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# Comparison of the Temperature Control System for the Space Simulation Chamber

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## 1. Introduction

A program called “Development of Evaluation Technology for Space Parts” has started to develop the space radiation environment based on the 100-MeV proton beam at Korea Multi-purpose Accelerator Complex (KOMAC) in 2021. One of the goals of the program is to develop a space simulation chamber which can supply not only thermal and vacuum conditions but also proton beam irradiation environment [1]. The requirement of the space simulation chamber is summarized in Table 1.

Table 1: Space simulation chamber specification

| Radiation | Proton |
|---|---|
| Proton energy | Max. 100 MeV |
| Temperature | -55~125 °C |
| Vacuum | < $10^{-6}$ Torr |
| DUT size | 254 mm × 254 mm |

The size of the device under test (DUT) was decided according to the European Space Components Coordination (ESCC) specification [2]. Because maximum energy of 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 the external beam dump. Generally, two methods are used to cool or heat the DUT 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 radiation in the platen. The chamber size to accommodate the DUT is such that the shroud diameter and length were 500 mm and 500 mm respectively. And the gap between shroud and vacuum chamber is 100 mm [1]. The space simulation chamber has been designed as shown in Fig. 1. The chamber will be installed in the target room of the low flux beam line at KOMAC. When we use the chamber during beam irradiation, the chamber will be located in the beam path, whereas the chamber will be located off the beam path when we don’t need to use the chamber, for example irradiation to the detector test, biology application and so on. The chamber located on and off the beam line center is shown in Fig. 2. The details of the chamber developments will be discussed elsewhere [3].

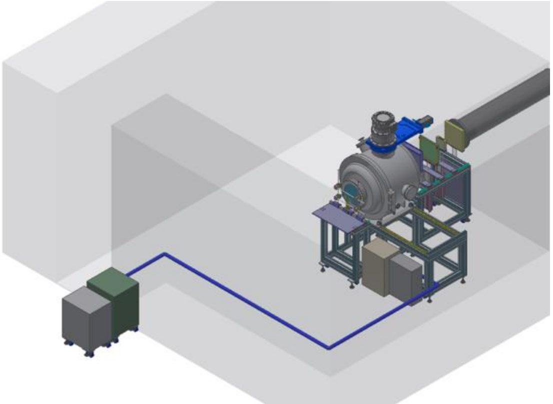

Fig. 1. Space simulation chamber located in the target room of the low flux beam line at KOMAC.

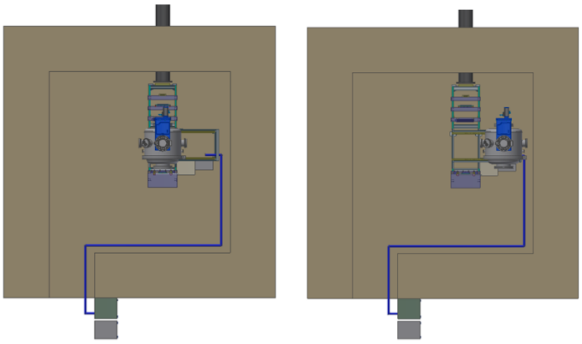

Fig. 2. Location of the chamber on line (left) and off line (right) from the beam axis.

Three methods were considered as a temperature control system of the space simulation chamber. In this paper, we will compare these three methods.

## 2. Temperature Control Systems

The requirement of the temperature control system is summarized in Table 2 [1].

Table 2: Requirement of the temperature control system

| DUT temperature | -55~125 °C |
|---|---|
| Shroud temperature | -100~130 °C |
| Cooling power | 80 W @ -100 °C |
| Heating power | 160 W @ 130 °C |
| Power for ramping | 700 W for 4 hours for full temperature range |

Three methods are considered. 1) Commercially available temperature control system, 2) Home-made temperature control system based on nitrogen, 3) Working fluid - free system based on cryo-cooler.

### *2.1 Commercially Available Temperature Control System*

There are many commercially available temperature control units for the thermal vacuum chamber. If we use this type of system, the temperature distribution of the DUT is shown in Fig. 3. The simulation was carried out with the condition that the DUT is cooled by radiation only. The temperature difference between maximum and minimum one is 5 °C, which is acceptable for the application.

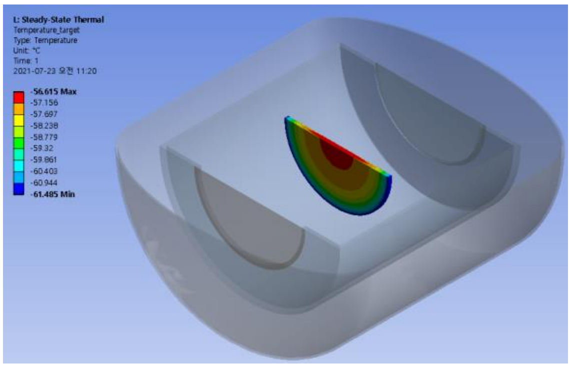

Fig. 3. Temperature distribution of the DUT.

