

# Test Technology in General Assembly of Large Satellites

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**Abstract.** The special test technology of the assembly, integration and test (AIT) of large satellites was studied, which accurately determine the leakage, alignment and mass property of large satellites, and ensure the reliable operation of large satellites in orbit. The local and total leakage testing technique was developed which based on quadrupole mass spectrometer and helium mass spectrometer. To meet large satellite quality and high precision, the satellite mass property testing equipment of large load bearing based on three coordinate conversion machine has been set up. A laser tracker uniting theodolite measure system with high positional precision and high angle measurement accuracy has been developed. Several large satellites have been tested in the process of AIT with these testing equipment. The quality of the large satellite has been effectively guaranteed.

## 1. Introduction

In the next few years, China will develop many large satellites, and these large satellites in the AIT. In the process, each satellite must be at least 4 times leakage testing, one time mass property measurement, 4 times alignment testing. This requires that the satellite chemical propulsion system leakage should be tested by helium mass spectrometer used helium as search gas, and then the satellite electric propulsion system leakage should be able to conduct direct leakage detection using work gas Xenon. In mass property measurement, satellite quality reached more than 5000 kg. In terms of installation alignment, the envelope of satellite structure size exceeds 10 meters, satellite angle measurement accuracy up angle of second order of magnitude. Therefore, it is necessary to develop the special test equipment and technology of the AIT of large satellites, to accurately determine the leakage, alignment and mass property of large satellites, and ensure the reliable operation of large satellites in orbit.

## 2. Large satellite leakage testing

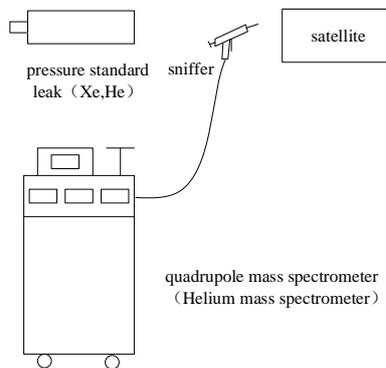
### 2.1. Large satellite local leakage testing

Chemical propulsion system of satellite leakage testing mainly adopts the helium mass spectrometer atmosphere accumulation method<sup>[1]</sup>. Satellite structure leakage are tested by the method of pressure change leak detection<sup>[2,3]</sup>. Mass spectrometer system leak detection are used in pipelines<sup>[4]</sup>. The total leakage detection technology in vacuum container is used to a higher sensitivity of spacecraft leakage<sup>[5,6]</sup>. Helium mass spectrometer is also used to test the total leak rate of the NASA space station and the Russian spacecraft leak detection test.

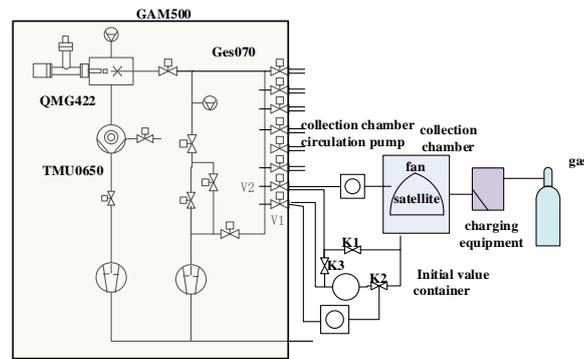
For large satellite electric propulsion system requirements of a local leakage detection, the test system was developed based on quadrupole mass spectrometer and helium mass spectrometer, as shown in figure 1. The test system is mainly composed of quadrupole mass spectrometer with a sniffer,



xenon positive pressure standard leak. A xenon calibration device with known leakage rate is developed to calibrate test system from  $10^{-6}$  Pa·m<sup>3</sup>/s to  $10^{-8}$  Pa·m<sup>3</sup>/s, and synthetic standard uncertainty is better than 5%. With the development of the test system, on the basis of linear comparison test, through the sniffer suck the local position of large satellite which is most likely to leak, quadrupole mass spectrometer or helium mass spectrometer leak detector can give leakage signal  $I_2$ . With the same testing conditions, background signal  $I_0$  and xenon positive pressure standard leak signal  $I_1$  are also tested, therefore, the large satellite local leakage is gotten as the Eq. 1 shown.



**Figure. 1** the diagram of the satellite local detector leakage test system



**Figure.2** the principle of satellite multi-system leak by mass spectrometer

$$Q = \frac{I_2 - I_0}{I_1 - I_0} Q_0 \quad (1)$$

## 2.2. Satellite total leakage testing with multi-system leak detector by mass spectrometer.

Nowadays, helium mass spectrometer technology is widely used in the leak detection of spacecraft. This technology can effectively solve leak problem of single sealing system. As the development of spacecraft, multi-system leak detection is needed. Based on the old detector, ESA developed a piezoelectricity crystal pulse sampling mass spectrometer leak detector<sup>[7]</sup>, which contrast the ion flow of search gas to the ion flow of compared gas. This method reduces effect of instability of vacuum system and mass spectrometer, the sensibility and reliability are increased. On the same sensibility level, the cost decreases clearly. Sodal<sup>[8]</sup> researched on the mass spectrometer using a pulsed gas sampling system, and acquired satisfying result. After many experiments of detectable gas analysis machine, and based on the GAM500 on-line mass produced by Germany IPI, we developed alternate circle sampling system and get over the instability of long-time measure<sup>[9]</sup>. The multi-system leak detector by mass spectrometer has been developed and used in the large satellite successfully.

