RECENT PROGRESS IN THE PILOT GAMMA PDX-SC SUPERCONDUCTING MIRROR

[1]M. SAKAMOTO, [1]N. EZUMI, [1]M. YOSHIKAWA, [1]M. HIRATA, [1]J. KOHAGURA, [1]T. NUMAKURA, [1]R. MINAMI, [1]T. KARIYA, [1]T. SETO, [1]R. MIYAUCHI, [1]T. OKAMOTO, [1]H. KAWAHARA, [1]H. BHATTARAI, [1]H. ICHIKAWA, [1]Y. KINASHI, [1]S. TOGO, [1]K. EMOTO, [1]D. HWANGBO

[1]Plasma Research Center, University of Tsukuba, Tsukuba, Japan

Email: sakamoto@prc.tsukuba.ac.jp

A superconducting (SC) mirror device was constructed to contribute to the DEMO divertor study. The new device consists of a pair of SC coils and a pair of Cu coils, a main chamber, a differential pumping chamber and a steady state plasma source. A cascade arc plasma source and a helicon plasma source have been developed in order to produce high density and large diameter plasma. An ICRF wave with a frequency of 1.8 MHz and a power of 160 kW was applied to plasma sustained by a cascade arc plasma source. An ion-sensitive probe indicated that high-energy ions were produced by the ICRF power. Fluctuations during ICRF heating were decreased by edge biasing.

Power and particle handling in the divertor is one of the most critical issues for DEMO [1]. It is necessary to accurately simulate the DEMO divertor. The following parameters seem to be necessary for DEMO divertor simulation: the plasma density is ~10^{20} m^{-3}, ion and electron temperatures are ~100 eV and the magnetic field is a few T. Linear plasma devices can contribute to DEMO divertor simulation and PWI issues for their high flexibility of experiments. In GAMMA 10/PDX tandem mirror device, divertor simulation studies have been extensively done using end-loss plasma of which temperature is comparable to that of the SOL plasma of DEMO [2-4]. In Plasma Research Center at University of Tsukuba, moreover, an SC mirror device named Pilot GAMMA PDX-SC was constructed for the DEMO divertor study. The target plasma parameters are the followings: plasma density 10^{19} m^{-3}, electron and ion temperatures several tens eV and discharge duration 10 − 100 s. Figure 1 shows a schematic drawing of Pilot GAMMA PDX-SC. The inner diameter of the main chamber is ~ 1.15 m. A pair of NbTi SC coils with the bore diameter of 0.9 m is installed at the both sides of the main chamber to produce a simple mirror configuration. The distance between the SC coils is 4.3 m. A pair of Cu coils with the bore diameter of ~1.5 m is installed near the midplane. The maximum magnetic field B_{max} is 1.5 T and the mirror ratio is 30 without the Cu coils and ~20 with them. The main chamber and differential pumping chamber are pumped by turbomolecular pumps with the pumping speed of 5,400 L/s and 2,700 L/s for hydrogen gas, respectively.

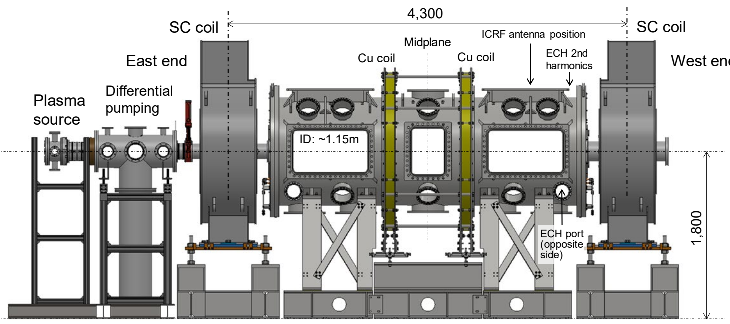

Fig. 1 Schematic drawing of Pilot GAMMA PDX-SC

One of the features of Pilot GAMMA PDX-SC is that steady state plasma is supplied from a plasma source installed at the east end region to the mirror cell and it is heated by ICRF and ECH. A cascade arc plasma source and a helicon plasma one have been developed for high density and large diameter plasma production. As for the cascade arc plasma source, a large diameter LaB_6 cathode (ϕ = 150 mm) is used and being developed to increase in cathode temperature and the discharge current. The electron density of 2.5 x 10^{18} m^{-3} was obtained at the mirror throat. As for the helicon plasma source, 13.56 MHz waves generated by a two-turn flat loop antenna with an outer/inner loop diameter of 10 cm/5.5 cm are injected through a quartz window to the differential pumping chamber in order to produce high density plasma [5]. The electron density of 3 x 10^{18} m^{-3} was obtained at 18 kW RF power at the mirror throat. Neutral gas used for the plasma source is mainly pumped through a differential pumping chamber installed between the plasma source and the main chamber.

