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DEVELOPMENT OF AN ADAPTIVE ROBOT GRIPPER DRIVE WITH LIMITED FORCE

ANNOTATION

Dissertation for the degree
Doctor of Philosophy (PhD) in specialty
6D060300 – “Mechanics”

Relevance of the research topic. An industrial robot contains: a mechanical part in the form of an actuator with a gripper, and an electronic part in the form of a control system. In addition, there are drives to fulfill the law of motion of the working body (gripper) of the robot, according to a given control. The working body (gripper) of the robot performs basic technological operations (grabbing, drilling, milling, etc.). The robot's gripper is the main executive body of the robot. The gripper is designed to grip products of various shapes and compositions, and the number of different types of grippers reaches several thousand.

In dissertation work, studies were carried out on various grippers of machines and robots (processing, lifting, agricultural, mining, etc.). Structural and kinematic diagrams of grippers are given.

In works, the process of gripping, orientation and gripping errors was studied. Modular schemes for the execution of grips are proposed. However, these works lack methods for increasing the versatility of grippers and ways to create innovative grippers. To reduce the cost of creating new grippers, new methods of their design are needed.

In almost all known robotic gripper devices, the same motor is used to move the working elements of the gripper and to generate gripping force. In typical types of robot gripping, one common motor is used for the process of grasping the part and creating the necessary force for holding it. But currently they are trying to separate these operations, and the engine is used for the gripping process, and the part is held by elastic elements or magnets. A significant characteristic of the gripper is the gear ratio of its drive, which affects the nominal gripping force.

It is proposed to divide the grippers, for unification, into functional and structural parts, which makes it possible to synthesize different types of grippers based on standard mechanisms. Robots with electromechanical drives have become widespread. For the most part, their grippers are driven by pneumatic drives. Pneumatic drives have high speed compared to electric drives, resulting in low inertia and the absence of heavy gearboxes. But the use of an electric drive has its advantages: simplicity of design and control, the ability to create unification and quick automatic replacement, and the absence of a high-pressure air supply. The advantage of using an electric drive in a grabber is high accuracy and load capacity when working under conditions of high dynamic loads.

Typically, in robot gripper drives, a lever mechanism and a screw-nut mechanism are used as an actuator, which are connected to an electric motor through a gearbox and coupling. The main requirement for the grabber, when the electric motor is turned off, is the inadmissibility of reverse motion. Therefore, various devices are used in grabber drives to eliminate this process: blockers, brakes, ratchets, etc. The disadvantage of these devices is their low reliability, increased weight and size. For the electric drive of the grabber, small-sized electric motors (DC, synchronous, asynchronous, commutator) with a power of up to 1 kW, rated speeds of up to 3000 rpm and rated torques of up to 10 N・m are widely used. Small-sized DC electric motors, which are used to create high-speed control systems, are widely used in the electric drive of the gripper.

Currently, robots use electric and hydraulic actuators with one degree of freedom. Such a drive provides an unambiguous connection between input and output motion. However, to overcome the variable resistance force, it is necessary to use a variable gear ratio between the input and output. The variable speed drive must include a controlled gearbox. Such a drive contradicts the requirement to minimize the weight and size of robot modules. Existing electrical and hydraulic systems have a “hard” connection between the movement of the input and output pistons. The output link moves at a constant speed. In machine drives, it is necessary to use mechanical and hydraulic mechanisms with a variable speed of movement of the output piston, corresponding to the variable load. Various control systems are used for this purpose.

The dissertation work proposes an adaptive output force control scheme for hydraulic cylinders using direct measurement of the output force through strain gauges. Due to the large and somewhat uncertain friction force of the piston, the chamber pressure control cylinder with Coulomb-viscous friction prediction may not be sufficient to achieve precise control of the force output. In the proposed approach, the output force error resulting from direct measurement is used not only for feedback control, but also to update the parameters of the corresponding friction model, which includes the Coulomb-viscous sliding friction force and the output force as a function of the sliding friction force. . Stability is guaranteed by both pressure force error and output force error. Under the constraint of the required output force and its derivative, asymptotic stability as an error, the pressure force and output errors are forced to also be guaranteed. Experimental results show that a good pressure force control system does not necessarily guarantee good output force control, and that adaptive friction compensation is superior to fixed-parameter friction compensation. Excellent control of force output (together with torque) performance implies dynamic equivalence between the hydraulic cylinder and the electric actuator for predefined bandwidths. This allows the robot's hydraulic drive to successfully compete with the robot's electric drive. However, such a control system turns out to be too complex and does not guarantee adequate operation.

