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SELECTION AND JUSTIFICATION OF PARAMETERS OF THE ADAPTIVE ACTUATING MECHANISM OF THE ROBOT GRIPPER AND THE DEVELOPMENT OF MATHEMATICAL MODEL AND SOFTWARE IMPLEMENTATION OF ITS MOVEMENT SIMULATING THE MOVEMENT OF THE HAND OF MAN

ABSTRACT

of the dissertation in partial fulfillment of the requirements
for the degree of Doctor of Philosophy (PhD) in specialty
6D060300 – "Mechanics"

Relevance of the research. As you know, to solve the urgent modern problem of improving the climate on Earth, to solve which in December 2015, a UN conference was held in Paris, at which all countries of the world were recommended to adopt their national programs to reduce greenhouse gas emissions into the Earth's atmosphere to improve climate. In connection with these circumstances, every citizen of the Republic of Kazakhstan should strive to offer innovative technical, technogenic solutions aimed at improving technological processes for the production of industrial and other products in the country, the most important of which is electricity generation. One of the relevant and promising directions for improving the technology of electricity production is a part of it, obtained from the operation of a nuclear power plant (NPP) operating on nuclear fuel created from uranium-containing minerals, for example, uranium and others, whose geological reserves in Kazakhstan are significant in the world. The Republic of Kazakhstan takes the 1-2 place in reserves of uranium-containing minerals among all countries of the world.

At present, nuclear power plants are operated in 30 countries of the world, where electricity is generated at 401 reactors. At the same time, the amount of electricity generated at nuclear power plants in the countries of the world is 5.6% of the total amount generated in the world. During operation of a nuclear power plant, greenhouse gases are not emitted into the Earth's atmosphere, which is its undoubted advantage. But, after the end of the operation of the NPP, solid highly radioactive waste is generated, which is extremely dangerous for the animal and plant world on Earth. Over the decades of operation of nuclear power plants in different countries of the world, 100 - percent safe methods for the disposal of solid highly radioactive waste have not been created.

Not a single nuclear power plant has yet been built in Kazakhstan. Nuclear energy in Kazakhstan has significant prospects for development. Kazakhstan has large raw material reserves of uranium ores. The republic has developed the infrastructure for basic and applied research, created high-tech centers, such as the National Nuclear Center in Kurchatov, institutes of nuclear physics and radiation safety, which have a modern laboratory and industrial base, including Tokomak

facilities. A technological chain has been worked out at the Ulba Metallurgical Plant, which includes the production of nuclear fuel (uranium pellets), and in the future, assembly fuels for nuclear reactors of nuclear power plants.

In 2002, the Government of the Republic of Kazakhstan adopted the concept of development of the uranium industry and nuclear energy for 2002-2030, which is aimed at significantly transforming Kazakhstan's energy sector into a dynamically developing industry that can become a reliable basis for economic development and improving the well-being of the people. Today, Kazakhstan ranks first in the world in uranium mining and second in terms of reserves, has 19% of the world's proven reserves of uranium. The uranium mining and processing industries of the Republic provide an opportunity to carry out research in the field of nuclear physics and nuclear energy.

In Kazakhstan, on the shores of the Caspian Sea, from 1972 until its shutdown in 1999, a nuclear power plant with a FN-350 reactor successfully operated, its thermal capacity was 650 MW, and its electrical capacity was up to 120 MW. It was also used for desalination of sea water. With operational experience of 25 years 10 months, Kazakhstan now plans to build one or two medium-sized nuclear power plants.

The use of nuclear energy is accompanied by risks of radiation internal and external human exposure and environmental degradation. This type of power generation leads to the generation and accumulation of radioactive waste, because at the present stage of civilization, mankind does not possess the tools and methods of converting a radioactive substance into non-radioactive, therefore, when operating a nuclear power plant, it is necessary to create conditions to minimize the amount of generated radioactive waste, to convert it to inert shape and reliably isolate them from the biosphere. For both developed countries and countries with developing nuclear infrastructure, the management of radioactive waste is one of the priority areas of scientific research and technological development.

The aim of the dissertation is development and creation of an adaptive gripper of a remotely controlled mobile robot for reloading a fuel element, etc. from an intermediate container with solid highly radioactive waste into the cavity (s) of the main container.

