Experiments on Simulation Microgravity of Composite Deployable Antenna

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Abstract. After the satellite is launched into a special orbit in space, its space environment is zero gravity or microgravity. Therefore, in ground simulation experiments, it is necessary to consider overcoming the gravity of the earth and try to reduce or eliminate the influence of gravity. In this paper, the method of counteracting gravity by air-floating platform is used to simulate the space microgravity environment, and to do the unfolding experiments for single deployable antenna. After the deployment of the single antenna, the connection structure of single antenna is tested by modal experiment. The microgravity simulation experiment shows that the shape memory hinge can normally satisfy the folding and unfolding of a single antenna. The whole unfolding process is smooth and there is no obvious vibration. The first six modes and natural frequencies are obtained and compared with the simulation results. The comparison shows that the experimental results are in agreement with the simulation results.

1. Introduction

After the satellite is launched into a special orbit in space, its space environment is zero gravity or microgravity. Therefore, in ground simulation experiments, it is necessary to consider overcoming the gravity of the earth and try to reduce or eliminate the influence of gravity. At present, the methods of simulating space microgravity environment include free falling, water floatation, suspension and air floatation [1]. For large space deployable antenna, space deployable truss or solar panel satellite accessories on the ground simulation experiments, air floatation or suspension is used more.

Air floatation is a method to simulate microgravity by lifting the aircraft on a smooth platform by means of air suspension that is, counteracting gravity with the lifting force [2]. The advantage of air floatation is that gravity compensation is relatively thorough, the experimental platform system is low cost, and the production cycle is short. Many space agencies, such as Tokyo Polytechnic University of Japan, adopt the air flotation [3]. In order to simulate the space microgravity environment more accurately, according to the characteristics of planar antenna structure and laboratory conditions, the air floatation method was selected. Using this method, the experiments of a single deployable antenna in simulated space microgravity environment are carried out. After the deployment of the single antenna, the connection structure of single antenna is tested by modal experiment. The modes and corresponding natural frequencies of the single antenna are tested, and the experimental values are compared with the simulation results.
2. Experiments on simulation microgravity of single planar antenna

2.1. Experiment scheme of simulation microgravity
The basic principle of air floatation is air suspension, high pressure air is ejected from air feet, the upper ends of the air feet support the aircraft, and the lower ends are supported by a smooth air platform. The gravity of satellite and other aircraft is offset by the air buoyancy support force to achieve the microgravity environment. Figure 1 illustrates the overall structure of an experiment system for simulating planar antenna deployment by air floatation.

Figure 1. The overall structure of the planar antenna deployment experiment system
As the supporting platform of the whole microgravity simulation system, the air-bearing platform has the characteristics of large area, large load, high precision, and stable operation. It is generally made of granite.

The air floatation control system includes air pump, air ducts and air feet. The air feet are installed at the bottom of the antenna substrate. There are many throttle holes on the sole of each air feet. When the equipment needs to float, high-pressure air will be ejected from the throttle hole at high speed, forming a layer of air film between the antenna substrate and the air-bearing platform to realize the frictionless deployment of the planar antenna on the air-bearing platform.

2.2. Configuration of air feet
The planar space deployable antenna designed in this paper is folded by four antenna veneers, as shown in figure 2. Therefore, it is necessary to consider the installation mode and location of the air feet in order to ensure the stability of the antenna deployment, offset the gravity thoroughly and avoid the interference of the air feet when the antenna is folded. Each antenna is equipped with two single-foot supports. The supporting air feet of two adjacent antennas are staggered, and the air feet position of the first plate is the same as that of the third plate. In this way, air feet interference can be avoided.

Figure 2. Schematic diagram of connected antenna in furled state.
2.3. Single Antenna Assembly Process
In this experiment, the antenna substrate is fixed on the simulated wall instead of the antenna is assembled on the satellite. Therefore, the experiment is completed by assembling and unfolding the planar antenna components on the simulated wall of the satellite. The specific operation items and procedures are as follows:

1. Debugging the air-bearing platform system of the test equipment before assembly;
2. Debugging the simulated wall and bracket of the test equipment before assembly;
3. Bending and adjusting the hinges;
4. Hinge assembly of prototype assembly;
5. Antenna substrate assembly for prototype assembly;
6. Adjusting the position of antenna substrate and then locking;
7. Unlocking of antenna deployment mechanism;
8. Experiments of antenna deployment.

