DEVELOPMENT OF A SELF-REGULATING ADAPTIVE DRIVE FOR SPACECRAFT DOCKING MECHANISM

Abstract

dissertations for the degree
of Doctor of Philosophy (PhD) in the specialty
6D060300 - "Mechanics"

Relevance of the research topic. The exploration of outer space has led to the emergence and development of new branches of science and technology. The creation of unique spacecraft systems required the development of design methods and the solution of a few scientific and technical problems related to the design, calculations and simulation of the operating conditions of these systems in terrestrial conditions. One of these systems is a docking mechanism designed to directly connect spacecraft in orbit.

The docking mechanism is a mechanical system of interconnection between the elements of the spacecraft and the orbital station, adapting to the continuously and spontaneously changing conditions of their interaction. The docking mechanism contains docking elements and a drive with a control system. The existing drive is a complex mechanical system containing two motors, transmission mechanisms, brake damping elements and sensors.

The interaction of these elements is performed by a complex control system.

The docking mechanism can be significantly simplified if it uses a transfer mechanism capable of adapting to a variable load independently without a control system. Such a drive can be called a self-regulating adaptive drive. The self-regulating adaptive drive simplifies the design and increases the reliability of the docking mechanism. The main design element of the adaptive drive is a self–regulating gear transmission mechanism with a variable gear ratio - an adaptive gear variator with a friction clutch.

The purpose of the work. The purpose of the thesis is to create a self-regulating (without a control system), simple and reliable adaptive drive of the docking apparatus based on the use of an adaptive gear variator.

To achieve this goal, the theory of mechanisms with two degrees of freedom and one input is used. The initial kinematic chain with two degrees of freedom is transformed into a structural chain containing a force-velocity constraint, which introduces a force constraint, ensures definability of movement and creates a new property – the property of force adaptation.

Definability of motion is an unambiguous correspondence of input and output power and kinematic parameters when the number of inputs is equal to the number of degrees of freedom.

When performing the work, the **following research tasks** are solved:

1) Investigation of the patterns of interrelation of kinematic and force parameters of adaptive gear mechanism;

2) Theoretical description of the action of the adaptive drive;

3) Analysis of adaptive drive driving modes;

4) Development of methods for calculating adaptive drive;

5) The development of design documentation includes: the development of an assembly drawing of an adaptive variator and a test bench, the development of drawings of the main parts.

6) Conducting tests of the prototype and analyzing the results obtained.

The object of the study. The object of the study is a self-regulating adaptive drive of the spacecraft's docking mechanism.

Research methods. At the beginning of the study, an initial two-movable kinematic chain with one input is used. To ensure the definability of the movement of this chain, it is necessary to introduce an additional force-velocity constraint into the two-moving chain, which preserves two degrees of freedom, but imposes a force restriction. Such a connection is a hinge in which there is a moment of interaction of forces, for example, a friction hinge. The interaction of friction forces in the form of a moment of forces in the friction joint at the relative angular velocity of the links creates a force-velocity coupling. This connection is ensured by means of a tension screw, which creates, in the presence of friction, the necessary normal reaction and the corresponding frictional force.

The friction moment created by the tension screw must be included in the equilibrium equation of the system. A definable two-movable chain with an additional frictional constraint obtained in this way will retain two degrees of freedom and will have a fundamentally new property, the property of force adaptation.

The scientific novelty of the work consists in the use of a fundamentally new technique for creating a definable structural chain of the drive mechanism. This technique consists in adding a fundamentally new force-velocity constraint to the initial two-movable kinematic chain with one input, which ensures definability of chain movement.

Scientific novelty provides a solution to the set tasks of studying a definable structural chain.

Scientific statements submitted for protection:

- The initial kinematic chain with two degrees of freedom and one input is transformed into a definable structural chain by adding a force-velocity constraint created in the friction joint.

- Force-velocity constraint the constraint is provided by means of a tension screw, which creates, in the presence of friction, the necessary normal reaction, corresponding to the frictional force and the frictional moment.

- The force-velocity constraint is introduced into the equilibrium equations in the form of the power consumed to overcome the moment of friction in the friction joint in the presence of the relative angular velocity of the links.

- The definable structural circuit of the drive creates the effect of force adaptation, in which the output angular velocity of the drive is inversely proportional to the moment of resistance.

The reliability and validity of the scientific provisions, conclusions and results of the dissertation is confirmed by the use of the basic provisions, principles and methods of mechanics and the confirmation of the theoretical results obtained by experimental studies of the developed prototype on a test bench.

