

Dynamic Behaviors of Tokamak Plasma Induced by Externally Rotating Helical Magnetic Field

Y. Kikuchi^a, V.P. Budaev^b, Y. Uesugi^c, M. Toyoda^a, S. Takamura^a

^a Graduate School of Engineering, Nagoya University, Nagoya, 464-8603, Japan

^b Russian Research Center "Kurchatov Institute", Moscow, Russia

^c CIRSE, Nagoya University, Nagoya, 464-8603, Japan

1. Introduction

Dynamic Ergodic Divertor (DED) has been proposed to improve the boundary tokamak plasma conditions on TEXTOR [1]. The idea of DED originates from our pioneering work, in which the rotating structure of edge plasma due to rotating helical magnetic field (RHF) was observed [2]. The time varying magnetic structure gives rise to smearing out the local heat load on the wall or the target plate. On the other hand, the plasma rotation would be driven by the screening current induced around the resonance surface. Therefore, the DED has a possibility to improve the plasma confinement by the shear flow.

To understand the interaction between the tokamak plasma and RHF, recently a new DED experiment has been started on a small tokamak, HYBTOK-II [3]. The radial profile of RHF and the plasma turbulence have been investigated with magnetic and Langmuir probes in the plasma. Our experiment has a diagnostic advantage, especially RHF penetration deep inside the plasma, compared with the DED experiment on TEXTOR.

In the present work, we have investigated the penetration process of RHF by changing the relative velocity between RHF and the plasma according to electrode biasing, which is discussed in terms of the relative velocity Ω (i.e. Doppler-shifted frequency).

2. Experimental Setup

HYBTOK-II is a small tokamak device with a major radius of 40 cm, a minor radius of 12.8 cm and a limiter radius of 11 cm. The device is equipped with Insulated Gate Bipolar Transistor (IGBT) inverter power supplies for Joule as well as vertical field coils. In this experiment the plasma current and toroidal field were set to 4.9 kA and 0.27 T, respectively. The RHF is created by two sets of local helical coils installed outside the vacuum vessel at eight toroidal sections among the 16 sections with the poloidal and toroidal mode numbers of $m = 6$ and $n = 1$. In TEXTOR-DED experiment, the perturbation coils will be located on the high field side with poloidal coverage of $\pm 60^\circ$ [1]. These partially located coils will make the poloidal mode spectrum very broad, so that it is difficult to control the stochastic region at the plasma edge. In contrast to TEXTOR, the helical coils cover full poloidal circumference in the 8 toroidal sections among 16 as shown in Fig. 1 so as to improve the

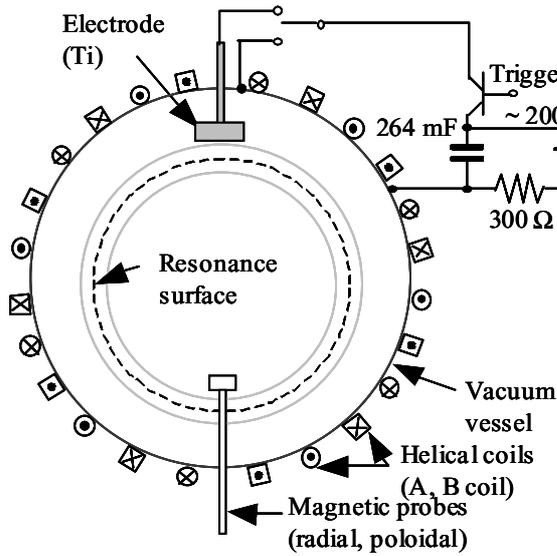


Fig. 1 Schematic view of poloidal cross section of HYBTOK-II. The current directions of helical coils (A, B) are indicated. The electrode and biasing circuit are shown.

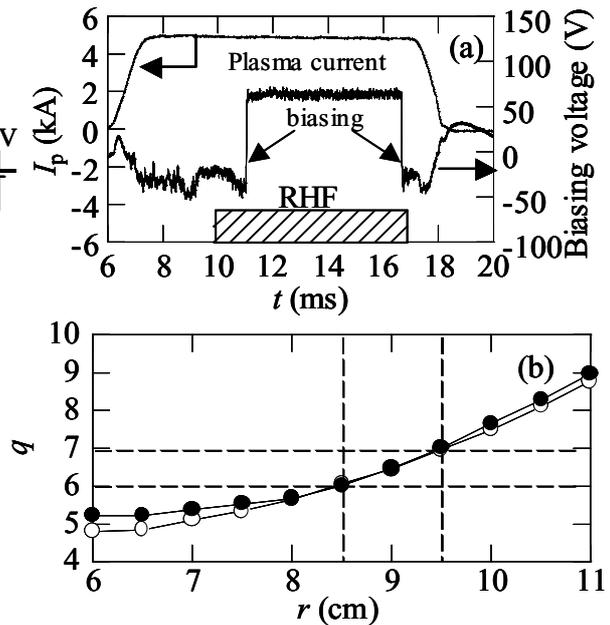


Fig. 2 (a) Time evolutions of plasma current I_p and electrode voltage. The DC biasing voltage is set to +60 V. (b) The q profiles with (closed circles) and without (open circles) electrode biasing.

