECTIONS OF RESEARCH REGARDING THE DETERMINATION OF THE REMAINING RESOURCE OF TRANSPORT STRUCTURES AND BUILDINGS

An analysis of the current state of developments regarding the determination of the residual resource of transport structures and facilities, which are operated in the conditions of long-term practice, uncertainty and risk in the adoption of final conclusions, is given. It has been established that the strategy for the development of technical diagnostics requires the exclusion of dependence on the human factor and subjective observation of changes in the physical, mechanical and operational properties of controlled objects for intellectual operations of determining the remaining resource associated with the collection, processing and analysis of diagnostic information. Analysis of the use of methods of non-destructive testing and flaw detection to assess the residual resource of transport structures and ratios showed the limitations of these methods of determining defects in the early stages of their development, which precede the state of degradation of the material, optimization of processes and technologies to ensure timely diagnosis and forecasting of the technical condition of structures. The current state of developments regarding the determination of the residual resource of transport structures and structures operated under conditions of complex dynamic loads is considered. The structuring of the main directions of research was carried out and the gradation of the main used methods of residual resource assessment was proposed based on the results of numerical methods of fracture mechanics, based on the results of non-destructive testing and defectoscopy, using normative documents and standards of modeling and information support. The essence, methodology of dignity and shortcomings of the used methods are highlighted. Purpose, scope of application, prospects of their further use in transport technologies are determined.

Keywords: diagnosis, calculation methods, mechanical properties, technical diagnosis, assessment methods.

INTRODUCTION

The problem of the reliability of transport equipment becomes especially urgent in connection with its aging, which significantly exceeds the pace of technical conversion, development and implementation of new modern technologies and designs. Lack of scientifically based concept of technical diagnostics and available information taking into account general trends and directions. Unabated interest in the problem of the residual resource of equipment is manifested in the presence of publications and reviews on various industry topics [1, 2]. Such reviews are mostly aimed at analyzing domestic experience and describing the details of their use in the practice of controlling aging equipment, the service life of which has either long expired or is approaching critical marks. The given review is aimed at evaluating the residual resource of equipment in a pre-critical state far from the limit and covers the results and recent achievements of foreign experience in this direction.

Prediction of equipment reliability is carried out by measuring at certain time intervals the maximum amount of damage that occurs: wear, corrosion, deformation, followed by extrapolation of dependencies to the maximum allowable amount of damage. This method makes it possible to obtain fairly accurate values of reliability indicators, if the type of dependence of damage on time is known. However, despite the fact that there are quite a lot of dependencies for different types of load and materials in practice, the influence of extreme and peak loads on operating equipment during its operation, which cannot be taken into account, restrains and sometimes excludes the use of these methods.

ANALYSIS OF LITERATURE DATA AND STATEMENT OF THE PROBLEM

Depending on the required reliability of forecasts, a simplified approach based on deterministic assessments of available information and a more complex - probabilistic approach based on failure theory can be used. Informative parameters for predicting the residual resource can be both significant damage manifested in the form of corrosion, wear, deformation creep, and parameters of accompanying processes, such as vibration levels, the amount of leaks, temperature of friction nodes, consumption of products and their displacement relative to average values.

Estimates of the residual life and its extension for pumping units are given in [3]. Three-dimensional modeling and the finite element method are used. A geometric model of operation was built, which allows to evaluate the strength of the pump housing and main bolted connections. A conclusion was made about forecasting qualities and residual resource for 15 years.

In [4], a method for predicting the residual life of bearings of rotating mechanisms is proposed. The method of noise suppression of wavelet packets and combination of information in the form of complex

characteristics of the service life of bearings is used. Statistical methods of reliability and residual resource forecasting based on deep learning and static information were successfully used in [5]. It is established that the prediction of the remaining resource does not give specific information about the decrease in the productivity of the equipment. For this purpose, a Bayesian technology for integrating information about equipment performance degradation with discrete random damage in multidimensional time series signals is proposed.

