Design and characteristic analysis of a four-claw spherical photoelectric stabilization platform

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Abstract. Airborne photoelectric stabilization platform is an important tracking and scanning equipment. In order to make the photoelectric stabilization platform smaller and lighter, a four-claw spherical photoelectric stabilization platform is proposed. The four-claw spherical photoelectric stabilization platform is driven by piezoelectric motors with parallel structure. SolidWorks software is used to build the three-dimensional model of the stabilized platform. After reasonable simplification, the finite element model is built in ANSYS software. Comparing different mesh generation methods in the process of establishing finite element model, the mesh distortion is reduced from 0.74 to 0.38 by changing the mesh correlation and refinement. Different materials are used to design the platform, and the mass of the platform under different materials is compared. The platform mass of the new material is 30.3% and 66.4% less than that of the other two materials. The static characteristics of the platform with new materials are analyzed, and the maximum deformation and stress of the platform are analyzed. The results show that the designed airborne spherical photoelectric stabilized platform with new materials meets the requirements of stiffness and strength, which provides a reference for the design of such platform.

Key words. Stable platform; finite element analysis; static characteristic 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 a necessary 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. Under the requirement of satisfying the function, stiffness and strength, making the volume smaller and the mass lighter has become a new design goal and a research hotspot.

In this paper, a four-claw spherical photoelectric stabilization platform is designed, which is driven by piezoelectric motors with parallel structure. It can reduce the volume and meet the function of isolating the motion of the aircraft. Digital modeling of the designed stable platform is carried out. After reasonable simplification, the finite element model is established by using finite element analysis.
software ANSYS. The airborne four-jaw spherical photoelectric stabilization platform is designed with different materials, and the mass of the platform is compared. The static characteristics of the lighter platform under different loads are analyzed. The stiffness and strength of the platform are obtained and checked to verify whether the stiffness and strength of the lighter platform meet the design requirements. The influence of different meshing methods on the finite element model is analyzed to lay a good foundation for better analysis of the stable platform.

2. Design of airborne four-claw spherical stabilization platform

2.1. Design requirements of airborne four-claw spherical stabilization platform

Airborne photoelectric stabilization platform is an important part of airborne reconnaissance system. The main requirements for its design are as follows:

(1) To realize the function. The designed airborne photoelectric stabilization platform can rotate around the pitch axis and azimuth axis.

(2) It can meet the stiffness and strength requirements of national standards. Specific requirements: No resonance occurs in 80-160 Hz, the deformation is less than 1 mm, and the strength meets the fourth strength theory.

2.2. Design and digital modeling of airborne four-claw spherical stabilization platform

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

The load sphere is the key part of the airborne four-claw spherical photoelectric stabilization platform, which mainly includes azimuth axis gyroscope, pitch axis gyroscope, optical scanning camera equipment, optical measuring equipment and corresponding counterweight. The internal structure diagram of the airborne four-claw spherical photoelectric stabilization platform is shown in Fig. 2.

The working process of the airborne four-claw spherical photoelectric stabilization platform is that the loaded sphere can rotate around the pitch axis by two symmetrical driving parts, while the other two symmetrical driving parts drive the loaded sphere so that the loaded sphere can rotate around the azimuth axis. The loaded sphere can rotate around the azimuth axis and the pitch axis at the same time, which meets the design function requirements of the airborne four-claw spherical photoelectric stabilization platform. Moreover, because the four symmetrical piezoelectric driving parts are driven at the same time, the transmission link is reduced, and the inertia, elastic deformation and reverse clearance of the intermediate link can be eliminated.

![Figure 1. Outline structure sketch of airborne four-claw spherical photoelectric stabilization platform.](image)
3. Establishment of finite element model for airborne four-claw spherical stabilized platform

SolidWorks software is used to simplify the solid model of the airborne four-claw spherical photoelectric stabilization platform. Then it is imported into ANSYS 15.0 software. The finite element model is established by combining shell element and solid element.

3.1. Simplified model

There are many parts in the airborne four-claw spherical photoelectric stabilization platform, and the connection relationship is complex. Therefore, the model is simplified in order to reduce the calculation time within the scope of meeting the calculation accuracy requirements. Whether the simplified model is reasonable or not is one of the keys to the correct establishment of the finite element model [3,4].

3.1.1. Simplified processing of piezoelectric driving part. The piezoelectric driving part of an airborne four-claw spherical photoelectric stabilization platform is analyzed. If two parts are connected through an intensive connection and have good stiffness, they are usually treated as rigid connections. If the connection of 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]. According to this rule, the piezoelectric driving part is simplified.

3.1.2. Simplified processing of piezoelectric driving part. The control board of the airborne four-claw spherical photoelectric stabilization 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. However, the static and dynamic characteristics of the whole model are little affected. Therefore, pins and circuits of the control board are removed and simplified.

3.1.3. Other simplified processing. The chamfer, roundness and holes less than 2 mm in diameter are removed from the model of airborne four-claw spherical photoelectric stabilization platform. The force-free parts such as azimuth axis gyroscope, pitch axis gyroscope and counterweight block of each axis are simplified as a whole, and the simplified model is obtained, as shown in Fig. 3.

