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Design And Simulation Of An Air Floating Platform With Zero Gravity Self-adjusting

Li Duanling[1*,2*], Fu Jincai[1*], Li Lin[3], Han Jiacheng[1], Li Bing[4]

1.Beijing University of Posts and Telecommunications, Beijing 100876, China
2. Shaanxi University of Science and Technology, Xi'an 712000, China
3. Beijing Institute of Spacecraft System Engineering, Beijing 100094, China
4. Harbin Institute of Technology, Shenzhen 518055, China

duanlingli@bupt.edu.cn, buptfujincai@163.com

***Abstract* - With the rapid development of space exploration, the performance of spacecraft is increasingly demanded. So, on the ground, we need to simulate the zero gravity environment and perform performance tests on the satellite antenna deployment system. In response to this demand, a kind of zero gravity self-adjusting air floating platform has been designed. The composition and principle of the air floating platform have been elaborated, and the performance of the platform has been measured and analyzed. The platform can realize automatic levelling and own high levelling precision and fast speed. It is a good simulation of the ground zero gravity environment and can effectively evaluate the simulation results.**

Index Terms - Air Floating Platform, Self-adjustment, Zero Gravity Environment

I. INTRODUCTION

In space, the spacecraft is in a zero-gravity environment [1][2][3]. The satellite antenna panel is not affected by gravity, and the connection hinge between antenna and antenna will not generate friction [4]. Before liftoff, the crew tests the system on the ground facing the satellite's antenna panel, which is affected by gravity, creating extra stress at the hinge. This will directly affect the accuracy of ground test results [5][6]. Therefore, it is urgent to design a zero gravity air floating platform, which can be applied to the test of antenna expansion system.

The earliest recorded air floating platform traced back to the literature is a three degrees of freedom air floating platform developed by the US Army [7]. The development of air floating platform technology has matured to this day and many air floating platforms with multiple degrees of freedom have emerged. The DSACSS system developed by Virginia Tech contains two air floating platforms owning three degrees of freedom [8][9], which are desktop and dumbbell structures respectively [10]. Two sets of air floating simulation test systems developed by the US Naval Postgraduate Institute, TASS I and TASS II, are three degrees of freedom systems that use spherical air bearing to achieve low-friction three-axis rotational motion [11]. In addition, the Massachusetts Institute of Technology and the Georgia Institute of Technology in the United States have successfully developed an air floating simulation test system with three degrees of freedom [12][13]. NASA Jet Propulsion Laboratory has developed a five degrees of freedom air buoyancy simulation test system, Formation Control Testbed, in which the platform moves with three planar and one spherical bearing. The lab is building a six degrees of freedom floating platform, which is driven vertically by an electric motor to move up and down.

The air floating platform generally simulates the zero gravity environment in space by adjusting the position of the center of mass. The air floating tables in the DSACSS system change the center of mass of the air floating table by moving the adjustment block mounted on the linear actuator. The adjustment balance of the TASS I of the US Naval Postgraduate School is divided into coarse and fine adjustments and has high adjustment accuracy [14].

Cao Xibin and others from Harbin Institute of Technology in China built a ground-based air flotation device, which includes air-conditioned propulsion system, gas cylinders and counterweight blocks [15]. In addition, the small satellite attitude control simulation system jointly developed by Harbin Institute of Technology and the university of Bremen, Germany, adjusts the center of mass of the air floating platform through the slider on the umbrella support rod, making it coincide with the rotation center [16].

The currently developed air floating platform is mainly used for ground simulation experiments of space vehicles and generally has high degree of freedom. This results in a large size, high mass, high cost, and complex jet system and actuator. For the new generation of satellite antenna deployment system, SAR, it consists of 12 antenna plates with 24 sets of air legs, and the deployment system is very complex. This requires that the air floating platform should have the characteristics of small size, light weight, simple structure and easy control. At the same time, the platform only needs to have two translational degrees of freedom in the vertical direction and the thickness direction of the antenna plate. The air floating platform used in the antenna development experiment in China can only realize the rise and fall of the vertical height and this progress is not controlled by the precise control system. As a result, in the process of adjustment and balance of several air floating platforms, due to the serious coupling between the platforms, the adjustment work is huge, and the precision of adjustment and balance cannot be guaranteed.