As for the electron heating, 28 GHz gyrotron is used for second harmonic heating. Significant increase in the electron density and expansion of plasma diameter were observed when ECH was applied, but the ECH duration was restricted to 10 ms due to the influence of the magnetic field leaking from the superconducting coil in the gyrotron tube. Magnetic shield will be installed around the gyrotron tube for longer ECH heating. As for the ion

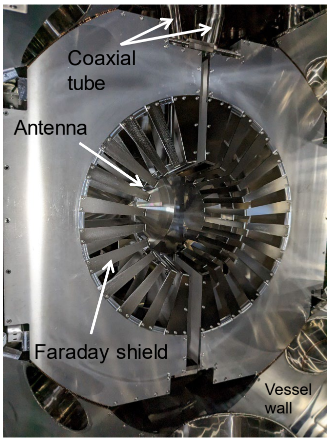

Fig.2 ICRF antenna system. It is located 1.1 m from the midplane to the west end.

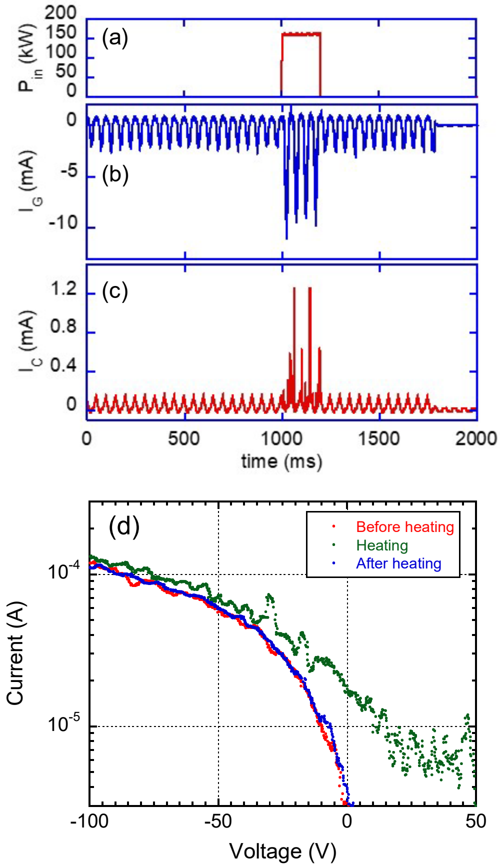

Fig.3 Time evolution of (a) ICRF power, (b) guard current and (c) collector current of ISP. (d) collector current as a function of applied voltage.

heating, ICRF differential-frequency (DF) wave heating [6, 7] is planned to heat the high density plasma. The beach heating with a slow wave is popular in the mirror device but it cannot be applicable to high density plasma. So, a DF wave between two fast waves which can propagate into a high density core plasma is a good candidate for high density heating. We plan to eventually install three antennas for the DF heating, and currently one antenna is in place as shown in Fig. 2. Figure 3 shows results obtained with an ion-sensitive probe (ISP) which is installed at 1.9 m from midplane to the west end. An ICRF wave with the frequency of 1.8 MHz and the power of 160 kW was applied to plasma sustained by a cascade arc plasma source. The plasma density at 0.92 m from the midplane to the east end was 3.4 x 10^{17} m^{-3}. The guard current (i.e. electron current) and the collector current (i.e. ion current) were increased by the ICRF power. As shown in Fig. 3(d), collector current-voltage characteristics reveal high energy ions are produced by the ICRF power, and preliminary analysis shows the ion temperatures before and during ICRF heating are 9 eV and 21 eV, respectively. Although the electron density was low in this experiment, the effect of beach heating was verified. The next step is to work on increasing the density.

In order to cope with MHD instability, three concentric electrodes are installed at the east end of the main chamber to apply a method of vortex confinement to suppress the growth of flute instability [8]. The inner diameters of the inner, middle and outer plates are ϕ70 mm, ϕ100 mm and ϕ130 mm, respectively. Preliminary experiments were done. When 250 V was applied to the outer electrode and the middle and inner electrode were grounded and floating, respectively, fluctuation during ICRF heating was reduced.

ACKNOWLEDGEMENTS

This work is performed with the support of NIFS Collaborative Research Program (NIFS23KUGM174).

REFERENCES

[1] ASAKURA, N., et al., Nucl. Fusion **61** (2021) 126057.
[2] NAKASHIMA, Y., et al., Nucl. Fusion **57** (2017) 116033.
[3] SAKAMOTO, M., et al., Nuclear Materials and Energy **12** (2017) 1004–1009.
[4] EZUMI, N., et al., Nucl. Fusion **59** (2019) 066030.
[5] SETO, T., et al., J. Plasma Phys. **90** (2024) 975900401.
[6] KAYANO, H., et al., Plasma and Fusion Research **16** (2021) 2402045.
[7] SUGIMOTO, Y., et al., Plasma and Fusion Research **18** (2023) 2402084.
[8] BEKLEMISHEV, A.D., et al., Fusion Science and Technology **57** (2010) 351-360.