Plasma Response on Penetration of External Rotating Helical Magnetic Field in HYBTOK-II Tokamak Edge Plasma

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1. Introduction. To improve the edge plasma conditions the concept of dynamic ergodic divertor (DED) with externally applied rotating helical magnetic field (RHMF) was proposed and tested on small tokamak [1,2]. Electromagnetic field produced by the RHMF coils, leads to ergodization of the magnetic structure in the boundary region. The RHMF can drive a modification of the edge plasma structure and rotation. In this work, the experiments with the RHMF in the HYBTOK-II tokamak are presented.

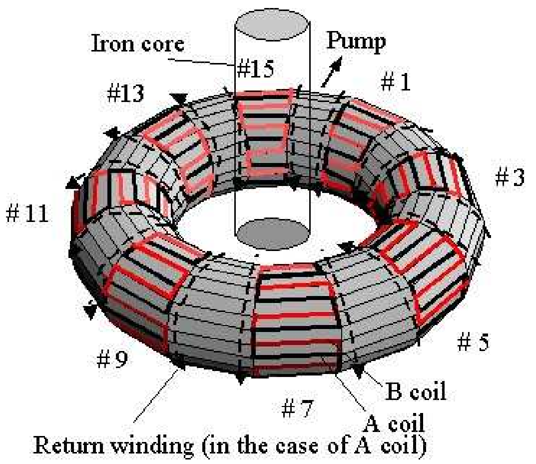

Figure 1. The RHMF is created by two sets of helical coils (black and red bars) with the poloidal and toroidal mode numbers of m = 6 and n = 1. Phase difference of the helical coil current between two coils is either + 90° (Case I) or – 90° (Case II)

Tokamak HYBTOK-II [2] has major and minor radii of R=40 cm and a=12.8 cm, the experiments were carried out at plasma current I_p = 5kA, the toroidal magnetic field B_t=0.28 T, the edge electron density about $1.2\times10^{18}m^{-3}$ and the edge electron temperature T_e about 20 eV. Circular ring limiter is installed at r=11 cm. Hydrogen was a working gas. The externally applied RHMF (Fig.1) is resonant with the natural magnetic helicity at rational magnetic surfaces. The RHMF coil current was of 110 Amps in amplitude. The fundamental resonance surface ($q(r_{res}) = m/n = 6/1$) was located at $r_{res}\approx$(7.5-8) cm at the plasma edge where q is the local safety factor (Fig.2), *m* poloidal and *n* toroidal mode numbers, the magnetic island width is about 0.8 cm [2]. As measured by movable magnetic coils, the radial components of the magnetic perturbation produces by coil in the vicinity of resonant surface r=8.5 cm is of ~ 3.5 Gauss for employed frequency, poloidal components of the magnetic perturbation is of ~ 2 Gauss . The rotation of the RHMF was in the electron diamagnetic drift direction (called as Case II) and in the reverse one (called as Case I). The magnetic perturbations of the helical coils generally include spatial sidebands to some extent in addition to the fundamental mode because of the toroidal effect. These sideband components have magnetic resonance surfaces at different radial positions, and some induced magnetic islands overlap. The detailed analysis of the mode structure was performed in Ref. [2]. The plasma current and toroidal magnetic field (i.e. safety factor *q)* are kept to be constant during applying the RHMF (*t* = 10–17 ms).

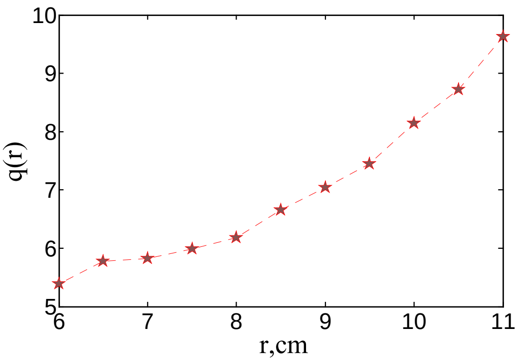

Figure 2. Radial profile of safety factor q.

2. Density fluctuations. The effects of the RHMF with frequency of 5 and 7 kHz on edge plasma properties are studied with movable magnetic and multi-pin Langmuir probes. Near the magnetic resonance surface, the RHMF has an effect on the density fluctuations of the time scale corresponding to the RHMF frequency (Fig.3, 4). In the radial domain of the resonant surface r=8.5 cm, during the RHMF operation with the frequency of 5 and 7 kHz, the RHMF has a selective amplification effect on the edge density perturbations with typical scale of ~200 μs and ~150 μs respectively as for the Case I as for the Case II (Fig. 3). We note that this time scales correspond to the reverse values of the RHMF frequency of 5 kHz and 7 kHz respectively. Some impact of the RHMF on the radial electric field was observed.

