Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 9-10, 2024

Feasibility of Induction Heating to Evaluate the Thermal Stability of Graphite Target

Jae Young Jeong, Jae Chang Kim, Chan Jung Kim, Junehyung Lee Bernaski, Gyuhyeon Sim, and *Yong Kyun Kim
Department of Nuclear Engineering, Hanyang University, Seoul 04763, Korea
**Corresponding E-mail: ykkim4@hanyang.ac.kr*

1. Introduction

Graphite is one of the most widely studied materials to generate surface muons in accelerator facilities [1,2]. In Korea, the new μSR facility, which contains the target system with a disk-shaped graphite target, was constructed in the Sindong area near Daejeon-city in 2021 and has performed the commissioning process. The main purpose of commissioning is to ensure that the target system meets the design criteria and check its stability during operation. So that the installed target system is scheduled to go through experiments to verify whether heat analysis calculation and surface muon production calculation are well performed.

The μSR facility at RAON will be provided with a 600 MeV proton beam through SCL2 and SCL3 of the RAON Accelerator. Since the construction of those accelerators is not completed, it is not able to proceed with commissioning using a proton beam. However, experiments using a proton beam have drawbacks for engineering research. The significant production of secondary radiation makes it challenging to use temperature-measuring equipment like thermocouples, and the overall facility's neutron activation complicates post-experiment analysis. Therefore, we developed a new commissioning method using radio-frequency (RF) heating, which is radiation-free, and economical.

2. Experimental configuration

The RF heating system consists of an RF heater and a copper coil, and the shape of the copper coil is particularly critical as it is the factor that has the greatest impact on the heating process and requires careful consideration. The copper coil shown in Fig. 1 was designed to cover the proton beam size and reproduce the heat generated by the beam [3]. The copper coil was connected to the RF heating machine, which could generate an input power of as much as 10 kW. The frequency has a value of 10–400 kHz depending on the state of the target. Before the experiments, preheating was performed to reduce the outgassing of the target and copper coil during the experiments. Considering that the magnetic field generated by the AC affects thermocouples, a thermal infrared imaging camera (IR camera) is also necessary. A calibrated Forward-Looking InfraRed (FLIR) SC660 IR camera that can measure the temperature range from −40 °C to 1500 °C with a maximum error of 2% was used. The IR camera measured the temperature of the graphite target through a window from outside the chamber during the heating experiment. Therefore, to observe the temperature of the target with an IR camera, a filter window through which IR rays can pass must be attached to the chamber. The FLIR SC660 is sensitive to wavelengths from 7.5 to 13 μm. A 2-inch germanium window was attached to enable IR rays with a 2–15 μm wavelength to transmit to the outside chamber so that a data point could be recorded using an IR camera.

Fig. 2 shows the inner view of the target chamber, including the copper coil and graphite target. After placing the target and coil, a Ge window was attached to the beam port facing the target. Fig. 3 shows the experimental setup, including the Ge window, IR camera, and target chamber during the experiment. With this configuration, the target was heated up to 8.6 kW while rotating and up to 1.096 kW for the stationary target.

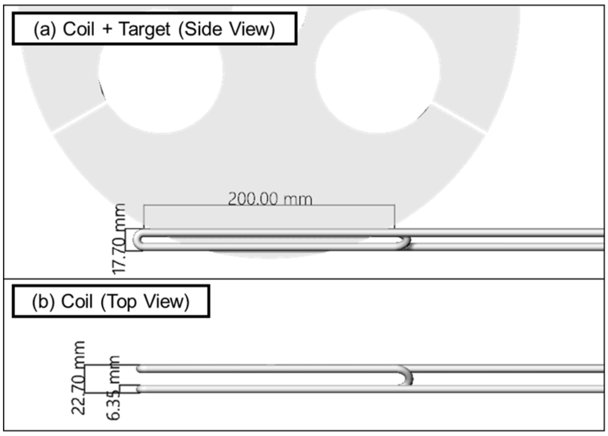

Fig. 1. Copper coil design for the experiment


Fig. 2. Inner view of the target chamber showing the copper coil and the graphite target