In view of this, a new kind of zero gravity self-adjusting air floating platform with two degrees of freedom, which is specially used for the performance test of the satellite antenna deployment system on the ground through the vertical direction and the translation of the antenna plate thickness direction, has been designed [17][18]. Adjust the center of mass of the antenna panel to eliminate excess stress at the joint hinge. We

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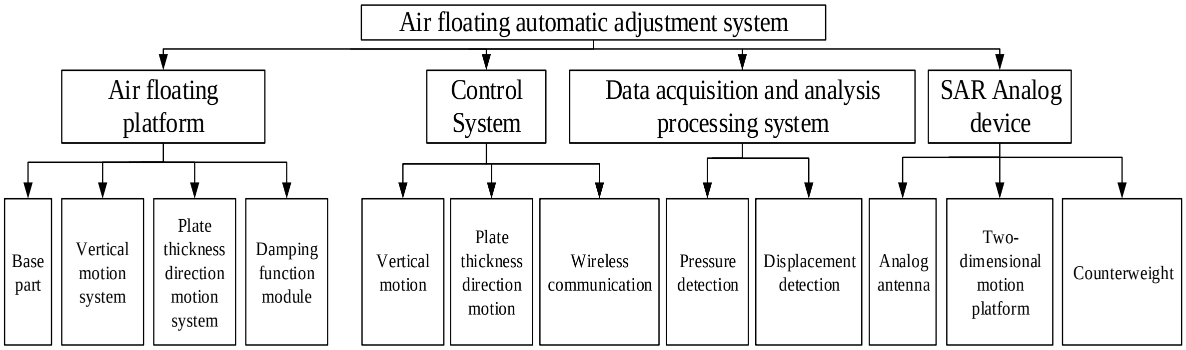

Fig. 1 System composition diagram

turn the manual adjustment method into program automatic control, which greatly improves the accuracy of the adjustment process and the adjustment speed. The whole system can calculate the unloading efficiency of the antenna weight based on the final leveling result.

II. Helpful Hints

The automatic air float adjustment system is composed of air float platform, control system, data acquisition and analysis processing system and SAR antenna tooling. The system composition is shown in Fig. 1, and the air floating platform is shown in Fig. 2. There are two motors in the platform. One drives the screw to adjust the height in the vertical direction, and the other drives the top horizontal module to adjust the position in the direction of the thickness of the antenna panel. The pressure sensor and laser displacement sensor are installed in the air floating platform, which provide parameters for the leveling of the control system. The SAR antenna fixture includes a two-dimensional motion platform, which can realize the movement of antenna panel direction and plate thickness direction, so as to change the centroid position of the fixture and realize the simulation of the actual antenna.

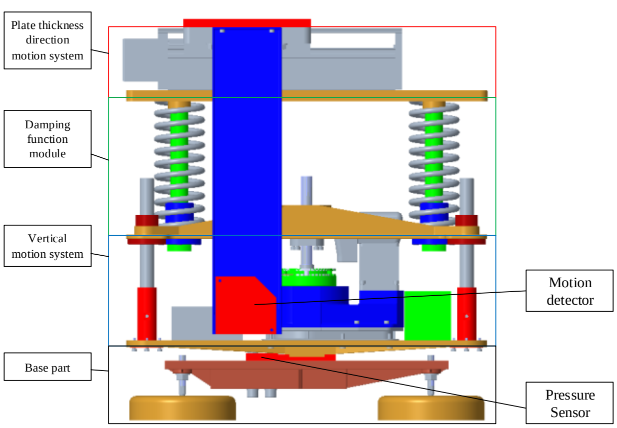

Fig. 2 Three-dimensional diagram of air floating platform

A. Air floating platform design

The whole air floating platform mainly consists of four parts: the base part, the vertical direction movement module, the shock absorption function module and the plate thickness direction movement module. The pressure sensor is installed in the base part and the total weight of the part above the pressure sensor is measured.

