Research on water vapor measurement and removal methods for the spacecraft sealed cabin

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Abstract. In order to develop a water vapor measurement and dewatering device suitable for ground test of spacecraft sealed cabin. A moisture measuring device suitable for the sealed cabin was designed. The existing moisture content measuring sensors were equipped with auxiliary devices to protect the electrical circuit of the sensor, and then the sensor was calibrated and analyzed. After calibration, it can meet the requirement of moisture measurement in vacuum environment. A small chamber was built to study water change rule in the pumping process. In the water removal system, the cabin was connected to the vacuum pump system through a two-way sealing flange, which can complete the water removal outside the vacuum chamber by pumping. When the pressure of the sealed cabin reached 100 Pa, high purity nitrogen gas was added to 97 kPa, then pumped in again. The results show that the water removal method can ensure that the dew point temperature of the sealed chamber is lower than 0°C during the vacuum thermal test. After protected, the dew point sensor can measure moisture at low pressure. The water removal system can effectively remove the moisture in the sealed cabin, thus ensuring the completion of the vacuum thermal test.

1. Introduction

During the vacuum thermal environment test of the spacecraft sealed cabin, a large amount of water vapor was found in the cabin with the process of the test. These vapors come from two aspects: on the one hand, it is due to the water vapor generated during the training of astronauts in the cabin; on the other hand, it is due to the water vapor brought by the operators during the installation and debugging of the equipment in the cabin [¹].

Excessive humidity of water vapor will affect the working status of various electronic instruments and equipment sensitive to moisture content. In order to ensure the successful completion of all testing in the thermal test of the sealed cabin, it is necessary to accurately measure the moisture content of gases in the sealed cabin of spacecraft and control the dew point temperature of gases in the sealed cabin below 0°C [²].

Because of the large volume and large gas amount of the sealed cabin, the requirement of dehumidification is very high. In addition, the sealed cabin is located in the vacuum container during the vacuum thermal test, the existing water vapor measurement and dewatering methods can not meet the dehumidification requirements of the sealed cabin.

Aiming at the dehumidification problem of spacecraft sealed cabin, a series of studies were carried out, and a moisture measurement and dehumidification system for sealed cabin was designed to ensure the successful completion of the thermal test of sealed cabin.
2. Water vapor measurement method

According to the source of water in the sealed cabin\[^3\], the following conclusions are drawn by analyzing the characteristics of water in the sealed cabin: a) the measured object is air (gas in sealed cabin); b) the gas pressure in the sealed cabin was negative pressure (50kPa) during the measurement; c) the air humidity in the sealed cabin is relatively high, and the relative humidity may reach more than 90%; d) the temperature of the gas in the sealed cabin is between 18°C ~20°C during the determination. It can be considered that the temperature of the tested gas sample is stable; e) most of the water molecules are adsorbed on the surface of materials and equipment by van der Waals force. The structure of the adsorbed surface molecules does not change much. Therefore, the chemical properties of the adsorbed water molecules and the adsorbed surface remain unchanged, which belong to physical adsorption.

According to the different measuring principles, the measuring methods of water vapor can be divided into gravimetric method, electrolysis method, dew point method and resistance-capacitance method\[^4\]. Analyzing the merits and demerits of various measuring methods, and combining with the characteristics of moisture content in the sealed cabin, this paper select the resistance-capacitance method to measure the moisture in the sealed cabin. The resistance-capacitance method uses metal aluminum as the measuring probe, and forms an oxide film on the surface of metal aluminum by electrochemical method. Then a thin layer of metal is deposited on the film. Thus, the metal aluminum of the probe core and the metal film on the surface of the probe constitute a capacitor, and the porous alumina film acts as the dielectric layer of the capacitor. When measuring, the gas is fully contacted with the probe, and the moisture in the gas is adsorbed by the porous alumina film, which results in the change of the impedance of the capacitor. The variation of capacitor impedance is related to vapor concentration, and the moisture content of gas is measured. The DMT152 type measuring sensor is selected in this paper.

Considering the use of sensors in vacuum and cryogenic environment, an auxiliary device is designed as shown in Figure 1. The sensor is built in an auxiliary device. The measuring port is connected with the flange of the auxiliary device, and the measuring signal is drawn out through a sealed plug. The auxiliary device is in a sealed state of atmospheric pressure, which can protect the electrical circuit in the sensor, thus ensuring the normal use of the sensor.

![Figure 1. Humidity sensor support device](image)

3. Calibration method of moisture measurement sensor

Usually the calibration pressure of the sensor is atmospheric pressure. It is necessary to measure the moisture content in the low pressure environment this time. In order to verify the measurement performance of DMT152 sensor at low pressure, calibration tests were carried out. Its process is as follows: 1) place DMT152 sensor and SH-2001 standard dew point meter in the same position in vacuum container; 2) measure water content under atmospheric pressure; 3) Turn on the vacuum pump and measure the moisture content under 0.5 atmospheric pressure; 4) repressure to atmospheric environment and measure moisture content under atmospheric pressure. The results of standard dew point meter and DMT152 sensor are compared as shown in Table 1.
Table 1 Dew point test record table

| Serial number | Standard dew point meter (°C) | DMT152 (°C) | Pressure value (kPa) | Time | Error (°C) |
|---------------|-------------------------------|-------------|---------------------|------|------------|
| 1             | 6.4                           | 7.90        | 100.38              | 18:34| 1.5        |
| 2             | 0.4                           | 0.68        | 56.26               | 19:28| 0.28       |
| 3             | 5.4                           | 6.49        | 100.00              | 19:37| 1.09       |

As can be seen from Table 1, all the errors are within the range of 2°C, which meets the technical requirements of the project.

