Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Thermal, Vacuum and Beam Window Design of the Space Radiation Simulation Chamber Based on Proton Beam for Testing Space Parts

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1. Introduction

As demand for the radiation test especially from the space-related sector is increasing, KOMAC (Korea Multi-purpose Accelerator Complex) is developing a space simulation environment based on a 100-MeV proton linac, which has been operated with user services since 2013. The key element of the space simulation environment is a thermal vacuum chamber with a feature of high energy proton beam irradiation on the specimen such as the electronic devices and/or semiconductor boards. Basic design requirements on the space simulation chamber include wide temperature range, high vacuum condition, large beam irradiation area and compatibility with the existing the accelerator facility. Such requirements were basically derived from the tentative users in the space-related research area.

2. Design of the Space Simulation Chamber

2.1 Basic features and requirements

Major difference between the common thermal vacuum chamber and the space simulation chamber is capability of high energy proton beam irradiation in the space simulation chamber case [1, 2]. Therefore, we should take the proton beam irradiation into consideration in designing the space simulation chamber.

First of all, we need to install the beam window to pass the proton beam to the specimen mounted in the space simulation chamber. To reduce residual radiation during and after irradiation, we need to minimize the number of components in the chamber, therefore, we removed the platen for mounting the specimen. This choice makes impact on the temperature control of the specimen because the only heat transfer to the specimen is through the radiation heat transfer.

In addition, we have to pay attention to the choice of the coolant considering the effect of irradiation on the coolant and residual radiation. Most simple way is using the single element coolant such as nitrogen instead of complex refrigerant, but using the nitrogen leads another problem of ventilation, which can be difficult in the existing KOMAC facility.

Last but not least, it is important to consider the compatibility of the space simulation chamber with the existing KOMAC accelerator facility, because the chamber should be installed in one of the existing target room in KOMAC facility. Compatibility includes not only the space limitation but also the overall control system to smoothly operate the newly installed the space radiation chamber and to perform the experiment of testing the space parts under radiation environment.

Schematics of the space simulation chamber is compared with conventional thermal vacuum chamber in Fig. 1. For the space simulation chamber, two beam windows are installed at both ends to permit the proton beam irradiation. Table 1 summarized the basic requirements of the space simulation chamber

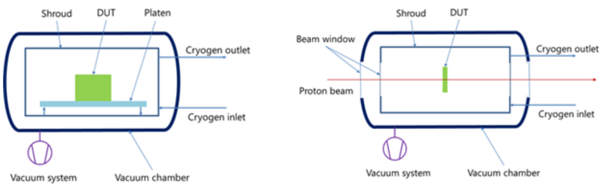

Figure 1. Comparison between the conventional thermal vacuum chamber and the space simulation chamber.

Table 1. Basic requirements of the space simulation chamber

Proton beam energy	Up to 100 MeV
Temperature range	-55℃ to 125℃
Vacuum level	Better than 10^{-5} torr
DUT area	254 mm by 254 mm
DUT electric power	5 W max.

2.2 Thermal and Vacuum Design

With the assumption that the only available heat transfer mechanism is radiation heat transfer between the specimen and the shroud, we performed the thermal analysis of the space simulation chamber as shown in Fig. 2 [3]. To maintain the specimen temperature at -55℃ with 5 W heat generation, the estimated heat load on the shroud was about 80 W, which determined the minimum cooling capacity of the cooling system. For the high temperature case, we assumed the heat generation in the specimen to be zero to estimate the minimum required heating capacity of the heater system. To maintain the specimen temperature at 125℃, the shroud should be maintained at about 130℃ with heat transfer of 157 W. For the thermal cycling of the specimen, the required temperature changing rate is 2 K/min. We considered aluminum and copper as shroud material and the required heat capacity to make 2 K/min variation was about 1.9 kW and 2.7 kW, respectively. If we permit 12 hours to stabilize the temperature of the specimen, the required heat capacity can be reduced to 500 W and 700 W, respectively.

