Design and simulation analysis of 6-DOF electric platform

Bin Li1, Song Guo1, Xuyao Mao1, Biaohua Cai1, Bo Wang1

1. Wuhan Second Ship Design and Research Institute, Wuhan, China
libinzju@sina.com, guosongjie555@163.com, dreamforty@126.com, cai_biaohua@sina.com, wangbo@qq.com

Abstract. Six degrees of freedom platform is a kind of space motion simulator, which can complete the simulation of any space motion within its allowed working range. It has been widely used in aerospace, military, automobile manufacturing, entertainment and other fields. The six degrees of freedom platform can simulate the transverse, longitudinal and heave motion of the ship under the influence of ocean environment such as wind, wave and ocean current. In this paper, the composition and structure of six degree of freedom platform are briefly introduced. Then the stress analysis of the key mechanical components of the six degrees of freedom platform shows that the main mechanical components meet the design results. The results of motion interference check show that the structure design is reasonable. Finally, through engineering application and simulation analysis, the control algorithm of six degrees of freedom platform is briefly introduced.

1. Introduction
Six degrees of freedom platform is a kind of space motion simulator, which can complete the simulation of any space motion within its allowed working range. It has been widely used in aerospace, military, automobile manufacturing, entertainment and other fields. The six degrees of freedom platform can simulate the transverse, longitudinal and heave motion of the ship under the influence of ocean environment such as wind, wave and ocean current. The six degrees of freedom platform can reproduce the ship operation status under various marine navigation conditions in the laboratory, which has a significant and far-reaching significance for the analysis and research of the ship's overall performance and maneuvering characteristics, as well as the training of the ship operator's driving technology, psychological adaptability and fault response ability. Compared with the navigation experiments carried out by real ships, the simulation results of ship navigation with a six-degree-of-freedom platform have obvious advantages such as no damage, controllability, economy, no pollution and reliability. At present, ship motion simulator technology based on six degrees of freedom platform has become one of the best ways to study ship motion and training navigation purpose under laboratory conditions.

2. Composition

2.1 Motion platform
The 6-DOF electric platform consists of a lower platform (fixed base), a moving platform, Hooke hinge and six actuators (servo electric cylinder), as shown in figure 1 below. The servo electric cylinder connects the fixed base and the moving platform in parallel through Hooke hinge, so that the six servo electric cylinders can be expanded and retracted independently. Through the coordinated
expansion and contraction of the six servo electric cylinders, compared with the fixed lower platform, the upper platform can flexibly realize the motion of the six degrees of freedom in the direction of the space.

Upper platform: used for the installation of load, and drive the load to achieve a variety of space movement. Upper hinge: a double-axis Hooke hinge structure used to connect the upper platform to the piston rod of the electric cylinder. Bottom hinge: single hook hinge structure used to connect the fixed base to the cylinder body of the electric cylinder. Lower platform: as the platform foundation, install the platform hinge.

![Diagram of six-degree-of-freedom platform](image)

Figure 1. Basic composition diagram of six degree of freedom platform.

2.2 Computer control system
PC: monitoring platform system working condition, accept the control movement command, guarantee safe and reliable platform system to complete the simulation work.

Servo control unit: it can start/stop the platform system, receive the posture control information from the upper computer, control the motion of the electric cylinder, monitor the working state of the servo motor driver, complete the fault treatment and safety protection.

Signal conditioning unit: complete the conditioning of various sensor signals, test signals and digital I/O signals related to the movement state of the platform system, as well as the driving of the servo driver.

2.3 Control software
The system control software consists of the software which works on the upper computer and the motion control computer. The software of the upper computer includes monitoring software and secondary development interface. Motion control computer software includes motion control software and logic control software.

The 6-DOF platform is mainly composed of mechanical system, control system and measurement system. The mechanical system is composed of electric platform and lifting platform, which are mainly used to provide driving force for the motion system. The control system consists of drive system, control system hardware and control system software.

The main components of the 6-DOF platform are shown in figure 2.
The parameters of the 6-dof platform designed in this paper are shown in Table 1.

Table 1. Parameters of the 6-DOF platform.

| Degree of freedom | Displacement or angular | Velocity | Acceleration |
|-------------------|-------------------------|----------|--------------|
| Trim              | +/-20deg                | +/-10deg/s | +/-10deg/s^2 |
| Heeling           | +/-20deg                | +/-10deg/s | +/-10deg/s^2 |
| Yaw               | +/-20deg                | +/-10deg/s | +/-10deg/s^2 |
| Heave(Z)          | +/-0.5m                 | +/-0.1m/s  | 1m/s^2       |
| Transverse oscillation(X) | +/-0.5m | +/-0.1m/s  | 1m/s^2       |
| Surge(Y)          | +/-0.5m                 | +/-0.1m/s  | 1m/s^2       |

3. Mechanical structure design

The upper and lower hinges are simulated and fixed in the software according to the actual installation mode. The contact surface with the copper sleeve is fixed, and the two ends of the shaft in contact with the hinge fork are applied with pressure of 2.06t. The material is 40Cr steel.

