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A Novel 3-Dof Electronic-driven Balanced Structure Model

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Abstract. This paper proposes a balanced structure model of electric platform based on 3-DOF parallel mechanism. Compared with the traditional hydraulic structure platform, the proposed electric platform consists of three independent electric cylinders and their respective rigid strut links, each electric cylinder has 2 degrees of freedom relative to the whole platform frame. At the same time, according to the force distribution characteristics of the frame, the mechanics performance of the mechanical transfer equation is simulated. The simulation results show that the proposed 3-DOF electric platform has more space balance and static mechanics than the conventional electric platform and the traditional hydraulic platform performance.

Introduction

The electronic-driven multi-degree-of-freedom (M-DOF) platform is always more controllable than hydraulic and pneumatic driven platforms besides of more flexible and powerful. More and more researchers focus on electronic-driven M-DOF. However, compared with the structure of hydraulic multi-degree-of-freedom platforms, the research intensity are still relatively weak especially about the mechanical equilibrium structure, hydraulic and atmospheric pressure. At present most of the literature on electric platform or from the hydraulic control point are carried by researching. The parallel mechanism of screw and fish eye proposed is applied to the design of the power platform. It is mainly used as a balanced support structure. The support structure is simple in design, compact in structure and flexible in movement, but the disadvantage of it is the lack of strong mechanical properties analysis, in practical application of the lack of effective mechanical transfer performance feedback. The structure of model [2] that responded a stiffness map reflecting the static transmission characteristics is established, and the transfer performance of the multi – degree – of - freedom equilibrium system is analyzed from the standpoint of statics. In [3], the mechanics of the parallel mechanism of the platform is analyzed by using the force analysis method similar to the "friction circle theory" analysis method. Anyway, the research document for power-driven equipment or mechanical performance analysis still lack of more in-depth theoretical support. In this paper, a design of balanced support structure based on electric drive is proposed. According to its structural characteristics, three mechanical cylinder transfer equations are deduced based on mechanical theory. The Jacobi matrix is used to analyze the torque transmission performance and the torque input equilibrium of the parallel electric platform in theory. The actual test results show that the novel model has a better mechanical transfer performance than the traditional hydraulic drive platform, with greater freedom of movement, better motion control performance and a larger rotating space.

The Platform Model and Mechanical Position Equation

A Mechanical Structure of the Platform Model. The model consists of three independent electric cylinders and a rigid strut parallel mechanism. The structure is shown in Fig. 1.

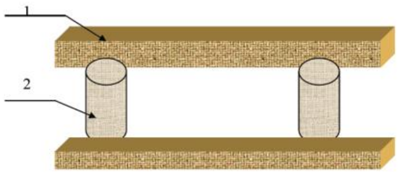

Figure 1. Platform structure

The platform is divided into two parts: one is rigid struts, distributed in the upper and lowers two layers; the upper layer from the four long struts to each other to build a rectangular socket interval, the middle embedded four short support rods to form a rigid platform. There is also a part of the three independent electric cylinder, can complete the direction of movement of three degrees of freedom (up and down, left and right and front and rear), the platform through the activities of the cylinder to achieve the purpose of rotation. The platform physical picture is shown in Fig. 2.

Figure 2. platform physical picture

Two dimensional structure of the electric cylinder is shown in Fig. 3.

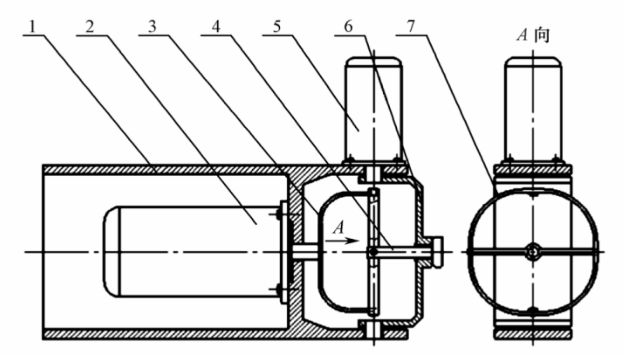

Figure 3. Dimensional structure of the electric cylinder

Where, each electric cylinder is equipped with a certain stroke of the screw, a fish eye, a motor timing belt pulley and matching mounting seat, a synchronous servo drive motor. The fisheye is mounted directly on the top of the cylinder and is mechanically fixed to the frame of the rigid strut. The main function is to allow the platform to rotate (within a certain angle). The servomotor drives the lead screw through the motor mounting seat. Screw drive platform in accordance with certain action instructions to complete transposition requirements. Electric cylinder end of the actuator is a fish eye, the bottom is a servo motor timing belt pulley, so theoretically a single rod with two degrees of freedom of rotation (up and down movement and left and right movement, but left and right angle is relatively small), the end of the electric cylinder The actuator is fixed directly to the power platform rigid structure with the fish eye. The new electric cylinder has a flexible steering, suitable for installation in the action control requirements of complex equipment.