In order to improve the safety of satellite antenna ground test, it is necessary to control the height of air floating platform strictly and reduce the center of gravity of the whole adjusting system. Therefore, in the vertical motion module, the motor shaft is arranged parallel to the screw shaft. Considering that the air floating platform needs to be adjusted in the height direction, synchronous belt transmission is selected between the motor shaft and the screw shaft to ensure the transmission accuracy of the whole adjustment process.

Since the single satellite antenna panel weighs 300kg, in order to prevent the screw from reversing when the motor is power off, on the one hand, a magnetic powder brake for power off braking needs to be added on the screw shaft. On the other hand, spring damping module is added to protect the rigid parts in the platform from damage. In practice, the center of mass of the satellite antenna panel is almost impossible to be located in the geometric center of the panel, which will generate a large deviation load on the air floating platform. In order to prevent the lead screw in the vertical direction movement module from getting stuck, it is necessary to add anti-bias load part in the module, use four guide columns to share the bias load, and ensure that the lead screw nut always moves in the vertical direction.

B. Working principle

As shown in Fig. 3, the air flotation automatic adjustment system supports a SAR antenna with two air floating platforms. Among them, S_1 and S_2 are the heights measured by the displacement sensor. K_1 and K_2 are the distance between the lower surface of the displacement sensor and the upper surface of the platform. L is the height of the antenna installation. And D is the distance from the connection hinge to the lower surface of the antenna.

In the fully leveled state, the lower surface of the antenna panel is completely horizontal and there is no excess stress at the mounting hinge. At this time, the sum of the readings F_1 and F_2 of the pressure sensor on the air floating platform below each antenna should be equal to the sum of the weights G of the upper part of the pressure sensor. At this time, the height relationship needs to satisfy (1).

$$L = D + K_1 + S_1 = D + K_2 + S_2 \tag{1}$$

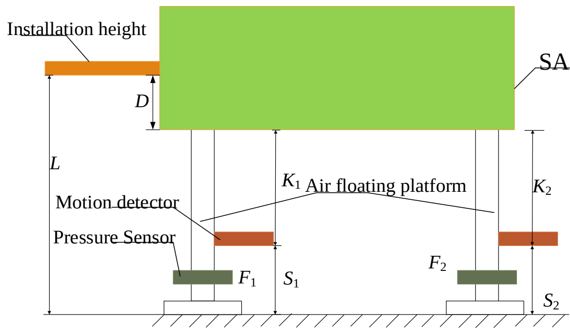

Fig. 3 Antenna installation diagram

The height of the air floating platform is adjusted by the vertical direction motion system to satisfy (1), and the force relationship between the antenna panel and the air floating platform is as shown in Fig. 4, where C is the centroid position of the antenna panel, A and B are the center positions of the air floating platform, , and the *yOz* plane is the plane of the antenna panel. After leveling, the height of the air floating platform is h_0. Calculate the moments of the coordinate axes of F_1, F_2, and G, respectively, as is in (2). The moment of the entire force system to the y-axis is not zero, and the torque balance cannot be achieved, and the stress is generated at the hinge of the antenna panel.

This indicates that only the adjustment of the height direction of the air floating platform cannot achieve the leveling of the antenna, and it is also necessary to increase the x-axis direction, that is the adjustment in the thickness direction of the antenna plate. We need to adjust the center of mass of the antenna panel to the plane on the center of the two screws.