The object of the research is industrial robots.

The subject of the research is adaptive grips for overloading fuel elements of nuclear power plants.

According to the aim, **the research objectives** are as follows**:**

– research of ensuring reliable capture of a fuel element by gripping phalanges;

– selection and justification of geometric, structural-kinematic and dynamic parameters of an adaptable gripper of a remotely controlled mobile robot for reloading fuel elements from an intermediate container with solid highly radioactive waste into the cavity of the main container made of a block of hard rock;

– development of a mathematical method and a computer model for the selection and justification of geometric, structural-kinematic and dynamic parameters of adaptive gripping;

– selection and justification of geometric, structural-kinematic and dynamic parameters of the adaptive gripping actuator taking into account the conditions of the stochastic environment of its functioning;

– selection and justification of the architecture of a remotely controlled mobile robot with an adaptive gripper for overloading a fuel element;

– development and creation of a physical prototype of a remotely controlled mobile robot with an adaptive gripper for reloading a fuel element from an intermediate container with solid highly radioactive elements into the cavity (s) of the main container made of a block of hard rock and its software implementation.

Methods of the research: methods of theoretical mechanics and theory of mechanisms and machines, theory of elasticity and dynamics of elements and structures; mathematical methods of analysis and modeling of physical and technological processes, probability theory and mathematical statistics, game theory, numerical methods and theory of information transfer and digital technologies.

The scientific novelty of the work is as follows:

– scientifically based criteria have been developed for choosing the structural and kinematic parameters of the adaptive gripper of a remotely controlled mobile robot for reloading a fuel element from an intermediate container with solid radioactive waste into the cavity of the main container rock;

– a mathematical method and a computer model for the selection and justification of geometric, structural-kinematic and dynamic parameters of an adaptive grip are developed taking into account the conditions of the stochastic environment of its functioning;

– Designs of three-phalangeal and two-phalangeal adaptive grips of a remotely controlled mobile robot were developed and created to reload a fuel element from an intermediate container with solid highly radioactive waste into the cavity of the main container made of a block of hard rock;

– A physical model of a remotely controlled mobile robot with an adaptive gripper, successfully tested in laboratory conditions for handling various forms of cargo, was developed and created;

– software was developed for a remote control system for a mobile robot for transferring a fuel element from an intermediate container with solid highly radioactive waste into the cavity of the main container.

Theoretical and practical significance of the research. The results obtained in the work and the very concept of increasing the accuracy of geometric, structural-kinematic and dynamic parameters of adaptive gripping, taking into account the stochastic environment of its functioning, are new, of scientific and practical interest and can be directly applied in engineering not only in the Republic of Kazakhstan, but also in others countries of the world. On the topic of the dissertation published more than 17 scientific papers published in domestic and foreign scientific journals.

Scientific provisions for the defense:

– scientifically based method for choosing the structural and kinematic parameters of the adaptive grip of a remotely controlled mobile robot, taking into account the conditions of the stochastic environment of its functioning;

– mathematical method and computer model for the selection and justification of geometric, structural-kinematic and dynamic parameters of adaptive gripping;

– innovative designs of a three-phalangeal and two-phalangeal adaptive grips of a remotely controlled mobile robot for reloading a fuel element from an intermediate container with solid radioactive waste into the cavity of the main container made of a block of hard rock;

– physical model of a remotely controlled mobile robot with an adaptive gripper, successfully tested in laboratory conditions for overloading various forms of cargo.

The reliability and validity of scientific statements, conclusions and results of the dissertation is confirmed confirmed by the use of well-known provisions, principles and methods of mechanics, mathematics and IT and the coordination of theoretical results obtained with experimental studies.

