**ABSTRACT**
of thesis
**"Kinematic analysis of a novel 3-PRRS tripod type parallel manipulator"**
submitted in candidacy for the PhD degree
in 6D060300 – "Mechanics"
by
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**The current state of the scientific problem and the relevance of the research topic.** Analysis of the state of modern robotics shows that the actuators (manipulators) of most modern robots are serial manipulators of an open (anthropomorphic) type of kinematic chain. Although the serial manipulators are versatile, have a wide workspace and high optimal movement, they also have a number of disadvantages, such as cantilever structure, low rigidity, low lifting capacity and low positioning accuracy.

An alternative method for creating kinematic schemes for robots is the use of a parallel manipulator with a closed kinematic chain. Compared to serial manipulators, the structure of the parallel manipulator is rigid, has a high lifting capacity and positioning accuracy, as well as significant speed. Because of these advantages, parallel robots are widely used in space, medicine, motion simulators, and industry.

**Purpose of the thesis:** is a kinematic analysis of the new tripod-type 3-PRRS parallel manipulator with six degrees of freedom

**Research tasks:**

1. Creation of a structural diagram of a new parallel manipulator of the tripod type and determination of the degree of freedom;
2. Solve the direct and inverse kinematic problems of a new tripod-type parallel manipulator to determine the movement and workspace of active (input) kinematic pairs;
3. Determination of the workspace;
4. Jacobian analysis, solution of direct and inverse kinematic velocity problems;
5. Determination of the singular configuration of the new tripod-type parallel manipulator;
6. 3D modeling of a new parallel manipulator in the form of a tripod to determine its work ability.

**Research methods.** The methodological basis of the research is mathematical modeling. The new design of the tripod-type parallel robot was obtained based on the advanced principles of constructing mechanisms and manipulators. The SolidWorks software was used for 3D modeling of a tripod-type manipulator, all calculations were carried out in Matlab.

**The theoretical and practical significance of the research results.** Currently, parallel robots are used in motion simulators, medicine, space, in many industries (automatic welding, grinding, cutting, control, loading and unloading, pipeline installation, oil well firefighting, shipbuilding, bridge construction, aircraft maintenance, shipbuilding transport, steel mounting). The parallel manipulator 3-

PRRS of the tripod type with six degrees of freedom, considered in the work, is new and can be used as a motion simulator or for smoothing or cutting operations.

**Scientific novelty of the work:**

1. Simplify the sinuscular configuration of the manipulator by reducing the number of legs on the Hauff-Stewart platform from six to three.

2. Increasing the horizontal working area of the parallel manipulator through the use of revolute kinematic pairs instead of translational kinematic pairs.

3. Expansion of the working area along the vertical Z-axis due to prismatic kinematic pairs moving in the plane of the fixed platform.

**Conclusions for the defense:**

1. Geometry and inverse kinematics of a new 3-PRRS type parallel manipulator.

2. Direct kinematics and the working area of the new parallel manipulator.

3. Singular analysis of the parallel manipulator of a new tripod, direct and inverse kinematic velocity problem.

- **Approbation of the work:** The main results of the dissertation were presented, discussed and positively assessed at the following international scientific conferences:
- International Conference on Robotics in Alpe-Adria Danube Region, RAAD 2019: Advances in Service and Industrial Robotics, «Geometry and Inverse Kinematics of 3-PRRS Type Parallel Manipulator» 08 May 2019, pp 12-18
- International Conference on Robotics in Alpe-Adria Danube Region, RAAD 2020: Advances in Service and Industrial Robotics, «The First Type of Singularity of a 3-PRRS Parallel Manipulator», 19 June 2020, pp 356-363
- Proceedings of the World Congress on Engineering, WCE 2019, «Parallel Manipulator of a Class RoboMech with Two End-Effectors», July 3-5, 2019, London, U.K.
- 2nd International Joldasbekov Symposium «Future Mechanics», «Geometry and Inverse Kinematics of 3-PRRS Type Parallel Manipulator», 1-5 March, 2021
- 5th IFToMM Symposium on, Mechanism Design for Robotics, MEDER 2021, «Invers Kinematics and Workspace of a 3- PRRS type parallel manipulator», June 23-25, 2021, Futuroscope-Poitiers, France.
- Scientific seminars of the Department of Mechanics of the Al-Farabi Kazakh National University (Almaty, Kazakhstan 2018-2020).

**Publications.** 10 papers have been published on the content of the thesis, including 6 at international conferences (indexed in the Scopus 3 database, not indexed 2), journals indexed in the Scopus 2 database, journals recommended by the committee on control in the field of education and science of the Ministry of Education and Science of the Republic of Kazakhstan 3.