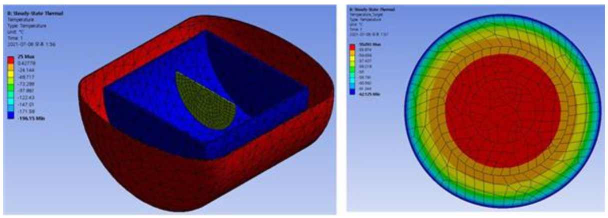

Figure 2. Thermal analysis of the space simulation chamber (emissivity ~ 0.6 case).

To determine the vacuum pumping requirement to make vacuum condition inside the chamber better than 10^{-5} torr, we performed the vacuum analysis using MolFlow code as shown in Fig. 3. The inner surface area of the chamber and the outgassing rate were assumed to be about 2.7 m^2 and 10^{-7} torr liter/s/cm^2, respectively. The assumed the outgassing rate is very conservative to be in safe side in determining the vacuum pump capacity. To maintain the vacuum level less than 10^{-5} torr, we need vacuum pump with pumping speed of 300 l/s and for 10^{-6} torr, we need 1000 l/s pumping speed, which can be easily obtained from commercial turbo-molecular pump or cryo-pump.

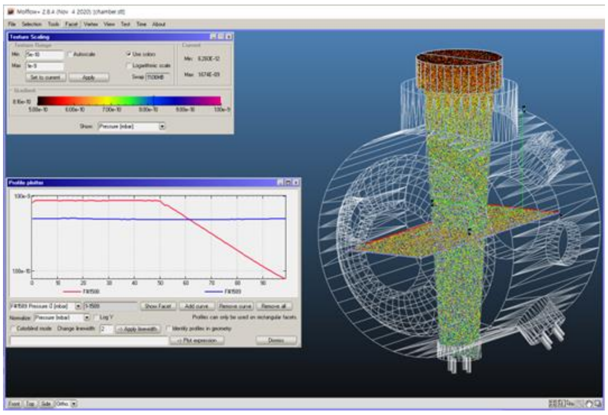

Figure 3. Vacuum analysis using MolFlow code.

2.3 Beam Window Design and Test

As material of a beam window to permit the proton beam irradiation, we chose AlBeMet with thickness of 0.5 mm to minimize the energy loss while giving mechanical stability to hold the vacuum pressure. The use of AlBeMet material is proven from the 100 MeV accelerator operation experience for past 10 years in KOMAC. Energy losses through the beam window (0.5 mm) and air layer (1000 mm) on track of the proton beam to the specimen were estimated to be about 0.6 MeV and 0.8 MeV, respectively. The increase of the proton beam energy spread was estimated to be less than 0.2 % for all cases, which would have no impact on the space part test.

We fabricated the beam window assembly to be installed on the space simulation chamber and performed vacuum test. Helicoflex metal seal was used, considering high radiation level. During the test, we found that the surface roughness was important. For good vacuum sealing performance, the surface roughness should be better than 0.8 um (Ra). With a 200 l/s TMP, vacuum level better than 2×10^{-6} torr could be obtained.

3. Future Plan

We completed a basic design study of the space radiation simulation chamber based on a 100 MeV proton linac at KOMAC. The chamber is going to be fabricated during this year and will be installed in 2023. The installation location of the space simulation chamber is one of the target rooms (TR102) in KOMAC facility, which is currently used as a target room for low-flux experiments, especially for semiconductor device test and bio-sample test (Fig. 4).

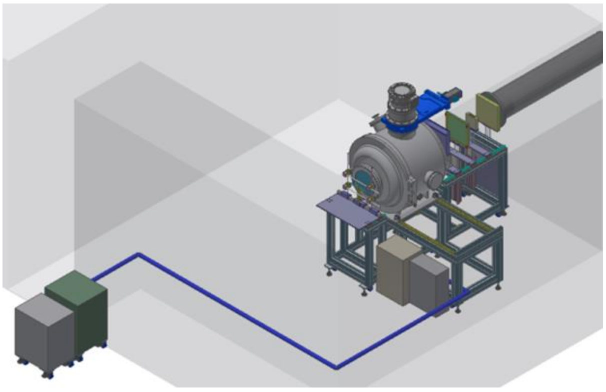

Figure 4. Installation planning of the space radiation simulation chamber in TR102 at KOMAC.

Acknowledgement

This research was supported by the National Research Foundation of Korea (NRF-2021M2D1A1045615).

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