Design of Zero-gravity Unloading Process Equipment for Satellite Overlapping Antenna on Ground Test

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Abstract. In this paper, the zero-gravity unloading scheme and the design scheme of the zero-gravity unloading process equipment are proposed for the three-overlapping antennas of a communication satellite. Due to the particularity of the structure, test state and unloading state of the communication satellite antenna, the zero-gravity unloading simulation process equipment commonly used at present cannot meet the test requirements. Based on the analysis of the requirements of zero-gravity deployment test and the process of the three-overlapping antennas zero-gravity unloading, a solution to meet the test requirements is proposed. System performance tests verified the effectiveness of the zero-gravity unloading system.

Keywords: zero-gravity; process equipment; satellite; antenna; ground test.

1. Introduction
Zero-gravity, also known as weightlessness or minus gravity, is one of the most important features of the space environment [1]. Due to the weightlessness of the spacecraft in space, the internal components of the state of stress and the ground is different, so in order to test the performance of the spacecraft and its components on the ground, it must simulate the weightlessness or micro-weight state in space [2].

As a result of the development of space technology, there is an increasing demand for beam-directed manoeuvrability of satellite antennas [3]. Therefore, a large number of satellites are equipped with mechanically movable antennas, and the antennas can be adjusted according to the needs of the mission, and communicate with different satellites or different ground stations[4]. However, due to the influence of ground gravity, the gravity of the mechanical movable antenna may cause damage to the antenna mechanism during the ground test [5]. On the other hand, due to the differences between the zero-gravity environment and the on-orbit, the effectiveness of the test is affected [6]. It may even affect the normal use of the antenna in orbit.

The effects of gravity have three main aspects. Firstly, the influence on the installation accuracy of the antenna; secondly, the influence on the accuracy of the shape of the antenna after unfolding; thirdly, the influence on the driving torque during the unfolding process [7]. As the size of the antenna increases, the impact of the ground gravity environment also increases [8]. Therefore, while developing the antenna, it is necessary to develop a corresponding zero-gravity environment simulation device.
In this paper, taking the three-overlapping antennas of a communication satellite as an example, the design of the antenna unloading scheme and the unloading system is proposed by analysing the working conditions of the ground zero-gravity deployment test of the three-overlapping antennas, which provides a technical basis for the antenna ground test.

2. Requirements for Antenna Deployment Conditions

A communication satellite is parked on a two-axis turntable during the EMC test. The unfolding of the three-overlapping antennas requires separate ground equipment for unloading and unfolding tests. The east and west sides of the satellite face the sides, and the antenna is deployed and locked using ground craft equipment. When the three-overlapping antennas are deployed on the ground, the deployment sequence is as shown in Figure 1.

During the unfolding process, the three-overlapping antennas can be connected to the unloading system through the lifting point respectively. Since they are sequentially deployed in position, there is no interference on the trajectory. During the unfolding of the three-overlapping antennas, the reflector is driven by the antenna pointing mechanism to perform two-dimensional motion, and the position of the unfolding axis moves in a two-dimensional plane, and the envelope of the unfolding axis motion path is an ellipse.

3. Detailed Design of the Antenna Unloading System

3.1. Overall Design

The process equipment used in the zero gravity unfolding test of the three-overlapping antennas includes a two-axis turntable, an antenna gravity unloading system and an antenna fixing device, and the three are not in contact with each other, and the use effect is shown in Figure 2.
3.2. Structural Form
The main body of the system is fixed by the support of the chassis of the suspension device. The support chassis is installed with a foot and a universal roller to adjust the flatness of the chassis and move the system on the ground respectively. A support column is installed on the support chassis, and the upper end of the column is fixedly connected with an 1 meter extension arm. The cantilever end is equipped with a two-stage deployable arm with a length of 2 meter through the bearings on both ends. The two-stage deployable arm can freely rotate around the first-stage deployable arm with a rotation range of more than ±90°. A linear guide rail is installed at the lower end of the rocker arm, and the travel distance of the guide rail is 1.6 meter. Part of the pulley block is installed on the slide block of the guide rail to realize zero gravity unloading of the unloaded antenna, which can provide a maximum lifting force of 50kg and a lifting height range of 0 to 7 meter. The position of the lifting point can be adjusted automatically with the change of the position of the connecting point. The antenna unloading system is not in direct contact with the antenna, and only the unloading lifting point is provided, which is basically applicable to the antenna of most satellites. After the antennas deployed, it needs to be locked with the antenna fixture.

![Figure 3. Schematic diagram of antenna unloading system](image)

1-the unloading system chassis; 2-the unloading system auxiliary support; 3-the unloading system main body; 4-the first-stage unfolding arm; 5-the second-stage unfolding arm; 6-the hanging system

3.3. Anti-overturning Design
Since the system is a cantilever structure, the system is stressed at the top during operation. Therefore, the system needs to be anti-overturned. The center of mass of the system is shown in Figure 4. The mechanical model of its anti-overturning design based on the system structure is as follows.

![Figure 4. Schematic diagram of system anti-overturning design mechanics](image)
When an external force $F$ is applied to the end of the secondary arm, the critical condition for the whole system to overturn is $T_a = 0$, so $G = 27489N$. When $T_a = 0$, the force analysis of the system is carried out $\sum M_i = 0$, that is $G \times (330 + 400) - F \times 2600 = 0$, $F = 7718N$. When $F > 7718N$, that is the suspension load greater than 7718N, the whole system will capsize around point B. The designed load of the hanging system is 90kg, so the capacity margin of anti-overturning load of the system is 757%, which can meet the requirements of use.