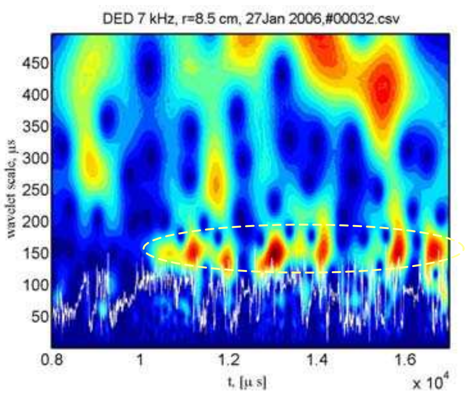

Figure 3. Signal of density (white) near the resonant surface r=8.5 cm and its wavelet decomposition. The RHMF of 7 kHz was started at 1 msec. Structures with time scale of ~150 μs *(indicated by doted line) are amplified by the RHMF.*

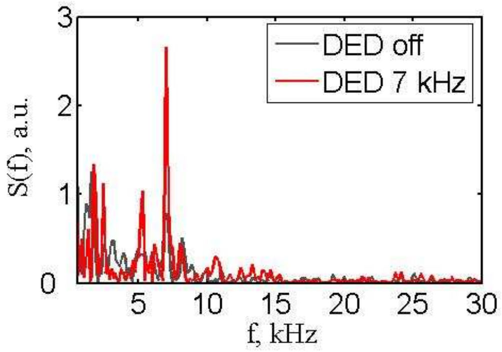

Figure 4. Power spectra of density fluctuations near the resonant surface without and with DED, r=8.5 cm

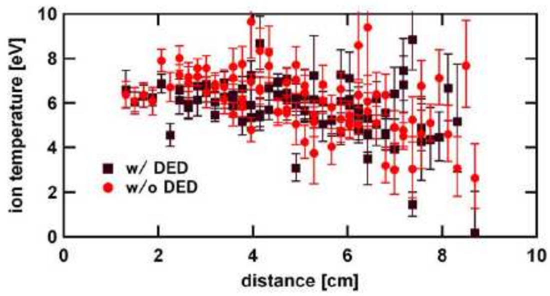

Figure 5. Ion temperature profiles without and with DED of 5 kHz (Case I).

3. Plasma velocity and ion temperature. In previous experiments was found [3] that during the RHMF operation the poloidal direction of the plasma density perturbation rotation coincides with the direction of the RHMF rotation. In this work, the toroidal and poloidal plasma rotation velocity and profiles of ion temperature have been measured by spectroscopic technique. Figure 5 shows profiles of ion temperature measured by Doppler broadening of helium ion emission line (He II 468.5 nm) in hydrogen-helium mixture plasma with a helium concentration of 14%. The ion temperature is around 6 eV near the central region. Anti-clockwise (direction of plasma current, toroidal magnetic field has opposite direction) toroidal plasma flow with velocity ~ (1-2) km/s is observed by Doppler shift of He II(468.5 nm) emission as shown in Fig. 6. The poloidal plasma flow velocity is not high, near resonant surface its direction coincides with Case II. However, there are no substantial influences in the case of DED driving frequency of 5 kHz, the coil current of 110 A and the rotation direction of Case I. On the other hand, in the pure helium plasma with I_p of 5 kA, we can distinguish the effect of DED, which shows the reduction of the troidal plasma flow with the DED.

4. Phase shift measurements. Profiles of magnetic field perturbation phases (poloidal and radial components) in the tokamak hydrogen plasma have been measured by movable magnetic pick-up coils (Fig. 6) in the toroidal section #11. The Doppler shifted frequency $\omega' = \omega + (m/r)(E_{r0}/B_t) + (n/R)V_{t0}$ is the key parameter to characterize the penetration effect [2,4], $\omega = 2\pi f$, f is the driven frequency, E_{r0} is equilibrium radial electric field, V_{t0} is equilibrium toroidal plasma velocity. When the plasma rotation is synchronized with Rotating Helical Magnetic Fields this frequency ω' goes to zero. The plasma response to penetration process is week in this case leading to a small phase changes of magnetic field $B_{r,\theta}$ perturbations. That is why we compare Case I (ion diamagnetic drift direction rotation of RHMF) and Case II (electron diamagnetic drift direction rotation of RHMF).

