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An easy-to-implement thermal test system for large deployable antennas

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ABSTRACT

Large deployable antennas (LDAs), having a wide range of applications in aerospace engineering, encounter extreme thermal conditions when subjected to the space environment. Ground thermal test facilities are used to validate LDA deployability and accuracy under extreme thermal conditions. General antenna thermal test facility is thermal vacuum test facility, which is complex and costly as the vacuum test chamber has to be pumped down and large enough to accommodate LDAs. In this paper, an easy-to-implement thermal test system is presented, which simulates atmospheric thermal environment for LDAs using an air cycle refrigeration system and electric heaters. Additionally, a series of measures are used to ensure uniform temperature and limit airflow turbulence. Test results show that the test system can provide dry, uniform temperature and small disturbance thermal environment for LDAs.

1. Introduction

Large deployable antennas (LDAs), with their lightweight and foldable structures which satisfy the needs of transporting rockets in limited cargo space, have a wide range of applications in aerospace engineering [1,2]. Recent years have witnessed a steady improvement on both the size and the accuracy of data transmission which draws heavily on the development of communication technology. Researchers are currently working to develop lighter, larger and more reliable LDAs [3–8]. Meanwhile, major challenges confronting these researchers are the deployment reliability and reflector accuracy of this structure. Therefore, it is essential that LDAs go through ground tests before being exposed to space environment [9–12].

National Aeronautics and Space Administration (NASA) was a pioneer of space antenna ground test. NASA Langley Research Center began researching hoop-column antennas in 1970s in a ground-based test program to develop the technology necessary to design, manufacture, deploy, evaluate and transport the hoop-column antenna [13–16]. Meanwhile, Air Force Aerospace Laboratory (AFAL) and Jet Propulsion Laboratory (JPL) collectively designed and built a flexible structure control laboratory. The configuration of the flexible structure to simulate a Large Deployable Antenna (LDA) is a 6 m diameter, 12 rib circular antenna-like flexible structure with a gimballed central hub and a long flexible feed-boom assembly. The structure was constructed to demonstrate and validate technologies at the time in the active control and identification of large flexible space structures [17–19].

However, in space, LDAs are exposed not only to zero-gravity but also vacuum, extreme thermal conditions and radiation which will preclude antennas from working normally [20]. Extreme thermal environment can cause thermal distortion which changes the shape of the reflector to an extent that exceeds its distortion tolerance. Furthermore, it can also increase the internal stress and friction of deployable structures, resulting in structural distortion or even deployment failure. Therefore, ground LDA deployment test under thermal environment can not only validate the antenna deployability under extreme thermal conditions but also help researchers to find unexpected problems and further optimize the overall design [21,22]. Growing number of organizations have currently begun their LDA thermal environmental tests [23–26]. Among the earliest ground thermal environment laboratories is the Space Simulator Chamber at JPL. The volume of the Space Simulator Chamber measures 6 m D × 7.5 m H, capable of providing thermal vacuum test environment for small apparatus, but not sufficient for large deployable structures [20]. In contrast, the Large Space Simulator (LSS) at the ESTEC was the largest space simulator, with internal chamber volume measuring 10 m D × 15 m H, enough room for thermal vacuum tests for most apparatus at the time [27,28]. China's KM6 space environmental simulation facility is the biggest one in China. In addition, its main vacuum chamber measures 12 m D × 22.4 m H, and the air pressure in the chamber can be pumped down to 45×10^{-6} pa. As to the shrouds, they can be cooled down below 95 K by LN2 circulation system and raised to room temperature by GN2 system [29]. The largest space environmental simulation facility in the world is the NASA Glenn Research Center's Space Power Facility (SPF) located at Sandusky, Ohio. The thermal vacuum chamber

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of Space Power Facility had a capacity of 22,653 m^3, 30.5 m in diameter and 37.2 m in height. Two liquid nitrogen storage vessels with a total capacity of 930 m^3 on site provide the cryoshroud with LN2 which allows a cryoshroud temperature range of −160°C–60°C. 5 turbomolecular pumps and 10 cryogenic pumps provide vacuum environment for the chamber, attaining vacuum (2.7×10^{-4} Pa) in less than 8 h [30,31]. Given that the large thermal vacuum test systems mentioned above are versatile, they are prohibitively expensive. Obtaining vacuum in a large test chamber requires sophisticated apparatus and, moreover, LN2 refrigeration system costs greatly.

