The Method of Field Simulation for Ultra-cryogenic Environment on Lunar

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Abstract. Based on the requirement of ultra-cryogenic test for lunar roving vehicle and its component, theoretical analysis was performed in this paper. Gaseous helium cold box was designed and numerical simulation was conducted to optimize the design of cold box. After manufacturing, it was put into use and finished the task successfully. The Test performance of cold box shows that temperature uniformity of the cold box’s during the test meets the requirement. The temperature of the cold box can be cooled down to 30K±1K, and the lowest temperature of test specimen is down to -205℃.

1. Introduction
The temperature of lunar ground changes with day and night period, and deepest temperature can reach to -180℃. As far as lunar roving vehicle concerned, the radiant heat comes from solar radiation, lunar reflect radiation and infrared radiation from lunar surface. Lunar roving vehicle receives the radiation during the daylight. However, it receives very little heat radiation during the night. What’s more, specific heat of the lunar surface is very small. Hence, when it comes to the night, lunar roving vehicle has to survive in the environment with the temperature of -180℃.

Based on the above analysis, the environment is a big challenge which encountered by lunar roving vehicle on the lunar[1~4]. Lunar roving vehicle must work successfully whenever day and night. Hence, thermal vacuum test must be conducted to testify the performance of lunar roving vehicle.

According to the hypothesis, the temperature of test specimen during thermal vacuum test should maintain in the range from -200℃~+140℃.

Shrouds cooled by liquid nitrogen are designed to simulate cold black environment in thermal vacuum facility which can make the temperature of test specimen down to -100℃~ -160℃. Hence, traditional nitrogen shroud can not meet the requirement of thermal vacuum test for lunar roving vehicle and its parts. The new test facility to conduct deep cryogenic test must be developed to solve the tough problem.

2. Simulation method for cryogenic environment of lunar surface
Deep cryogenic test should take new cold source to simulate the environment of lunar surface. Gaseous helium cryogenic system is the new cold source instead of liquid nitrogen system. The principle of vacuum thermal test is shown in Figure 1. It consists of vacuum chamber, liquid nitrogen shroud, gaseous helium cold box, vacuum pumping system, nitrogen system, and gaseous helium cryogenic system. Gaseous helium shrouds and gaseous helium cryogenic system are designed to achieve deep cryogenic environment.
3. The study of the helium cold box

3.1. The structure of the helium cold box

The helium cold box is the key equipment of the cryogenic simulation system. The structure of the cold box is shown in Figure 2.

3.2. Gas helium cold box numerical computation

The software called Flowmaster is performed to establish the model and simulate the heat transfer of gaseous helium filling in the cold box[5]. The temperature distribution curve can be achieved.

The fluid structure of the cold box is shown in Figure 3 and Figure 4.
Figure 3. The pipe number of 1, 2, 5 Shroud

Figure 4. The pipe number of 3, 4, 6 Shroud

According to the technical specification of deep cryogenic system, the boundary of the model is as follows:

a. Working fluid of the cold box is gaseous helium;

b. The volumetric flux is 900 Nm$^3$/h;

c. Working pressure of gaseous helium is 0.15MPa;

d. Inlet temperature of gaseous helium is 28.7K.

Numerical model of the cold box is shown in Figure 5.

Temperature distribution of branch tube in each cryopanel is shown in Figure 6, and the accurate result is shown in table 1.
Figure 6. The distributing of the helium cold box temperature

Table 1. The temperature of the helium cold box /K

| Pipe Number | 1# Shroud | 2# Shroud | 3# Shroud | 4# Shroud | 5# Shroud | 6# Shroud |
|-------------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1           | 29.28     | 30.25     | 30.12     | 29.67     | 29.84     | 29.30     |
| 2           | 29.31     | 30.26     | 30.14     | 29.68     | 29.87     | 29.33     |
| 3           | 29.34     | 30.27     | 30.16     | 29.69     | 29.90     | 29.36     |
| 4           | 29.37     | 30.28     | 30.18     | 29.69     | 29.92     | 29.39     |
| 5           | 29.39     | 30.28     | 30.19     | 29.69     | 29.95     | 29.42     |
| 6           | 29.41     | 30.27     | 30.19     | 29.69     | 29.96     | 29.44     |
| 7           | 29.42     | 30.27     | 30.19     | 29.69     | 29.97     | 29.44     |
| 8           | 29.42     | 30.26     | 30.19     | 29.68     | 29.97     | 29.45     |
| 9           | 29.41     | 30.25     | 30.18     | 29.67     | 29.96     | 29.44     |
| 10          | 29.39     | --        | 30.16     | --        | 29.95     | 29.42     |
| 11          | 29.37     | --        | 30.14     | --        | 29.92     | 29.41     |
| 12          | 29.34     | --        | 30.14     | --        | 29.90     | 29.37     |
| 13          | 29.31     | --        | 30.12     | --        | 29.87     | 29.35     |
| 14          | 29.28     | --        | 30.12     | --        | 29.84     | 29.30     |

From the numerical computation, the total pressure loss of the cold box is 0.01bar, and the maximum temperature gradient 1K. Hence, above results can meet the requirement of technical specification.

4. The experimental test result and discussion
4.1. The test system
The specimen was put into the helium cold box, the position of the helium cold box in the vacuum chamber is shown in Figure 7. The material of the test specimen is aluminum, of which the size is 500mm × 400mm × 5mm. The specimen emissivity is 0.07. The heat transfer between the specimen and the helium cold box only depends on the radiation.

![Figure 7. The position of the helium cold box in the vacuum chamber](image)

4.2. The result and discussion
Figure 8 shows the curve of temperature versus time for the helium cold box. Figure 9 shows the specimen temperature versus experiment test time.

![Figure 8. Temperature versus time for helium cold box](image)
From Figure 8, it can be seen that the lowest helium cold box temperature is 30K±1K, it takes about 42hrs from 300K to 30K. Figure 9 shows the relationship of the specimen temperature versus the test process, the specimen temperature can reach -205°C, it takes about 116hrs from 27°C to -205°C.

From above calculation and analysis, we can see that the temperature of the test specimen temperature can meet the requirement of the deep space exploration.

5. Conclusion
The gaseous helium cryogenic system can be taken as the cold source of the cryogenic environment simulated for deep space exploration. The lowest temperature of cold box is 30K±1K, and the specimen temperature can reach -205°C. The test certifies that the cold box can meet the needs of cryogenic environment test’s requirement for the deep space detection.

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