As shown in Fig. 4, the cylinder parallel mechanism can be simplified as a spatial sphere motion standard system: the link rod of each electric cylinder is constructed by two branch chains. , The axes of the branches intersect the center of the sphere O. Considering that the rotation of the cylinder exhibits two degrees of freedom (up, down, left and right) in a single plane, the mechanical structure can be simplified to the orthogonal form of parallel, AB, BC and The central angle of DE is 90 °. The action system O-XYZ in Fig. 4, the X -axis is directed from O to C, the Y-axis from O to E, the Z- axis from O to B.

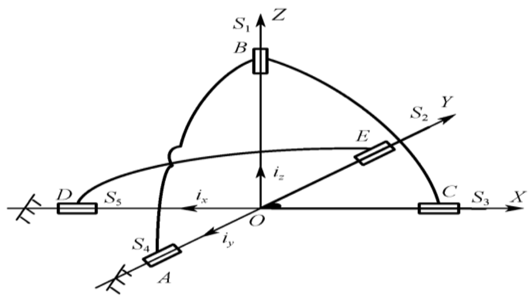

Figure 4. 3-DOF balanced parallel mechanism of an electric cylinder

Mechanical Position Equation. Assuming the electric cylinder space attitude change angle is α, β, the input rotation angles are ε1, ε2. According to analytical mechanical position equation [5], the dynamic position matrix of cylinder can be deduced as follows:

$$R = \begin{Bmatrix} \cos\beta & 0 & \sin\beta \\ \sin\alpha\sin\beta & \cos\alpha & -\sin\alpha\cos\beta \\ -\cos\alpha\sin\beta & \sin\alpha & \cos\alpha\cos\beta \end{Bmatrix} \tag{1}$$

According to mechanism diagram 4, S2 coordinates in the O-XYZ movement standard system is

$$S_2 = R(0 \quad 1 \quad 0)^T = (0 \quad \sin\alpha \quad \cos\alpha)^T \tag{2}$$

According to the structural characteristics of the electric cylinder, when the motor rotation input angle is ε1, and S2 can be expressed as the input angle ε1 relationship, S2

$$S_2 = (0 \quad \sin\varepsilon_1 \quad \cos\varepsilon_1)^T \tag{3}$$

Where, from (2) and (3), we get:

$$\varepsilon_1 = \alpha \tag{4}$$

The coordinates of S3 in the O-XYZ coordinate system are as follows:

$$S_3 = R(1 \quad 0 \quad 0)^T = (\sin\beta \quad \sin\alpha\sin\beta \quad -\sin\alpha\cos\beta)^T \tag{5}$$

Where, S1 in the O-XYZ coordinate system under the action of the relationship and ε2 relationship:

$$S_1 = (\sin\varepsilon_2 \quad 0 \quad \cos\varepsilon_2)^T \tag{6}$$

By the electric cylinder's own geometric relations, the following relationship can be obtained:

$$S_1 \cdot S_3 = 0 \tag{7}$$

$$\varepsilon_2 = \alpha \tan 2(\cos\alpha\sin\beta, \cos\beta) \tag{8}$$

The dynamic position equation of electric cylinder is:

$$\begin{cases} \varepsilon_1 = \alpha \\ \varepsilon_2 = \alpha \tan 2(\cos\alpha\sin\beta, \cos\beta) \end{cases} \tag{9}$$

For the time derivative of equation (9), the kinematic equation is shown as follows:

$$\omega = J \cdot \mu \tag{10}$$

Where, ω is the output angular velocity in rad / s; t is the input angular velocity in rad / s; J is the angular velocity Jacobian matrix, can be expressed as:

$$\mathrm{J} = \begin{pmatrix} 1 & 0 \\ \dfrac{\sin\varepsilon_1 \sin\varepsilon_2 \cos\varepsilon_2}{\sin^2\varepsilon_2 + \cos^2\varepsilon_1 \cos^2\varepsilon_2} & \dfrac{\cos\varepsilon_1}{\sin^2\varepsilon_2 + \cos^2\varepsilon_1 \cos^2\varepsilon_2} \end{pmatrix} \tag{11}$$