4. Study on dewatering technology of sealed cabin

4.1 Variation rule of water in the process of vacuum pumping

In order to remove the moisture in the sealed cabin, first of all, the change rule of water in the process of vacuum pumping should be studied. A test system is established as shown in Figure 2. It includes vacuum vessel, vacuum acquisition system, platinum resistance temperature measurement system, vacuum measurement system and water pressure measurement equipment. The effective volume of the vacuum vessel is 0.2m³. The physical adsorption of water on the material surface is simulated by spraying water on the surface of the degreased gauze. Use stainless steel plate to simulate the cabin material, and the gauze with water is placed on the stainless steel plate. The gauze with added water is placed on the stainless steel plate. The gauze size is 270 x 400 mm and the amount of added water is 30g. A platinum resistance temperature sensor is arranged on the surface of gauze and the bottom of stainless steel plate. The temperature of water evaporation surface and material bottom are measured respectively. The water vapor partial pressure is measured by dew point meter. Open the vacuum pump and vacuumize the container until the vacuum degree reaches the limit (below 100Pa). Measure the change of partial pressure of water vapor in the container, as shown in Figure 3.

The experimental results show the variation rule of water in the sealed cabin during vacuum pumping process. With the process of pumping, the partial pressure of water vapor decreases continuously. One part of the liquid water changes to water vapor and the other to ice. Without external heat source, the sublimation rate of ice is very small, and there is no method relying solely on vacuum pumping. The method of extracting all water from the container is consistent with previous studies[5]. Therefore, the method of applying external heat source is adopted to provide the sublimation latent heat needed and accelerate the extraction of water vapor.

Figure 2. Schematic diagram of the small container test system

Figure 3. Variation of water vapor partial pressure during pumping
4.2 Dewatering system of spacecraft sealed cabin

Based on the above pumping and dewatering tests, the dewatering system of sealed cabin for vacuum thermal test is designed, including vacuum pump set, cold trap, sealing flange and vacuum pipeline, as shown in Figure 4. Because the sealed cabin is in the space environment simulation container during the vacuum thermal test, its dewatering system can only be outside the container. The metal bellows are used to connect the sealed cabin with the oil-free vacuum pumping unit outside the container through the sealing flange, and the water vapor in the sealed cabin is removed by vacuum pumping. A cold trap is placed in front of the vacuum pump set to absorb water vapor in the pipeline.

The flange connection in the space environment simulator needs both vacuum pumping and inflation. Besides, the temperature of heat sink in the container is very low and the sealing effect is difficult to guarantee, so the flange connection should be minimized in the process of connecting the pipeline. The structure of the sealing flange is shown in Figure 5. The radial and axial two-way seals are adopted to seal the flange. This structure can ensure the double-way seals without interfering with each other and play the role of multi-channel seals. Meanwhile, insulation measures are installed to the flange to ensure that it is used in room temperature environment. In addition, a heating belt is installed on the outside of the pipeline and a multi-layer heat insulation component is wrapped to heat the pipeline and the gas so as to avoid condensation of water vapor on the inner wall of the pipeline.

The cold trap is installed on the pipeline outside the container to collect moisture in the sealed cabin. It is cooled by liquid nitrogen and the inner gallbladder structure is used. In addition to collecting water in the sealed cabin, the cold trap can also collect various organic compound molecules with high boiling point in the sealed cabin, which is of great significance for purifying the sealed cabin, especially for pollutant composition analysis and material selection in the manned sealed cabin.

4.3 Dewatering process and results of sealed cabin

Using the above dewatering system, the dewatering process of the sealed cabin is carried out during the thermal test, and the dew point temperature in the cabin is monitored in real time by the moisture measuring sensor. The dewatering process is as follows: From 10:30 to 12:30, the vacuum unit is used to pump the sealed cabin through the sealing flange. The suction lasts for 2 hours, and the pressure in the sealed cabin drops to 100 Pa; from 12:30 to 14:30, the sealed cabin holds pressure for 2 hours; from 14:30 to 17:20, the sealed cabin is filled with pure nitrogen to 96 kPa; from 17:50 to 18:47, the sealed cabin is pumped again to reduce the dew point temperature of the gas; from 18:58 to 20:15, the sealed cabin is re-pressurized to 97 kPa by using the air passing through the liquid nitrogen cold trap. So far, the dewatering test of the sealed cabin is completed. The dew point temperature curve of the gas in the dewatering process of the sealed cabin is shown in Figure 6.
Figure 6. Dew point curve in the process of dewatering

As can be seen from Figure 8, compared with the first pumping and dewatering, the dew point temperature decreases faster, and the dew point temperature obtained is lower in the second pumping after adding high purity nitrogen and the dewatering efficiency is improved significantly. During the whole thermal balance test period, the dew point temperature of the gas in the spacecraft sealed cabin is always below 0°C, which meets the test requirements. Therefore, the dewatering system and the dewatering method established in this paper are feasible for dewatering the sealed cabin.

5. Conclusion

Based on the problem of humidity control and the physical characteristics of water vapor in spacecraft sealed cabin, this paper presents a humidity measurement method and dewatering method suitable for spacecraft sealed cabin.

The existing sensors are improved and calibrated to meet the water content test requirements of spacecraft sealed cabin in low pressure environment.

According to the variation rule of water in the process of vacuum pumping, the dewatering technology of sealed cabin was established and the dewatering system of sealed cabin was developed.

The sealed cabin is dewatered prior to the thermal test so as to the dew point temperature of the gas in the spacecraft sealed cabin is always below 0°C during the whole thermal balance test period, which avoids the influence of moisture on the operation of electronic equipment.

This method has an ideal dewatering effect, which guarantees the safety of electronic equipment in spacecraft during thermal test and ensures the smooth process of thermal test. It provides a new thought for the dehumidification of large spacecraft sealed cabin.

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