The stress distribution diagram of the front hinge fork is shown in Figure 3, and the displacement distribution diagram is shown in Figure 4. As can be seen from the figure, the maximum stress is 30MPa and the maximum displacement is 0.008mm. The material is 40Cr steel, and the ultimate stress is 780MPa.

Safety factor: 780/30 = 26.

Safety factor meets the design requirements.
The stress distribution diagram of the bearing seat is shown in figure 5, and the displacement distribution diagram is shown in figure 6. As can be seen from the figure, the maximum stress is 97.4MPa and the maximum displacement is 0.04mm. The material is 40Cr steel, and the ultimate stress is 780MPa.

Safety factor: 780/97.4=8
Safety factor meets the design requirements.

4. Force analysis of electric cylinder
Based on the Adams kinematics simulation results, the model selection of the six-DOF motion platform driving equipment is discussed.
According to the calculated size of the upper and lower hexagon of the platform, the Adams model is established as follows. During the modeling, many parts of the platform are simplified.

4.1 Pitch attitude
Stress analysis is carried out on several joint parts under the condition of pitching attitude, and the results are shown in figure 8.

Under this movement posture, the maximum expansion speed of the electric cylinder is 438mm/s, and the maximum force of the electric cylinder is 1.93t. The allowable stress of the electric cylinder is 3t, therefore, the design result is reasonable.

4.2 Roll profile
Stress analysis is carried out on several joint parts under the condition of roll profile, and the results are shown in figure 9.
Figure 9. The stress of the electric cylinder.

Under this movement posture, the maximum expansion speed of the electric cylinder is 400mm/s, and the maximum force of the electric cylinder is 0.87t. The allowable stress of the electric cylinder is 3t, therefore, the design result is reasonable.

4.3 Yaw attitude
Stress analysis is carried out on several joint parts under the condition of yaw attitude, and the results are shown in figure 10.

Figure 10. The stress of the electric cylinder.

Under this movement posture, the maximum force of the electric cylinder is 1.2t. The allowable stress of the electric cylinder is 3t, therefore, the design result is reasonable.

4.4 Lifting attitude
Stress analysis is carried out on several joint parts under the condition of lifting attitude, and the results are shown in figure 11.

Figure 11. The stress of the electric cylinder.

Under this movement posture, the maximum force of the electric cylinder is 1.68t. The allowable stress of the electric cylinder is 3t, therefore, the design result is reasonable.

5. Interference checking
When all the electric cylinders reach the limit state during the movement of the mechanism, it is the limit position of the mechanism. If the electric cylinder is extended to the limit of 1 and shortened to the limit of 0, the combination of the limit position of the mechanism is shown in the following table.

| Limit state | Cylinder state of | Cylinder state of | Cylinder state of | Cylinder state of | Cylinder state of | Cylinder state of |
|-------------|------------------|------------------|------------------|------------------|------------------|------------------|

Table 2. Limit state of platform.
The following states are the possible dangerous states: figure 12 is the state of 001100, figure 13 is the state of 010010.

6. Control algorithm

Through a large number of simulation and engineering practice, the robust control method eliminates the adverse effect caused by load disturbance outside the system, and has good load resistance and robustness. Its advantages are reflected in the following two aspects:

1) the control system presents strong robustness to uncertainties caused by time-varying, external load interference, cross-linking and nonlinear factors.

2) the control algorithm is simple and feasible with good real-time performance.

The continuous state transfer function of the six degree of freedom platform robust controller:

\[
K(s) = \frac{2.21}{2097.1526e^{-0.005} s^2 + 0.001875 s + 0.075}
\]

The initial value of the state variable is set to zero:

\[
y(k) = CG^t x(0) + \sum_{i=0}^{t} G^{t-1-i} Hu(i) + Du(k) = \sum_{i=0}^{t} G^{t-1-i} Hu(i) + Du(k)
\]  

According to the positive kinematics solution of the platform, the Angle between the axis of the upper and lower hinge is obtained by the control system, and then the cylinder length error is calculated to compensate the feedback of the encoder.

7. Conclusions

According to the development status of six degree of freedom platform, the composition and structure of six degree of freedom platform are briefly introduced in this paper. And stress analysis of key mechanical components is also carried out to ensure the design safety. On the basis of this, the motion interference inspection of the electric cylinder is carried out for different motion states to ensure the smooth operation of the 6-dof platform in each state.

This paper also introduces the control algorithm of six degree of freedom platform and provides a basic method for the design of six degree of freedom platform.

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