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Particle flux enhancement using in-vessel electromagnet in particle flux irradiation facility at KAERI

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1. Introduction

A divertor particle flux simulation facility has been developed and operating at Korea Atomic Energy Research Institute (KAERI) [1,2]. The KAERI divertor particle flux simulation facility consists of a cylindrical vacuum chamber with a length and diameter of 1.5 m, two cryopumps, four turbomolecular pumps, a dry pump, an AF-MPD thruster, an NdFeB permanent magnet, and a target system equipped with a water loop (see Fig. 1). An Applied-Field MPD (AF-MPD) thruster is used as a plasma source to produce hydrogen, deuterium, and helium particle fluxes corresponding to those expected in the fusion divertor region.

The AF-MPDT is a type of electric propulsion in which ions are accelerated by the Lorentz force generated from the interaction between the discharge current and an externally applied magnetic field, thereby producing a high-energy ion beam. The resulting particle flux varies depending on several operational and geometrical parameters, including the configuration and strength of the applied magnetic field, the distance between the thruster and the target, the discharge current, the propellant mass flow rate, and the operating pressure.

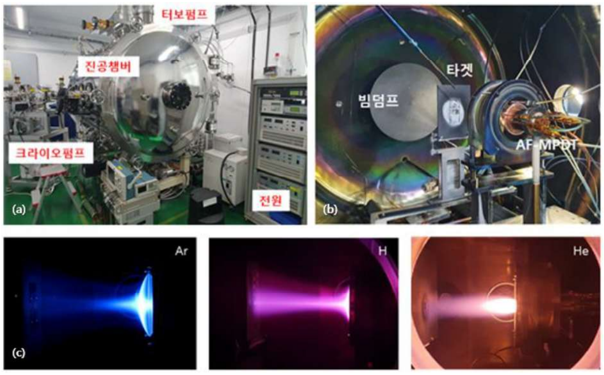

Fig. 1 Photos of (a) KAERI divertor simulation facility, (b) inside the vacuum chamber, and (c) Ar, H, and He discharges

The current KAERI divertor simulation facility is capable of generating a deuterium particle flux up to 1.7×10^{23} $m^{-2}s^{-1}$, corresponding to 17% of the expected ITER divertor particle flux.

To further increase the particle flux, a vacuum-compatible electromagnet has been installed inside the vacuum chamber to generate a stronger magnetic field of approximately 1000 G near the target region, compared to the existing 120 G provided by the permanent magnet. The enhanced magnetic field is intended to improve beam focusing and thereby increase the particle flux delivered to the target. This paper presents the design, fabrication, and operational validation of the newly developed electromagnet and outlines future plans using the upgraded particle flux irradiation facility.

2. Design, Fabrication, and Testing of the in-vessel Electromagnet

A new electromagnet consisting of an internal coil, a vacuum-compatible case, and a supporting structure was fabricated. The internal coil was wound around a bobbin with a diameter of 205 mm and a thickness of 90 mm. The coil is a rectangular with a cross-sectional area of 2×5 mm^2, and the total number of turns is 360. The design target was to generate a magnetic field of approximately 0.1 T at the center of the electromagnet when a current of 60 A is applied to the coil.

The electromagnet case functions as a water tank, designed so that the internal coil is immersed in water. The case was designed to maintain vacuum integrity and prevent coolant leakage. The case has a diameter of 360 mm and a thickness of 158 mm, and made of aluminum.

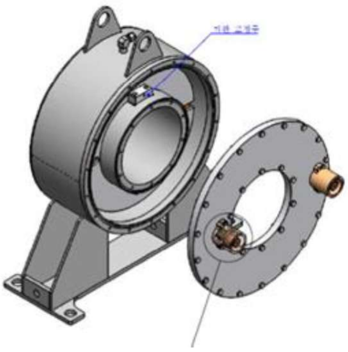

Fig. 2 Detailed drawings of the electromagnet housing case and electrical feedthroughs

Two electrical feedthroughs for supplying current to the coil are mounted on one side of the case (Fig. 2), and electrical insulation between the feedthrough and the case was achieved using a PEEK (polyether ether ketone) insulator. Cooling water inlet and outlet ports were installed on the lower and upper surfaces, respectively.

