ABSTRACT

of the Thesis «Mathematical and Computer Modeling of Non-Linear Thermomechanical Processes in the Rods of High-Temperature Alloys» represented by Askarova Assel in candidacy for a degree of doctor (PhD) in specialty «6D070500 – Mathematical and computer modeling»

Relevance of the research topic. In the technological lines of copper smelting, aluminum smelting and metallurgical plants, load-bearing rod elements of the main structures operate in a complex thermal field. The load-bearing elements of nuclear reactors, thermal power plants, large gas-fired power plants, internal combustion engines, jet engines and oil heating plants and refineries are the core elements. These rods are made of high temperature and refractory alloys. They can withstand high temperatures and stresses. The tensile strength of the materials of such rods is an order of magnitude higher than the tensile strength of conventional steels. For the reliable operation of the above equipment, it is necessary to ensure the thermal strength of the rod bearing elements. To study the thermo-mechanical state of such rods, it is necessary to develop special models, methods, and application packages.

This work is devoted to the development of a computer-mathematical model of the thermo-mechanical state of the rod based on the law of conservation of energy, taking into account the simultaneous effects of dissimilar local types of heat sources. The geometric characteristics of a bar of limited length and constant cross-section are also taken into account. The physical and mechanical properties of the rod material are taken into account in the functionals of the total thermal energy, potential energy, elastic deformations, taking into account the temperature field.

Bearing elements of internal combustion engines, jet engines, hydrogen engines, gas generating power plants and thermal, nuclear power plants, as well as processing industries operate in a complex thermal and force field. The reliability of these equipment will strictly depend on the thermal resistance characteristics of these load-bearing elements. Therefore, the development of a computer-mathematical model of the thermophysical state of load-bearing elements in the form of rods of limited length, which works under the simultaneous influence of local temperatures, heat flows, thermal insulation and heat exchanges, is an urgent problem of computer-mathematical modeling of complex thermophysical processes in load-bearing structural elements. These models, on the other hand, must be based on fundamental laws of conservation of energy.

The purpose of the thesis. The purpose of this work is to develop, on the basis of fundamental laws of energy conservation, computational algorithms, methods, as well as a package of applied programs that allow to study nonlinear thermophysical processes that occur in load-bearing structural elements in the form of rods of limited length with the simultaneous presence of local temperatures, heat fluxes, thermal insulation and heat exchanges.

Research Objectives:

- development of methods and algorithms for the formation of the functional of the total thermal energy for the rod, taking into account the simultaneous presence of local temperatures, heat fluxes, convective heat exchanges and thermal insulation;

- development of methods for minimizing the total thermal energy and forming a system of linear equations for assessing the temperature at the nodal points of the rod;

- development of methods for assessing the law of temperature distribution and displacement along the length of the rod;

- development of methods for determining the thermo-mechanical characteristics of the rod;

- creation of software for determining the thermo-mechanical characteristics of the rod.

Object of study. Bearing elements for internal combustion engines, jet engines, hydrogen engines, gas and thermal power plants and nuclear power plants, as well as the processing industries. In the form of rods of limited length, which are simultaneously affected by local temperatures, heat fluxes, thermal insulation and convective heat exchanges.

Subject of study.

Thermomechanics, thermoelasticity, thermal physics, variational problem.

Research Methods. Mathematical modeling, variation method, optimization methods, methods for solving systems of equations, basic laws of conservation of energy, etc. are applied. The proposed methods and algorithms are implemented as a package of applications developed in the modern Python programming language.

The scientific novelty of the study.

- quadratic spline functions are constructed in the local coordinate system, which ensure the continuity of the desired function in the transition from one discrete element to the neighboring one;

- a mathematical model of the total thermal energy functional has been built to determine the law of temperature distribution along the length of the rod with the simultaneous action of dissimilar heat sources, taking into account convective heat exchanges and thermal insulation;

- a computer-mathematical model has been built to determine the thermo-mechanical characteristics of the rod with the simultaneous effect of different types of heat sources;

- a computer-mathematical model was built to determine the displacement field along the rod with the simultaneous effect of different types of local heat sources.

Theoretical and practical significance of the results. The developed computational algorithms, methods, as well as complexes of applied programs for the study of nonlinear thermophysical states of the bearing element of structures located with the simultaneous presence of local temperatures, heat fluxes, thermal insulation, heat exchanges is an enrichment of the theoretical foundations of mathematical modeling of nonlinear processes in rod elements made of heat-resistant alloys.

The practical significance of these developed products is the developed methods for solving applied and engineering problems for the study of thermal strength of load-bearing elements of strategic structures.

