ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS053

PROTON BEAM IRRADIATION SYSTEM FOR SPACE PART TEST*

H.-J. Kwon†, H.-S. Kim, J.-J. Dang, S. Lee, S.-P. Yoon,
W.-H. Jung, Y.-G. Song, K-R. Kim, K. Kim
Korea Multipurpose Accelerator Complex,
Korea Atomic Energy Research Institute, Gyeongju, South Korea

Abstract

A proton beam irradiation system for space part test has been developed at Korea Multipurpose Accelerator Complex (KOMAC) based on 100 MeV proton linac. It consists of a thermal vacuum chamber, a beam diagnostic system and a control system in the low flux beam target room. The thermal vacuum chamber accommodates the capacity for proton beam irradiation in addition to temperature control in vacuum condition. The beam diagnostic system is newly installed to measure the lower dose rate than existing one. In this paper, the proton beam irradiation system for space part test including a thermal vacuum chamber, newly installed beam diagnostic system is presented.

INTRODUCTION

In recent days, commercially available off the shelf (COTS) are tried to be used in many parts of the satellite in order to reduce cost [1]. The COTS which is going to be used as a space part should be confirmed its hardness to space radiation. Until now, many single event effect (SEE) tests have been done by using a 100-MeV proton accelerator at KOMAC. But most of them has been driven by a few 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 irradiation environment, improve the test conditions and setup test procedures based on 100-MeV proton accelerator in 2021. In this paper, the low flux beam line is briefly introduced, design of the thermal vacuum chamber and beam diagnostic system for the space part test are discussed.

LOW FLUX BEAM LINE

The low flux beam line at KOMAC started its operation 2017. The specification of the low flux beam line is shown in Table 1. To reduce the beam intensity by more than three orders of magnitude, we installed a locally shielded collimator. Two octupole magnets were installed to provide a uniform beam with a uniformity better than 10 % in a 100 mm by 100 mm area at the sample position [2]. The low flux beam can be further collimated by using an in-air collimator to restrict the irradiation to a specific sample position. The target room of the low flux beam line is shown in Figure 1. The beam comes from the left side through the beam window. Beam shutter, beam current monitor and beam profile monitor are installed. The sample is installed at the right side. The reference dose rate monitoring system is also installed at the target position. Ion chamber is used as a reference dosimeter. The beam profile at the sample position is shown in Figure 2. We can reliably provide a proton beam with an intensity as low as 10^6 proton/cm^2/sec. Even a lower intensity was possible from the accelerator, precise dose monitoring was difficult up to now. But we apply another tool to decrease the possible intensity, which will be discussed in later section.

Table 1: Low Flux Beam Line Specification

Parameters	Values
Energy at target	20~100 MeV
Max. average power at collimator	800 W
Max. average beam power at target	1 W
Quality assurance beam size at target	100 mm × 100 mm
Beam uniformity at target	< 10 %

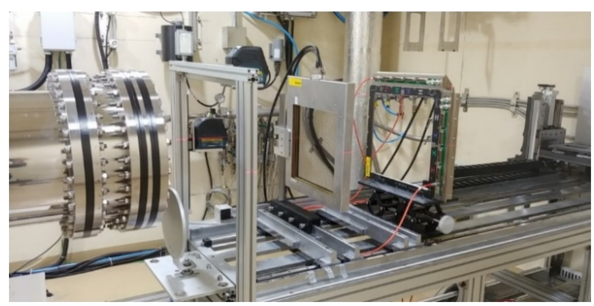

Figure 1: Low flux beam line target room. The proton beam comes from the left through the beam window. Beam shutter, beam current monitor, beam profile monitor are installed.

SPACE SIMULATION CHAMBER

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. Therefore, we should take the proton beam irradiation into consideration in designing the space simulation chamber [3, 4]. The basic requirements of the space simulation chamber are summarized in Table 2.