On the basis of the load spectra and, of course, the elemental analysis of the axle shaft of the wheel loader in [6], a list of operating conditions and prediction of its fatigue life using Miner's criterion was compiled. Taking into account the impact of uncertainty on fatigue life, a sensitivity analysis and estimates of fatigue life were performed. It was found that the fatigue life increases by 3.7 times when the surface residual compressive stress reaches 100 MPa and decreases by 80% when the load amplitude increases by 10%. The presented approach is aimed at predicting fatigue life and improving its structural performance.

Further development of methods for estimating the residual resource based on the results of numerical methods of fracture mechanics is given in [7], where the problem of fracture of hydraulic turbine parts after a long service life is considered. The analysis of the condition of the elements of the power plants of the blades of the blade rotation mechanism of turbomachines and the method of estimating the residual resource of the parts during cracking are presented. The problem of assessing reliability and extending the service life of equipment is served. In [8], the occurrence of failures during the life cycle of the equipment and the modeling of their frequency were investigated. The shape of the failure intensity curve from the probabilistic property of the interaction of load and strength is analyzed. Based on the stress-strength interaction, a model of failure intensity from stochastic loads throughout the entire service life has been developed. From the point of view of uncertainty of load and uncertainty of strength, a mechanism of allocation of statistical risk of load and degradation of strength by failure frequency is proposed.

It is shown in [9] that the failure of machines and equipment is mainly caused by the intersection of critical states, which are determined by the limit values of stresses and strains at critical load points. The results of the development of methods for estimating the fields of deformations, stresses and residual life using experimental and numerical methods of fracture mechanics are presented.

Numerical methods of the mechanics of destruction of parts and nodes of transport technologies are used to assess the technical condition of heat engineering installations in real time, taking into account operational factors [10]. The value of the residual resource of the lining of the steel ladle after 30 melts was determined. Comparison of calculation results with practical use allows to adapt estimates of the remaining resource for steel ladles of a wide class of high-temperature units.

The experience of using numerical methods of fracture mechanics in estimating the residual resource of long-lasting equipment is described in the planning of microgrids taking into account uncertainty in [11]. The planning of microgrids integrating renewable energy sources is presented by the framework of mixed holistic programming. The objective function is to minimize the life cycle cost at the end of the planning period. Load uncertainty, electricity prices, wind speed and solar radiation are taken into account. For their integration, a combined model with the clustering technique is used. Numerical simulation for the test microgrid showed the effectiveness of the proposed model.

The results of work [12] should be included in measures to reduce risks in determining the remaining resource. The causes of uncertainty associated with the means of control and the quality of the source information are indicated. Using the example of the analysis of coercive damage of the inner surface of the pipelines, unjustified increases in the estimated remaining service life and necessary adjustments are shown.

The method of estimating the residual life of the cable during thermal aging is described in [13]. The method is based on a second-order kinetic model and an improved Arrhenius thermal aging equation. The model is used as a theoretical support for timely identification of risks when predicting service life and residual resource to eliminate potential accidents.

To estimate the residual resource based on the results of numerical methods of fracture mechanics, it is necessary:

- diagnose the operational state of the object at the current moment;
- determine the load and consequences of the equipment's environmental impact;
- obtain data on equipment elements based on the results of laboratory tests of samples;
- carry out calculations of the remaining resource;

PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of the study is an analytical review of information materials on determining the residual resource of transport structures and facilities. Achieving the specified goal requires solving tasks related to

the analysis of literary sources of technical diagnostics, basic principles, models and methods of determining the residual resource of equipment during its operation, determining the parameters that must be taken into account to assess the technical condition of products.

RESEARCH RESULTS

Available information on the problem of assessing the technical condition of equipment during its operation, which offer methods for assessing the residual resource of transport structures and facilities, can be conditionally divided into groups:

- methods based on the results of non-destructive testing and defectoscopy;
- methods that use regulatory documents and various standards;
- methods based on modeling and information support for decision-making.

