ABSTRACT

of T.Yu. Ratushnaya's thesis on the topic:
"Development of Innovative Technology for Recovery of Blades of Complex Geometry of Steam and Gas Turbines of CHP Using Highly Concentrated Sources of Plasma Energy",
submitted to the applying for PhD degree in specialty
6D071200 - Machine Engineering

Relevance of the work.

Global achievements in science-intensive industries are fundamental for technology transfer and development of the country's intellectual potential. The particular interest to world powers in the field of energy and heavy engineering are strategic facilities such as thermal power plants and hydroelectric power plants. Improving their energy efficiency, productivity and ensuring trouble-free operation today form the basis of industrial and technological development of Kazakhstan.

According to statistics, the energy capacity of the leading countries of the Customs Union and Europe provides more than 600 thermal power plants and hydroelectric power plants, and Kazakhstan accounts for about 53 units. Almaty region is provided with heat and electricity by a hydroelectric power station built on the Charyn river, and in the future, a hydroelectric power station on lake Balkhash will be put into operation. In the program of energy development of the country, together with foreign investors, it is planned to build a nuclear power plant in Aktau. The Fund of worn-out turbine units of existing thermal power plants and HPPs in the Republic is about 67%. Trends in price policy for energy resources, repair and maintenance are influenced by global monopolists. The problem of dependence on other countries can only be solved by developing an import substitution strategy through the development of recovery production by developing an energy-efficient plasma technology for the renovation of substandard (currently discarded) turbine blades of CHP plants.

The market for repair and diagnostic services is poor in offering quality evaluation of restored power plant parts due to strict requirements. Kazakhstan CHP and HPP are strategic objects, and to participate in the contest for the diagnosis and prediction of foreign firms is not always possible, and if you pass the requirements, then request a higher price, comparable quality.

A wide range of proposed recovery methods and technologies is usually based on thermodynamic effects with the introduction of fluxes and additives into the base metal welding puddle. The thermal operation is known to lead any inevitably to the formation of internal stresses of the metal, the value of which depends on the coefficient of thermal expansion.

These factors influence the modification of the physical and mechanical properties of the formed coating, and lead to degradation of the initial phase structure. The main ways to improve their quality are described by leading scientists Klubnikina V. S., Kostikova V. I., Shestin Yu.a., Lashchenko G. I. and

others who have made a significant contribution to the development of welding technologies. However, existing technologies are aimed at restoring the geometric parameters of parts and the mechanical properties of their surfaces. From previous studies, it was found that the dynamic load of the cyclic action is perceived by the base of the detail and its surface reacts to the influence of an aggressive environment. To date, despite the achievements in the field of recovery technologies, the direction of forming the optimal phase structure of turbine blades made of austenitic and martensitic steels has not been sufficiently studied. Therefore, there is a scientific problem in forming the knowledge base and establishing the dependencies of the influence of the concentration of internal stresses on the phase composition of the structure with different variations of technological recovery modes.

The occurred technical accidents at a number of HPPs and CHPs power plants showed an acute shortage of technologies for non-destructive quality control of restored power units and forecasting their service life. Existing diagnostic methods are aimed at detecting already formed defects and, as a rule, in the upper layers of the details surface. The measuring instruments do not always correctly identify such defects because of their types variety. Sometimes devices define the concentration of a small defects group as a single one, so complicates the operator's interpretation of them and increases the area of uncertainty.

A set of studies by leading Russian and foreign scientists has shown that the knowledge base of surface layer defects is not enough to effectively predict the resource of highly loaded aggregates. In this connection, a complex scientific and technical task is formed to study the process of their origin in the structure of the base material of the blade. The scientific problem is to establish and justify the dependence of the influence of the phase structure of the blade on the rate of formation of microcracks and determine their causes.

This issue is proposed to solve by modernizing the method for diagnosing hidden defects in the material structure based on the magnetoelastic effect and using eddy current fields. The main problem is that there is no method for identifying areas of residual stress localization and setting limits of mechanical stress due to a defect characterized by physical discontinuity of the blade metal. This problem is proposed to be solved by substantiating the physical meaning of the energy criterion for evaluating the equilibrium state of magnetic fields. Today, in the practice of mechanical engineering, a special indicator of the mathematical derivative of the magnetic field strength is used for flaw detection. The forcibly created magnetic field does not correlate, and does not reflect a direct dependence on the deformed state and the structural – phase composition of the metal. Also, one of the scientific problems is the lack of a reasonable degree of reproducibility of the results of the measurement experiment. This is the main drawback of the methodology for analyzing magnetograms using the proposed method.