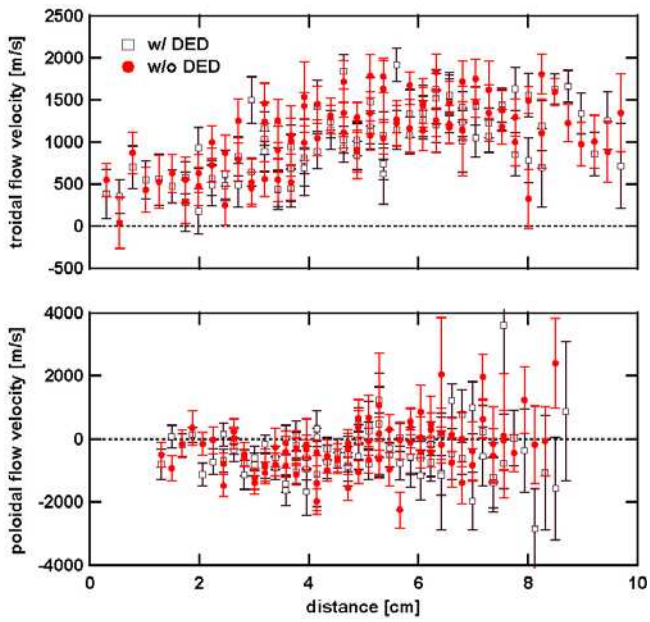

Figure 6. Toroidal and poloidal flow velocity without and with DED of 5 kHz (Case I). He seeded hydrogen plasma.

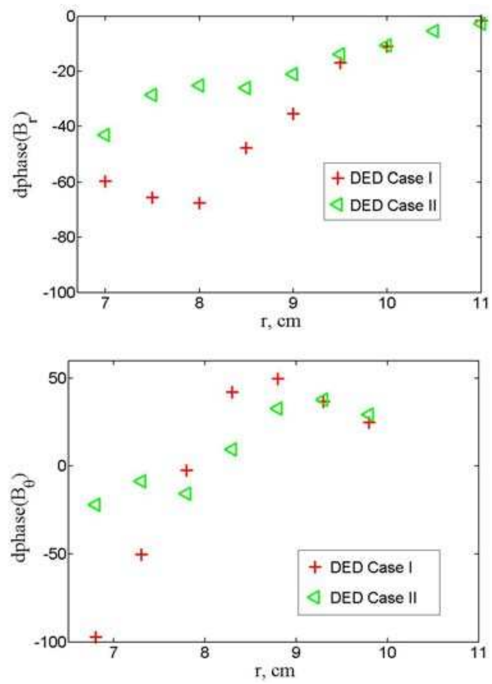

Figure 7. Profiles of phase changes (degrees) of magnetic field $B_{r,\theta}$ perturbations.

Profiles of magnetic field perturbation (poloidal and radial components) in plasma have been measured by movable magnetic pick-up coils. For Case II (Fig.7) phase changes of $B_{r,\theta}$ are smaller by factor of two than that of Case I. It can be interpreted as follow: plasma rotation near the resonant surface is in the same poloidal direction as the RHMF of Case II. The Doppler shift is smaller of 5 kHz. Hence, the poloidal plasma rotation velocity is not higher than (300-400)m/s. Note, the Doppler shift from toroidal plasma rotation with velocity (1-2) km/s is the order of (0.5-1) kHz.

In conclusions, we have investigated the dynamic effect of rotating helical magnetic field on the edge plasma in tokamak HYBTOK-II with the RHMF operation at 5 kHz and 7 kHz. From our measurement by using Langmuir probes, the strong effect of the RHMF on plasma density perturbations is observed during the RHMF operation at 5 kHz and 7 kHz. Edge plasma density is modulated by the RHMF with typical time of $\approx$ 200 μs for 5 kHz and $\approx$ 150 μs for 7 kHz. Plasma velocity and ion temperature are measured by spectroscopic technique. Toroidal plasma rotation with velocity ~ (1-2) km/s and ion temperature ~5 eV are found. Measurements of magnetic fields in DED operation is interpreted in terms of theoretical model considered the Doppler shifted frequency as a key parameter to determine the penetration process. Spectroscopic and magnetic measurements give the similar estimates of poloidal plasma rotation velocity.

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