* Work supported by the Nuclear Research and Development Program (2021M2D1A1045615) through the National Research Foundation of Korea
† hjkwon@kaeri.re.kr

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS053

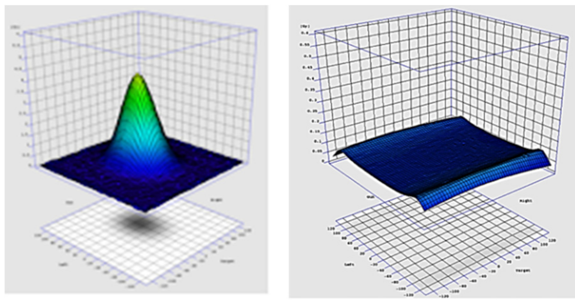

Figure 2: Beam profile at the sample position. Beam profile without octupole magnet excitation (left). Beam profile with octupole magnet excitation (right).

Table 2: Requirement of the Space Simulation Chamber

Parameters	Values
Proton beam energy	Up to 100 MeV
Temperature range	-55°C to 125°C
Vacuum level	Better than 10^{-5} torr
DUT holding area	254 mm × 254 mm
DUT power consumption	< 5 W

First of all, we need to install the beam window to pass the proton beam to the specimen mounted in the space simulation chamber. We are going to install two beam windows, one is at foreside and the other is at rear side of the chamber. The beam dump is located out of chamber. The beam window material is AlBeMet with 0.5 mm thickness. A helicoflex seal is used as a vacuum seal.

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 between samples and shroud. To maintain the specimen temperature at -55°C 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°C, the shroud should be maintained at about 130°C with heat transfer of 157 W. The temperature distribution of the sample is shown in Figure 3. The maximum temperature deviation is less than ± 3°C.

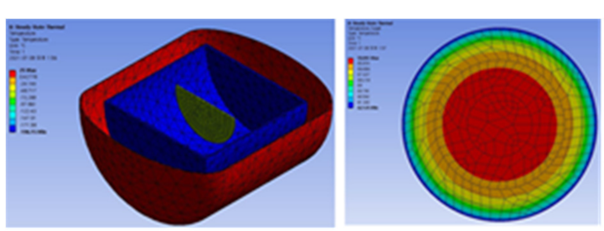

Figure 3: Thermal analysis of the space simulation chamber (left) and the temperature distribution of the sample (right).

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. Therefore, we are going to use silicon fluid (Polydimethylsiloxane, PDMS) as a coolant. It is reported when PDMS is irradiated to the radiation (gamma ray), its viscosity increases and hydrogen, methane gases are generated [5, 6]. But its threshold value seems to be 10 kGy, which is large value in low flux beam line target room. Therefore, we are going to change the coolant periodically.

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. The installation plan of the space simulation chamber is shown in Figure 4.

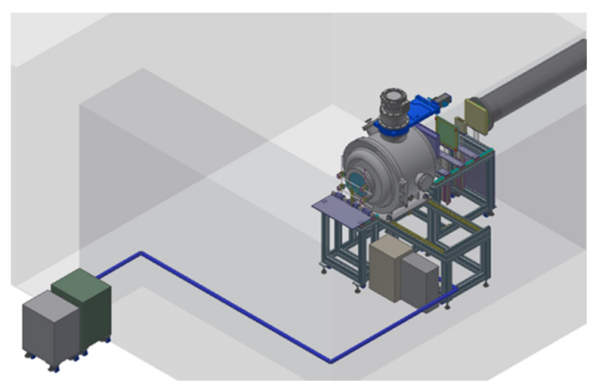

Figure 4: Installation layout of the space simulation chamber in the low flux beam line target room.

LOW FLUX PROTON MEASUREMENT

We can reliably provide a proton beam with an intensity as low as 106 proton/cm2/sec. But the users want lower beam intensity than we can provide. The accelerator itself can provide lower beam intensity, but the measurement tool was not prepared yet. Two types of ion chambers were compared to check the lower intensity measurement range. One is the Farmer ion chamber (PTW, 30013) and the other is the Bragg Peak ion chamber (PTW) [7]. The effective volume of the Bragg Peak ion chamber is 4.2 times larger than that of the Farmer ion chamber. And the nominal response of the Bragg Peak ion chamber is 3.9 times larger than that of the Farmer ion chamber. Two types of the ion chamber was installed at the low flux target room as shown in Figure 5. Two ion chambers are installed near the same position. We checked the beam uniformity less than 5 % within the effective measurement location. The charge was measured with the UNIDOS (PTW). The test results showed that there was a linear relationship between two

ISBN: 978-3-95450-227-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2022-THPOMS053

ion chambers down to 5×10⁴ proton/cm²/sec, which means we can provide the proton beam intensity as low as that value. The measurement result is shown in Figure 6. When we considered the nominal response, we can measure the proton intensity down to 1×10⁴ proton/cm2/sec by using Bragg Peak ion chamber alone [8].

