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Influence of low-frequency MHD bursts on plasma rotation near the peripheral transport barrier in TUMAN-3M tokamak

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Introduction

The experiments described were aimed on investigation of the low frequency MHD activity burst effect on the ohmic H-mode in the TUMAN-3M tokamak. It was observed that the magnetic island structure developing near plasma edge can result in deterioration of peripheral transport barrier [1]. To clear up a mechanism of MHD burst influence on the H-mode, the plasma rotation evolution has been studied using Doppler reflectometry technique [2]. The results obtained, apart from the ohmic H-mode physics, are closely related to plasma rotation evolution near ergodic divertor and stationary magnetic islands in a stellarator.

Ohmic H-mode with a burst of MHD activity

Measurements were performed in a typical TUMAN-3M scenario (R = 53 cm, a = 25 cm, B_T = 0.6 T, I_p= 117 kA) with the ohmic H-mode transition triggered by a pulse of gas puffing. The transition is characterized by increase in plasma density accompanied by D_α emission decrease; see Figure 1. Just after the H-mode transition a short burst of MHD activity was observed, which was probably caused by the plasma current profile variation due to the gas puffing pulse. The excitation of the MHD burst resulted in a transient deterioration of the plasma confinement. This was manifested by a reduction of plasma density growth rate and an increase in D_α emission. The MHD burst was followed by a flattening of the profile at plasma periphery, with simultaneous density gradient increase in the core region. Analysis of microwave interferometer and magnetic probe array signals [3] reveals that the dominating MHD mode was the m/n=2/1 mode, with some admixture of the higher harmonics m/n=4/2 and m/n=3/1. The magnetic island m/n=2/1 was found to be usually developed near r_s=17 cm, with a width of about 3-4 cm.

Doppler reflectometer in TUMAN-3M

Doppler reflectometry is based on deriving the plasma fluctuation poloidal rotation velocity V_θ from the Doppler frequency shift Δf_D of backscattered radiation expected under an oblique incidence of microwave beam onto cutoff surface [2]. A single antenna scheme described in detail elsewhere [2] was employed in the Doppler reflectometry on the Tuman-3M. The reflectometer operated in the K-band (17-25 GHz for O-mode propagation), so that the microwave cutoff was located in a vicinity of the H-mode transport barrier.

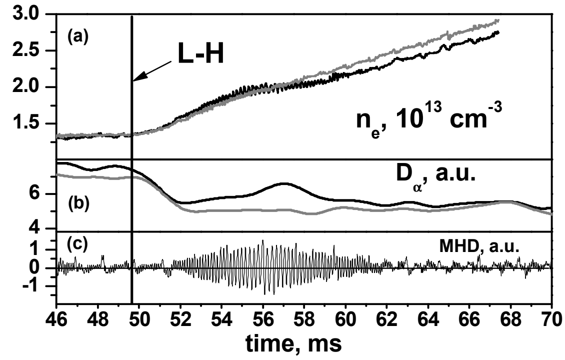

Fig. 1 Time evolutions of the signals measured in a shot virtually without MHD activity (gray lines) and in a shot with a sharp MHD; (a) line averaged plasma density measured along central chord, (b) D_α emission intensity (c) magnetic probe signal

The actual velocity extracted from the Doppler shift V_θ consists of two terms: $V_\theta = V_{E\times B} + V_{ph}$, where V_{ph} is scattering fluctuation phase velocity with respect to plasma media, $V_{\mathbf{ExB}}$ is the plasma drift velocity caused by a radial electric field. If the phase velocity of the density fluctuation is negligible, then the measured V_θ may be interpreted as the **E**x**B** drift velocity. Estimation of the ITG mode phase velocity for peripheral region of the TUMAN-3M shows that it is small, as compared with neoclassical poloidal rotation velocity. It justifies the assumption that the derived velocity V_θ may be attributed to the **E**x**B** drift velocity.

Temporal behavior of plasma rotation

The waveforms in Figure 2 depict the evolution of the fluctuation poloidal velocity with the respective radius (r_c) of the cut-off during the transition to the Ohmic H-mode for

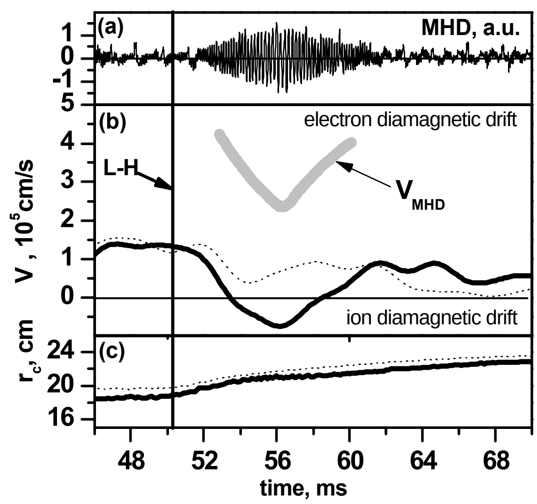

Fig. 2 Time evolutions of (a) magnetic probe signal, (b) MHD poloidal velocity (gray line) and Doppler velocities for discharges nearly without MHD activity (dotted line) and with strong MHD burst, (c) cut-off radius

