Modal analysis of an airborne four-claw spherical stabilized platform based on ANSYS

Shan Xue, Yanlei Gong, Jianbo Guo, Zhengbin Liu, Qiongying Lv*
Changchun University of Science and Technology, Changchun, China

*Corresponding author e-mail: 1660348815@qq.com

Abstract. In order to make the design of an airborne four-claw spherical stabilized platform better and determine whether the dynamic characteristics of the stabilized platform with new materials meet the design requirements, the three-dimensional model of the stabilized platform is established by using SolidWorks software. After reasonable simplification, the finite element model is established by importing ANSYS software. The first six natural frequencies and modes of an airborne four-claw spherical stabilized platform with new materials are obtained by modal analysis using ANSYS software. In the process of establishing the finite element model, different mesh generation methods are compared, and the mesh distortion is reduced from 0.74 to 0.38 by changing the mesh correlation and refinement. The comparison results show that the comprehensive mesh generation method can improve the quality of the mesh. The modal analysis results show that the designed four-claw spherical stabilized platform has no resonance in the frequency range of 80 MPa ~ 160 MPa, which meets the design requirements.

Key words: Stable platform, modal analysis, ANSYS analysis

1. Introduction
The airborne photoelectric stabilization platform can isolate the motion of the aircraft, output the angular signal of the frame, and track or scan according to the control command. As an important tracking and scanning equipment, airborne photoelectric stabilization platform has been widely used in various types of aircraft reconnaissance tasks, and has become an essential means of aviation reconnaissance [1, 2]. With the rise of UAV, the development of new materials and the improvement of national standards, higher requirements are put forward for the airborne photoelectric stabilization platform. In order to meet the requirements of function, stiffness and strength, it has become a new design goal and a research hotspot because of its smaller size and lighter weight.

An airborne four-jaw spherical stabilized platform with parallel structure reduces its volume. The new material PLA is adopted to make the mass lighter. However, whether its dynamic characteristics meet the design requirements needs to be verified urgently. In this paper, the digital modeling and finite element modeling of the airborne four-claw spherical stabilization platform are carried out, and the modal analysis is carried out. The first six natural frequencies of the platform are obtained to check
whether it resonates with the environmental frequencies of the aircraft and whether its dynamic characteristics meet the design requirements.

2. Digital model of an airborne four-claw spherical stabilization platform

An airborne four-claw spherical stabilization platform mainly includes control board, connection board, four-claw spherical stabilization platform frame, piezoelectric drive part and load sphere part. SolidWorks software is used to digitally model the airborne four-claw spherical stabilized platform, and the shape structure of the airborne four-claw spherical stabilized platform is obtained as shown in Fig.1.

![Figure 1](image)

**Figure 1.** The outline structure of an airborne four-claw spherical stabilized platform.

3. Establishment of finite element model for an airborne four-claw spherical stabilized platform

The SolidWorks software was used to simplify the solid model of airborne four-jaw spherical stability platform, and then imported into ANSYS15.0 software. The finite element model was established by combining shell element and solid element.

3.1. Simplified model

There are many parts of an airborne four-jaw spherical stable platform, and the connection relation is complex. So, in the case of the finite element model, it is to reduce the calculation time, to simplify the model, to reduce the calculation time. Whether the simplified model is reasonable or not is one of the keys to the correct establishment of the finite element model [3, 4].

The driving part of an airborne four-claw spherical stabilized platform is analyzed. Through analysis, if two parts are connected through a more intensive connection and have good stiffness, they are usually treated as rigid connections. If the connection between the two parts is very small and the joint has a greater flexibility effect, the joint is equivalent to a dynamic model composed of several springs, and the equivalent spring stiffness is calculated by Yoshimura integral method [4, 5]. The driving part is simplified according to this rule.

The control board of an airborne four-claw spherical stabilized platform is analyzed. It is found that the pins and circuits of all kinds of chips on the control board need a lot of calculation by ANSYS software, which takes a lot of time, but it has little influence on the static and dynamic characteristics of the whole four-claw spherical stabilized platform, so the pins and circuits of the control board are removed and simplified.

The chamfer, roundness and holes less than 2mm in diameter are removed from the model of an airborne four-claw spherical stabilized platform. The force-free parts such as azimuth axis gyroscope, pitch axis gyroscope and counterweight blocks of each axis are simplified as a whole, and the simplified model is obtained, as shown in Fig. 2.
3.2. Material selection
With the progress of science and technology, more and more new materials appear. The use of new materials in the design of various stable platforms has become a trend of modern design. A four-claw airborne spherical stabilized platform uses a new material PLA, which makes the weight lighter under the same volume and structure. The parameters of new PLA materials and commonly used aluminum alloys and structural steels are shown in Table 1.

Table 1. Parameters of selected materials.

| Number | Young's modulus E/GPa | Poisson ratio μ | Density $\rho$ $10^3$ g/mm$^3$ |
|--------|------------------------|----------------|-------------------------------|
| 7A10   | 71                     | 0.33           | 2.77                          |
| PLA    | 3.5                    | 0.35           | 1.2                           |
| Q235   | 200                    | 0.3            | 7.83                          |

3.3. Mesh generation
One of the most important steps before finite element analysis is meshing, which will directly affect the accuracy of the results [6]. The methods of mesh generation include tetrahedral mesh, hexahedral mesh, sweeping mesh, multi-area mesh, etc. On this basis, mesh refinement and subdivision can be carried out, and the quality of mesh can be further changed by changing the degree of mesh association. The finer the theoretical mesh is, the more accurate the result is. However, when the mesh is small to a certain extent, stress singularity will occur, so the refinement of the mesh should be moderate and the correlation degree of the mesh should be moderate, and the mesh correlation should be moderate. The mesh distortion degree is an important parameter to evaluate the mesh quality. The smaller the distortion degree value is, the better the mesh quality will be [7].

