Design of the Space Simulation Chamber for the Space Part Test Based on the Proton Beam

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1. Introduction

New space is a technology development tendency related with the space mostly led by the private company in recent days, whereas old space was led by the government and military many years ago. One of the targets of the new space is a small-sized low earth orbit satellite, whose life is about 3 years. In order to reduce the cost, commercially available off the shelf (COTS) are tried to be used in many parts of the satellite [1]. The COTS which is going to be used as a space part should be confirmed its hardness to space radiation. There are also several programs, one of them is "Space Pioneer Project", which support the space part development in National institutes and private companies in Korea. When they succeed in development of the space part, they should test the part in radiation environment in order to confirm the radiation hardness of the developed part. Until now, many single event effect (SEE) tests have been done by using a 100-MeV proton accelerator at Korea Multi-purpose Accelerator Complex (KOMAC). But most of them has been driven by the major companies and there were no systematic test procedures for the beginners in this field. A program called "Development of Evaluation Technology for Space Parts" has started to develop the space radiation environment, improve the test conditions and setup test procedures in 2021. One of the goals of the program is to develop a space simulation chamber. Whereas a general space simulation chamber is a thermal vacuum chamber [2], this chamber should accommodate the function of proton beam irradiation. In this paper, a design of the space simulation chamber for proton beam test is presented.

2. Space Simulation Chamber Design

2.1 Design Parameters and considerations

The design parameters are; 1) the maximum proton beam energy is 100 MeV, 2) the temperature range is -55 °C ~ 125 °C, 3) the vacuum level is below 10^{-5} Torr. Most of the device under test (DUT) will be a board for electrical, electronic and electromechanical (EEE) parts, we decided the DUT size to be 254 mm X 254 mm according to European Space Components Coordination (ESCC) specification [3]. Because maximum 100 MeV proton beam will be irradiated to the sample located inside the chamber, the beam window will be installed downstream as well as upstream of the sample stage. The upstream window is due to the proton beam transmission to the DUT and the downstream window is also due to the transmission of the proton beam to external beam dump. Generally, two methods are used to cool or heat the sample in thermal vacuum chamber. A shroud is used for radiation heat transfer and a platen for conduction heat transfer. But it is not planned to use a platen in this case, because a platen is located in the beam path, which will produce unnecessary radioisotopes in the platen. The chamber size to accommodate the DUT is such that the shroud diameter and length were 500 mm and 500 mm. And the gap distance between shroud and vacuum chamber is 100 mm. The schematics of the chamber based on the above considerations is shown in Fig. 1.

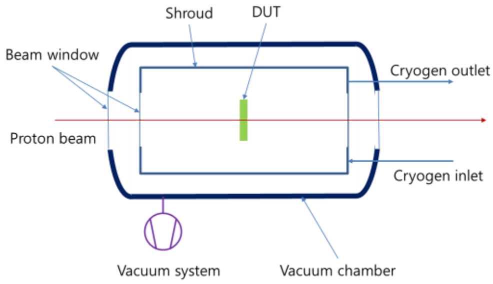

Fig. 1. The schematics of the space simulation chamber.

2.2 Thermal Calculation

The only heat transfer mechanical mechanism is radiation. There are two heat sources. One is from the radiation heat transfer from the vacuum chamber at ambient temperature. The other is the heat generation in the DUT at minimum -55 °C. The shroud temperature and heat load on the shroud are shown in Fig. 2, Fig. 3 respectively. In the Figure, the heat from the DUT was assumed in three cases, 1 W, 5 W, 10 W. Indeed, most of the DUT will be a circuit board to test the memory device, the power consumption will be less than 1 W. Also the emissivity range of the material was 0.2 ~ 1.0. Both the inner surface of the vacuum chamber and outer surface of the shroud will be mechanically polished to minimize the emissivity, and the inner surface of the shroud will be black painted to maximize the emissivity. Therefore, the estimated emissivity of inner surface of vacuum chamber and outer surface of the shroud is less than 0.2, and that of inner surface of the shroud about 0.8. The temperature of the shroud is divided into three groups according to the heat generation at DUT, when the DUT is kept to be -55 °C. If we choose the maximum heat generation less than 5 W and the emissivity of the inner surface of the shroud is higher than 0.6, the lower temperature limit of the shroud is -100 °C. The heat load is also divided into three groups and with the same limits with the above, the maximum heat load of the shroud is 80 W.