Figure 2. Internal structure sketch of airborne four-claw spherical photoelectric stabilization platform.
3.2. Material selection
With the progress of science and technology, more and more new materials appear. The important way to achieve the design goal of lighter weight airborne four-claw spherical photoelectric stabilization platform is to use new materials, which can meet the requirements of function, stiffness and strength.

Different materials are selected for the designed four-claw spherical photoelectric stabilization platform and its mass is compared. The materials of the control board and the connecting board are kept unchanged during comparison. Aluminum alloy, structural steel and new PLA materials are used respectively for the frame and load sphere of the platform. The parameters of the three materials are shown in Table 1. The mass of platform with different materials is analyzed.

| number | Youngmodulus E/GPa | Poissonratio μ | Density ρ/10^−3mm³ |
|--------|--------------------|----------------|---------------------|
| 7A10   | 71                 | 0.33           | 2.70                |
| PLA    | 3.50               | 0.35           | 1.26                |
| Q235   | 200                | 0.30           | 7.83                |

The results show that the frame and load sphere parts are respectively made of new PLA material, aluminum alloy and steel. The mass of the platform is 0.094 kg, 0.135 kg and 0.28 kg, respectively. The mass of the airborne four-claw spherical photoelectric stabilization platform using PLA material is 66.4% less than that using steel, and the mass of the airborne four-claw spherical photoelectric stabilization platform using PLA material is 66.4% less than that using aluminium alloy.

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. But when the mesh is small to a certain extent, the stress singularity will occur, so the refinement should be moderate, and the correlation should be moderate. An important parameter for evaluating mesh quality is the distortion of mesh. The more the distortion 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 platform, as shown in Fig. 4. The mesh distortion obtained by the first method and the second method is 0.74 and 0.38.
4. Static characteristics analysis of airborne four-claw spherical stabilized platform

Static characteristic analysis is one of the most commonly and widely used methods in engineering. Static characteristic analysis is also one of the most basic analysis in platform characteristic analysis. Airborne four-claw spherical photoelectric stabilization platform is subjected to its own gravity during flight and centrifugal inertia force produced by the rotation of the loaded sphere at an angular velocity. In this paper, the static characteristics of airborne four-claw spherical photoelectric stabilization platform are analyzed based on the D'Alembert's Principle, and the static characteristics of the platform under two conditions are analyzed respectively. The first is that the platform is only subject to gravity. The second is the effect of gravity and centrifugal inertia force produced by the rotation of the loaded sphere at 80 degrees/S speed. The load diagram, deformation and stress distribution of the airborne four-claw spherical photoelectric stabilization platform under the first loading condition are shown in Fig. 5, Fig. 6 and Fig. 7. The load diagram, deformation and stress distribution of the platform under the second loading condition are shown in Fig. 8, Fig. 9 and Fig. 10.

Figure 4. Schematic diagram of a platform with different meshing methods.

Figure 5. Loading diagram of platform in the first case.

Figure 6. Deformation diagram of platform in the first case.

Figure 7. Stress diagram of platform in the first case.

Figure 8. Loading diagram of platform in the second case.
From Fig. 5 to Fig. 10, it can be seen that the deformation of the platform is 0.00108 mm and the stress is 0.084 MPa in the first case, while the deformation of the platform is 0.00108 mm and the stress is 0.084 MPa in the second case. The results show that the centrifugal inertia force has little effect on the platform; the deformation is less than 1 mm, and the rigidity of the platform meets the requirements.

Strength check: It is required that the maximum stress of the platform should be less than the allowable stress.

\[
\sigma_{\text{max}} \leq [\sigma]
\]

\[
[\sigma] = \frac{\sigma_y}{n}
\]

Among them, \(\sigma_{\text{max}}\) is the maximum stress of the platform, \([\sigma]\) is the allowable stress, \(\sigma_y\) is the yield limit of materials. The value of \(n\) is 1.22.5. For the purpose of high strength check, the value of \(n\) is 2.5. According to the fourth strength theory.

\[
\sigma_{\text{max}} = \sigma_{14} = \sqrt{\frac{1}{2} \left[ (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right]}
\]

\[
[\sigma] = \frac{\sigma_y}{n} = \frac{60}{2.5} = 24 \text{ MPa}
\]

The maximum stress of the platform is less than 0.084 MPa, which indicates that the strength of the four-claw spherical photoelectric stabilized platform with PLA material meets the design requirements.

5. Conclusion
(1) An airborne four-claw spherical photoelectric stabilization platform is designed. It is a parallel platform, which reduces the transmission link and reduces the inertia, elastic deformation and reverse clearance of the intermediate link. SolidWorks software is used to build the three-dimensional model of the platform. Steel, aluminium alloy and PLA materials are used to compare the mass of the platform. The platform mass of the new material is 30.3% and 66.4% less than that of the other materials.
(2) The finite element model of an airborne four-claw spherical photoelectric stabilization platform is established. 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) The static characteristics of the platform with new materials are analyzed. The analysis results show that the stiffness and strength of the designed four-claw spherical photoelectric stabilized platform meet the design requirements and provide a reference for similar design.
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