Application of an Externally Applied Rotating Magnetic Field for Control of MHD Relaxation Phenomena in the HIST Spherical Torus Device

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Application of an externally applied rotating magnetic field (RMF) for control of MHD relaxation phenomena driven by a coaxial helicity injection has been proposed in the HIST spherical torus device. In this letter, the plasma responses to the RMF evaluated by magnetic fields inside the plasma in HIST are shown.

Keywords: rotating magnetic field, MHD relaxation, coaxial helicity injection, spherical torus

1. Introduction

Coaxial Helicity Injection (CHI) using a magnetized coaxial plasma gun (MCPG) is one of most attractive methods to achieve a non-inductive current drive and a plasma start-up in a spheromak and a spherical torus (ST). The CHI current drive has been performed in some experimental devices (1). A rotating kink mode of \( n = 1 \) and a toroidal plasma rotation in the \( E \times B \) drift direction have been observed during the CHI current drive, so that an electron locking model has been developed to explain the current drive mechanism of CHI (2). Here, \( n \) is a toroidal mode number. Therefore, there is a possibility to improve the controllability and efficiency of CHI through control of the MHD relaxation phenomena. On the other hand, it is well known that an externally applied static or dynamic magnetic field is used as a worthwhile tool for control of MHD instabilities such as resistive wall modes (3) and edge localized modes (4) in recent tokamak devices. Since MHD relaxation phenomena during the CHI strongly relates to the plasma rotation, a force transfer from the RMF to the plasma plays an important role for the control of the CHI current drive. For the purpose of revealing the ability of an externally applied rotating magnetic field (RMF) as a control method for the CHI current drive, we have recently started to develop a RMF coil system in the HIST spherical torus device.

In this letter, we report the RMF coil system and preliminary experimental results of plasma responses to the RMF in HIST.

2. RMF Coil System in HIST

Figure 1 shows the experimental setup of the RMF coil system in HIST (major radius: 0.30 m, minor radius: 0.24 m). The detail description of HIST is presented in the reference (1). Eight coils are located above and below the midplane at four toroidal locations so that the RMF is resonant with \( n = 1 \) rotating kink mode driven by the CHI. In addition, the RMF coil set is installed inside a flux conserver of 5 mm thickness (cut-off frequency \( \sim 170 \) Hz) so that the RMF penetrates into the plasma. The coil winding is made of 16 turns of enameled copper circular wires (conductor cross section of 1.5 \( \text{mm}^2 \)), covered with a thin stainless steel case of 0.5 mm thickness (cut-off frequency \( \sim 710 \) kHz). The RMF system is driven by an IGBT inverter power supply (nominal current: 1 kA, nominal voltage: 1 kV) with an operating frequency band from 10 kHz to 30 kHz. Figure 2 shows the RMF coil current waveform and the time developments of the RMF in vacuum measured by magnetic pick-up coils that are embedded in the RMF coil.
Fig. 2. Time evolutions of (a) the RMF coil current (coil I-III, II-IV), (b) the $B_r$ at the coil I, (c) the $B_r$ at the coil II, (d) the $B_r$ at the coil III, (e) the $B_r$ at the coil IV.

Fig. 3. Time developments of (a) the plasma current $I_p$ and the line-averaged electron density $\bar{n}_e$, (b) the RMF coil current $I_{RMF}$, (c) the $B_r$ in vacuum, (d) the $B_r$ in the plasma. The RMF frequency is 30 kHz.

3. Plasma Responses to the RMF

In this study, the RMF was applied to the decay phase of the ST plasma in order to investigate plasma responses to the RMF since strong MHD activities appear during the current driven phase by the CHI. Figure 3 indicates the time evolutions of the plasma current, the line-averaged electron density measured by CO$_2$ laser interferometer and the time derivative of the radial magnetic field $\dot{B}_r$ at the edge ($R = 0.375$ m) generated by the RMF. It should be noted that the $\dot{B}_r$ in vacuum was very small, because the magnetic probe was installed far from the RMF coils. One can see that the $\dot{B}_r$ in the plasma was amplified in comparison with that in vacuum. It could be considered that a shielding current was excited by the RMF in the plasma. An amplification factor is defined by $|\dot{B}_{r,p}|/|\dot{B}_{r,v}|$, where $|\dot{B}_{r,p}|$ represents the amplitude of $\dot{B}_r$ at the RMF frequency with (without) the plasma. Figure 4 shows the dependence of the amplification factor on the driving frequency of the RMF ($f_{RMF}$). Here, the positive value of $f_{RMF}$ means that the RMF rotates in the same direction of the plasma current. One can confirm that the curve is asymmetric with respect to the toroidal rotation direction of the RMF. Here, the relative rotation velocity of the RMF ($v'_{RMF}$) with respect to the plasma rotation velocity ($v_{plasma}$) is introduced as $v'_{RMF} = v_{plasma} - f_{RMF} \cdot 2\pi R/n$. The plasma rotation velocity measured by Mach probes was 10–15 km/s during the decay phase. In addition, the plasma rotates in the direction of the plasma current. Thus, it can be considered that the amplification factor shown in Fig. 4 has the minimum value under the condition where $v'_{RMF} = 0$.

4. Summary

We have investigated the plasma responses to the RMF in the HIST spherical torus device. As the results, it was clarified that the plasma responses to the RMF depend on not only the driving frequency of the RMF but also the toroidal plasma rotation.

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References