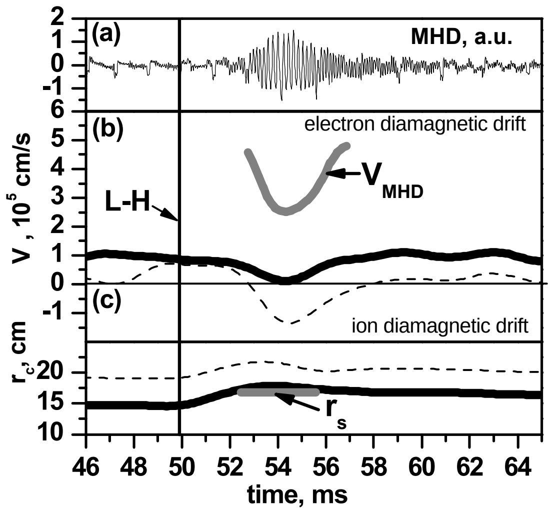

Fig. 3 Time evolutions of (a) magnetic probe signal, (b) MHD poloidal velocity (gray line) and Doppler velocities for microwave frequencies 19.45 GHz (dashed line) and 25.61 GHz (solid lines)

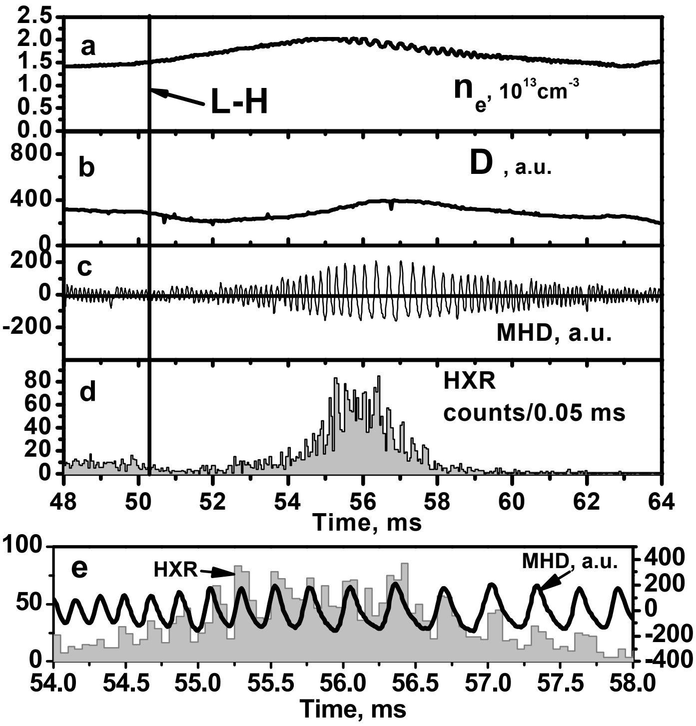

Fig. 4 Time evolutions of the signals (a) line averaged plasma density, (b) D_α emission intensity, (c) magnetic probe signal, (d) and (e) HXR intensity with 0.05 ms integration time

two similar shots: one virtually without MHD activity (dotted lines) and another with a strong burst of MHD activity (solid lines). Normally, the plasma fluctuation rotation was in the electron diamagnetic drift direction, i.e. in the direction of the drift in negative radial electric field (E_r<0). During the MHD activity burst, the measured poloidal velocity drastically decreased and even changed its sign. The velocity reversal correlated with a transient degradation of the H-mode confinement. After the burst the velocity magnitude reverted to its initial level. Following the point of view that the Doppler reflectometry allows recovery of the plasma rotation velocity, one can conclude that the observed velocity reversal is mainly due to the positive radial electric field penetration into the peripheral transport barrier. This is in qualitative agreement with the results of direct measurements of the radial electric field performed on the TUMAN-3M earlier with Langmuire probes [1]. In Figure 3, the fluctuations in poloidal velocity evolutions are compared for two different incident microwave frequencies (19.45 and 25.61 GHz). One can see that the larger is the distance between the resonant radius r_s of the magnetic islands m/n = 2/1 and the cut-off radius r_c, the greater is the change in the derived poloidal velocity. In other words, the closer the cut-off is located to the magnetic island, the less pronounced is the difference between the derived fluctuation velocity and the island rotation velocity ($V_{MHD} = 2\pi f_{MHD} r_s/m$; see gray curves in Figures 2 and 3). However, the velocity difference remained rather high and was about the electron diamagnetic drift velocity.

Discussion

The interplay between the rotating MHD island and background plasma was studied theoretically in [4, 5]. According to the theory, in a vicinity of the island, plasma has to rotate with the MHD mode velocity. Indeed, the measured poloidal velocity was decreased with the MHD velocity reduction during the MHD burst developing. However, there is substantial difference between the velocities. The similar difference has been reported from the JFT-2M [6] and the HBT-EP [7] tokamaks. Moreover, the islands were always observed to rotate in the electron diamagnetic drift direction, so this rotation by itself could not be a reason of the surrounding plasma rotation in the ion diamagnetic drift direction. The most likely reason of the positive electric field propagation from the LFCS to the inner plasma region is a fast electron loss due to the chaotic behavior of the magnetic field lines in the region between the island chains. In that case, the reversal of the radial electric field could be due to a dramatic change in the electron–ion balance caused by the parallel escape of the fast electrons to the limiter. To verify this assumption, the measurements of HXR have been performed in a shot with the intensive MHD activity burst. The diagnostic tool employed for the bremsstrahlung registration described elsewhere [8]. The temporal behavior of the HXR intensity (number of counts per 0.05 ms) is shown in Figure 4. It is evidently seen that the intensity is drastically increased during the MHD activity developing. Besides, a correlation between HXR emission counts and the magnetic probe signal can be seen from this figure. All this evidences the loss of fast electron due to the perturbation of the flux surfaces caused by the rotating island. This perturbation, together with positive radial electric field generation near the location of the H-mode transport barrier, is, probably, the main reason of the observed transient deterioration of the H-mode confinement.

Acknowledgements

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