mode quality of RHF compared with that of TEXTOR [4]. These two sets of coils are powered independently by IGBT inverter power supply with a phase difference of 90° . We can control the poloidal rotation direction of RHF by choosing either + or -90° . Hereafter the terms “Case I” and “Case II” denote the rotation directions of RHF, corresponding to the directions of ion and electron diamagnetic drift, respectively. The maximum available frequency is 30 kHz. The radial profiles of RHF and the poloidal magnetic field in the plasma were obtained with absolutely calibrated small magnetic probes (radial, poloidal component), which are inserted vertically from the bottom of the vacuum vessel at the section with the helical coils (see Fig. 1). In addition, a triple probe is also used to measure the floating potential, electron temperature and density. A movable electrode made of titanium is inserted from the top of the vacuum vessel for the biasing experiment as shown in Fig. 1. We have adjusted the biasing voltage and the position of the electrode so as to change uniquely the radial electric field without any drastic change of electron temperature. Figure 2(a) shows the time evolutions of the plasma current and electrode voltage.

3. Experimental Results and Discussion

The safety factor q profile measured with the magnetic probe in the plasma is shown in Fig. 2(b), in which the resonance surface of $m/n = 6/1$ is found at $r = 8.5$ cm. The plasma rotation velocity was evaluated from the $E \times B$ drift velocity as follows: The plasma potential is estimated from the formula $V_p = V_f + 3T_e$ (in H_2 plasma), where V_p and V_f are the plasma

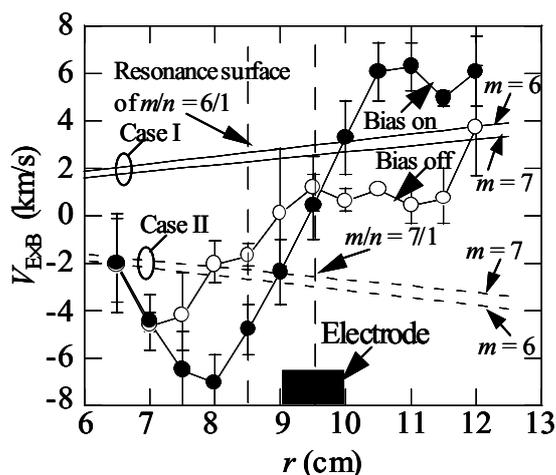


Fig. 3 Radial profiles of the $E \times B$ drift velocity with (closed circles) and without (open circles) the electrode biasing, and the phase velocity of RHF for $m = 6, 7$. The solid (dashed) line shows the phase velocity in Case I (Case II)

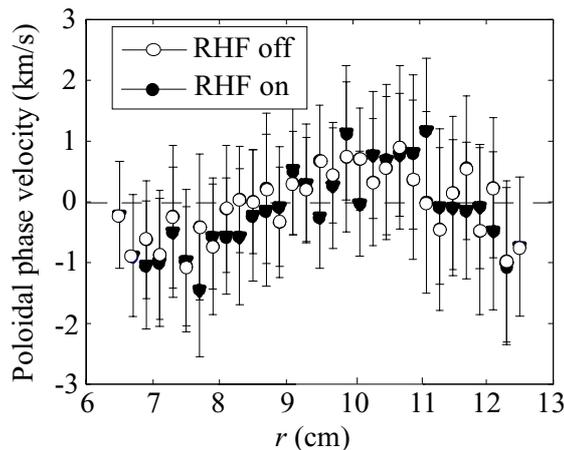


Fig. 4 Radial profiles of the poloidal phase velocity of the fluctuation with (closed circles) and without (open circles) RHF. The RHF frequency was set to 10 kHz in Case II. The bars correspond to the extent of the phase velocity distribution.

potential and the floating potential, respectively. The radial electric field is obtained from the radial derivative of V_p . Figure 3 shows the radial profiles of the $E \times B$ drift velocity with and without the electrode biasing, and the phase velocity of RHF. This result shows us that the Ω is very much increased when the direction of RHF is set to Case I at the $m/n = 6/1$ resonance layer. The poloidal phase velocity of the fluctuation of the ion saturation current has been calculated by using wavelet correlation technique as shown in Fig. 4 [5]. Figure 4 shows that the phase velocity has the similar radial profiles in comparison with that in Fig. 3.