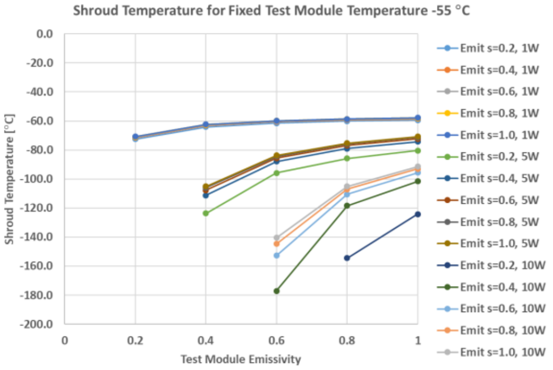

Fig. 2. Shroud temperature for fixed DUT temperature -55 °C depending on DUT heat and emissivity.

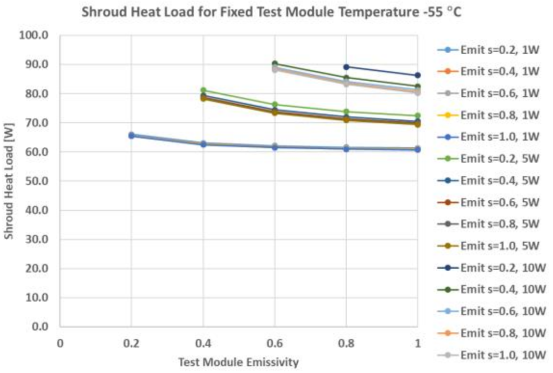

Fig. 3. Heat load on the shroud for fixed DUT temperature -55 °C depending on DUT heat and emissivity.

2.3 Temperature Control Method

A thermal conditioning unit (TCU) is a commercially available system for general purpose thermal vacuum chamber [4]. But it has large value of cooling and heating power for satellite test. Moreover, nitrogen is supplied and vented during operation. In our case, the working fluid could become radioactive during test, therefore, it is preferable to adopt entire closed loop system. The proposed temperature control system is shown in Fig. 4. The designed working fluid is nitrogen gas. The loop is divided into two parts, one is cooled through the heat exchanger and then mixed with the bypassed nitrogen gas. When we cool the shroud temperature, the valve through the heat exchanger is controlled to adjust the heat removal from the nitrogen. When we heat the shroud, the valve through the heat exchanger is entirely closed and the all the nitrogen pass through the bypass line and the in-line heater controls the temperature. As a starting point, it is assumed that the nitrogen gas follows the ideal gas law. The pressure of the nitrogen is shown in Fig. 5 depending on its temperature and density. If we want to limit the pressure less than 5 bar, the density should be less than 4 kg/m^3. If we limit the temperature rise of the nitrogen gas for 80 W heat load is 2°C, the required mass flow and volume flow rate are shown in Fig. 6. When the density is too low, the required volume flow rate is very high, therefore the initial operation density range is 3 ~ 4 kg/m^3. The pressure drop depending on the pipe size is shown in Fig. 8 for 4 kg/m^3 case. The pressure drop through the shroud is less than 1 bar, if we choose the pipe diameter larger than 12 mm.