Professor Ivanov K.S. previously performed theoretical studies of the force-adaptive mechanism. The adaptive mechanism has two degrees of freedom, and carries out force adaptation to variable external load. The adaptive mechanism adapts to variable external loads and operates without a control system. The adaptive drive operates without a gearbox and without a control system. It is advisable to use an adaptive mechanism to drive the robot's gripper, overcoming a variable technological load.

This is especially true for grabbers for handling cargo with a thin “delicate” outer surface, such as agro-horticultural products (tomatoes, apples, cucumbers, etc.). After harvesting, it is necessary to carry out selection and packaging using automatic lines. However, when packaging agro-horticultural products, rune labor is mainly used. To automate the tasks of collecting and packaging agro-horticultural products, it is necessary to increase the efficiency of the grippers when working with this type of product without damage. These technological operations are currently performed manually and/or using complex robot grip control systems, which leads to increased product costs. The gripper is the most important component of the robot in the process of working with agro-horticultural products, as it acts as an important intermediate organ between the robotic system and the product.

General description of dissertation work. The paper examines the issues of analysis and synthesis of the structural, kinematic and power characteristics of the adaptive drive of a robot gripper with limited force based on the use of the theory of force adaptation for load handling.

The purpose of the dissertation work is the development and selection of parameters for the adaptive drive of the robot's gripper, which ensures the grasping of objects without damage.

Main idea of the work is to use the effect of force adaptation of the robot's gripper drive with limited effort based on the theory of force adaptation of mechanisms with two degrees of freedom

The object of the study is the drives of robot grippers.

The subject of the research is adaptive drives of robotic grippers for Reloading agro-horticultural products that have a thin “delicate” outer surface.

To achieve this goal, it is necessary to solve the following interrelated research tasks:

- analyze adaptive mechanisms:
- develop a methodology for analysis and synthesis of an adaptive gear mechanism;
- develop a method for calculating the adaptive drive of the robot gripper;
- develop a dynamic model of the adaptive drive of the robot gripper;
- to select and justify the structural and kinematic parameters of the robot’s grip for reloading agro-horticultural products;
- develop a three-phalanx robot gripper for reloading agro-horticultural products;

- conduct experimental studies of the adaptive gear mechanism;
- conduct experimental studies of the adaptive drive of the robot gripper for reloading agro-horticultural products;
- automate the process of packing tomatoes using a robot with a three-phalanx gripper with an adaptive drive.

Research methods: theoretical studies were carried out on the basis of classical methods of studying mechanisms and machines (kinematics, force analysis, dynamics) and the theory of force adaptation of mechanisms with two degrees of freedom of Professor K.S.Ivanov using research and design algorithms on a computer. The work adopted a comprehensive research method, including analysis and generalization of previously performed research and technical solutions, theoretical and experimental studies on physical models. Methods of mathematical analysis, methods of theoretical mechanics and methods of studying mechanisms and machines were used for analytical studies. During the experimental studies, methods of numerical analysis and computer modeling were used using the SimulationX software package, and strain gauge methods with digital sensors.

The scientific novelty of the work is as follows:

- analysis of adaptive mechanisms for use as a drive for a robot gripper was carried out;
- a methodology for analysis and synthesis of an adaptive gear mechanism has been developed and its prototype has been designed;
- a method for calculating the adaptive drive of the robot gripper has been developed;
- a dynamic study of the adaptive drive of the robot gripper was carried out;
- the main structural and kinematic parameters of the robot grip for reloading agro-horticultural products were determined;
- a three-phalanx robot gripper for reloading agro-horticultural products was designed and its prototype was manufactured;
- experimental studies of the adaptive gear mechanism were carried out;
- experimental studies were carried out on the adaptive drive of the robot gripper for reloading agro-horticultural products.
- automation of the process of packing tomatoes using a robot with a three-phalanx gripper with an adaptive drive was carried out.

Theoretical and practical significance of the research.

The results obtained in the work and methods for creating and calculating an adaptive drive for a robot gripper for reloading agro-horticultural products, based on an adaptive gear mechanism, can be used when conducting theoretical studies for a wide class of robot grippers. The practical significance of the work lies in the methodology for conducting an experimental study of the adaptive drive of a robot gripper for reloading agro-horticultural products. In addition, the automation of the process of packing tomatoes using a robot with a three-phalanx gripper with an adaptive drive is of practical interest. The results of experimental studies will be useful in the development of various types of robotic grippers that require adaptation during the product gripping operation.

