Application of High-Speed Photography in Amplitude Measurement of a Satellite Antenna

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Abstract: Spacecraft antenna is an antenna loaded on the spacecraft and an indispensable part of the spacecraft system. It is particularly important to measure the assembly accuracy of the antenna. A certain type of satellite needs to test the amplitude of antenna A and B in sinusoidal vibration test. Because the distance between antenna A and antenna B is very close to the fairing, it is necessary to measure the amplitude of antenna A to verify the spatial compatibility of antenna A with carrier fairing and antenna B in the test process. By comparing four kinds of antenna measurement technology, this paper chooses high-speed photography technology to measure the amplitude of the antenna, uses recognition processing computing technology to binarize the image, changes the image into calculable coordinate value, obtains the amplitude data of X-direction and Y-direction, and verifies the space composite compatibility requirements between antenna A, carrier fairing and antenna B under vibration conditions. There will be interference and collision.

1. Introduction
Spacecraft include many kinds, such as satellites, space probes, spacecraft, space shuttles, space stations and so on. Spacecraft antenna is the antenna loaded on the spacecraft, that is, spaceborne antenna. In space activities, spacecraft should communicate between space and ground, between spacecraft (space and space, constellation) and even between deep space or interstellar space, as well as wireless transmission of various information. Spacecraft antenna is to construct corresponding wireless transmission channels for the spatial wireless transmission of these information. Spacecraft antenna is the equipment that undertakes the electromagnetic energy conversion between space wave and guided wave field in the process of information wireless transmission. Spacecraft antenna is an indispensable part of spacecraft system. According to the different tasks of spacecraft, spacecraft antenna has many shapes and types. It is the link between ground system and satellite. Therefore, the measurement of antenna assembly accuracy is particularly important.

2. Current status of antenna measurement technology
Because of the different configurations and sizes of spacecraft carriers, the functions of various spacecrafts are different, and the antennas of spacecrafts are of various types and forms. Therefore, the measurement systems used are different. At present, there are four main types:
1) Electronic theodolite measurement system: The electronic theodolite measurement system takes more than two high-precision electronic theodolites as the core measuring equipment, combines with other accessories and measuring software, realizes non-contact measurement of the measured object (antenna) based on the principle of angle intersection. The measuring speed is fast, the measuring range is from several meters to tens of meters, and the measuring accuracy is (+0.05~0.2) mm. Because of its outstanding advantages, the system has been widely used in the manufacture and assembly of spacecraft antenna.[1]

2) Electronic Total Station Measurement System: The measurement system of electronic total station takes a high precision electronic total station as the core measuring equipment, equipped with the equidistant measuring mark of reflector, and measures the measured object (antenna) according to the principle of polar coordinates. The measurement range is from several meters to two hundred meters, and the measurement accuracy is (+0.2~0.5) mm. Compared with the electronic theodolite measurement system, the single electronic total station measurement system has the characteristics of low cost, easy operation, fast establishment of measurement coordinate system and long maintenance time.

3) Photogrammetric System: Photogrammetric system takes single or multiple high precision measuring cameras as the core measuring equipment, and uses intersection measuring principle to carry out fast non-contact measurement. It has large measuring range and high speed, and is especially suitable for dynamic measurement occasions. With the upgrading of Arecibo telescope in the United States, the accuracy of total station can no longer meet the requirements. For this reason, photogrammetry is used to measure the total station, and its surface measurement accuracy is better than (+2mm). Wang Baofeng and others in China have used photogrammetry system to measure and adjust the surface of large antenna with high accuracy. The point coordinate measurement accuracy is better than 0.11mm, and the surface calculation accuracy reaches 0.4mm.[2][3]

4) Laser Tracker Measurement System: Laser tracker measurement system takes a single laser tracker as the core measurement equipment, and uses the measuring principle of spherical coordinates for fast tracking measurement. In the range of 10m, the precision of coordinate repetition measurement can reach 15 micron. As long as the reflector (cat eye reflector, corner reflector or tool ball reflector) is moved on the surface of the measured object, the rapid measurement of the surface can be realized, especially for the measurement and accuracy evaluation of a single antenna panel.[4]

3. Antenna Amplitude Measurement Scheme

3.1. Test target
A certain type of satellite has three antennas, antenna A, antenna B and antenna C. The configuration of transmitting and closing states is shown in Figure 1. According to the analysis of satellite configuration layout, under static conditions, the minimum clearance between antenna A and carrier fairing is 79 mm and that between antenna B is 99 mm. The space compatibility of antenna A with carrier fairing and antenna B can be verified by measuring the amplitude of antenna A in sinusoidal vibration test. At the same time, because the boundary conditions of mechanical test of antenna A and B are different from those of on-board satellite, the amplitude test can also provide a basis for the formulation of mechanical environment conditions of components.
The main objectives of antenna A and B amplitude measurement in sinusoidal vibration test are as follows:

1. Verify the spatial compatibility of antenna A with carrier fairing and antenna B under vibration conditions;
2. Provide basis and reference for the formulation of mechanical environment conditions of antenna A and B.

3.2. Test method
Based on the above two test objectives, this paper chooses high-speed photography technology in photogrammetric system for measurement.