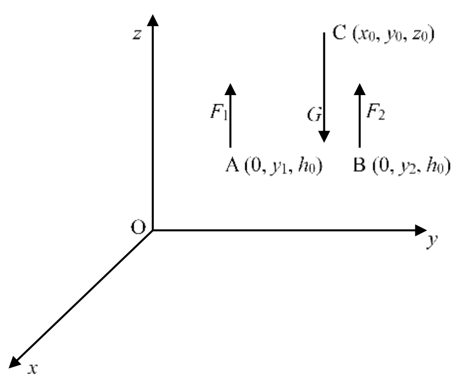

Fig. 4 Force analysis chart after height direction adjustment

$$\begin{cases} M_x(\boldsymbol{F_1}) = y_1F_1,\ M_y(\boldsymbol{F_1}) = 0,\ M_z(\boldsymbol{F_1}) = 0 \\ M_x(\boldsymbol{F_2}) = y_2F_2,\ M_y(\boldsymbol{F_2}) = 0,\ M_z(\boldsymbol{F_2}) = 0 \\ M_x(\boldsymbol{G}) = y_0G,\ M_y(\boldsymbol{G}) = -x_0G,\ M_z(\boldsymbol{G}) = 0 \end{cases} \quad (2)$$

Use the plate thickness direction motion module to adjust the support position of the air floating platform. During the adjustment process, the position of the centroid of the antenna does not change, but the position of A and B is changed. The force analysis is shown in Fig. 5. The spatial force system is also analyzed to obtain the moments of the respective forces on the coordinate axes, as is in (3). At this time, the center of mass of the antenna panel is located on the plane where the support centers of the two air floating platforms are located, and the two supporting forces don't have excess torque at the center of mass of the antenna.

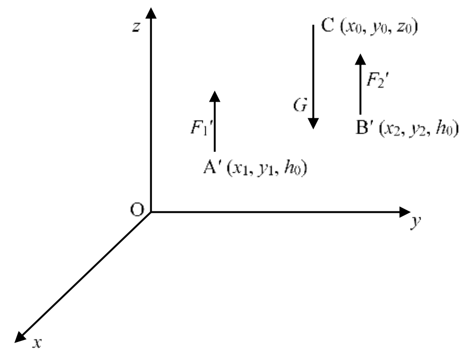

Fig. 5 Stress analysis after adjustment of plate thickness direction

$$\begin{cases} M_x(\boldsymbol{F_1'}) = y_1F_1',\ M_y(\boldsymbol{F_1'}) = -x_1F_1',\ M_z(\boldsymbol{F_1'}) = 0 \\ M_x(\boldsymbol{F_2'}) = y_2F_2',\ M_y(\boldsymbol{F_2'}) = -x_2F_2',\ M_z(\boldsymbol{F_2'}) = 0 \\ M_x(\boldsymbol{G}) = -y_0G,\ M_y(\boldsymbol{G}) = x_0G,\ M_z(\boldsymbol{G}) = 0 \end{cases} \quad (3)$$

In this way, the force balance equation and the moment balance equation are obtained, as is in (4).

$$\begin{cases} F_1' + F_2' = G \\ y_1F_1' + y_2F_2' - y_0G = 0 \\ -x_1F_1' - x_2F_2' + x_0G = 0 \end{cases} \quad (4)$$

Solving the equations yields the relationship between F_1', F_2', and x_1, x_2, as is in (5). After the leveling is completed, the supporting force of the air floating platform is determined by its relative mounting position with the antenna panel and the position of the center of mass, and is not affected by the offset of the center of mass in the thickness direction. The adjustment of the air floating platform in the thickness direction satisfies the relationship in (5), that is, the supporting force of the two air floating platforms is in the same plane as the antenna gravity.

$$\begin{cases} F_1' = \frac{y_2 - y_0}{y_2 - y_1}G \\ F_2' = \frac{y_0 - y_1}{y_2 - y_1}G \\ (y_2 - y_0)(x_0 - x_1) = (y_0 - y_1)(x_0 - x_2) \end{cases} \quad (5)$$

III. Simulation and Performance Analysis

A. *Anti-offset experiment*

On the one hand, the air floating platform needs to be adjusted in the direction of the antenna plate thickness. On the other hand, the entire air-floating platform relies only on the vertical screw in the vertical direction moving module to support, which will cause the antenna to act on the platform pressure. It will deviate from the center axis of the platform itself, that is, the vertical axis of the screw. In order to prevent the screw from being jammed due to large eccentric load, the vertical direction motion module utilizes the cooperation of four guiding columns and linear bearings to share a certain eccentric load, ensuring smooth and smooth transmission of the ball screw.

