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Research on the Structural Design of the 9-3 Stewart-type Parallel Robot

Jinxin Gao

Noncommissioned Officer Academy Of PAP, Hangzhou, 311400

ABSTRACT

This paper conducts an in-depth study on the structural design of the 9-3 Stewart-type parallel robot. Firstly, a detailed analysis is carried out for application scenarios such as aerospace and industrial manufacturing. Secondly, in the part of structural parameter design, from multiple aspects including platform size, chain parameters, and joint design, the influence of different design factors on the performance of the robot is expounded. Finally, SolidWorks is used to construct a three-dimensional model, and the ADAMS software is employed for kinematic and dynamic simulations. The model is verified and the structure is optimized through the simulation results.

KEYWORDS

9-3 Stewart-type parallel robot; Structural design; Simulation analysis

1 Analysis of the Application Scenario Requirements of the 9-3 Stewart-type Parallel Robot

In the aerospace field, the manufacturing and assembly of aircraft and satellite components require extremely high precision and stability. For example, the processing of aircraft engine blades requires the robot to have high-precision positioning to complete cutting and grinding operations, ensuring that the blades meet strict standards. In addition, the accurate docking of tiny components in satellite assembly also relies on high-precision robot operations. Therefore, the 9-3 Stewart-type parallel robot needs to have a motion accuracy at the sub-millimeter level and maintain stable operation under complex mechanical conditions.

In the industrial manufacturing field, the application scenarios of robots are more diverse. In the automotive manufacturing industry, the 9-3 Stewart-type parallel robot can be used in parts handling, assembly, and welding. During the assembly of automotive engines, the robot needs to quickly and accurately handle parts and perform precise assembly to improve production efficiency and product quality. In the electronics manufacturing industry, the requirements for the precision and flexibility of robots are increasingly high. For example, in the chip manufacturing process, the robot needs to perform operations such as photolithography and etching on the surface of tiny chips, requiring a precision at the sub-micron level and a fast response ability.

2 Structural Parameter Design of the 9-3 Stewart-type Parallel Robot

2.1 Platform Size Design

The design of the platform size is a key link in the structural design of the 9-3 Stewart-type parallel robot, which directly affects the working space and motion performance of the robot. Therefore, it needs to be accurately determined according to performance indicators and application requirements.

In terms of shape selection, the fixed platform and the moving platform usually adopt regular shapes such as circles, equilateral triangles, or squares. The circular platform, due to its isotropic characteristics, is uniformly stressed during rotational motion, which helps to improve the motion stability. The equilateral triangle platform is suitable for application scenarios that require symmetrical arrangement of chains, which can make the force on the chains more balanced and improve the load-bearing capacity. The square platform performs well in occasions with high space utilization, and its right-angle sides can better match the boundaries of the working area, thereby improving work efficiency.

The size of the platform significantly affects the working space of the robot. Generally speaking, increasing the platform size will expand the working space, but it will also bring some problems. A larger platform size will increase the motion inertia of the robot, resulting in a decline in the dynamic response performance, making it difficult for the motion speed and acceleration to change rapidly. In addition, a large-sized platform may increase the manufacturing cost and the occupied area. Therefore, when designing the platform size, it is necessary to comprehensively consider the requirements of the working space and the motion performance to achieve a reasonable balance. When the requirement for the working space is large and the requirement for the motion speed is not high, the platform size can be appropriately increased; while when the requirement for the motion performance is high, the platform size should be controlled to ensure the dynamic response performance.

2.2 Chain Parameter Design

The chains are key components of the 9-3 Stewart-type parallel robot, and their design directly affects the load-bearing capacity and stiffness of the robot. When designing the chain parameters, factors such as length, cross-sectional shape, and material need to be comprehensively considered.

The length of the chains affects the working space and motion performance of the robot. Longer chains can expand the working space, but they will reduce the stiffness and load-bearing capacity and increase the motion inertia. Shorter chains, on the other hand, will improve the stiffness and load-bearing capacity but limit the working space. During the design, it is necessary to balance the requirements of the working space and performance requirements and select an appropriate length.