3.4. Deformation Analysis

Deformation analysis of the suspended part of the antenna unloading bracket system. The total load of the system is 110kg, of which the load is 90kg and the constant force hanging device is 40kg. The hanging point is located at the end of the secondary deployment arm, the middle of the secondary deployment arm and the root of the secondary deployment arm, and the angle between the secondary deployment arm and the primary deployment arm is analyzed at 0 and 90 degrees. The specific results are shown in the Figure 5.

![Figure 5. Overall deformation analysis](image)

| Working condition       | Maximum deformation under rated load | Maximum deformation fluctuation during system oscillation under maximum load |
|-------------------------|---------------------------------------|--------------------------------------------------------------------------------|
|                         | The angle between the two arms is 0°   | The angle between the two arms is 90°                                        |
| Stressed on the outermost side | 1.438                                | 2.472                                                                     |
| Force midpoint          | 1.067                                | 1.747                                                                     |
| Stressed on the innermost side | 0.697                               | 1.021                                                                     |

It can be seen from the above table that under the rated load, the maximum deformation is 2.47 mm, and the deformation amount is 1.034 mm during the rotation of the antenna by 90°. This data basically satisfies the requirements of the three-overlapping antennas unloading process.
3.5. Intensity Analysis
The maximum stress of the system occurs at the rocker joint, which is 113.8 MPa, and the rest is between 20 and 50 MPa. According to the material and force of the suspension system, the safety factor of the system is discussed as follows. The minimum safety factor of the system is 1.67, which is located at the maximum stress of the system, that is, the connection of the rocker arm, as shown in Figure 6. In summary, the strength of the suspension system meets the requirements, and the minimum safety factor of the system is 1.67, which can be further optimized to achieve a system safety factor of more than 2.

![Figure 6. Intensity analysis](image)

4. System Performance Test Verification

4.1. Downwarping Test
The downward deflection test is performed on the deployment arm for the technical requirements of the ground test of the overlapping antenna. The 40kg counterweight is hung at the hanging point, and the measuring points are respectively arranged at the corresponding positions of the second-stage unfolding arm and the first-stage unfolding arm, and the measuring points are measured by the laser tracker and the theodolite.

The test is divided into two states, one of which is that the primary deployment arm and the secondary deployment arm are in a straight line state (denoted as 0° state), and the result is shown in Table 2; the other state is that the primary deployment arm is perpendicular to the secondary deployment arm (recorded as 90° state), and the result is shown in Table 2. The measured points on the selected first-stage unfolding arm and second-stage unfolding arm are shown in Figure 7.

| Measuring point | no-load (Z-axis coordinate) | full load (Z-axis coordinate) | Amount of downwarping |
|-----------------|-----------------------------|-------------------------------|-----------------------|
|                 | 0° state (mm) | 90° state (mm) | 0° state (mm) | 90° state (mm) | 0° state (mm) | 90° state (mm) |
| P1              | 7202.9600    | 7202.9801    | 7201.4369    | 7200.708    | 1.5231      | 2.2721      |
| P2              | 7203.9147    | 7203.9247    | 7202.5573    | 7201.9971   | 1.3574      | 1.9276      |
| P3              | 7204.5302    | 7204.5216    | 7203.3816    | 7202.7204   | 1.1486      | 1.8012      |
| P4              | 7204.8184    | 7204.8246    | 7203.897     | 7203.4384   | 0.9214      | 1.3862      |
| P5              | 7207.8685    | 7207.8569    | 7207.244     | 7206.7293   | 0.6245      | 1.1276      |
| P6              | 7243.8185    | 7243.8123    | 7243.5714    | 7243.4869   | 0.2471      | 0.3254      |

![Figure 7. Schematic diagram of unloading system](image)
4.2. Friction Test

For the general technical indicators, the system is tested for translational friction and rotational friction. After hanging 40kg counterweight, turn on the air source, and apply a pulling force parallel to the secondary deployment arm at the end of the weight with a tension meter. When the pneumatic slider follows the movement, the tension value displayed on the dynamometer is the translational friction of the system; The pulling force is applied to the counterweight weight end perpendicular to the second unwinding arm by the dynamometer. When the second unfolding arm starts to rotate along the unwinding axis, the tension value displayed on the dynamometer is the system rotating friction. The test results are shown in Table 3.

| Friction type       | Friction test site          |
|---------------------|-----------------------------|
|                     | Front of the secondary arm  |
| Translational friction | Middle of the secondary arm |
| Rotational friction  | End of the second arm       |

|                     | less than 1N               |
| Translational friction | less than 1N               |
| Rotational friction  | 1N~3N                      |

5. Conclusion

In this paper, a zero-gravity unloading scheme and a zero-gravity process equipment design scheme for three-overlapping antennas of a communication satellite are proposed. Based on the analysis of the working conditions of ground zero-gravity test of three-overlapping antennas, the theoretical design of zero-gravity unloading process equipment is carried out in detail from the aspects of the overall design, unloading system structure form, anti-overturning design, deformation analysis and intensity analysis. Finally, through the system performance test, the effectiveness of the designed zero-gravity unloading process equipment performance is verified.

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