Plasma Rotation and Turbulence during application of Resonant Magnetic Perturbation field

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Introduction The interaction between the resonant magnetic perturbation (RMP) field and the plasma rotation is one of the important physics issues for an application of instability control using RMP fields in the next fusion devices, i.e. ITER. In addition, determination of the influence of the RMP fields on the plasma turbulence is important for understanding the physics of the density pump-out effect. On TEXTOR, the Dynamic Ergodic Divertor (DED) produces either static or rotating magnetic perturbation fields [1]. The O-mode polodial correlation reflectometry has been used to measure the influence of RMP on turbulence and the plasma perpendicular velocity ($v_\perp$) [2].

Rotation and turbulence during an application of m/n=6/2 static RMP

The DED is operated in 6/2 configuration in ohmic plasmas with toroidal magnetic field (B_t) of 1.9 T, plasma current (I_p) of 300 kA and a line averaged density of 1.25×10^{19} m^{-3}. The DED current (I_{DED}) slowly ramps up to ~ 6kA in 2.5 seconds and quickly ramped down to zero in 0.2 seconds as seen in Fig.1 (a). An m/n=3/2 mode is excited at time ~ 2.9 s (I_{DED} ~ 4.5 kA) during the DED ramp-up phase. This mode keeps in locking until t~3.6s when the I_{DED} is reduced to ~ 1.8 kA. A flattening in pressure profile (Fig.2) induced by the excitation of the 3/2 locked mode has been observed by the Thomson scattering system [3]. The location of the 3/2 mode is at a plasma minor radius (r) of 0.25m. In this experiment, a frequency scan of the reflectometry has been established pulse by pulse from 26 GHz to 37 GHz with a step of 1 GHz. The radial dependences of the plasma rotation and turbulence characters are studied in two distinct phases: 1) The first one is the phase of 'before mode penetration' from 1.0s to 2.9s in which the tearing mode is absent. 2) The second is the 'locking phase' from 2.9s to 3.6s in which a 3/2 mode is excited and locked to the external perturbation field.

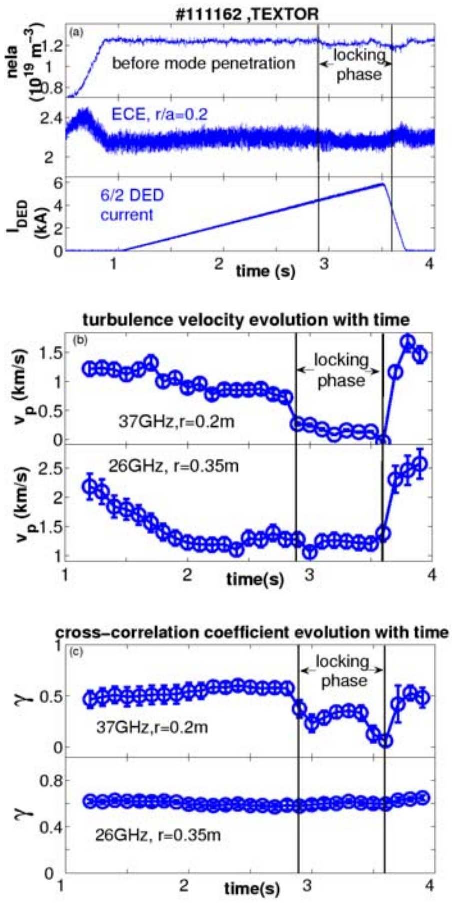

Fig. 1 (a) Ohmic plasma with 6/2 DED. (b) Turbulence velocity v_p evolution with time. Positive value indicates the EDD direction. (c) Evolution of zero time-lag cross-correlation co-efficient between E and C antennae.

In the first phase, $v_\perp$ is observed in the electron diamagnetic drift (EDD) direction and decreases in amplitude with an increasing of the I_{DED}. The change of $v_\perp$ saturates at I_{DED}=2.5 kA (t~2.1s) which is below the threshold of the 3/2 mode penetration. This phenomena has been identified in a wide radii (0.4<r/a<0.8, a is the minor radius of the last closed flux surface) covered by the reflectometry measurement. Fig.1 (b) shows the time-evolution of the statistic turbulence phase velocity v_p measured from the innermost and the outermost measurement points with the standard two-point correlation technique [4]. By assuming that the turbulence parallel wave-number, $k_{//}$, equals zero, the v_p determined from two poloidally separated points represents the turbulence perpendicular phase velocity [2]. Here, v_p contains two components: one is the turbulence phase velocity in the reference frame of the plasma, another is the plasma $\mathbf{v}_\perp=\mathbf{E}_r\times\mathbf{B}$ velocity. Since there is no change in the plasma density and temperature during the phase 'before mode penetration', the decrease of v_p is mainly due to an reduction of the $\mathbf{E}_r\times\mathbf{B}$ velocity. The rotation braking in the first phase can be attributed to the boundary stochastic torque on TEXTOR [5]. Fig. 1 (c) shows the time evolution of the zero time-lag cross-correlation coefficient between two receiving antennae E and C. Here, antennae E and C have a fixed poloidal separation angle of ~ 0.025 rad. No influence of the 6/2 RMP field on the cross-correlation coefficient has been observed. The result implies a weak impact of RMP on the perpendicular correlation length $L_\perp$ of the turbulence before the mode penetration.