Scientific provisions submitted for defense:

- method of analysis and synthesis of an adaptive gear mechanism;
- method for calculating the adaptive drive of the robot gripper;
- dynamic model of the adaptive drive of the robot gripper;
- experimental research methodology for the adaptive drive of a robot gripper for reloading agro-horticultural products.
- automation of the process of packing tomatoes using a robot with a three-phalange gripper with an adaptive drive.

The reliability and validity of the scientific statements, conclusions and results of the dissertation are confirmed by the correct formulation of the problem and the use of well-known mathematical methods, methods of theoretical mechanics, methods of studying mechanisms and machines, and methods of experimental research.

Connection of the dissertation work with other research works. This dissertation work was carried out under the grant scientific project of the Ministry of Education and Science of the Republic of Kazakhstan for 2020-2021 "Development of drive structures for sucker rod pumping units for the oil and gas industry" (IRN of the project: AP08052127).

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

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

– international scientific seminar "Current problems of engineering mechanics", dedicated to the 95th anniversary of Academician of the Academy of Sciences of the KazUSR, Doctor of Technical Sciences, Professor, Honored Scientist of Kazakhstan Zh.S. Erzhanova (Almaty, July 18-19, 2017);

- International conference "Green Bridge - a partnership platform for best innovation practices", EXPO-2017, Astana, Republic of Kazakhstan, 2017;
- International scientific and practical conference of the Academy of Sciences of the Republic of Kazakhstan, Almaty, Republic of Kazakhstan, 2017;

-World Congress of Engineers and Scientists "Future Energy: Innovative Scenarios and Methods for Their Implementation" WSEC-2017, (Astana, June 19-20, 2017);

- International scientific conference "4th IFToMM Symposium on Mechanism Design for Robotics" (Udina, Italy, September 11-13, 2018);
- International scientific conference "Slovak international Conference", Slovakia, 2018;
- International scientific and practical conference "Current problems of computer science, mechanics and robotics. Digital technologies in mechanical engineering", Almaty, 2018

- International conference “2nd International Conference of IFToMM Italy, IFIT 2018” (Cassino, Italy, November 29-30, 2018);

- Second International Joldasbekov Symposium “Mechanics of the future”, Institute of Mechanics and Mechanical Engineering named after Academician U.A Joldasbekov (Almaty, 2021).

Publications. On the topic of the dissertation work, the author published 23 works, of which 8 publications in scientific publications recommended by the Committee for Control in the Sphere of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan for the publication of the main results of scientific activities; 9 publications in scientific journals and proceedings of international conferences included in the Scopus database; 9 publications in the proceedings of domestic and foreign scientific international conferences, 4 patents .

Dissertation structure. The dissertation contains a title page, contents, introduction, five chapters, conclusion, list of used sources and applications. The total amount of the dissertation is 76 pages.

Main content of the dissertation. The introduction shows the relevance of the dissertation work, outlines the formulation of the problem and the stages of their solution.

First section is devoted to the current state of methods of analysis and synthesis of an adaptive gear mechanism. The rationale for the choice of design and adaptive gear mechanism is given. Kinematic and force analysis and synthesis of an adaptive gear mechanism were carried out.

In the second section The analysis of adaptive drives of robot grippers is considered. The design of the adaptive drive of the robot gripper, based on the adaptive gear mechanism, has been developed and justified. A dynamic model of the adaptive drive of the robot gripper has been developed using the SimulationX software package.

In the third section A robot gripper is being developed for reloading agro-horticultural products. The structural and kinematic parameters of the robot's grip for reloading agro-horticultural products were obtained. A three-phalanx robot gripper has been developed for reloading agro-horticultural products.

Fourth section devoted to experimental studies of the adaptive drive of a robot gripper for reloading agro-horticultural products. Experimental studies of the adaptive gear mechanism were carried out. Experimental studies of the adaptive drive of a robot gripper for reloading agro-horticultural products are shown.

In the fifth section The development of automation of the process of packing tomatoes using a robot with a three-phalanx gripper with an adaptive drive is considered. Experimental studies of the installation of a robotic cell for packing tomatoes are presented.

Personal contribution of the author.

The main results of the research conducted in the dissertation work were obtained by the author independently.

In article, the applicant substantiated the location of the holding jaws of a robot gripper for reloading agro-horticultural products. In articles, the applicant substantiated the structural-kinematic diagram of the actuator of the working body of the machine. In articles, the applicant conducted theoretical and experimental studies of a three-phalange adaptive gripper of a robot when grasping cylindrical and spherical objects. In work, the applicant obtained a structural-kinematic design of a two-phalange adaptive gripper, for which a patent for the invention was received.