**2.2.1. Composition of total leakage testing equipment.** The equipment is composed by on-line mass spectrometer named as GAM500, gas cycle sampling system, collection chamber, charging equipment and so on, the principle chart is shown on figure 2. GAM500 on-line mass spectrometer is combined with QMA422 mass spectrometer, Ges070 sampling system, TMU0650 molecular pump vacuum system and 8 sampling valve, which can acquire more sampling points.

Gas cycle sampling system is combined with two route: one route includes sampling valve, collection chamber cycle pump, stop valve, the other route includes initial value container, sampling valve, stop valve and initial value container cycle pump. A fan cycle system is installed in the collection chamber which blows chamber air mixture equally in 5 minutes. The airproof capability of collection chamber is: after charging 2kPa pure Nitrogen, the pressure reduces 150 Pa in 24 hours.

Charging equipment is combined with compressor, gas cylinder, standard container, mechanical pump, control meter, control valve and so on. The charging equipment can pump the satellite system, charge and recycle the search gas.

**2.2.2. Test principle.** Charge specific pressure search gas (there are some kinds of inert gases such as He, Ne, Kr, Xe, CF<sub>4</sub>) into different test systems in satellite, seal the inter-face and push into the

collection chamber, operate the fan in the collection chamber, reduce the background search gas in the chamber. Close the chamber door and seal the chamber. Startup two cycle pump, open K3, close K1 and K2 valves to make the initial value container air the same as chamber air. Close K3, open K1 and K2 valves, as the GAM500 operates well, cycle test collection chamber and the initial value container have the same detectable gas ion flow. Stay the satellite in the chamber for  $t$  seconds to make the leak search gas accumulate and the density increases. Open the fan cycle system and initial value container cycle pump. The gas in the initial value container and the gas in the collection chamber flow into the mass spectrometer alternately, and we achieve corresponding ion flow  $u_{i10}$  and  $u_{i1}$ . After testing several steady sampling cycle, inject standard gas  $W_i (P_{ib} \cdot V_b)$  into collection chamber, and then open the fan cycle system to make the standard gas, search gas and air mixed uniformly. The ion flow in initial value container gas and chamber gas are  $u_{i20}$  and  $u_{i2}$  respectively. Because the test time is short and we test alternately, the stability of pumping speed, and the stability of QMS can be ensured, and the test ion flow keep stable and can be repeated well. The ratio between standard gas  $W_i (P_{ib} \cdot V_b)$  and chamber atmosphere gas is about 1%. After injecting standard gas, the collection chamber pressure changes a little. The total leakage of different satellite system can be acquired as following equation:

$$Q_i = \frac{W_i(u_{i1} - u_{i10})}{t[(u_{i2} - u_{i20}) - (u_{i1} - u_{i10})]} \quad (2)$$

In the equation,  $W_i (P_{ib} V_b)$  is the standard gas ( $\text{Pa m}^3$ ),  $W_i = P_{ib} V_b$ ,  $V_b$  is the volume of standard gas flow container,  $P_{ib}$  is the pressure of search gas of injecting collection chamber.

In the atmosphere, the minimal He concentration can be test is  $13 \times 10^{-9}$ ,  $\text{CF}_4$  concentration is  $10 \times 10^{-9}$ , Ne concentration is  $3 \times 10^{-6}$ ,  $\text{SF}_6$  concentration is  $0.3 \times 10^{-9}$ , Kr and Xe concentration is  $10 \times 10^{-9}$ . For the collection chamber with  $100 \text{ m}^3$  volume, in 24 hours, the minimal He leak rate can be test is  $1.5 \times 10^{-6} \text{ Pam}^3/\text{s}$ ,  $\text{CF}_4$  leak rate is  $1.1 \times 10^{-6} \text{ Pam}^3/\text{s}$ , Ne leak rate is  $3.5 \times 10^{-5} \text{ Pam}^3/\text{s}$ ,  $\text{SF}_6$  leak rate is  $3 \times 10^{-8} \text{ Pam}^3/\text{s}$ , Kr and Xe leak rate are  $1.1 \times 10^{-6} \text{ Pam}^3/\text{s}$ .

### 3. Mass property testing

Mass Properties of an object, including mass, center of gravity, moment of inertia, and product of inertia are determined by satellite material, shape, and structure. They are important parameters that reflect the satellite's intrinsic mechanical characters. Mass and center of gravity are measured by three point support equipment. Moment of inertia, and product of inertia are tested by the torsional pendulum technology<sup>[10]</sup>. But those measurement can only carry out single axis direction, the horizontal axis and vertical axis direction need different adapter tools, lifting and rotating satellite repeatedly, the security hidden danger of satellite, and the test efficiency is very low.