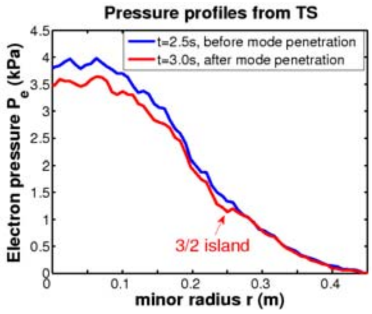

Fig. 2 Pressure profiles form Thomson scattering

When the DED current ramps up to 4.5 kA, a 3/2 mode is excited. Once the field penetration happens, a quick braking in the turbulence phase velocity (v_p) and a reduction of the cross-correlation co-efficient (γ) are observed in the plasma core region, while no change of both v_p and γ are measured in the outer region as seen in Fig.1 (b) and (c). Comparisons of the v_p and γ profiles measured before and after the 3/2 mode penetration are shown in Fig. 3 and Fig. 4. The decrease of v_p appears mainly in the core region of r<0.33m while the reduction of γ happens within q=1.5 surface (r=0.25m) where the 3/2 island locates. The mechanism of the observed v_p decrease is considered to be due to a large $\mathbf{j}\times\mathbf{B}$ torque induced by a formation of the 3/2 island at the q=1.5 rational surface [6]. Reduction of the γ implies that the perpendicular correlation length, $L_\perp$, decreases in the region within the q=1.5 surface after the 3/2 mode penetration.

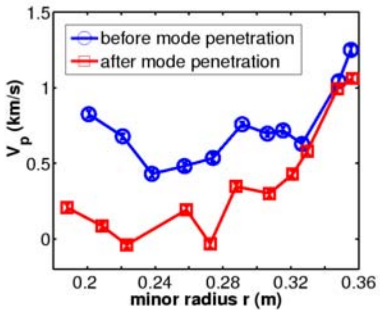

Fig.3 Comparison of turbulence phase velocity profiles before and after mode penetration.

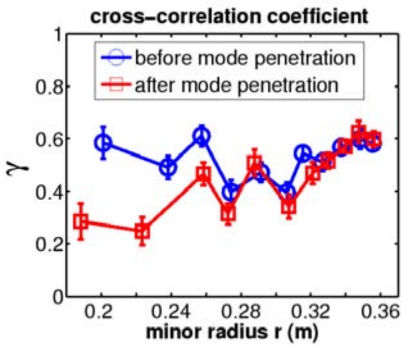

Fig.4 Comparison of cross-correlation coefficient between antennae E and C before and after mode penetration.

Plasma rotation during application of ac +5 kHz m/n=3/1 RMP

On TEXTOR, the DED system can produce an ac field rotating in either EDD or IDD (ion diamagnetic drift) direction. In this paper, the frequency of the ac field rotating in the EDD direction is defined as a positive sign, while a negative sign is used for the ac field rotating in the IDD direction. Previous experimental results showed a spin-up of the plasma rotation in IDD direction with an application of either a static or a slow rotating (~1 kHz) RMP field [1, 5]. This has been explained by generating a positive radial electric field at the plasma edge ergodic zone, where the electron transport is much enhanced rather than the ion transport.

In present experiment, the influence of a high frequency rotating field on the plasma rotation has been studied on TEXTOR. In Ohmic discharge, the turbulence velocity is in the EDD direction and gradually increases in amplitude with an increasing of the I_{DED} when an ac +5 kHz 3/1 RMP field is applied as seen in Fig. 5. Such plasma acceleration in EDD direction is also observed in the balance beam heated plasmas during an application of a +5 kHz 3/1 RMP. Fig. 6 shows the amplitude of the increase of the plasma toroidal rotation, $\Delta\Omega_\phi=\Omega_{\phi,Ided>0}-\Omega_{\phi,Ided=0}$, as a function of the effective DED current measured from the plasmas with different total beam powers. The amplitude of $\Delta\Omega_\phi$ decreases with an increasing of the heating beam power. However, no effects on the plasma velocity were observed when an ac -5kHz 3/1 RMP is applied. This observation can not be explained by the edge ergodisation effect.

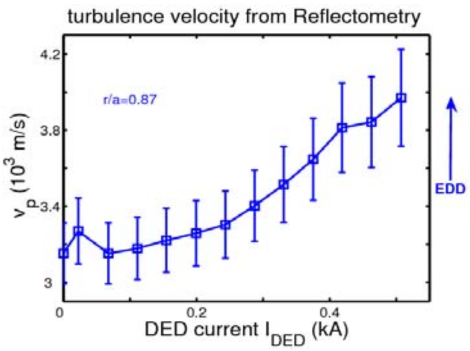

Fig.5 Perpendicular velocity increase with +5 kHz 3/1 DED current

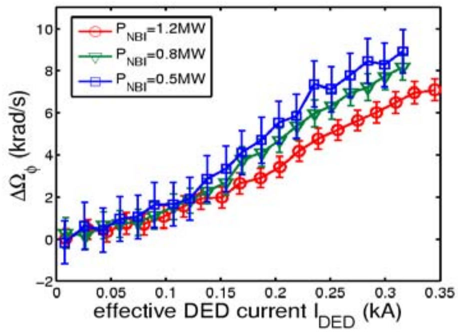

Fig.6 $\Delta\Omega_\phi$ Vs. DED current at position r ~0.25 m.

Summary Plasma rotation braking has been observed during an application of a static 6/2 RMP. No influence of RMP fields on the zero time-lag cross-correlation coefficient (γ) of E and C antennae was observed in a wide radial range ($0.4<r/a<0.8$) before the 3/2 mode penetration. Once field penetration happened, a rapid drop in the γ is observed within the q=1.5 surface. Plasma rotation increase in the EDD direction has been observed when an ac +5 kHz 3/1 RMP is applied. The increment of toroidal rotation decreases with an increasing of heating beam power.

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