The cross-sectional shape plays an important role in the mechanical properties of the chains. Common shapes include circles, squares, rectangles, and I-shapes. The circular cross-section is suitable for withstanding torque but performs weakly under bending forces; the square and rectangular cross-sections are more suitable for withstanding bending forces, but their mechanical properties vary in different directions; the I-shaped cross-section has the advantages of both and is suitable for occasions with high requirements for mechanical properties. When designing, an appropriate cross-sectional shape should be selected according to the main force direction of the chains.

The material selection directly affects the performance and cost. Aluminum alloy is lightweight and easy to process, making it suitable for applications that are sensitive to weight and cost; steel has high strength and is suitable for occasions with high load-bearing capacity requirements, but it is heavy and costly; titanium alloy has the advantages of being lightweight, high-strength, and corrosion-resistant, but it is expensive and is usually used in high-end fields such as aerospace.

2.3 Joint Design

Joints are key components of the 9-3 Stewart-type parallel robot, and their design directly affects the motion flexibility and precision of the robot.

In terms of joint types, spherical joints and Hooke joints are commonly used choices. The spherical joint allows rotation in three directions and has a high degree of freedom, which is suitable for complex motion trajectories and can accurately adjust the position and posture of the end effector. In contrast, the Hooke joint can achieve rotation in two directions. Although it has a smaller degree of freedom, it provides a more stable connection and motion performance in specific applications.

The structural design of the joints should consider factors such as the connection method, sealing, and lubrication. The connection methods include bolt connection, pin connection, and welding, each with its own advantages and disadvantages. A good sealing design can prevent impurities from entering the joints, and appropriate lubrication can reduce friction and improve the motion efficiency.

Joint parameters such as clearance and stiffness have an important impact on the motion precision and performance. The clearance needs to be strictly controlled, and high-precision machining and pre-tightening devices can be used to improve the precision. Material selection and structural optimization (such as increasing the wall thickness and reinforcing ribs) can enhance the joint stiffness, thereby improving the load-bearing capacity and stability.

3 Establishment and Simulation Analysis of the Structural Model of the 9-3 Stewart-type Parallel Robot

3.1 Establishment of the Three-dimensional Model

In the research and development of the 9-3 Stewart-type parallel robot, the establishment of the three-dimensional model is a key step, which provides an accurate physical model for the subsequent kinematic and dynamic analysis. In this study, the SolidWorks software is used for three-dimensional modeling.

In SolidWorks, each component is first drawn according to the design parameters. The shape and size of the fixed platform are determined according to the design requirements. For example, for a circular platform, parameters such as the diameter and thickness need to be specified. The contour is sketched using the sketch tool, and then the modeling is completed through extrusion and hole-making. The modeling of the moving platform is similar. The shape and size are determined according to the design scheme, and the three-dimensional modeling is completed.

The modeling of the chains is more complex, and factors such as length, cross-sectional shape, and joint connection method need to be considered. The three-dimensional model is generated according to the cross-section and path of the chains through the scanning feature, and the joint part is precisely assembled by creating a part model. During the assembly process, it is necessary to ensure the accurate positional relationship and constraint conditions of each component.

After completing the modeling of each component, the assembly stage is entered. In the assembly environment of SolidWorks, the fixed platform, the moving platform, and the chains are assembled according to the actual structure, and constraints are added to ensure that the relative positions and motion relationships of each component are consistent, and finally a complete three-dimensional model is constructed.

During the modeling process, attention is paid to the detailed design, such as the joint connection and the connection points between the chains and the platform, to ensure the accuracy of the model. According to the selected materials, material properties are assigned to each component, including density, elastic modulus, etc., so as to accurately simulate the mechanical properties during the analysis.

3.2 Kinematic Simulation

Kinematic simulation is of great significance in the research of the 9-3 Stewart-type parallel robot. It can verify the correctness of the kinematic model, analyze the motion trajectory and posture change of the robot, and provide a basis for the optimization design and control strategy. In this study, the ADAMS multi-body dynamics simulation software is used for kinematic simulation, which has powerful functions in the dynamic analysis of multi-body systems.