Most of this type of temperature control system use silicon fluid (polydimethylsiloxane) as working fluid. It has characteristics of wide service temperature range, low viscosity change depending on temperature. And it is thermally stable, chemically inertness and low toxicity. The radiation effects are such that the cross linking is occurred and viscosity increases above $10^7$ ~ $10^8$ rad [4]. The methane and hydrogen gases were released through radiolysis [5].

### *2.2 Nitrogen Gas Based System*

The nitrogen gas is an excellent candidates for the working fluid with the viewpoint of radiation effects. It works very similar to the ideal gas within wide temperature range. A previous study showed that the mass flow rate is 40 g/s if we limit the temperature rise between supply side and return side to be 2 K. If we select the pipe diameter of 12 mm, we can limit the pressure below 0.5 MPa. The schematic diagram is shown in Fig. 4. 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. One disadvantage of this system is that the costs of the blower and control valve are expensive when we want to develop it in house.

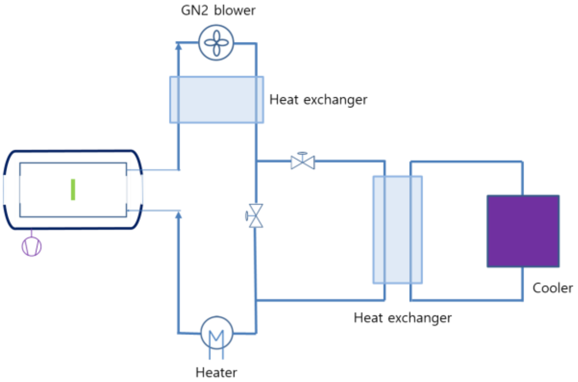

Fig. 4. Schematics of the temperature control system.

### *2.3 Working Fluid Free System*

In this case, a cyro-cooler will be used to cool the shroud and additional heater around the shroud will be used to heat the shroud. The temperature distribution of the DUT is shown in Fig. 5 when one cryo-cooler is installed. The temperature distribution is asymmetry depending on the contact location of the cryo-finger, and the temperature difference is 5 °C, which is the same with the above case. A commercially available cryo-cooler is 1.5 W cooling power at 4.5 K. If we consider the equivalent cooling capacity with different temperature, it corresponds to the inversion of the Carnot efficiency as shown in Fig. 6. From the Fig. 6, the heat at 172 K (which is the minimum temperature of the shroud) reduced to 1 % at 4.5 K. This means that 1.5 W cryo-cooler at 4.5 K can remove the heat of 150 W at 173 K.

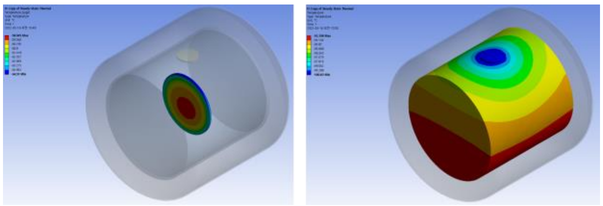

Fig. 5. Temperature distribution of DUT (left) and shroud (right) when a cryo-cooler is used

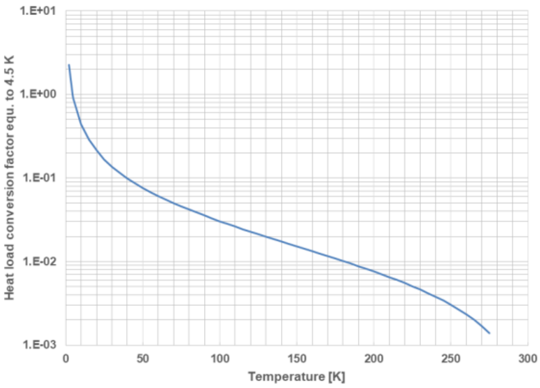

Fig. 6. Heat load conversion factor to 4.5 K equivalent.

## 3. Conclusions

Three methods were compared for the temperature control system of the space simulation chamber. Commercially available system is simple and the cost is reasonable but the radiolysis of the working fluid is a potential risk. A nitrogen working fluid system is favorable with a viewpoint of working fluid radiolysis but the high cost is a disadvantage. A working fluid free system is also simple in cooling circuit only but it needs additional heating system. And the helium system of the cryo-cooler should be considered when the shroud works high temperature.

## ACKNOWLEDGEMENT

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