Approbation of the work. The main provisions and results of the dissertation were reported and discussed at the following scientific events:

– World Congress of Engineers and Scientists. "Energy of the future: innovative scenarios and methods for their implementation." WSEC 2017. (Astana, June 19-20. Volume 2;

– 2nd International Conference "2nd International Conference of IFToMM Italy, IFIT 2018" (Cassino, Italy, November 29-30, 2018);

– 4th Symposium Mechanics and Robotics International Scientific Conference “4th IFToMM Symposium on Mechanism Design for Robotics” (Udine, Italy, September 11-13, 2018);

– International scientific-practical conference “Actual problems of computer science, mechanics and robotics. Digital technologies in mechanical engineering ”, Almaty, 2018;

– International scientific conference "Slovak international Conference", Slovakia, Bratislava 2018;

– International Scientific and Practical Conference of the Academy of Sciences of the Republic of Kazakhstan, Almaty, Kazakhstan, 2017;

– International conference "Green Bridge - a partnership platform for best practices of innovation", EXPO-2017, Astana, Kazakhstan, 2017;

– International scientific seminar "Actual problems of engineering mechanics" dedicated to the 95th anniversary of the academician of the Academy of Sciences of the Kazakh SSR, doctor of technical sciences, professor, honored worker of science of Kazakhstan Zh.S. Yerzhanova (Almaty, July 18-19, 2017);

– scientific seminars of the Institute of Mechanics and Engineering named after academician U.A. Dzholdasbekova and the Department of Mechanics of the Mechanics and Mathematics Faculty of KazNU al-Farabi (Almaty, 2015-2018).

Publications. On the topic of the dissertation, the author published 17 works, among which 3 publications in scientific journals recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for publishing the main results of scientific activity; 4 publications in scientific journals and proceedings of international conferences indexed by the Scopus database; 10 publications in the proceedings of foreign and domestic scientific conferences, 1 patent “Bulldozer device”, where when it was developed by the author for evaluating the parameters of its actuator taking into account the conditions of the stochastic environment of its functioning were used; Priority certificate was received on the invention of the "Mechanical Arm".

Personal contribution of the author. The main results of research conducted as part of the dissertation, obtained by the author independently.

In the article [2], the applicant developed a mathematical method for calculating the parameters of the main structural elements of the three-phalangeal adaptive matchmaker of an industrial robot manipulator, taking into account the stochastic conditions of its functioning, using the example of calculating the parameters of its holding tooth. And co-author Kaimov Abylay owns the results of the justification of the location of the holding teeth of the phalanx of the gripper arms of an industrial robot during their interaction with the shell of the outer section of the fuel element of a nuclear reactor of a nuclear power plant.

In articles [32, 33, 34, 35, 39, 40, 42], the applicant cites the results of the implementation of his method of increasing the accuracy of estimating the parameters of the actuator of the working body of the machine, which consists in rationalizing its main constructive on the example of the design of the actuator mechanism of the dozer blade, taking into account the stochastic conditions of its functioning. And co-author Kaimov Abylay owns the results of the justification of the structural-kinematic scheme of the actuator mechanism of the blade of a bulldozer with a removable cutting knife for destruction of a section of the soil mass.

In articles [23, 24, 25, 27, 28, 29, 30, 31, 43, 44, 59, 60, 61, 62] the applicant presents mathematical methods for selecting and substantiating geometric, structural-kinematic and dynamic parameters of adaptive gripping and their 3D computer models. Various variants of structural-kinematic schemes of adaptive gripping of the robot for overloading fuel elements were selected and justified. 3D computer models have been developed for reloading fuel elements from a transport container to the main one. The dependences between the efforts of the capture of the fuel element from the geometric parameters of adaptive gripping are established. The calculations on the strength and stiffness of the elements of its design. The original mathematical model for calculating the geometric, structural-kinematic and dynamic parameters of the actuator of the adaptive gripper of the robot for overloading fuel elements, taking into account the stochastic environment of the technological process of reloading them from the transport container to the main one, is also presented there. The idea of a methodology is based on a systematic approach in which the aggregate of the adaptive gripping actuator with a fuel element is considered as a single system of interconnected and interacting

elements. And co-author Kaimov Abylay participated in conducting experimental studies and he owned the results of mathematical processing of empirical results of experimental studies and built a regression function for correlating the random process of changing the gripping force of an overloaded object from the geometric parameters of the three-phalanx adaptive gripper of the PR manipulator during the implementation of stochastic processes of its interaction with the fuel element reloaded from intermediate container to main container.

In [25], the applicant developed the design of a two-phalangeal adaptive gripper, for which a positive decision was obtained on the grant of a patent for an invention. Co-author Kaimov Abylay developed structural-kinematic scheme.

