Calibration principle and structure analysis of the decoupled calibration device for six-axis heavy force sensor

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Abstract. A calibration device of six-axis heavy force sensor based on the parallel orthogonal mechanism is presented. The calibration principle of the force or moment in different direction is proposed. The finite element analysis of the frame and the fixture are conducted. Results show that the deformation influence of the gantry frame and the fixture are small to the calibration error.

1. Introduction
As an important feedback device, six-axis heavy force sensor is widely used in the different fields including robot and industry. The accuracy of the six-axis force is determined by the calibration device. Deformation of calibration device frame and fixture during calibration directly affects calibration error. Therefore, it is of great significance to study the deformation of each component of the calibration device in the calibration process.

Dai[1] has designed a calibration device with the proving ring as the force source. But the proving ring cannot bear heavy force. Zhao[2] has developed a six-axis force calibration device with hydraulic loading, and six-axis force can be loaded by adjusting the positions of the two loading units. However, the force source position error influences the calibration accuracy seriously. Zhang [3] has proposed a calibration device of six-axis heavy force with single force source, and the six-axis force is applied by changing the pose of the sensor. Kim [4] has developed a six-axis force calibration loading station. The calibration device is not suitable to calibration of the six-axis heavy force. Kistler company [5] has presented a calibration device based on the Stewart platform. But the applied force is coupled, which will affect the calibration accuracy. These calibration devices above are all applied to calibrate the six-axis force sensor without heavy load. Then the deformation of the frame and fixture is so small that it is of no influence to the calibration accuracy.

In this paper, a calibration device of six-axis heavy force sensor is presented. The calibration process of the force or moment in different direction is proposed. The finite element analysis of the frame and the fixture are conducted.

2. Calibration process of force or moment in different directions
The calibration device is composed of the gantry frame, electric cylinder and the fixture of the six-axis heavy force. Six electric cylinders are divided into three groups. Two parallel electric cylinders are in one group. The three groups electric cylinders are parallel to x,y and z axis separately. Three-jaw chuck is selected as fixture to mount the lower end of sensor. The wedge expansion fixture is used on the stage to fix the upper part of the sensor. The whole calibration device is shown in Figure 1.
The method of loading force is as follows: when the forces with the same magnitude are exerted by the two electric cylinders in the x-axis direction, the loading $F_x$ will be applied on the sensor, as shown in the Figure 2(a). Similarly, when two electric cylinders in the y-axis exert the same size of the same direction force, the y-direction force $F_y$ can be loaded. When two electric cylinders in the z-axis exert the same size of the same direction force, the z-direction force $F_z$ can be loaded. When the two electric cylinders in the x-axis exert the same size and opposite direction, the z-axis moment $M_z$ can be loaded. When the force of the two electric cylinders on the y-axis is the same magnitude and the direction is opposite, the loading of the moment $M_x$ can be realized. When the force of the two electric cylinders in z-axis is the same magnitude and the direction is opposite, the loading of the moment $M_y$ can be realized.

3. Force analysis of the fixture

In the calibration process, the reciprocating tension of the electric cylinder causes large tension and pressure to the moving platform and gantry frame. Then the accuracy and reliability of the calibration system should be guaranteed. And it is necessary to conduct force analysis because The stage and gantry frame are required to have enough bearing capacity and stiffness.
Figure 3. Stress and deformation cloud chart of the stage under 50 kN loading in X and Y direction.

The maximum stress is 27524 Pa, which is far less than the allowable stress of 200 MPa. The stage meets the static strength requirement. The maximum deformation is 0.883e-08 m, which also meets the design requirements within the allowable range of accuracy.

4. Analysis of the gantry frame

The gantry frame is the supporting mechanism of the whole calibration system. It not only bears the gravity of each part of the calibration machine, but also bears the reaction force when the electric cylinder is loaded. Its deformation may affect the final calibration result. Therefore, it is necessary to conduct the finite element analysis to study the influence of its deformation on the calibration error.

Analysis results show that the maximum stress is 0.134 MPa, which happen as the gantry frame is loaded with Z-direction maximum force. The value is much less than the allowable stress 200 MPa. The maximum deformation of gantry frame is 0.685e-06 m. The deformation results in relatively small calibration error, which meets the design requirements. The stress and strain cloud chart are shown in the Figure 4.
Figure 4. Stress and deformation cloud chart of the stage under 50 kN loading in X and Y direction

5. Conclusion

Based on the parallel orthogonal mechanism, a calibration device of six-axis heavy force sensor is proposed. For the force or moment in different direction, the calibration method on the calibration machine is presented. The force analysis of the frame and the fixture are conducted with finite element method. Results show that the deformation of the gantry frame and the fixture will produce small calibration errors, which is of no influence to the calibration result.

Acknowledgments

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