Evaluation of the remaining resource based on the results of non-destructive testing and flaw detection

The development of methods of non-destructive control and technical diagnostics of the condition of equipment operating under pressure is presented in [14]. A correlation was established between the safety of the equipment and its residual resource, determined by the results of radiation methods, ultrasonic, electromagnetic and X-ray methods. The main fields of research in this direction and the key tasks of equipment operation safety are outlined.

[15] proposed an acoustic-emission method for predicting the degree of degradation of mechanical properties and residual life of metal structures under complex deformation stresses. It is shown that changes in operating conditions, peak loads, and thermal changes lead to irreversible structural changes in the material. A method of determining the residual resource is proposed, based on the full approximation of the results of acoustic measurements and the construction of limit curves that separate the area of serviceability from destruction. The attractiveness of using the proposed method lies in the elimination of the need to stop the measurement equipment.

The experience of using nondestructive testing to assess the residual resource of transport petrochemical equipment is presented in [16]. The probability of failure of equipment elements is estimated taking into account the available statistical data registered in the industry. It is shown that the probability of failure of a particular installation, operated for a long time, can change significantly due to the variety of initial properties of materials, differences in technological modes and maintenance procedures. Systematic monitoring of the microstructure is a way to reduce the uncertainty associated with the probability. Among the methods of non-destructive control of the residual resource and their practical applications, the description of the work [17] is interesting, in which an approach to determining the kinetics of crack growth in the maneuvering mode of operation of the equipment is formulated. The influence of aggressive hydrogenating media on the residual service life of structural elements was evaluated. Calculation models of subcritical growth of creeping cracks are proposed.

A similar work emphasizing the correctness of the chosen direction was published in [18]. The work is devoted to the assessment of the residual resource of the steam turbine rotor disk, taking into account the number of starts and stops of the equipment. The methodology for calculating low-cycle fatigue and registering the mode of operation of creeping cracks is presented. The obtained information can be a means of diagnosing the state of equipment elements of responsible purpose.

In [19] it is shown that on the basis of periodic maintenance, increasing the reliability of determining the residual resource of railway equipment is achieved due to dynamic adjustment of the time interval between diagnostic processes. The calculation of the average residual resource is carried out by maintaining the modulation in the railway track chain. In [20], a new technology for assessing the technical condition of electrical equipment is presented, based on the registration of electromagnetic radiation accompanying the operation of high-voltage equipment. At the same time, the residual resource and technical condition of the electric power system is determined by analyzing the electromagnetic field.

Non-destructive control of the current state and residual resource of metal structures based on the results of coercive force measurements is presented in [21]. Coercive force is recognized as one of the structurally sensitive characteristics of magnetic defectoscopy. The mechanical properties and the dynamics of their changes during operation are controlled. It was established that the coercive force is directly related to the operational stresses and the accumulation of stresses in the metal, which determine the residual resource of the structure.

An important related task regarding the factors that affect the estimation of the residual resource is the selection of specific signals indicating the localization of the problem, which leads to an abnormal condition

and wear of the equipment. The causes of deviations of such signals from normal values and equipment degradation are indicated in [22].

Methods of assessing the residual resource using regulatory documents and standards

When evaluating the residual resource of the equipment, the evaluation of the available information plays a significant role. In [23], the experience of using service life information to improve services is presented. It is shown that maintenance is a key branch of improvement and certification of diagnostic processes and determination of residual resource of industrial service.

[24] provides an analysis of data on the operation of thermomechanical equipment of a jet plant and their compliance with existing standards and the regulatory framework. The need to develop uniform rules for the selection of physical parameters characterizing the condition of the equipment, taking into account its degradation, was established. The structural formulation of the classification criteria of regulatory and legal support allows to improve the assessment of the remaining resource.

A systematic study of the causes, conditions, and mechanisms of corrosion and mechanical damage to long-term pipe products is described in [25]. Contradictions and uncertainties in the regulatory and technical documentation of the services for monitoring the condition of pipelines operating in aggressive environments and the need to create a base for comparative analysis of crack resistance parameters are indicated.