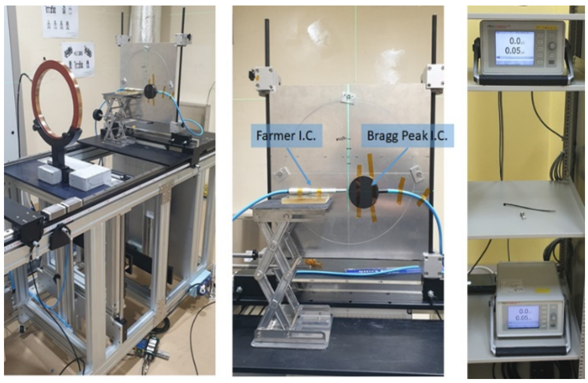

Figure 5: Target room configuration (left), two types of ion chamber installed at sample position (middle) and charge integrator (right).

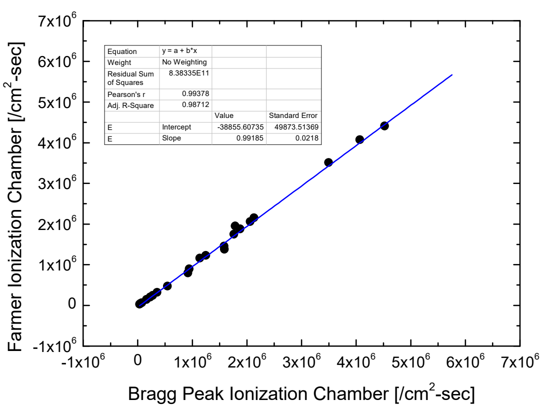

Figure 6: Comparison of the measurement results between Farmer ion chamber and Bragg Peak ion chamber.

SUMMARY

Proton beam irradiation system for space part test based on the low flux beam line of KOMAC 100-MeV accelerator is introduced. A space simulation chamber was designed not only for the temperature and vacuum environment but also for the proton beam environment. Its design was completed and it will be installed at 2023. To increase the range of the proton beam intensity which we can supply, two types of the ion chamber were compared in the low flux beam line. The result showed that we can measure lower intensity proton beam down to 5×10⁴ proton/cm²/sec.

REFERENCES

[1] Kirby Kruckmeyer, Reduce the risk in New Space with Space enhanced plastic products, Texas Instruments Application Report, SBOA344, July 2019.

[2] Yu-Mi Kim, Sang-Pil Yun, Han-Sung Kim, Hyeok-Jung Kwon, "Beam characterization of the low flux proton beam line at KOMAC for application to radiation effect testing", *Nuclear Inst. And Methods in Physics Research Section A*, vol. 950, no. 11, Jan. 2020, 162971. doi: 10.1016/j.nima.2019.162971

[3] Han-Sung Kim, *et al.*, "*Design of the Space Radiation Simulation Chamber based on Proton Beam for Testing Space Parts*", Korean Nuclear Society, Jeju, Korea, 2022.

[4] Hyeok-Jung Kwon, *et al.*, "Comparison of the Temperature Control System for the Space Simulation Chamber", Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 19-20, 2022.

[5] Jay A. LaVerne, *et al.*, "Gas production in the radiolysis of poly(dimethysiloxanes)", *Radiation Physics and Chemistry*, vol. 142, Jan. 2018, pp. 50-53. DOI:10.1016/j.radphyschem.2017.01.027

[6] http://www.shinetsusilicone-global.com/catalog/pdf/kf96_e.pdf

[7] http://www.ptwdosimetry.com/en/support/online-catalogs/.

[8] Kye-Ryung Kim, *et al.*,"Low Flux Measurement of the Space Simulation Chamber Based on High Energy Proton Accelerator", Online Presentation at Korean Physical Society Spring Meeting, Oct. 14, 2022.