In this paper, an easy-to-implement thermal test system at the Xi'an Institute of Space Radio Technology in Xi'an, Shaanxi Province, is presented. And it simulates atmospheric thermal environment for a large deployable antenna suitable to test the reflector in deployed state. The test chamber of the system is 20 m L × 20 m W × 13 m H, allows an overall temperature ranges from −100°C to 130°C, horizontal temperature difference ≤ 2.5°C, vertical temperature difference ≤ 4°C, and airflow rate ≤ 5 m/s. Compared to thermal vacuum test chambers, the system complexity and the cost of the atmospheric chamber presented are much lower. Specifically, this system replaces large LN2 storage vessels with two turbines and features cost-effective standard air refrigeration cycles with heat exchangers. Meanwhile, measures are taken to control the air dew point while the test chamber is being cooled, thus eliminating possible water precipitation. To ensure an evenly distributed temperature and minimized air turbulence environment, the practice of returning air from the bottom and supplying air from the perforated plate at the top of the test chamber is carried out. Gravity compensation suspension truss, solar radiation array and other auxiliaries can be installed in the test chamber and, more to the point, atmospheric design of the system allows on-site observation and adjustment while the system is in operation.

2. Test system description

In order to provide a thermal test environment for a LDA, we built a large scale atmospheric test chamber capable of accommodating a LDA and simulated thermal environment by controlling the temperature of air in the test chamber. Compared with the popular thermal vacuum chamber, an atmospheric chamber can simulate the thermal test environment though it cannot simulate the vacuum environment. Nonetheless, what the atmospheric temperature test chamber need to overcome is to reduce the flow disturbance so as to diminish its impact on the antenna test.

2.1. System flow

The main flow of the system is shown in Fig. 1. This system is composed of subsystems including test chamber, gas supply system, refrigeration system, heating system, clean system, pressure control system and monitoring system. The thermal test system simulates thermal environment in the test chamber and all subsystems serve the environmental test.

2.1.1. Test chamber

The test chamber structure is shown in Fig. 2. Its test volume is 20 m (length) × 20 m (width) × 13 m (height). There are temperature sensors and pressure sensors in the test chamber to monitor the temperature and pressure in real time. The test chamber provides a stable clean dry thermal environment for a LDA, allowing it to be tested under thermal environment in the test chamber. The inner walls and the floor of the test chamber are made of stainless steel to withstand the temperature changes and effectively control the amount of dust in the test chamber. Outside the wall of the test chamber is covered with thermal insulation materials, isolating the inner thermal environment from outside. A recirculating air duct structure is designed to circulate the air in the test chamber to improve air uniformity. The inlet of the recirculating air duct is 1.2 m high and there are four recirculating fans installed inside the duct. The inlet of each fan communicates with the interior space of the test chamber, and the outlet is connected with the recirculating air duct. Each fan outlet is equipped with an electric heater for heating the test chamber air. Electric heater outlet is equipped with an efficient filter for purifying the air inside the test chamber. A perforated plate is installed on the top of the test chamber, through which filtered air flow can be rectified and return to the test chamber. In the test chamber, the practice of returning air from the bottom recirculating duct inlet and supplying air from the perforated plate at the top of the test chamber, at minimal air disturbance, assures an evenly distributed ambient temperature. The walls of the test chamber are covered with aluminum heat sinks into which cold air can flows to convective cool the air in the test chamber maintaining the low temperature environment. A test chamber inlet valve and a heat sink inlet valve are installed on the test chamber inlet pipe so that air can be controlled to flow into the test chamber or heat sinks. During antenna testing, passing cold air through the heat sinks to control the temperature in the test chamber can minimize airflow interference on the antenna.

The test chamber door is 6 m in length, 0.15 m thickness, and 6 m high. Double door structure design is used on the test chamber door, that is, a thermal insulation door is set at the inside and outside of the insulation wall respectively. The outside door opens vertically upwards and is equipped with an electric heating device to prevent freezing. The inside door opens horizontally, which is resistant to low temperature and has deformation capacity. The role of the inside door is to block the temperature impact on outside door to ensure the sealing performance of the outside door. Each side of the door fits with a small door (1 m L × 2 m H × 0.15 m T). During the test, staff can enter the test

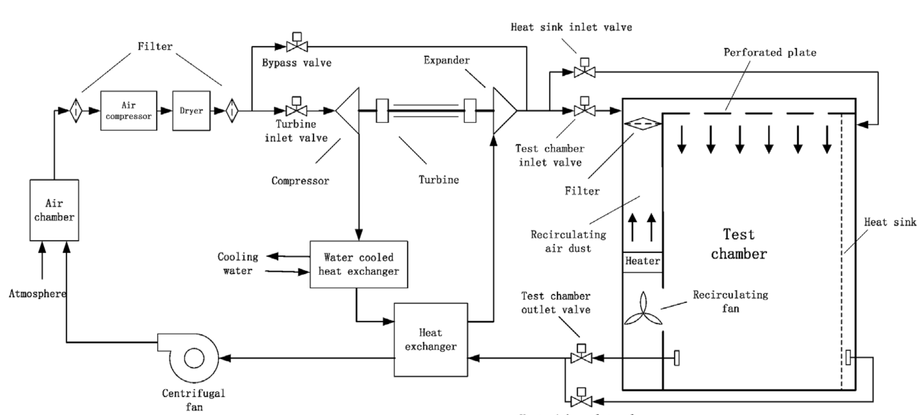

Fig. 1. System flow chart.