The attractiveness of the dissertation research increases due to the introduction of energy-efficient technology for restoring non-coding turbine blades by "implanting" the working part of the blade through the use of highly concentrated laser-plasma energy sources. The effectiveness of nondestructive

testing and quality assessment of the physical and mechanical properties of the restored blades is achieved through the introduction of an integrated methodology for complex assessment of structural parameters.

The purpose of this dissertation is to develop an innovative technology for restoring substandard blades of complex design geometry of steam and gas turbines of a thermal power plant with a highly concentrated plasma energy source, which allows increasing the resource and performance of the turbine.

Research problems.

- to justify the criteria for assessing the severity of the consequences of accidental defects in turbine blades and establish dependencies that determine the limits of effective changes in the energy generated by the turbine on the specific costs of recovering from the consequences of failure with adaptation to operating conditions;
- to improve the mathematical model of dynamic processes in the steam-blade-turbine system»;
- to conduct simulation and study the restored turbine blades of the CHP for internal stress concentration and vibration reliability in Solid Works SOFTWARE;
- to develop and adapt a methodology for integrated assessment of the quality of recovery of turbine blades in CHP plants;
- to develop and adapt a methodology for integrated assessment of the quality of recovery of turbine blades in CHP plants;
- to justify the quality criteria and develop an algorithm for selecting a technology for restoring substandard blades of complex geometry of steam and gas turbines of a thermal power plant with a highly concentrated source of plasma energy;
- to determine the dependence of changes in structural and phase components on the parameters of the technological process of plasma recovery of substandard blades;
- to develop an innovative technological process for restoring substandard turbine blades of CHP by plasma spraying.

The object of research is the technological process of restoring substandard blades of complex geometry of steam turbine units with a highly concentrated source of plasma energy.

The subject of the research is based on changes of structural-phase components of the material parameters of the technological process of plasma recovery blades with complex geometry steam and gas turbines CHP.

Methods of research. It is assumed that analytical and mathematical methods, the method of multi-factor experiment, methods of simulation and circuit modeling, development and design of experimental samples, layout, testing of technical solutions on models and tests in production conditions at Kazakhstan thermal power plants were widely used.

Scientific novelty lies in the following propositions and results:

- to substantiated the criteria (S, O, D, RPN) for assessing the severity of the consequences of accidental defects of turbine blades are justified and the dependencies (RPNS=0.0004(RPN)2+0.0026(RPN)+2.9779; P=-23.42 lnW+140.45; S= 1.6666 lnW+0.4897) of the effective change in the generated energy from the specific cost of restoring the consequences of failure during operation;
- to improved the mathematical model of dynamic processes at unstable moments of inertia J'_η and J'_ξ for each stressed section of the turbine blade taking into account fatigue stresses changes in the design geometry due to erosion and corrosion processes in real operating conditions;
- to proposed a simulation model for studying the turbine blades of a thermal power plant for the concentration of internal stresses and vibration reliability, and the maximum permissible values of tensile and compressive stresses in the main zones of deformation of the blades are justified: 1-stretching 0.000060 - 0.000074 MPa; 2 - compression 0.000041-0.0000697 MPa. In cross sections of the blade without load – stretching 0.000004-0.000014 MPa;
- to established dependences describing the influence of technological recovery modes on changes in the physical and mechanical properties of the part base and coating, as well as modification of the phase structure of turbine blades;
- to substantiated the optimal design and technological parameters of plasma restoration of substandard blades during implant insertion.

Work's practical relevance.

The developed algorithm and technology for restoring substandard turbine blades by implantation allows expanding the range of restored parts and ensuring the restoration of the structure of heavy loaded details, which will significantly increase the efficiency of the CHP turbines, with the cost of the received electricity is reducing. A method of integrated quality assessment has been developed and a database has been created that allows determining stress formation zones in the phase structure of the turbine blade and establishing a cause-and-effect relationship between the origin and development of hidden defects in the predicted time period f(t).

The method and algorithm for selecting the technology for restoring substandard turbine blades of the CHP are developed, and the quality indicators of the technological process are justified by modifying the structural-phase transformations in the material of the martensitic and austenitic classes. The developed technology for the structure recovering and design geometry of the substandard turbine blades for CHP through the introduction of the implant. At the same time upgraded design of the plasmatron by introducing triple-inputs vortex mixer for dosing multicomponent powder mixture and managing physical and mechanical properties of the coating.