In ADAMS, the three-dimensional model established in SolidWorks is first imported. Since ADAMS has specific requirements for the model format, the SolidWorks model needs to be converted into a format that can be recognized by ADAMS, such as Parasolid. After import, according to the actual structure and motion relationship of the robot, the constraint settings are carried out. Corresponding revolute joint constraints are added to the spherical joints and Hooke joints to limit the degrees of freedom of motion. At the same time, a drive function is set for the telescopic motion of each chain to simulate the motion mode in actual work and accurately control the telescopic speed and displacement change of the chains.

In terms of simulation parameter settings, the time step and the total simulation time are set. The time step needs to balance the accuracy and calculation efficiency. A smaller time step can improve the accuracy but increase the calculation amount, while a larger time step will reduce the accuracy but speed up the calculation. After experimental analysis, an appropriate time step and total simulation time are determined to ensure a complete simulation of the motion process of the robot.

After setting the simulation parameters, the kinematic simulation is started. ADAMS calculates the motion states of each component, including position, velocity, and acceleration, according to the constraints and drive conditions. Through the post-processing module, the motion trajectory and posture change of the robot can be observed, and the motion trajectory of the end effector can be analyzed to ensure that it meets the design requirements. ADAMS can also display the rotation and tilting of the robot through a three-dimensional animation to intuitively feel the posture change.

By comparing the simulation results with the theoretical calculation results, the correctness of the kinematic model is verified. In the forward solution calculation, according to the given joint displacements, the position and posture of the end effector are calculated using the formula; in the simulation, the actual motion results are obtained. If the two match well, it indicates that the model is correct; if there is a deviation, it is necessary to check the model establishment, parameter settings, and calculation process and make corrections and optimizations. The kinematic simulation provides an in-depth understanding of the motion characteristics of the robot and provides support for the structural optimization and control algorithm design.

3.3 Dynamic Simulation

In the research of the 9-3 Stewart-type parallel robot, the dynamic simulation is carried out based on the dynamic model to analyze the mechanical behavior and motion stability of the robot under different working conditions and provide a basis for structural optimization.

In ADAMS, after completing the model import and constraint settings, forces and loads need to be added. According to the mass and installation position of each component of the robot, the direction and magnitude of gravity are set to simulate the force situation of the robot. At the same time, according to the characteristics of the drive system, a driving force function is set for the chains to ensure that the inertial force and friction force can be overcome during rapid movement. In addition, the friction coefficient is set at the joints and the connection points of the chains to simulate the influence of friction on the motion.

To simulate different working conditions, multiple simulation conditions are set: the full-load working condition to simulate the force situation under the maximum load; the high-speed motion working condition to analyze the dynamic characteristics at high speeds; and the complex trajectory working condition to study the force and stability under specific trajectories.

During the simulation process, ADAMS calculates the changes in the force, acceleration, and velocity of each component over time, and detailed results are output through the post-processing module. In terms of force analysis, the force curve of the chains is drawn to determine their load-bearing capacity and provide a reference for the structural design. In terms of motion stability, the posture change and vibration situation are observed to evaluate its stability, and the structure can be optimized or the control strategy can be adjusted.

According to the simulation results, the cross-sectional dimensions of the chains can be optimized: increasing the cross-section of the high-stress parts to improve the load-bearing capacity; reducing the cross-section of the low-stress parts to reduce the weight and optimize the material utilization. At the same time, the structural layout can be adjusted, the joint stiffness can be optimized, or damping can be increased to improve the motion stability.

4 Conclusion

In conclusion, through a detailed analysis of the structural design requirements of the 9-3 Stewart-type parallel robot, this study has completed a series of work from the structural parameter design to the establishment of the three-dimensional model and simulation analysis. The specific requirements of different application scenarios for the performance of the robot have been clarified, providing a clear target orientation for the structural design. In the future, more advanced algorithms and models can be considered to be introduced to improve its performance. Overall, this study provides valuable references for the development of the 9-3 Stewart-type parallel robot and is expected to promote its wide application and technological innovation in more fields.

About the Author

Jinxin Gao; Gender: Male; Date of birth : 1997.01; Native place: Linfen, Shanxi; Nationality: Han; Highest education: Bachelor; Current title: Assistant; Research direction: Mechanical and Electronic Engineering.

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