In order to verify the anti-offset capability of the vertical direction motion module, a simple anti-offset experimental platform was designed. The experimental platform is shown in Fig. 6.

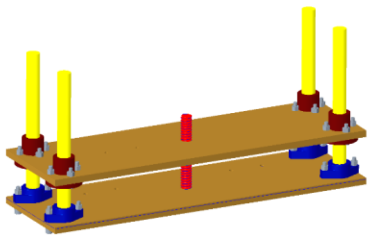

Fig. 6 Anti-offset experimental platform

The anti-offset experimental platform is a simplification of the vertical direction motion module of the air floating platform, and also includes two bearing plates, four guiding columns, guiding column supports and linear bearings. The driving part of the experimental platform replaces the deceleration part in the air floating platform with a screw. During the experiment, fix the lower bearing plate on the base or the ground, load the end of the upper bearing plate, and then turn the screw. Observe the motion of the experimental platform after a certain eccentric load, and measure the displacement of the upper bearing plate to the horizontal plane.

The load was loaded at one end of the anti-offset experimental platform, and the simulated platform was subjected to the eccentric load. Then the platform was analyzed using Ansys software. The simulation results are shown in Table 1. In the first experiment, the simulation results show that the maximum strain of the upper bearing plate is 0.231mm. The simulation results of the second experiment show that the maximum strain of the upper bearing plate is also 0.231mm. It can be seen that the friction between the guiding column and the linear bearing has no significant influence on the anti-offset capability of the vertical moving module. In the third experiment, the simulation results show that the maximum strain is 0.199mm. It can be seen that the size of the eccentric load will significantly affect the strain of the platform.

TABLE 1
Simulation result table

	Coefficient of friction	Load (N)	Maximum strain(mm)
First group	0.005	300	0.231
Second group	0	300	0.231
Third group	0	200	0.199

Through three different simulation experiments, the friction between the guide column and the linear bearing has no effect on the anti-offset capability of the vertical moving module, and the magnitude of the eccentric load has a great influence on it. Next, through the physical experiment of the anti-offset experimental platform, it is verified whether the platform can play the role of anti-offset under certain strain conditions and ensure the normal movement of the moving module in the vertical direction.

In the physical experiment, the strain condition of the upper bearing plate is represented by the change in the distance between the two bearing plates (near the loading end). During the experiment, the experimental platform was fixed on the table top, and then a load of 600N was applied to one end of the upper bearing plate, and the variation of the distance between the two bearing plates before and after loading was measured. Each time a set of data is measured, the screw is screwed, and the screw drives the upper and lower forces to move on the plate to change the distance between the two plates to measure a larger set of data. A total of 4 sets of data were measured in the experiment, and the final 4 sets of experimental data are shown in Table 2.

TABLE 2
Anti-offset test result table

	Pre-load spacing (mm)	Post-loading spacing (mm)	Spacing change (mm)
First group	170.10	169.51	0.59
Second group	195.52	194.82	0.70
Third group	196.56	195.87	0.69
Fourth group	143.15	140.30	2.85

According to the data in Table 1, the fourth group of data deviates greatly from the other three groups of data and is not included in the analysis. From the analysis of the results of the first three groups, it can be seen that when the anti-offset experimental platform bears a load of 600N at one end, the distance between the two plates changes to about 0.65mm. In the experiment, the anti-offset experimental platform can still achieve the upper and lower translation of the upper bearing force by screwing the screw in this case, and the moving process remains stable.

Through the analysis of the results of Ansys simulation and physical experiments, the anti-offset capability of the vertical moving module is not affected by the friction between the guide column and the linear bearing. When the load of 600N is applied at one end and the maximum strain of the platform 2 reaches 0.65mm, the vertical direction motion module can still be driven by the screw to make the platform 3 move smoothly up and down without the screw being stuck.