Management of the life cycle of the equipment from the example of electrical network fluctuations is described in [26]. It is noted that the costs of repairing the equipment in the future will exceed its complete replacement with new equipment with similar parameters. A software product has been developed for managing the life cycle of power grid equipment. Estimated functions were obtained taking into account discount factors and residual book value.

The development of the fatigue life analysis direction is presented in [27] for a high-temperature reactor under normal operating conditions. In [28], the results of the work on the optimal placement and determination of the sizes of renewable energy sources based on the cost of the life cycle, taking into account uncertainty, are given. A multi-scenario investment optimization model aimed at accounting for the probability density of states using a test system is proposed.

An assessment of the life cycle of a geothermal power plant in Iceland was performed in [29]. Geothermal power plants of the country provide about 25% of electricity and almost all heat supply. A life cycle assessment was carried out in accordance with international standards. The carbon layer produced at the NPP was used as an indicator of the condition of the material for the continuation of the service of the power plant.

In [30], the results of solving the problem of assigning a resource for the safe operation of storage devices after carrying out technical diagnostics according to the permissible technical parameters of oil refining production are given. A mathematical model and an algorithm for estimating the residual resource are proposed, diagnostic coefficients are calculated, and measures of informativeness are determined.

Evaluation of the remaining resource based on the results of modeling and information support

Modern information technologies for determining the residual resource are based on the use of telecommunications equipment, the capabilities of modern smartphones and tablets with Internet access.

Further development of diagnostics and determination of the residual resource was obtained with the help of information and analytical methods. The paper [31] considered the potential of using a mathematical approach for the purpose of estimating the levels of contamination by solid oil particles. Uncertainties and difficulties in predicting failures based on previous system failures, monitoring component degradation and strain rate are noted. The method of selection of diagnostic signals and their processing with the help of an odd output system and neural networks is presented. The concentration of iron and soot particles in used oil was chosen as the most significant model variables. Information on the condition of both lubricants and mechanical systems was obtained, with a conclusion on the degradation of mechanical equipment and an estimate of the remaining service life of the equipment.

Determination of the residual resource of the equipment and its forecasting taking into account information resources is described in [32]. The method of digital doubles integrates various factors in the formation of maintenance standards. Due to this, the volume of diagnostic information increases, without additional intrusion into the structure of the engine, which is part of the power plant. The performed simulation experiment and modeling of the digital double technology made it possible to determine a number of measures regarding planning and preventive works and equipment resource assessment.

In [33], to solve the problem of modeling the maintenance of complex electromechanical equipment, a model for predicting the residual resource in the improved Wiener process with random coefficients based on the data of the posterior distribution of the degradation processes is proposed. The model, which is

implemented using Bayes' theorem and target reliability indicators, allows you to estimate the residual resource of the equipment in operation with a higher accuracy of the convergence of the decision algorithm.

Accounting for uncertainty in estimating the residual resource of durable equipment is described in [34]. A fault-tolerant method for controlling the sliding mode of an automatic steering system in the field of intelligent unmanned engineering is considered. Uncertainty compensation measures are described to enhance the slip angle control effect. An adaptive method for controlling the sliding mode and determining the angle of inclination of the front wheels using the Kalman filter and uncertainty interference is proposed.

[35] presents the development of software for managing the performance of network information systems based on combat readiness at the level of information resources. Measures of intelligent fault dynamics, residual resource and maintenance decision support tools are proposed.

The method of determining the location and size of active distribution networks, based on stochastic programming, is presented in [36]. A programming model with restrictions on the stochastic parameter is proposed, which takes into account system uncertainty and necessary restrictions on the power, configuration and reliability of the operating equipment. In [37], the results of mathematical modeling of the residual resource of power plant units based on finite element methods and three-dimensional modeling are given. Equipment sizes and operating conditions are taken into account.

[38] describes the method of determining the residual resource of high-temperature aggregates of operating equipment using simulation modeling. [39] provides an analysis of the reliability and residual life of pressure vessels containing cracks. It is shown that the uncertainty of operational loads leads to the initiation of cracks. The methodology of early notification and the probability of refusals are described.