The article [36] presents the results of the implementation of the mathematical method for constructing the perspective appearance of a technical object developed by the applicant, using the example of constructing the perspective appearance of the mathematical model of a bulldozer. This scientific idea was realized by co-author Kaimov Abylay and was built the mathematical model of a bulldozer. Based on the results obtained, the applicant constructed a promising image of a remotely controlled mobile robot with an adaptive gripper.

In [39], the applicant developed a design for the dozer blade for the destruction of soils, taking into account the stochastic conditions of its functioning. An innovative patent of the Republic of Kazakhstan was received for this design. By co-author Kaimov Abylay was proposed a structural-kinematic diagram of the actuator mechanism of the dozer blade.

Structure and scope of the dissertation. The dissertation includes the title page, contents, list of symbols and abbreviations, introduction, four sections, conclusion and list of references, consisting of 62 titles. The total volume of the dissertation is 107 pages, including 55 illustrations and 15 tables.

The main content of the dissertation. The introduction reflects the relevance of the thesis topic, purpose, object, objectives of the study, methods used, the justification of scientific novelty of the work, its theoretical and practical importance, scientific provisions submitted for protection, the number of available publications, information about testing and degree of its development.

The first section discusses the problem formulation and the analysis of the works of their predecessors to ensure reliable retention in the grip of the fuel element when given two conflicting requirements: the limited elastic movement (or distortion) of thin-walled object and ensure the supply of the bearing capacity of the gripper after transfer. This problem is considered for a circular ring. The problem of capturing a circular ring by two or three working elements is considered. Then the gripping of the ring at four, six, eight points of contact are considered.

The second section presents mathematical methods for the selection and justification of geometric, structural, kinematic and dynamic parameters of the adaptive Tong and their computer 3D models. Selected and justified the various options structurally-kinematic schemes of adaptive robot gripper for handling of fuel elements. Computer 3D models are developed at an overload of fuel elements from a transport container in the main. The dependences between the capture

forces of the fuel element on the geometric parameters of the adaptive gripper are established. Calculations for strength and stiffness of its structural elements are carried out.

In the third section of the dissertation, a physical prototype of a promising appearance of a remotely controlled mobile robot with an adaptive gripper for overloading a fuel element from a transport container to the main one is developed and created. It is built on the basis of the idea that the transition from the existing appearance (initial state) of a set of machines to its new appearance of a promising state of machines is carried out in order to increase the efficiency (effectiveness) of their operation. In general terms, the methodological approach to the justification and selection of a rational version of the appearance of the machine is based on the basic principles of system analysis and synthesis of complex structures according to the criterion of "cost-effectiveness". The solution to the problem of economic assessment of the options for the appearance of a promising reloading robot should be carried out by the two-level optimization method according to the multi-criteria analysis of alternatives.

In the same place, for the constructed physical model of the perspective appearance of a remotely controlled mobile robot with an adaptive grip, experimental studies were carried out to implement a mathematical model developed by the applicant for calculating the geometric, structural-kinematic and dynamic parameters of the actuator of the adaptive grip of the robot using the example of fruit overload, medium spherical shape, having a heat-generating elements taking into account the stochastic environment of the technological process their overload Visiting from the transport container to the main oneIn this case, the best approximation to the true coordinate was obtained. x_{k+1} (gripping forces) from the geometric parameter (sponge height) of the adaptive grip, the so-called “golden” middle between the reading z_{k+1} source from the sensor and $x_k^{opt} + u_k$, being a prediction of what is expected from him.

The fourth section of the dissertation presents the materials of the software user manual “simulation of the functioning of a remotely controlled mobile robot with an adaptive gripper for reloading cylindrical objects with different section diameters. The used components of this robot are described, as well as the principle of its operation and the relationship of component components, the interaction schemes of the components are presented, as well as user instructions and a listing of this software.

The results obtained in this work and the very concept of constructing a promising appearance of a controlled mobile robot with an adaptive grip and the development of mathematical methods for improving the accuracy of estimating the geometric, structural-kinematic and dynamic parameters of an adaptive gripper taking into account the stochastic environment of its functioning are new, are of scientific and practical interest, and may be directly applied in engineering not only in the Republic of Kazakhstan, but also in other countries of the world.