Modal analysis and optimization of the main frame of a spherical stable platform

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Abstract. The frame of spherical stabilized platform is the main part and the key component. The initial main frame of a spherical stabilized platform is designed. In order to make the main frame of a spherical stable platform lighter and more rigid, the improved design is carried out. The SolidWorks software is used to conduct 3d model for the initial design and the improved design, and to compare the quality of the two designs. The finite element model of the two designs is carried out by using ANSYS software, and then the modal analysis is carried out to obtain the first natural frequency of the main frame. The comparison results show that the improved design is lighter than the initial design, the first-order natural frequency is improved, the corresponding stiffness is greatly improved, and the resonance does not occur in the frequency range of 80Hz ~ 160Hz, which meets the design requirements. Finally, the improved four-jaw design is adopted to provide a reference for similar platform design.

Key words. Main frame, dynamic characteristic analysis, structural design.

1. Introduction
Airborne photoelectric stabilized platform can be isolated from the movement of the aircraft, complete tracking and scanning task, has become a necessary method of aerial reconnaissance. A spherical stabilized platform is an airborne photoelectric stabilized platform driven by piezoelectric motor. With the progress of science and technology, higher requirements are put forward for the design of airborne photoelectric stabilization platform [1]. How to make it lighter in weight and better in all kinds of characteristics under the condition of satisfying the function has become the difficulty of design. As for the main frame of a spherical stable platform, how to make its mass lighter and stiffness greater has become a research hotspot.

In this paper, the main frame of a spherical stabilized platform is initially designed and improved. The two designs are modeled digitally using SolidWorks software, and the quality of the two designs is compared. The finite element models of the two designs are established and the modal analysis is carried out. The first order natural frequencies of the two designs are obtained. Comparing the first-order natural frequencies of the two designs, it is verified that the improved design improves the first-order natural frequencies and stiffness.
2. The design of the main frame of a spherical stable platform

Main body of a spherical stable platform framework mainly includes the framework and driving part. The initial design and the improved design of the main frame of a spherical stable platform are carried out respectively. The initial design and the improved design are modeled digitally by using SolidWorks software. The external structure of the two designs is shown in Fig. 1 and Fig. 2, and the internal structure is shown in Fig. 3 and Fig. 4.

![Figure 1](image1.png)  
*Figure 1. Outline structure sketch of initial design.*

![Figure 2](image2.png)  
*Figure 2. The outline structure diagram of the improved design.*

![Figure 3](image3.png)  
*Figure 3. Internal structure schematic diagram of initial design.*
3. Establishment of finite element model for main frame of a spherical stabilized platform

SolidWorks software is used to simplify the initial design and improved design of the main frame of a spherical stabilized platform, and then ANSYS software is imported to establish the finite element model by combining shell element and solid element.

3.1. Simplified model

The driving part of the main frame of a spherical stabilized platform is analyzed and simplified. 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 of 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 [2, 3]. According to this rule, the driver part is simplified.

The chamfers, rounded corners and holes less than 2 mm in diameter are removed from the main frame model, and the simplified model is finally obtained, as shown in Fig. 5 and Fig. 6.

3.2. Material selection

With the progress of science and technology, the new material has appeared more and more. The use of new materials in the design of various stable platforms has become a trend of modern design. The main frame of a spherical stabilized platform adopts a new material PLA, which makes the mass of the platform lighter under the same volume and structure. The parameters of new PLA materials and commonly used aluminium alloys are shown in Table 1. New material PLA is used in both designs and quality analysis is carried out. The analysis results are shown in Fig. 7 and Fig. 8 below.
Table 1. Parameters of selected materials.

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

From figure 7 and figure 8, the body of the initial design framework of quality is 0.04 kg, improve the quality of design main body frame is 0.037 kg. The improved design is 8% lighter than the original design.

3.3. Mesh generation

One of the most important steps before finite element analysis is meshing, which will directly affect the accuracy of calculation results. 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. It is theorized that finer results are more accurate, but stress singularity occurs when the mesh is small, so that the refinement of the grid is moderate and the degree of relevance of the grid is moderate [4].

In this paper, a hexahedral mesh generation method is proposed, which integrates mesh refinement and mesh correlation. The finite element models of the initial design and the improved design are shown in Fig. 9 and Fig. 10.
4. Modal analysis of the main frame of a spherical stable platform
Modal analysis is a modern method to study the dynamic characteristics of structures. It is 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. The corresponding stiffness of structures with large first-order natural frequencies is also large [5].

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

$$[M][\ddot{u}] + [C][\dot{u}] + [K][u] = [P(t)] + [N] + [Q]$$  \hspace{1cm} (1)

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

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

(2)

The corresponding characteristic equation is

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

(3)

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

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

(4)

Solve equation (4) to obtain N roots of the polynomial: \( \omega_1, \omega_2, \ldots, \omega_n \) and N non-zero eigenvectors: \( \{\Phi_1\}, \{\Phi_2\}, \ldots, \{\Phi_n\} \). \( \omega_i \) and \( \Phi_i \) 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 [6, 9].

The first six natural frequencies of the main frame of a spherical stabilized platform are shown in Fig. 11 and Fig. 12. The first modes of the initial design and the improved design are shown in Fig. 13 and Fig. 14, respectively.

| Mode | Frequency [Hz] |
|------|---------------|
| 1 1 | 159.45        |
| 2 2 | 236.23        |
| 3 3 | 471.62        |
| 4 4 | 771.15        |
| 5 5 | 1140.8        |
| 6 6 | 1385.5        |

**Figure 11.** Schematic diagram of the initial design of the sixth natural frequency

| Mode | Frequency [Hz] |
|------|---------------|
| 1 1 | 314.86        |
| 2 2 | 314.95        |
| 3 3 | 705.27        |
| 4 4 | 852.92        |
| 5 5 | 1281.8        |
| 6 6 | 1383.2        |

**Figure 12.** Schematic diagram of the improved design of the sixth natural frequency.
Figure 13. Schematic diagram of the first mode of the initial design

Figure 14. Schematic diagram of the first mode of the improved design

As can be seen from Figs. 11 and Fig. 12, the first natural frequency of the original design of the main frame is 159.45 Hz, while that of the improved design is 314.86 Hz. The first natural frequency of the improved design is much higher than that of the original design, and the corresponding stiffness is also greatly improved. The first natural frequency of the improved design is much larger than that of the concerned frequency from 80 Hz to 160 Hz, and there is no resonance in the concerned frequency range, which meets the design requirements.

5. Conclusion
The initial design and improved design of the main frame of a spherical stabilized platform are carried out. SolidWorks software is used for digital modeling.

The new material PLA is used in the initial design and the main frame of the improved design, and their quality is compared. The results show that the improved design is lighter.

Finite element models are established for both initial design and improved design, and modal analysis is carried out. The sixth-order natural frequencies and modes of the two designs are obtained through analysis. Comparing the first-order natural frequencies of the two designs, the results show that the first-order natural frequencies of the improved design are higher, the stiffness is greater, and there is no resonance in the concerned frequencies, which meets the design requirements.
The improved design of the main frame of a spherical stabilized platform has lighter weight and greater stiffness, which provides a reference for the design of similar main frame.

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