Theoretical and practical significance of the research.

The theoretical significance of the work is:

- in the development of a structural scheme of a mechanism with an additional force-speed constraint on the central axis of the planetary variator mechanism;
- in the study of patterns of interrelation of kinematic and power parameters of adaptive gear mechanism;
- in the theoretical description of the action of the adaptive drive;
- in the analysis of adaptive drive driving modes;
- in the development of a methodology for calculating an adaptive drive.

The practical significance of dissertation research is as follows:

- in the development of design and technological documentation of a prototype and a test stand;
- in the creation of a prototype of the drive mechanism and a test bench;
- in conducting tests of the prototype and analyzing the results obtained.
- in the creation of a design methodology for a self-regulating adaptive gear variator.

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

- scientific seminars of the U.A. Dzholdasbekov Institute of Mechanics and Machine Science (2015-2020, Almaty);
- International Conference "Sustainable Energy, Environment and Information Engineering" (Bangkok, Thailand, March 2016);
- International Scientific Conference of Students and Young Scientists "III Farabi Readings. The World of Science" (Al-Farabi Kazakh National University, Almaty, Kazakhstan, April, 2016);
- XI International Scientific and Technical Conference "Energy, Information and Communication Technologies and Higher Education" (AUES named after G. Daukeev, Almaty, Kazakhstan, October 2021);
- International Conference "Mechanisms and Machine Science, Mechanism Design for Robotics, MEDER2021" (Poitiers, France, June, 2021);
- The 7th Asian Conference on Mechanisms and Machine Science "Asian MMS 2024" (U.A. Dzholdasbekov Institute of Mechanics and Machine Science, Almaty, Kazakhstan, August, 2024);
- scientific seminars of the Department of Mechanics of Al-Farabi Kazakh National University (2015-2020, Almaty).

Publications. The author published 11 papers on the topic of the dissertation, including 4 publications in scientific journals included in the list recommended by the Committee for Control in the Field of Education and Science of the Ministry of

Education and Science of the Republic of Kazakhstan for publishing the main results of scientific activity; 2 publications in scientific journals indexed by the Scopus database; 5 publications in the proceedings of foreign and domestic scientific conferences, including of which there are 3 publications in the materials of foreign conferences, 2 publications in the materials of the domestic conference.

Personal contribution of the author. The author of the dissertation, D.T. Tulekenova, developed a structural scheme of a mechanism with an additional force-speed coupling on the central axis of the planetary variator mechanism and the main research results presented in the dissertation work. The applicant completed the main part of the work planned by the domestic scientific supervisor K.S. Ivanov (theory and construction) and the foreign scientific supervisor M. Ceccarelli (theoretical guidance and experiment).

The structure and scope of the dissertation. The dissertation work consists of a title page, contents, notations and abbreviations, an introduction, four sections, a conclusion, and a list of 82 sources used. The total volume of the dissertation is 92 pages, including 69 illustrations and 2 tables.

The main content of the dissertation.

The introduction reflects the following points: the relevance of the topic of the dissertation research, the main purpose of the work, the object, subject and methods of research, scientific novelty, scientific and practical significance of the thesis, the degree of its elaboration.

The first chapter examines the overview and analysis of existing spacecraft docking mechanism designs, classification of docking mechanisms, description of docking mechanism designs and characteristics of the moment of resistance, technical requirements for the designed electric drive of the docking mechanism and analysis of existing docking mechanism designs.

The subject of the second chapter is the task of developing an adaptive gearbox circuit for driving the docking mechanism. Structural synthesis of an adaptive reducer. Kinematic analysis of an adaptive gearbox. Force analysis of an adaptive gearbox. Development of an efficient adaptive gearbox design.

In the third chapter, the design of an adaptive gearbox is being developed. Description of the docking device design. Determination of the main design parameters of the adaptive gearbox. Dynamics of adaptive drive (construction of drive characteristics). Analysis of the drive movement modes.

In the fourth chapter, the practical implementation of an adaptive gearbox. Development of design documentation. Creation of an experimental sample and a test stand. Experimental characteristics of the prototype. A design and technological complex for designing adaptive drives for aerospace equipment has been developed. Experimental tests and analysis of the operation of the variator in various driving modes have been performed. An animation model of an adaptive gear variator has been developed.

In conclusion, the main results and conclusions obtained in the thesis are presented.

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