The main provisions to be defended. On the basis of the law of conservation of fundamental energy, a computer-mathematical model has been created to study the thermomechanical state of a rod of mixed length under the influence of various local heat sources. Algorithms and models are obtained for determining the regularities of the distribution of temperature, temperature, thermoelasticity, stresses and displacements from various local heat sources along the length of the rod of the maximum length of the mixture. An algorithm has been developed for determining the magnitude of the elongation of a rod from a mixture of fixed lengths with one end fixed under the action of various local heat sources. Algorithm for determining the magnitude of the axial compressive force caused by various local heat sources on a rod of fixed length, made of a mixture, fixed at both ends. All developed algorithms and models are implemented in the Python programming language.

Personal contribution of the researcher. A computer-mathematical model has been developed for the study of thermomechanical states arising from the action of various heat sources on a rod of constant length with a constant cross-sectional area. The energy method was used here. He also showed how to create a system of basic equations using the energy method. The values of the obtained solutions were discussed in graphical and tabular form, showing how to take into account the natural limiting conditions and obtain a complete solution to the problem in a particular situation. Basically, the work was carried out jointly with a scientific advisor and a foreign scientific advisor.

Volume and structure of the dissertation. The dissertation consists of an introduction, three chapters, a conclusion, a list of references. The total volume of the research is 81 pages, including 12 figures, 7 tables.

The first section provides an overview of the work of previous scholars on the research topic and presents the necessary concepts for the research work that is the basis of the dissertation. The functionality of energy is being studied.

In the second section, second-order spline functions were created for the length of each finite element required for the study, and its properties were studied. Its properties ensure the continuity of the desired function from one element to another. Mathematical research has created a computer model of the results obtained as a result of the proof.

The third section describes the work on creating a software package for the tasks considered in the dissertation.

In conclusion, the main conclusions and results of the work are formulated.

Testing the results of the dissertation. The main results of the study were presented and discussed at the following conferences and seminars:

- «Проблемы и перспективы развития науки в начале третьего тысячелетия в странах Европы и Азии» XXXVII Международной научно-практической интернет-конференции (Переяслав-Хмельницкий, Украина, 29-30 апреля, 2017).

- «Проблемы и перспективы развития современной науки в странах Европы и Азии» III Международной научно-практической интернет-конференции (Переяслав-Хмельницкий, Украина, 30 апреля, 2018).

- Посвященная 80-летнему юбилею профессора Бияшева Р.Г «Информатика и прикладная математика» III Международной начной конференции (Алматы, 2018).

On the topic of the dissertation, 8 articles were published and 2 monographs:

1. Investigation of the Steady Nonlinear-Thermomechanical State of a Rod of Limited Length and Constant Cross-Section in the Presence of Symmetrical Local Thermal Insulation, Lateral Heat Exchanges and End Heat Fluxes // Journal of Advanced Physics. Vol.7, pp.1-5,2018

2. A computational algorithm and the method of determining the temperature field along the length of the rod of variable cross section// Open Engineering, Vol. 8, pp.170-175, 2018 (CiteScore – 1,2; 46 percentile)

3. Жумаханова А.С., Кудайкулов А., Ташев А.А., Калиева Г.С., Асқарова А. Энергетический метод в исследовании установившегося теплофизического состояния стержня переменного сечения при наличии теплового потока, теплообмена и теплоизоляции// Известия Национальный Академии Наук Республики Казахстан. – Алматы, 2017. – №3 (313). – С.38-48.

4. Кудайкулов А., Аршидинова М.Т., Асқарова А. Основные соотношения нелинейгых квадратичных элементов и термоупругих энергетических принципов и моделирование термомеханических процессов в стержнях ограниченной длины при наличии переменного теплового потока// Монография. – Алматы, 2017. – ISBN 978-601-208-995-4 – С.147.

5. Кудайкулов А., Аршидинова М.Т., Асқарова А. Численное моделирование термонапряженного состояния защемленного двумя концами стержня при наличии источников тепла// Монография. – Алматы, 2017. – ISBN 978-607-280-996-1 – С.87.

6. Жумаханова А.С., Ногайбаева М.О., Аршидинова М.Т., Бегалиева К.Б., Кудайкулов А., Ташев А.А., Асқарова А. Аналитическое решение задачи о установившегося термомеханического состояния стержня ограниченной длины при одновременном наличии концевых температур и боковых теплообмена// Известия Национальный Академии Наук Республики Казахстан. – Алматы, 2018. – №1 (317). – С.25-33.

7. Аршидинова М.Т., Бегалиева К.Б., Кудайкулов А., Асқарова А. Исследование и разработка метода учета наличия локальных поверхностных теплообменов в стержнях переменного сечения// Вестник КазНИТУ. – Алматы, 2019. – №3 (133). – С.276-283