Detection and diagnosis of malfunctions in internal navigation networks intended for transport by computer diagnostic methods is presented in [40]. Inland navigation networks are used for transportation with economic and environmental benefits. In the conditions of climate change and man-made interventions associated with military actions and extreme depletion of water resources, the control and supervision of the level of shipping becomes crucial. A method of modeling and diagnostic classification of faults in shipping channels is proposed [41, 42].

DISCUSSION OF RESEARCH RESULTS

The analysis of the use of non-destructive testing and flaw detection methods to assess the residual resource of transport structures and structures showed the limitations of these methods for identifying defects at the early stages of their development when irreversible changes have occurred at the level of the structure, causing a defective state due to fatigue. The level of sensitivity of these methods does not allow detecting these conditions and identifying zones of future destruction. The joint use of methods of non-destructive testing and hardness testing with portable devices allows to increase the reliability of estimates of the residual resource.

Existing regulatory documents and standards for determining the residual resource, as shown by the practice of their global use, have limited application. This especially applies to the equipment that is in the process of operation. The reasons for the limitations are scale, corrosion of the outer metal layer, the need to account for the specifics of control and product forms, which cause uncertainty and the risk of accepting final conclusions.

The largest number of analyzed works on the assessment of the residual resource of transport structures and structures, as shown by the world experience of their development directions, belongs to mathematical modeling and probabilistic methods, as well as information support for conclusions about the continuation and assessment of the residual resource of equipment during its operation. All diagnostic centers of the world are currently working on the development of this direction. This group of residual resource assessment methods is based on the hypothesis of a diagnostic relationship between the energy of the interacting fields and the physical effects accompanying the metal destruction mechanisms. By combining subjective expert and objective elements of technical diagnostics of operational parameters with methods of processing available information using the method of mathematical modeling and probabilistic diagnostics, it is possible to obtain a reliable method of monitoring long-term operating equipment during its operation.

CONCLUSIONS

A distinctive feature of the existing reviews of information on the use of non-destructive testing and diagnostics methods is the structuring of the main areas of residual resource research, which is performed using a variety of methods. This structuring made it possible to separately identify the problems that are present in each group, the shortcomings, the difficulties of application and the possibilities of further use in order to evaluate the remaining resource. It is noted that the general feature of the methods used is the

uncertainty of the nature of the loads and the limitation of their use for the assessment of the critical state that precedes the destruction of the material. It is of interest not only to fix and diagnose destruction, but also to determine the initial stage of changes in the structure of materials, which allows determining the degree of serviceability of materials and the remaining resource. Prospective use of digital technologies for new diagnostic parameters aimed at increasing the efficiency of monitoring the technical operation of vehicles and facilities.

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O. Sharko, A. Yanenko Structuring the main directions of research to value the excess resource of transport structures and materials

An analysis of the current state of developments regarding the determination of the residual resource of transport structures and facilities, which are operated in the conditions of long-term practice, uncertainty and risk in the adoption of final conclusions, is given. It has been established that the strategy for the development of technical diagnostics requires the exclusion of dependence on the human factor and subjective observation of changes in the physical, mechanical and operational properties of controlled objects for intellectual operations of determining the remaining resource associated with the collection, processing and analysis of diagnostic information. Analysis of the use of methods of non-destructive testing and flaw detection to assess the residual resource of transport structures and ratios showed the limitations of these methods of determining defects in the early stages of their development, which precede the state of material degradation, optimization of processes and technologies for ensuring timely diagnosis and forecasting of the technical condition of structures. The current state of developments regarding the determination of the residual resource of transport structures and structures operated under conditions of complex dynamic loads is considered. The structuring of the main directions of research was carried out and the gradation of the main used methods of residual resource assessment was proposed based on the results of numerical methods of fracture mechanics, based on the results of non-destructive testing and flaw detection, using normative documents and standards of modeling and information support. The essence, methodology of dignity and shortcomings of the used methods are highlighted. Purpose, scope of application, prospects of their further use in transport technologies are determined.

Keywords: diagnosis, calculation methods, mechanical properties, technical diagnosis, assessment methods.

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