In this paper, two methods are used for mesh generation. One method is to use tetrahedral mesh generation method; the other is a hexahedral mesh generation method which integrates mesh refinement and mesh correlation. The two methods are used to mesh the airborne four-claw spherical stabilized platform, as shown in Fig. 3. The mesh distortion obtained by the first method and the second method is 0.74 and 0.38, respectively.

4. Modal analysis of an airborne four-claw spherical stabilized platform
The inherent characteristic of mechanical system is natural frequency. Once the natural frequency of mechanical system is determined, it will be determined. In order to avoid the damage and damage caused by resonance, it is necessary to know the natural frequency of the system so as to keep it away from the external interference frequency. Modal analysis is the most basic and important part of dynamic feature analysis. It is a modern method to study structural dynamic characteristics and a powerful tool for structural design and performance evaluation of various products. The natural frequencies, modes and relative deformations of the system can be obtained by modal analysis, so that stiffness analysis and system resonance can be avoided [5]. The purpose of modal analysis is to obtain the natural frequencies and vibration patterns of the system at the stage of product design. Meanwhile, modal analysis is also the basis of other dynamic characteristics analysis [6, 7].
Using tetrahedral mesh generation method.

(b) Comprehensive partition method based on hexahedron.

Figure 3. Schematic diagram of airborne four-claw spherical stabilization platform using different mesh generation methods.

Based on the variational principle of elasticity, the equilibrium equation of motion of the stabilized platform can be obtained by analysis:

\[ [M]\ddot{u} + [C]\dot{u} + [K]u = \{P(t)\} + \{N\} + \{Q\} \]  

Where \([M]\) is the mass matrix; \([C]\) is the damping matrix; \([K]\) is stiffness matrix; \([P(t)]\) is the vector of the external force function; \([N]\) is the nonlinear external force term vector related to \([u]\) and \([\dot{u}]\); \([Q]\) is the reaction vector of boundary constraint; \([u]\) is the displacement vector; \([\dot{u}]\) is the velocity vector; \([\ddot{u}]\) is the acceleration vector.

In order to solve the natural frequency and mode of the free vibration of the platform, that is, to stabilize the natural frequency and mode of the platform, make the external force and damping equal to 0. If we set the right-hand side of (1) equal to 0, it can get

\[ [M]\ddot{u} + [C]\dot{u} + [K]u = \{0\} \]  

The corresponding characteristic equation is

\([([K] - \omega^2[M])u = \{0\}]\)  

Where \(\omega\) is the natural frequency. Since the amplitude of the free vibration of the system cannot be zero, it can get

\([K] - \omega^2[M] = 0\)  

Solve equation (4) to obtain N roots of the polynomial: \(\omega_1, \omega_2, \ldots, \omega_N\) and N non-zero eigenvectors: \(\{\Phi_1\}, \{\Phi_2\}, \ldots, \{\Phi_N\}\). \(\omega_j\) and \(\Phi_j\) are the natural frequencies and modes of the i-th mode of the stabilized platform. Natural frequencies and modes can be used to characterize dynamic characteristics [8, 10].

ANSYS software was used to conduct modal analysis on an airborne four-jaw spherical stable platform, and the first six natural frequencies of the platform were obtained through analysis, as shown in Fig. 4, and the modes were shown in Fig. 5 to Fig.10.
Figure 4. The first six modes of an airborne four-claw spherical stabilized platform.

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 254.12         |
| 2    | 254.28         |
| 3    | 521.18         |
| 4    | 952.7          |
| 5    | 1020.0         |
| 6    | 1025.6         |

Figure 5. First-order modes of an airborne four-claw spherical stabilized platform.

Figure 6. Second-order modes of an airborne four-claw spherical stabilized platform.
Figure 7. Third-order modes of an airborne four-claw spherical stabilized platform.

Figure 8. Fourth-order modes of an airborne four-claw spherical stabilized platform

Figure 9. Fourth-order modes of an airborne four-claw spherical stabilized platform
Figure 10. Sixth-order modes of an airborne four-claw spherical stabilized platform.

From Fig. 4 to Fig. 10, the first natural frequency of an airborne four-claw spherical stabilized platform is 254.12 Hz. The environmental frequencies of all kinds of aircraft, that is, the frequencies of the main components range from 80 Hz – 160 Hz. The first natural frequency of the platform is much larger than the ambient frequency of the aircraft, so resonance will not occur, which meets the design requirements.

5. Conclusion
(1) An airborne four-claw spherical stabilization platform is designed, and its digital model is built by using SolidWorks software.
(2) The three-dimensional model of an airborne four-claw spherical stabilized platform is simplified and introduced into ANSYS software to establish the finite element model. The mesh distortion obtained by different mesh generation methods is compared. The comparison results show that the method of hexahedron partition with comprehensive refinement and correlation can improve the quality of mesh.
(3) Modal analysis is carried out for the platform with new materials, and the first six natural frequencies and modes of the platform are obtained. The results show that the first natural frequency of a four-claw airborne spherical photoelectric stabilization platform is much larger than the frequency range of the relationship, and there will be no resonance, which provides a reference for similar design.

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