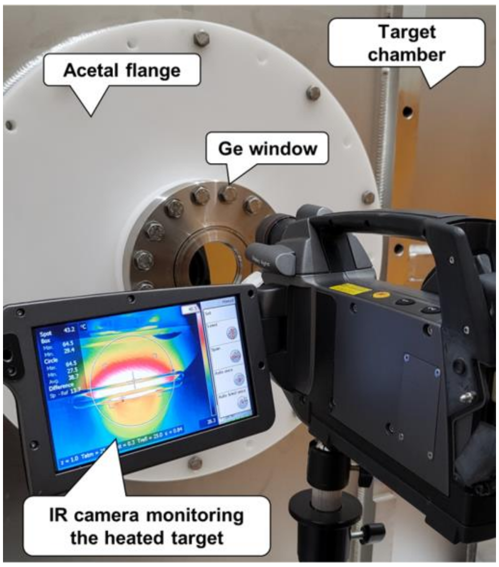

Fig. 3. Experiment setup including Ge window, IR camera, and the target chamber during the experiment

3. Experimental results

When the target was stationary while heated, the temperature of the target increased partially and not uniformly. Partial heating can cause distortion and breakage of the graphite plate. Accordingly, the input power was increased stepwise, and the maximum temperature was limited to 500 °C. First, the maximum temperature was measured for each input power. Since the current in the machine was only one digit, an excessively low current increased the error in the input power, thus, measuring was started from 5 A.

For the rotating target, the maximum temperature of the target was measured with the same method as for the stationary state. When the target rotated, the generated heat was distributed evenly to the target edges, applying a higher input power than in the stationary experiment. The resonance frequency was 297.5±0.6 kHz for stationary and rotating target states, indicating that tank resonance circuits consisting of the copper coil and the graphite target were almost the same despite the rotation of the target.

The maximum temperatures of the graphite target are listed in Table 1. Although the target was rotating, the graphite target was heated successfully by RF heating, following the power laws as expected. Furthermore, a rotation experiment was performed to determine the long-term stability of the target system at a high temperature. The highest input power possible was applied, and the target was checked after two weeks to determine whether damage had occurred. Following the application of a maximum input power of 8.6 kW for two weeks, the vacuum on the chamber was released, and the target was visually inspected, confirming that there were no breaks or cracks. The rest of the target system had no problems that were considered in advance, such as the shaft sticking owing to thermal expansion and coolant leaks.

	Voltage (V)	Current (A)	Input Power (kW)	*M. temp. (°C)	**E. temp. (°C)
Stationary	37	2	0.074	76.3	111.9
	94	5	0.470	203	322.6
	116	7	0.812	247	395.8
	137	8	1.096	288	464.0
Rotating	129	7	0.903	170	267.8
	169	12	2.028	230	367.5
	230	17	3.91	285	459.0
	282	21	5.922	321	518.9
	344	25	8.6	356	577.1

*M. temp.: Measured temperature by IR camera
**E. temp.: Estimated temperature after calibration

Table. 1. Experiment result for RF heating the stationary and rotating target

4. Conclusion

We introduced a novel RF heating method to analyze the target thermal stability, even when the proton beam is unavailable. RF heating is cost-effective, radioactivity-free, available in a vacuum, and contactless. These advantages enable flexible heating distribution for the graphite target in the vacuum chamber. These results show that the RF heating method can be a viable option for heating a rotating graphite target in a vacuum. One observed limitation in this experiment is that the input power is too low to check the thermal stability during operation with a 100-kW proton beam. This work aims to establish the viability of the RF heating approach for achieving desired operational parameters.

5. Acknowledgement

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety(KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission(NSSC) of the Republic of Korea. (No. RS-2023-00242425)

REFERENCES

[1] D. Kiselev, P. A. Duperrex, S. Jollet, S. Joray, D. Laube, D. Reggiani, R. Sobbia and V. Talanov, The Meson Production Targets in the high energy beamline of HIPA at PSI, SciPost Phys. Proc. **5**, pp. 3,2021
[2] J.Y. Jeong, J.C. Kim, Y. Kim, K. Pak, K. Kim, J. Park, J. Son, Y.K. Kim, W. Lee, J.H. Lee, Design of muon production target system for the RAON μSR facility in Korea, Nuclear Engineering and Technology, Vol. 53, No. 9, pp. 2909-2917, 2021
[3] Pak, K., et al., Beam Optics Design for the μSR Facility at the RAON Facility in Korea. Journal of the Korean Physical Society, 2020. **77**(5): p. 438-442.