Mechanical Properties Analysis

Mechanical Transfer Equation. Let $\tau = (\tau_1 \quad \tau_2)^T$ is as the torque vector of the cylinder, and $M = (M_x \quad M_y)^T$ as the external moment vector of the corresponding fish-eye at the end of the cylinder. So that the virtual corner of the fish-eye is ζ_ϑ, $\zeta_\vartheta = (\zeta_{\vartheta 1} \quad \zeta_{\vartheta 2})^T$; The virtual corner of the input cylinder is ζ_ε, $\zeta_\varepsilon = (\zeta_{\varepsilon 1} \quad \zeta_{\varepsilon 2})^T$. According to the principle of virtual work, in addition to the binding force that all the external moments and the sum of the work done

$$T \cdot \zeta_\varepsilon - M \cdot \zeta_\vartheta = 0 \tag{12}$$

Considering that the imaginary rotation angles ζ_ε and ζ_ϑ of the electric cylinders are not independent, the geometric constraint between them is determined by the Jacobian matrix J:

$$\zeta_\vartheta = J \cdot \zeta_\varepsilon \tag{13}$$

Integrated (12), 13), the establishment of a balanced electric cylinder mechanical transfer equation is:

$$M = G \cdot T \tag{14}$$

Where, for the electric cylinder force Jacobian matrix, and

$$G = (J-1)^T \tag{15}$$

Mechanical Properties. From the mechanics of the electric cylinder transfer equation (14) can be seen in the cylinder in motion, the Jacobi matrix determines the input torque and output torque size, according to the matrix theory of the norm content, type (14) to 2 norm , which is

$$\| M \|^2 = T^T G^T G T \tag{16}$$

Suppose the input quantity is unit quantity

$$\| T \| = T^T T = 1 \tag{17}$$

Reference to Lagrangian operators:

$$L_M = T^T G^T G T - \lambda_M (T^T T - 1) \tag{18}$$

In the formula, it is Lagrange multiplier. According to (18), the output torque of the extreme conditions:

$$\frac{\partial L_M}{\partial T} = 0; G^T G T - \lambda_M T = 0 \tag{19}$$

From (19), the extreme value is

$$\| M \|_{\max} = \sqrt{\lambda_{M\max}}, \| M \|_{\min} = \sqrt{\lambda_{M\min}} \tag{20}$$

The mechanical torque transmission performance of the cylinder is determined by the extreme value analysis cylinder as follows:

$$K_M = \| M \|_{\min} \tag{21}$$

According with (11) and (21), the KM transfer profile is shown in Fig. 5.

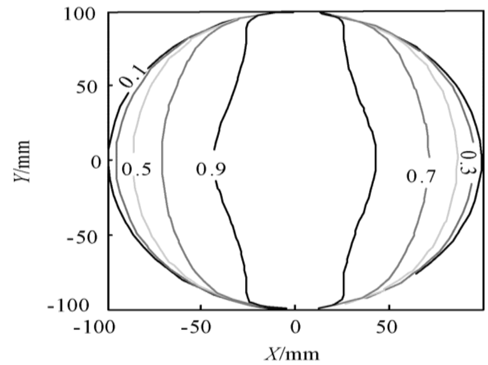

Figure 5. Distribution of torque transmission performance evaluation indicators

It can be seen from Fig. 5, K_M value in a range of symmetrical distribution, the greater the value that the cylinder torque transmission performance the better. When the difference between the input torques is larger, the performance of the cylinders becomes worse. In order to reasonably determine the torque input performance of the motor, a torque input equilibrium performance parameter K_{MR}, which can be expressed as:

$$K_{MR} = \frac{\| M \|_{\max} - \| M \|_{\min}}{\| M \|_{\max}} \tag{22}$$

Conclusion

In this paper, a3-DOF electric structure model is proposed. According to its structural characteristics, the spatial position of the electric cylinder structure is deduced by the mechanics theory, and the mechanical transfer equation is deduced. The Jacobi matrix was used to analyze the torque performance and the torque input equilibrium performance of the platform. Simulations were carried out to test the two performances. From the test results, this new model has a better torque transfer performance, torque transmission performance with the servo motor input rotation angle increases. The torque transfer presents a symmetrical distribution with very good performance and kinematic stability at the initial position. When reaching the limit of the working space, the worse the movement stability, the shorter the service life of the screw used by the balancing motor cylinder.

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