The radial profiles of the radial component of RHF B_{r1} are shown in Fig. 5, where the open circles, the closed triangles and the closed circles denote the amplitudes in vacuum, with and without the electrode biasing, respectively. It is found from Fig. 5(a) that the large Ω created by the electrode biasing enhances the attenuation of B_{r1} in the plasma in the Case I. We focus on the main mode, $m/n = 6/1$, in this work. However, it should be considered how the sideband components of RHF, especially $m/n = 7/1$, affect the attenuation of B_{r1} . On the other hand, the *amplification* of B_{r1} in the plasma was observed in Case II as shown in Fig. 5(b). A growth of magnetic islands (i.e. perturbed plasma current) causes the *amplification* of B_{r1} in the resonance layer due to the spatial modification of plasma current [6]. The enhancement of the *amplification* of B_{r1} was observed with the electrode biasing in Case II. We can recognize from the *amplification* of B_{r1} around the resonance surface of $m/n = 6/1$ and $7/1$ with the electrode biasing that the decrease of Ω enhances the growth of magnetic islands of $m = 6$ and 7 . The strong shear of the plasma rotation was generated by the electrode biasing around the resonance surface of $m/n = 6/1$ and $7/1$ so that the accuracy of the evaluation of Ω may be not so high in this region.

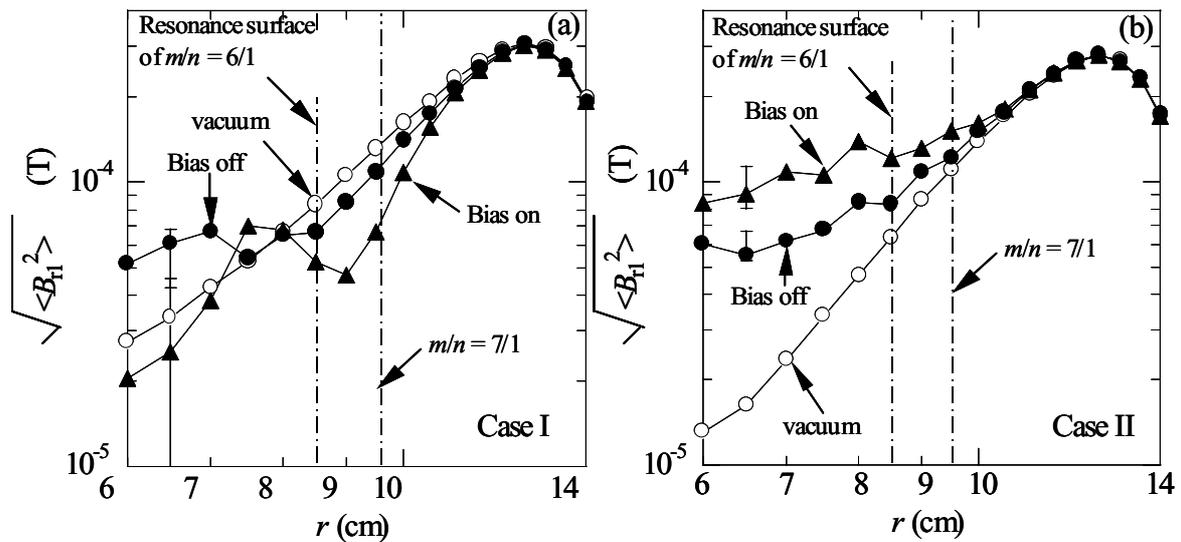


Fig. 5 Radial profiles of B_{r1} in vacuum (open circles) and in the plasma with (closed triangles) and without (closed circles) the electrode biasing. The directions of RHF are set to (a) Case I and (b) Case II. The driving frequency is 30 kHz.

3. Summary

We have performed the detailed measurement of the penetration of RHF into the tokamak plasmas on HYBTOK-II. In comparison with the results of CSTN-IV [7], the large attenuation of B_{r1} has been found. In addition to this, a strong shielding of B_{r1} by changing the natural plasma rotation velocity by means of the electrode biasing has been shown. From these results it is concluded that even if electron temperature is very high such as TEXTOR-DED, both the screening current and the redistribution of plasma current due to the growth of the magnetic islands must be considered in the penetration process of RHF into tokamak plasma.

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