Design and multi-body dynamics analysis of a four-claw spherical stabilization platform based on Adams

Shan Xue, Zhengbin Liu, Zhen Zhang, Guangqing Li, Qiongying Lv*
Changchun University of Science and Technology, Changchun, China

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

Abstract. Airborne photoelectric stabilization platform is one of the most effective devices to isolate aircraft motion from tracking and scanning equipment. In order to make the airborne photoelectric stabilization platform lighter in weight and better in performance, a four-claw spherical stabilization platform is designed. The multi-body dynamic analysis of the four-claw spherical stabilized platform is carried out to verify whether the designed platform meets the functional requirements, that is, whether the four-claw spherical platform can isolate the movement of aircraft and whether the spherical platform can rotate around the pitch axis and azimuth axis. SolidWorks software is used to build a three-dimensional model of a four-claw spherical stabilized platform. Then simplify the three-dimensional model of the platform, import Adams software, carry out multi-body dynamic analysis of a four-claw spherical stabilized platform, verify whether the platform can meet the function. The analysis results show that the designed four-claw spherical stabilized platform can isolate the motion of the aircraft and rotate around the azimuth axis and pitch axis to meet the function, which provides a reference for the design of similar platforms.

Keywords. spherical turntable; multi-body dynamics analysis of Adams

1. Introduction
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 aerial reconnaissance [1]. 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. With the development of science and technology, the development of new materials and the improvement of national standards, the design of airborne photoelectric stabilization platform requires lighter weight, smaller volume and better performance [2]. How to design the platform to make it lighter, smaller and meet the functional requirements has become a research hotspot.

In this paper, an airborne four-claw spherical stabilization platform is designed, which is driven by piezoelectric motors in parallel. It can reduce the volume and weight by using new materials. But whether the platform can meet the design requirements, that is, whether the platform can rotate around the azimuth axis, around the pitch axis, and around the azimuth axis and the pitch axis, needs to be verified. The platform is modeled by SolidWorks software. Then, the model is simplified and imported into Adams software for multi-body dynamics analysis. After the platform is driven, the motion of the
platform is analyzed to lay a good foundation for better analysis and design of stable platform.

2. Design of a four-claw spherical stabilized platform
A four-claw spherical stabilization platform is an airborne photoelectric stabilization platform. Its function design requires that the designed platform can isolate the movement of the aircraft during the operation of the aircraft. Specific requirements: Driven by piezoelectric motor, the load sphere can rotate around the azimuth axis, around the pitch axis, and around both the azimuth axis and the pitch axis. The platform can rotate 0° ~ 360° around the azimuth axis, - 60° ~ 60° around the pitch axis, and can rotate around both axes at the same time.

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

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

The working process of a four-claw spherical stabilization platform is that the loaded sphere can rotate around the pitch axis by driving the sphere with 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 load sphere can rotate around the azimuth axis and pitch axis at the same time, which meets the functional design requirements of a four-claw spherical stabilized platform. 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. Schematic chart of shape structure of a four-claw spherical stabilized platform.

Figure 2. Schematic diagram of internal structure of a four-claw spherical stabilized platform.
3. **Model simplification of a four-claw spherical stabilized platform**

In the simulation of multi-body dynamic system, it is usually necessary to simplify the multi-body model of the solid system first, then automatically generate the dynamic model, and finally, accurately solve the dynamic model [3]. The three-dimensional model of a four-claw spherical stabilized platform is simplified. The simplified model is shown in Fig. 3.

![Figure 3. Simplified model sketch of a four-claw spherical stabilized platform.](image)

4. **Multi-body dynamics simulation analysis of four-claw spherical stabilized platform**

The simplified model of a four-claw spherical stabilized platform is imported into the multi-body dynamic analysis software Adams for simulation analysis.

4.1. **Material selection**

With the progress of science and technology, more and more new materials appear. In order to design the spherical stabilized platform better, the weight of the platform should be lighter to meet the requirements of stiffness and strength. In order to lighten the weight of a four-claw spherical stabilized platform, a new material PLA is used. The parameters of the new material PLA are shown in Table 1.

| number | Youngmodulus E/GPa | Poissonratio μ | Density ρ/10^{-3}mm^3 |
|--------|---------------------|----------------|-----------------------|
| PLA    | 3.50                | 0.35           | 1.26                  |

4.2. **Adding motion pairs**

Before using Adams software to carry out multi-body dynamics simulation analysis, it is necessary to add corresponding motion pairs [4,7] to the system. A four-claw spherical stabilized platform is driven directly by piezoelectric motor. Four symmetrical piezoelectric parts and load sphere parts are simulated by adding corresponding ball pairs.

4.3. **Simulation analysis**

A four-claw spherical stabilized platform is simulated by using Adams software.

(1) The simulation of a four-claw spherical stabilized platform rotating independently around the azimuth axis is carried out. The motion state diagram of the loaded sphere rotating around the azimuth axis for one cycle at 360 degrees is shown in Fig. 4 to Fig. 7, the velocity detection diagram of the sphere rotating around the azimuth axis is shown in Fig. 8, the force diagram of the contact point between the driving foot and the driven sphere when the sphere rotates around the azimuth axis is shown in Fig. 9.
**Figure 4.** Motion state diagram of a sphere rotating 1/4 cycles around azimuth axis.