B. Performance simulation and precision accounting

The air bearing platform has a large bearing capacity, and it is necessary to control the buffering time of the damping function module as much as possible to improve the overall air floating platform adjustment speed. According to the existing design, the experimental model of the damping function module is established. The spring elasticity coefficient of the module is k=20N/mm, and the simulated load is 150kg. The displacement, velocity and acceleration curves of the platform 1 are shown in Fig. 7 in the state where the damping spring has no preload. It can be observed that the vibration range of the platform 1 in the vertical direction has been reduced to about 1 mm at 15s after loading the 150kg weight, and the speed is also substantially close to zero. At this point, the damping function module has completed the damping function and can start preparing for the next vertical adjustment.

When the air-floating platform is adjusted in the vertical direction, the acceleration time of the motor that drives the lead screw is 0.75s, the positioning time is 3s, and the damping time of the damping function module in the simulation is 15s, which can calculate the height of the air floating platform. The adjustment in the direction takes 18.75s, and the time for a single adjustment is much lower than the manual adjustment.

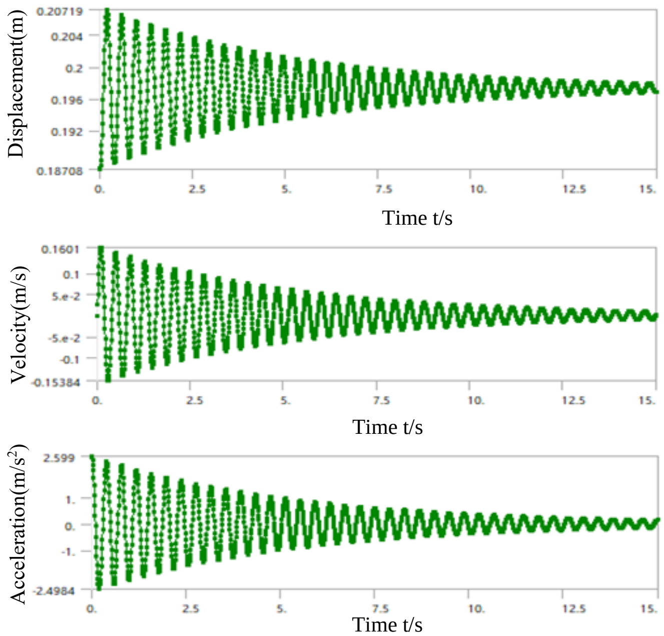

Fig. 7 Top platform displacement, velocity, acceleration curve

The lead screw lead error is 5μm, the stepping motor positioning accuracy is 0.03mm, and the selected linear module repeat positioning accuracy is ±0.02mm. It can be calculated that the zero gravity self-adjusting air floating platform is the largest in the vertical direction when adjusting. The positioning error is 0.035mm, and the maximum positioning error in the thickness direction of the antenna plate is 0.05mm. Compared with manual adjustment, it can only rely on the naked eye and measuring tools to improve the accuracy. The air-floating platform designed in this paper will greatly improve the adjustment accuracy, thus ensuring the high-gravity unloading efficiency of the whole air-floating platform.

IV. Conclusions

According to the application scenario of the air-floating platform, this paper analyzes its working principle, completes the design of the whole zero-gravity air-floating self-adjusting system, verifies the feasibility of the mechanical structure of the air-floating platform, and simulates the whole leveling process. The results showed that this platform can realize automatic adjustment of height and antenna thickness direction through the control system, and the adjustment speed is fast and the precision is high, and the unloading efficiency can be effectively evaluated. The anti-offset test results show that the anti-offset structure of the air-floating platform is not affected by the friction of the guide column, which can effectively enhance the anti-offset capability of the platform.

In the next step, we will further study the adjustment time and adjustment accuracy, and solve the zero-gravity environment verification problem through the centroid position comparison test.

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