2.4. Results of unfolding experiment
After the single planar antenna is assembled, the deployment angle and time are measured and recorded by means of camera capture and stopwatch timing. Unfolding experiment were carried out for the hinges with length of 300 mm and 200 mm, respectively. Deployment time and angle recorded during the experiment were plotted in figure 3.

![Figure 3](image)

Figure 3. Expansion time-angle curves of single antenna when the hinge has different lamellar lengths.

From figure 3, it can be seen that in the initial stage, the deployment speed of the antenna is slow, and with the increase of time, the deployment speed increases; deployment speed is basically stable from 100° to full deployment.

From the whole deployment process, the deployment is relatively slow, compared with the traditional deployment method, it has the advantages of stable deployment and small impact vibration.

3. Modal experiment of single antenna in microgravity environment
The planar space deployable antenna designed in this paper has large area and small mass. It is a large space flexible structure. Under the action of various disturbance forces in space, the caused vibration directly affects the overall stability of satellite. To solve this problem, we need to start with the basic modal experiments to obtain the modal characteristics of planar antenna.

3.1. Design of modal experiment scheme
The design of modal test scheme mainly includes the selection of microgravity simulation scheme, the arrangement of measurement points, the vibration excitation mode and the selection of excitation points [4].
3.1.1. **Microgravity simulation scheme.** The method of simulation experiment is air flotation, and the method of placing is still that the substrate is placed vertically with the air flotation platform.

3.1.2. **Layout of experimental measuring points.** Nine acceleration sensors are evenly distributed on the antenna substrate. The position and number of the measuring points are shown in figure 4.

![Figure 4. Layout of measuring points on substrate.](image)

3.1.3. **Vibration excitation mode.** There are many ways of excitation, such as large displacement exciter excitation method, large thrust exciter excitation method and so on. Large displacement exciter is with relatively large ultimate displacement but relatively small thrust, which is suitable for large structures requiring small thrust and large displacement. Large thrust exciter is with larger thrust but smaller ultimate displacement. The test object of this paper is a single planar antenna with relatively large stiffness and relatively small amplitude. A large thrust mode exciter is selected. The relevant instruments for modal experiments are shown in figure 5.

![Figure 5. The relevant instruments for modal experiments.](image)

3.2. **Modal experiment and result analysis**

Shape memory composite hinges are not like ordinary mechanical hinges. Whenever they undergo a bending-unfolding process, the hinged lamellar structure itself will be damaged to a certain extent. Therefore, this modal test experiment is to test the antenna after bending and unfolding, rather than installing a pair of new hinges, so as to better reflect the actual working situation.

Limited to the number of signal interfaces of data collector, the test and data acquisition are divided into three steps. The 1-9 measuring points are divided into three groups. The acceleration sensors are installed at three measuring points in each group, one group of data is tested each time, and the last put them together for analysis.

The first six natural frequencies of a hinged planar antenna plate are measured by modal testing. The first and second bending and torsion modes are compared with the simulation values, as shown in
table 1 [5]. Compared with the simulation results and experimental results of the natural frequency of a single antenna, the two results are basically the same. Some of the results of natural frequencies are slightly different. The reason is that the air floatation method is used in the experiment. The air feet have an effect on the direction of the antenna rotating around the x-axis, and it is also subject to air resistance in the experiment. Many factors may cause slight difference between the experiment and the simulation results, but they are basically in accordance with the normal error range.

| Orders       | 1        | 2        | 5       | 6       |
|--------------|----------|----------|---------|---------|
| Simulation  /Hz | 3.118    | 10.276   | 39.785  | 45.337  |
| Experimental /Hz | 2.422    | 9.309    | 32.879  | 47.475  |
| Modals       | First order bending | First order torsion | Second order torsion | Second order bending |

4. Conclusion
In this paper, the commonly used air floatation method is used to simulate the microgravity environment of deployable antenna in space. The microgravity simulation experiment shows that the shape memory hinge can normally satisfy the folding and unfolding of a single antenna. The whole unfolding process is smooth and there is no obvious vibration, which effectively reduces the vibration caused by the deployment process of the antenna to the satellite body.

After the deployment of the single antenna, the connection structure of single antenna is tested by modal experiment. The first six modes and natural frequencies are obtained and compared with the simulation results. The comparison shows that the experimental results are in agreement with the simulation results.

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