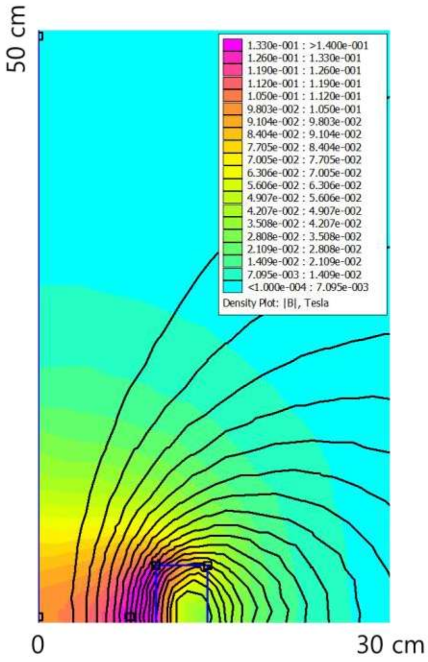

Fig. 3 Magnetic fields obtained from FEMM simulation when the coil current is 60 A.

After the electromagnet was fabricated, the strength and geometry of magnetic fields produced by the electromagnet were calculated using the electromagnetic simulations program (FEMM). The calculated magnetic field profile when the coil current is 60 A is shown in Fig. 3. As seen in the figure, the strength of the magnetic field is greater than 1000 G (0.1 T) at the center of the magnet, consistent with the design target.

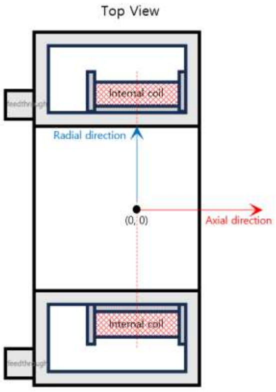

Fig. 4 Magnetic field measurement directions of the electromagnet

Before the electromagnet is installed in the vacuum chamber, the magnetic field produced by the electromagnet was measured using a teslameter (KANETEC TM-801 EXP). The measurement positions were varied along the axial direction from 0 to 20 cm at 5 cm intervals and along the radial direction from 0 to 7 cm at 1 cm intervals (see Fig. 4). For each position, the coil current was increased from 0 to 50 A in 10 A increments, and each condition was measured three times.

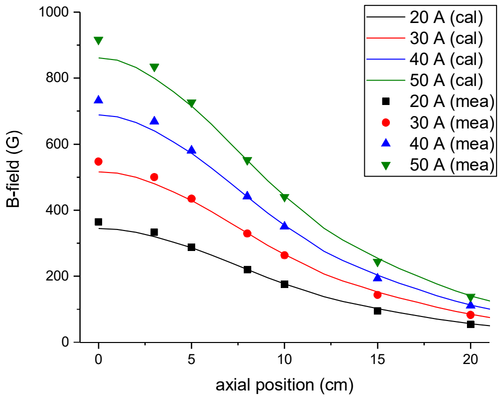

Fig. 5 Comparison between measured axial magnetic field (symbols) and FEMM simulation results (solid lines)

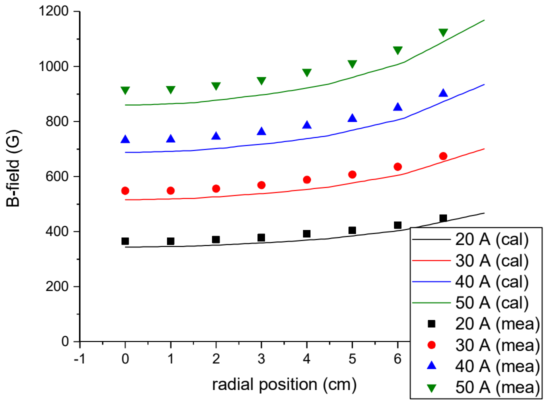

Fig. 6 Comparison between measured radial magnetic field (symbols) and FEMM simulation results (solid lines)

The axial and radial magnetic fields measured by the teslameter were compared with the simulation results obtained from FEMM as shown in Figs. 5 and 6, respectively. In both the axial and radial directions, good agreement was observed between the measured magnetic fields and the FEMM simulation results. While good agreement in overall trends was observed, the measured magnetic field values were found to be several tens of Gauss higher than those predicted by FEMM simulations. Further investigation will be conducted to identify the sources of this discrepancy.

Future work will focus on installing the electromagnet inside the vacuum chamber and performing plasma experiments to assess the effectiveness of the in-vessel electromagnet in enhancing the particle flux.

3. Concluding remarks

The newly developed in-vessel electromagnet met the design requirements for magnetic field strength. Experimental measurements showed good agreement with numerical simulations, validating the electromagnet design. The installation of the electromagnet near the target region is expected to focus ion beam and to increase the particle flux to the target. Future plasma experiments will be carried out to verify this.

REFERENCES

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[2] K.-B. Chai, D.-H. Kwon and M. Lee, Plasma Phys. Control. Fusion **63**, 125020 (2021).