**The structure and scope of the thesis.** The dissertation consists of an introduction, three chapters, a conclusion and a bibliography.

**The introduction analyzes** the current state of the research problem and provides a review of the literature, substantiates the relevance of the topic, goals and objectives, form, subject of research. The results of research, their scientific novelty, theoretical and practical significance are presented.

**In the first section of the thesis**, the degree of freedom of a parallel manipulator is determined, to study the geometry, kinematics and dynamics of a parallel robot tripod in each kinematic pair, two Cartesian coordinate systems were connected, and not one Cartesian coordinate system, as in the well-known Denavit-Hartenberg method. Each Cartesian coordinate system is strictly associated with each element of the kinematic pair. Then the transformation matrix of the selected coordinate system will have six parameters instead of four, as in the Denawith-Hartenberg matrix. Indeed, the position of a rigid body in space is determined by six independent parameters. These six parameters were used to determine the matrices of binary links, kinematic pairs, base and local coordinate systems of the new parallel manipulator 3-PRRS of tripod type.

When solving the direct problem of kinematics, the values of the input parameters are set, and the position and orientation of the moving platform are determined in accordance with these parameters. In our case, two input parameters $s_i$, $\theta_{2,i}$ were given, for each support, from the condition of the constancy of the distances between the spherical joints, were given a system of three equations consisting on three variables $\theta_{3,i}$ was compiled. This system of equations is reduced to a 16th degree polynomial, which depends on one variable. Thus, various positions of the moving platform of the parallel manipulator were identified, depending on the values of the input parameters.

When solving the inverse problem of kinematics, the position of the moving platform, that is, the position and orientation of the $PX_PY_PZ_P$ local coordinate system relative to the base coordinate system are specified as a 4x4 matrix. On the other hand, the coordinates of the spherical joints are defined as functions depending on constant and variable parameters for each support of the parallel manipulator. In our case, a system of equations is created for one leg, consisting of three equations and three unknowns. Two input parameters were considered unknown: the parameter of the prismatic motion of the hydraulic cylinders $s_i$, the parameters of the revolute motion of the motors $\theta_{2,i}$ and the angles of rotation of the passive nodes $\theta_{3,i}$ ($i$=1,2,3). However, since the first two of the three equations linearly depend on each other, the input parameters $s_i$ are given, and the parameters $\theta_{2,i}$ and $\theta_{3,i}$ are determined from two equations depending on two variables.

**The second chapter of the thesis** examines the workspace of a parallel manipulator. When determining the workspace, the planes of the legs of the parallel manipulator were determined, were proved that the trajectory of the moving platform is an arc of a circle belonging to the sphere. The workspace was determined by direct and reverse kinematics. According to the inverse calculation of the kinematics, the coordinates of the center of the moving platform of the manipulator are set from the volume of a rectangular prism in space, and the program determines by checking that these points correspond to the workspace of the manipulator. When determining the workspace by direct kinematic calculation, the input parameters of the prismatic kinematic pairs $s_i$ are specified and the center of the moving platform is determined, when the input parameters of the revolute kinematic pairs $\theta_{2,i}$ change in three cycles. Thus, by numerical selection, the workspace of the parallel manipulator was determined.

With fixed prismatic kinematic pairs of this parallel manipulator of the tripod type, that is, if the rods of the hydraulic cylinders are fixed at equal distances from the center $s_1 = s_2 = s_3 = s$, then it is known that the manipulator becomes a completely parallel manipulator with three degrees of freedom, while taking into account the dependence between the parameters determining the position $X_P, Y_P, Z_P$ and orientation $\psi, \theta, \varphi$ of the center of the moving platform in space, the workspace of the parallel manipulator was determined.

**In the third chapter of the dissertation,** the construction of Jacobi matrices from the equations for closing the contours of the legs of a parallel manipulator is given, by adding additional equations to the Jacobi matrix, taking into account the limitation of revolute kinematic pairs, direct and inverse kinematic problems of velocities the parallel manipulator were solved, comparison and verification of the correctness of the solution were performed.

This chapter discusses singular configurations of a parallel robot, because in singular configurations the robot loses a certain degree of freedom or gains an additional degree of freedom, therefore, in these cases, the parallel robot is not controlled. The singular configurations of the parallel robot were determined based on the analysis of the Jacobi matrices $\mathbf{J_x}$ and $\mathbf{J_q}$, which establish the relationship between the moving platform and the velosity of the motors. Depending on the singularity of each of the Jacobians $\mathbf{J_x}$ and $\mathbf{J_q}$ or both, three types of singular configurations of the parallel robot have been defined. It is also known that $\mathbf{J_x}$ is associated with forward kinematics and $\mathbf{J_q}$ is associated with backward kinematics.