The upgraded design of the plasmatron allows to use various compositions of complex powder mixtures during plasma spraying. The introduction of the developed mixer for plasmatron makes it possible to control the operating parameters with a flexible approach in the formation of physical and mechanical

properties, with quality of the resulting coating and controlling the coefficient of thermal expansion in the restored parts is improving.

The proposed integrated method for assessing the quality of restored turbine blades of CHP allows timely detection of defects at the structural-phase level of the blade material at an early stage of their origin and predicting their residual life, taking into account the current dynamic and vibration loads.

Connection with government programs.

The research presented in the dissertation was conducted within the framework of grant financing of the MES RK (state registration 0115PK01226) on the topic: "Development and Implementation of Energy Efficient Technologies for Restoration of Complex Geometry Blades for Steam and Gas Turbines CHP Highly Concentrated Sources of Plasma Energy System with Adaptive Process Control" where the author was a performer.

Scientific propositions of the thesis submitted for defense (scientific results):

- The justified criteria for assessing the severity of the consequences ($d_p \leq$ 0.5 mm, σ_{-1} = $40 \cdot 10^6$ N/m^2, a_σ=1±0.05, P = 95 MW, W = 23 million tg) of accidental defects in turbine blades and dependencies that determine the limits of effective changes in the energy generated by the turbine depending on the specific cost of recovering from the failure.
- The improved mathematical model of dynamic processes in the steam-blade-turbine system, taking into account changes in the design geometry due to erosion, corrosion and fatigue processes in real operating conditions.
- The method of integrated assessment of the quality of restoration of the structure of turbine blades of thermal power plants and prediction of failures of loaded parts at the pre-collapse stage.
- The dependencies describing the effect of technological recovery modes on changes in the physical and mechanical properties of the part base and coating.
- The optimal design and technological parameters of plasma restoration of substandard blades during implant insertion.
- The innovative technological process for restoring the structure and design geometry of substandard turbine blades of CHP plants.

Practical approval. The main results of the dissertation research were reported and discussed at: the international scientific and practical conference "Science 2017: Results, Achievements, Prospects" (Stavropol, Russia, 20.12.2017); the International scientific and practical conference "Kozybaev Readings-2017: Kazakhstan and Modern Challenges of Time" (2017 Petropavlovsk, Kazakhstan,); the XII scientific and technical international conference "Modern Methods and Technologies for Creating and Processing Materials" (2017 Minsk, Belarus, 2018), 5th international conference on green design and production 2019 Icondm 2019 (Bandung, Indonesia, April 29-30, 2019).

Publications. The main results of the research have been reflected in 16 scientific works, including 4 articles in journals recommended by Committee for

control in education sphere and science MES RK, 2 articles in international scientific journal with impact factor (indexed in the database Scopus, the percentile - 25); 5 papers included in the proceedings of international scientific conferences, including 3 abroad (one conference in the database Web of Science), 5 in national journals.

Specific personal participation of the author.

The main results of theoretical and experimental research were obtained by the author independently. In printed works that are co-authored, the applicant has a leading role in summarizing and analyzing the results obtained.

Thesis structure and scope.

This thesis has a classical structure: introduction, main part (five chapters), conclusion, the list of references and the applications. The work is presented on 141 pages of computer text, includes 51 figures, 30 tables and 165 names of bibliographic sources.

Research results.

After analyzing the standard methods for evaluating the reliability of turbine blades, it was found that their essence is reduced to theoretical calculations of the acting centrifugal forces, moments of inertia and the stress state of the root section and the blade pen in static mode. This approach does not take into account the dynamic moments that occur in the actual operating conditions of a CHP turbine, which reduces their resource life. To improve the accuracy of predicting turbine failures, an integrated method and algorithm has been developed to determine the vibration reliability of the blades, taking into account the physical and mechanical properties of their phase structure. This knowledge base increases the reliability of the strength calculation and interpretation of the obtained measurement results.

The proposed concept allowed us to take into account the actual changes in the mechanical characteristics of the austenitic class material used for the manufacture of working blades that have passed a certain period of operation. In turn, fatigue processes in the phase structure of the blade material reflect the negative impact of dynamic loads acting in real operating conditions. The studied processes of degradation of the blade surface allowed us to expand the range of restored blades that were previously rejected.

Justification of the negative influence of tensile and compressive stresses in the material structure allowed us to develop an innovative technology for restoring both geometric parameters and phase-structural and physical-mechanical properties of the turbine blades of the CHP.

Papers published on the topic of the dissertation.

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