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The digital high-speed camera used in high-speed photography technology belongs to industrial camera. It is a professional fast and continuous acquisition of images. Its essential function is to convert optical signals into electrical signals. Since 1851, Fox Talbot of England made the world’s first high-speed camera, the high-speed camera has experienced 160 years of development. Unlike ordinary cameras, high-speed cameras have higher image stability, which can take pictures quickly, transmit and save pictures quickly, and grasp the moment that the naked eye can not see. When high-speed cameras store results, they can choose many different formats, such as image format and video format, to facilitate the preservation of research results.

The main parameters of high-speed camera include resolution, pixel depth, maximum frame rate, exposure mode, pixel size and spectral response characteristics. The image sensitive chips of high-speed cameras can be divided into two kinds: CCD chips and CMOS chips. High-speed cameras on CMOS chips mostly use electronic curtain shutters. Compared with CMOS chips, the cost of CCD chips is
slightly higher. The global shutter is usually used in high-speed CCD cameras. Sampling and holding function is added at each pixel to keep the stored data unchanged.[5,6]

3.3. Test configuration
The test is carried out on a shaking table. The test contents are as follows: while the acceptance level and appraisal level of the satellite sinusoidal vibration test in X and Y directions are tested, the swing of the feed tower at the top of antenna A is photographed by a high-speed camera. Specifically divided into four working conditions, each working condition test content as shown in Table 1.

| Whole star state | Whole Star Vibration Direction | Working condition | Test content                                          |
|------------------|--------------------------------|-------------------|-------------------------------------------------------|
| X direction      | Working condition 1            | Amplitude measurement in vibration test process of acceptance stage |
| Y direction      | Working condition 2            | Amplitude measurement in vibration test process of appraisal level |
| Vertical state   | Working condition 3            | Amplitude measurement in vibration test process of acceptance stage |
|                  | Working condition 4            | Amplitude measurement in vibration test process of appraisal level |

A total of two high-speed cameras are equipped to shoot the swing of the top of antenna A from -X direction and -Y direction. Target 1, target 2, target 3 and target 4 are respectively pasted on the top of antenna A +X direction, +Y direction and -X direction. The photographic direction and target pasting schematic are shown in Figure 2. The two cameras are basically at the same altitude with the target. It ensures that high-speed camera A can measure target 1, target 2 and target 4 simultaneously from photographic direction A. High-speed camera B can measure target 1, target 3 and target 4 simultaneously from photographic direction B.
The composition of the equipment used in this test is shown in Table 2, and the main performance parameters of the high-speed camera are shown in Table 3.

Table 2. Hardware composition of high-speed camera.

| Serial number | Name                      | Model       | Number |
|---------------|---------------------------|-------------|--------|
| 1             | High Speed Camera Host    | Phantom V641| 2      |
| 2             | Tripod                    |             | 2      |
| 3             | Computer                  | DELL        | 2      |
| 4             | High light                |             | 3      |

Table 3. Main performance parameters of high-speed camera.

| Parameter                          | Value                                      |
|------------------------------------|--------------------------------------------|
| Resolving power                    | 2560 x 16004 mega-pixels                   |
| Maximum resolution shooting speed  | 1450 Frame / sec                           |
| Maximum shooting speed             | 219,000 Frame / sec                        |
| Pixel size                         | 10 micron                                  |
| Minimum exposure time              | 1 Microsecond                              |
| Image depth                        | 12 position                                |

3.4 Test configuration
The X-direction vibration test uses a high-speed camera to shoot from the direction B of the camera at a frequency of 750 frames per second. The shooting time is 49.856 seconds for each working condition.
and 37393 frames are taken. The coordinate origin is located in the upper left corner of the graph. During the vibration, the position of each target relative to the coordinate origin is measured.

Two high-speed cameras are used in the Y-direction vibration test. The left camera is located in the direction A in Figure 2 and the right camera is located in the direction B in Figure 2. The shooting frequency is 600 frames per second. The front image of the left camera is tracked by the rightmost point of the three points, and the Y-direction displacement of the antenna A is taken. The side image of the right camera is tracked by the left-most point of the two points, and the X-direction displacement of the antenna A is taken. The left camera takes 35S and 21000 frames at each working condition. The right camera takes 25 seconds for each working condition and 15,000 frames.

4. Scanning Recognition Processing Computing Technology

To change an image into a computable coordinate value, it is necessary to binarize the image. The gray value of the image is set to a total of 256 brightness levels ranging from 0 to 255. The most important thing is to extract edges from images into recognizable markers. The accuracy of the extraction directly determines the accuracy of the final recognition. Because edge has been widely used in motion reconstruction, stereo vision, target tracking, target recognition and other fields, there are many kinds of detection algorithms based on edge industry, including Sobel operand corner detection algorithm, Harris corner detection algorithm and SUSAN corner detection algorithm. At present, the common step is to detect the edge contour of the target first, and then to binarize it. In general, the Sobel operands often generate pseudo-boundaries, and often form unclosed regions. Unclosed regions have a great impact on edge extraction. Therefore, this paper adopts a more accurate algorithm than Sobel, Camy operator method, and makes some improvements accordingly. The basic steps of image edge detection are shown in Figure 3.

![Figure 3. Basic steps of image edge detection.](image)

5. Concluding remarks

Through the amplitude test, it can be found that the minimum distance between satellite antenna A and carrier net envelope is about 55 mm, and between antenna A and antenna B is about 87 mm. Under the vibration condition, the space composite compatibility between antenna A and carrier fairing and antenna B is required, and there will be no interference and collision. And the successful application of high-speed photography technology in the field of satellite antenna amplitude measurement is realized.

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