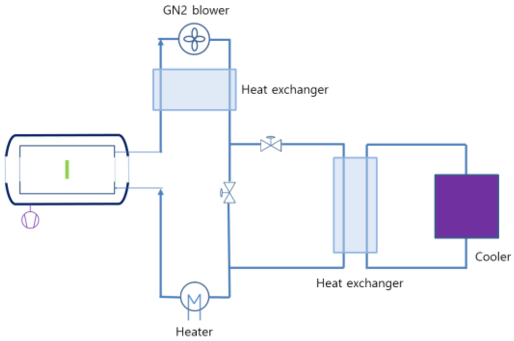

Fig. 4. Schematics of the temperature control system.

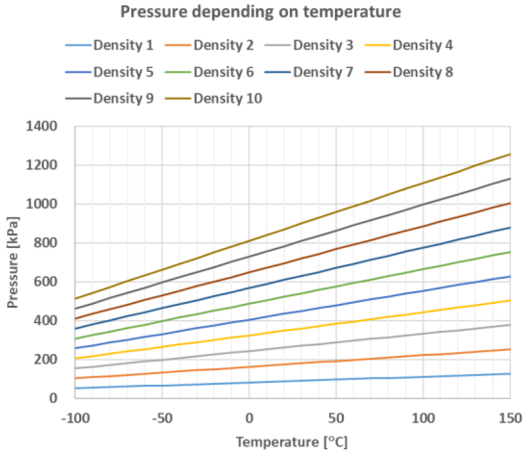

Fig. 5. Nitrogen gas pressure depending on density and temperature.

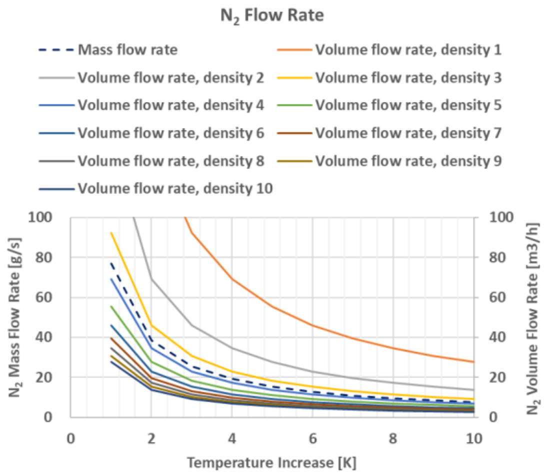

Fig. 6. Nitrogen gas mass and volume flow rate.

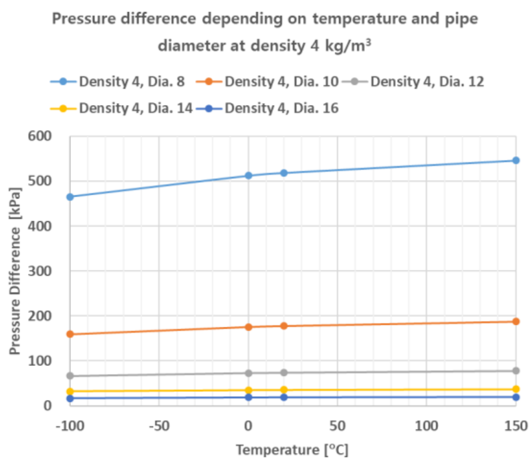

Fig. 7. Pressure drop through the shroud depending on the pipe diameter and temperature at nitrogen gas density 4 kg/m^3.

3. Conclusions

The design parameters and considerations have been described for the space simulation chamber. The unique difference of this chamber is that it should accommodate the proton beam irradiation. From the heat calculation, the heat load of shroud was 80 W and the lowest shroud temperature was -100°C. The temperature control system should also consider the radioisotope generated in the working fluid. The temperature control system is a closed loop with two-way loop, one is for coolers and the other is bypass line in order to cool the nitrogen gas. Also in-line heater is installed in the loop to heat the nitrogen gas. The working density and pipe size are decided in order to limit the maximum working pressure less than 6 bar.

Acknowledgement

The work was supported by the “Development of the Evaluation Technology for Space Parts” project through the National Research Foundation of Korea.

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