**Figure 5.** Motion state diagram of a sphere rotating 2/4 cycles around azimuth axis.

**Figure 6.** Motion state diagram of a sphere rotating 3/4 cycles around azimuth axis

**Figure 7.** Motion state diagram of a sphere rotating 1 cycle around azimuth axis

**Figure 8.** Velocity detection diagram of sphere rotating around azimuth axis.
Figure 9. Force diagram of contact point between driving foot and driven ball when sphere rotates around azimuth axis.

From the analysis of Fig. 4 to Fig. 9, it can be concluded that the loaded sphere of a four-claw spherical stabilized platform can rotate $0^\circ \sim 360^\circ$ around the azimuth axis independently and meet the functional design requirements.

(2) The simulation of a four-claw spherical stabilized platform rotating independently around the pitch axis is carried out. The motion state diagram of the load sphere when it rotates around the pitch axis $+ 60$ degrees is shown in Fig. 10 and Fig. 11, the velocity detection diagram is shown in Fig. 12, and the force diagram of the contact point between the driving foot and the driven sphere is shown in Fig. 13. The motion state diagram of the load sphere rotating around the pitch axis at $-60$ degrees is shown in Fig. 14 and Fig. 15, the velocity detection diagram is shown in Fig. 16, and the force diagram of the contact point between the driving foot and the driven sphere is shown in Fig. 17.

Figure 10. Initial state diagram of sphere rotation around pitch axis

Figure 11. Motion state diagram of sphere rotating around pitch axis $+ 60$ degrees.

Figure 12. Velocity detection chart of the sphere rotating around the pitch axis
Figure 13. Force diagram of contact point between driving foot and driven ball when sphere rotates around pitch axis.

Figure 14. Initial state diagram of sphere rotation around pitch axis.

Figure 15. Motion state diagram of a sphere rotating - 60 degrees around the pitch axis.

Figure 16. Velocity Detection Chart of the Sphere Rotating around the Pitch Axis.

Figure 17. Force diagram of contact point between driving foot and driven ball when sphere rotates around pitch axis.
From the analysis of Figs. 10 to Fig. 17, it can be concluded that the loaded sphere of a four-claw spherical stabilized platform can indeed rotate around the pitch axis ± 60 degrees independently under the driving force, which meets the functional design requirements.

(3) A four-claw spherical stabilized platform is simulated to rotate around both pitch and azimuth axes. The motion state diagram of the load sphere rotating 60 degrees around the azimuth axis and the pitch axis is shown in Fig. 18 and Fig. 19, the velocity detection diagram is shown in Fig. 20, and the contact force diagram is shown in Fig. 21.

Figure 18. Initial rotation chart of loaded sphere

Figure 19. Motion state diagram of loaded sphere rotating 60 degrees around azimuth and pitch axis at the same time

Figure 20. Velocity detection diagram of Loaded sphere rotating around azimuth and pitch axis at the same time.

Figure 21. Force diagram of contact point of load sphere rotating around azimuth axis and pitch axis at the same time

From the analysis of Fig. 18 to Fig. 21, it can be concluded that the load sphere of a four-claw spherical stabilized platform can indeed rotate around the pitch axis and azimuth axis at the same time, which meets the functional design requirements.
5. Conclusion
(1) A four-claw spherical stabilized platform is designed. SolidWorks is used for three-dimensional model.
(2) The model of a four-claw spherical stabilized platform is simplified and analyzed by multi-body dynamics software Adams. Whether the load sphere of a four-claw spherical stabilized platform can rotate independently around the azimuth axis, independently around the pitch axis and simultaneously around the azimuth axis and the pitch axis is analyzed. The analysis results show that the platform meets the functional design requirements.

References
[1] Ping Wang, Guoyu Zhang, et al. Topological optimization design of the inner frame of airborne photoelectric platform [J]. Journal of Mechanical Engineering, 2014, 50 (13): 0135-0141.
[2] Shan Xue, Xianyu Meng, et al. Design and characteristic analysis of lightweight shipborne radar stabilization platform [J]. Manufacturing Automation, 2016, 38(10), 0133-0138.
[3] Jungang Wang, Hongkui Jiang, et al. Multi-body dynamics simulation and analysis of ball screw pair performance [J]. Combination machine tools and automatic processing technology, 2016, (2). 0023-0025.
[4] Shan Xue, Guohua Cao, et al. Dynamic characteristics analysis of turnplate, a key component of a photoelectric radar stabilization platform [J]. Applied Optics, 2011, 32 (6): 1067-1071.
[5] Quanchao Li, Songnian Tan and et al. Frame structure design and analysis of an infrared camera stabilization platform [J]. Infrared technology, 2016, 38 (9): 0728-0732.
[6] Shan Xue, Guohua Cao, et al. Modal analysis and optimization of an inner rotor photoelectric radar stabilization platform [J]. Optical technology, 2011, 37 (5): 0562-0565.
[7] Meng Han. Research on Parallel Stabilization Platform Technology [D]. Nanjing: Nanjing University of Technology, 2015.
[8] Zhongyu Liu, Tao Zhang, et al. Structural optimization design of photoelectric stabilized platform reference frame for ultra-small UAV [J]. Journal of Nanjing University of Aeronautics and Astronautics, 2013, 45 (1): 0104-0109.