Since 2009, we have successfully developed three coordinate conversion instrument with capacity of 3 tons. According to the need of large satellite quality, high precision, as shown in figure 3, we developed satellite mass property equipment based on three coordinate conversion machine of large load bearing. The equipment is divided into two parts. One part is three coordinate conversion and other part is test platform. The test platform is three point support equipment or torsional pendulum equipment. The mass, center of gravity, and moment of inertia for larger satellite are tested just one lifting. The longitudinal center measurement principle of its satellite is shown in Eq.3:

$$X_c = \frac{(Y_c - Y_c \cdot \cos \alpha)}{\sin \alpha} - R - H \quad (3)$$

**Figure. 3** The large satellite mass property equipment

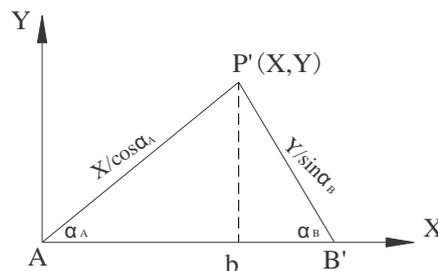
Using three coordinate conversion equipment, in vertical A state,  $\alpha = 0$ , get the direction cosine (0, 1),  $I_x$  can be measured. Using three coordinate conversion, change satellite install direction  $\alpha$ , and test out the several groups of direction cosine respectively corresponding to the moment of inertia of  $I_1, I_2, I_3, I_4$ , can use the Eq.4, test out along the different moment of inertia of axis of rotation of the satellite.

$$I_y = \frac{1}{2\sin^2\alpha}(I_1 + I_2 - 2I_x) + I_x, \quad I_z = \frac{1}{2\sin^2\alpha}(I_3 + I_4 - 2I_x) + I_x, \quad I_{yz} = \frac{I_1 - I_2}{2\sin 2\alpha}, \quad I_{xz} = \frac{I_3 - I_4}{2\sin 2\alpha} \quad (4)$$

Large satellite mass property test system maximum load reach 5000 kg, 50000 Nm moment of inertia. One lifting can detect different axis center of gravity, moment of inertia, synthetic standard uncertainty is better than 0.1%.

#### 4. Alignment of satellite assemble

Satellite installation alignment is for relative to the satellite coordinate system to the installed instrument precision position and normal vector measurement products generally used the principle of theodolite intersection test<sup>[11]</sup>, however, the space dimension of the large satellite has reached dozens of meters, requires both direction test to high precision, also requires a positional accuracy is high. With the laser tracker measurement location high precision, widely used in aerospace assembly manufacture, we developed a laser tracker uniting theodolite measurement system<sup>[12]</sup>, Which effective use the characteristics of the theodolite with high Angle measurement and laser tracker the advantages of high precision of observation points. A set of conversion standard benchmark was made. The measurement system can simultaneously test satellite by a theodolite and the laser tracker. Fig 4 is theodolite measurement system. The position can be tested according to Eq.5:



**Figure. 4** Principle of theodolite measurement system

$$X = \frac{\sin\alpha_B \cos\alpha_A}{\sin(\alpha_B + \alpha_A)} b, \quad Y = \frac{\sin\alpha_A \sin\alpha_B}{\sin(\alpha_B + \alpha_A)} b, \quad Z = \frac{1}{2} \left[ \frac{\sin\alpha_A \cot\gamma_{BP} + \sin\alpha_B \cot\gamma_{AP}}{\sin(\alpha_B + \alpha_A)} b + h \right] \quad (5)$$

#### 5. Summary

The large satellite of leakage, mass property, alignment testing and testing calibration problems have been effectively solved. The testing systems have been set up and the testing reliability is effectively improved. Several large satellites have been tested in the process of AIT. The quality of the larger satellite has been effectively guaranteed.

Large satellite calibration device of leakage test system has less than the 5% synthetic standard uncertainty, range of the total leakage rate from  $1 \times 10^{-3} \text{ Pam}^3/\text{s}$  to  $1 \times 10^{-5} \text{ Pam}^3/\text{s}$ . The local leakage testing range is from  $1 \times 10^{-3} \text{ Pam}^3/\text{s}$  to  $1 \times 10^{-8} \text{ Pam}^3/\text{s}$  and synthetic standard uncertainty of calibration is better than 20%. The test system of large satellite mass property can be used to test more than 5000kg satellite. The moment of inertia can reach 50000Nm, the precision of the testing system is better than 0.1%. Large satellite alignment testing system has been developed. The calibration device synthesis standard uncertainty is better than that of 1 um, angle synthesis standard uncertainty is better than that of 3 ". The position synthesis standard uncertainty of alignment testing system is about 10 um, and angle testing synthetic standard uncertainty is better than that of 12 ".

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