Plasma potential structure nearby the magnetic island in the TUMAN-3M tokamak

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Whereas magnetic islands have been under intensive theoretical and experimental investigation since the very beginning of the plasma and fusion studies, the phenomenon of the island's rotation is not fully understood yet. Traditional point of view is based on assumption that the island rotates in electron diamagnetic drift direction with the rotational frequency ω due to the radial electric field and electron pressure gradient [1]. A theory taking into account neoclassical momentum balance and ion anomalous viscosity yields a relation between rotation frequency ω and radial electric field near the island $E_r^{island} = -\langle B_T\rangle \omega r_s/m$ ($\langle B_T\rangle$ is surface-averaged toroidal magnetic field on resonant magnetic surface of radius r_s, m is poloidal mode number) [2]. Outside some spatial region δ radial electric field goes to the unperturbed neoclassical electric field E_r^{neo}. The value of δ depends on the level of ion viscosity anomaly η^{an}/η^{neo}. If it is not too small, one may hope to register this perturbation by measurement of plasma potential or E_r evolution in a vicinity of the island.

The goal of this work was to measure the E_r evolution near the rotating island using Langmuir probes and to try to compare the results with the theoretical predictions. Measurements have been performed in ohmic and ohmic H-mode plasmas with the following parameters: I_p=100-130kA, B_{tor}=0.7T, $n_{L\text{-}mode}=1.3\ 10^{19}m^{-3}$, $n_{H\text{-}mode}<4\ 10^{19}m^{-3}$. The MHD instability under investigation had poloidal/toroidal mode number m/n=2/1 or m/n=3/1, with some admixture of higher modes, and frequency f_{MHD}~5-12 kHz. Poloidal structure and temporal evolution of MHD oscillations were measured using a poloidal array of 24 magnetic probes. In all regimes, the direction of perpendicular rotation of the island corresponded to negative E_r (i.e. directed to the plasma center). The rotating MHD island caused considerable perturbation of electron density profile. From the analysis of 10 channel microwave interferometer signals following the procedure described in [3], it was found that

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m=3 MHD island in TUMAN-3M usually resides at r_s~16…17cm and has width of approx.1.5-2.5 cm.

The experimental set up is similar to described in [4]. The three-electrode probe was immersed into the boundary plasma of the TUMAN-3M tokamak up to r=19cm; that is 4 cm inside the LCFS and very close (~1cm away) to the island boundary. To make the probe more resistant to thermal load from the plasma influence, the pyrolitic boron nitride (BN) was used as a material for probe's insulators. Two electrodes with length difference d=6mm were used for measurement of gradient of the plasma floating potential. The third electrode was used for occasional electron density/temperature evolution measurement. Then, radial electric field was calculated $E_r = -\nabla\Phi_{float}$, neglecting the impact from ∇Te, which is usually small in the peripheral plasma of TUMAN-3M [4].

The time trace of $E_r = -\nabla\Phi_{float}$ signal measured in ohmic discharge with intensive MHD oscillations is shown in Fig.1. The rotating MHD oscillations appeared in the plasma at t=36ms, and then exist till the end of the discharge, decelerating slowly from f~9kHz to ~5kHz and increasing in amplitude. As it was mentioned above, the direction of MHD perturbation rotation corresponds to the negative radial electric field. However, as one can see from Fig.1, measured $E_r<0$ only at the initial stage of the island evolution, t<46ms. Later, a positive E_r~3.5kV/m builds up and remains approximately constant through the duration of the shot. If one tries to take into account the ∇T_e term influence on probe measurements of E_r, it will make the radial electric field even more positive. Radial electric field evolution, together with theoretical value [2] $E_r^{island} = - \langle B_T \rangle \omega r_s/m$ and MHD mode frequency is shown in Fig.2. In the beginning of the island evolution measured E_r is negative (and close to the E_r^{island}), however it becomes positive later, when the island is large enough.

A positive radial electric field was observed during the MHD burst in ohmic H-mode as well. Earlier [4], the peripheral E_r evolution during the ohmic L-H transition was measured in edge transport barrier region by Langmuir probe and was found to become E_r ~ -2kV/m as a result of the transition. The timescales of E_r evolution and transport reduction were approximately the same. Those experiments were deliberately performed in no-MHD scenario, as MHD activity deteriorates the quality of plasma confinement. In this work we have repeated the E_r measurements in a set of the ohmic H-mode transition discharges with pronounced MHD activity in order to investigate its influence on E_r behaviour. It occurred to be rather difficult to obtain a set of reproducible shots with ohmic H-mode transition and stable level of MHD activity. All the shots under investigation were more or less different in a degree of H-mode confinement improvement. As one would expect, the higher was the MHD activity level, the less pronounced was confinement improvement caused by the H-mode. The results of peripheral radial electric field measurements are in accord with this observation: in low-level MHD shots with clear H-mode transition radial electric field at r=19cm changes from positive value $E_r^{L\text{-}mode}$~1.5kV/m to negative $E_r^{H\text{-}mode}$~-2.5kV/m (see Fig.3, red curves, shot #05051929). On the other hand, if the ohmic H-mode transition was initiated during the intensive MHD oscillation stage, the degree of confinement improvement was lower, an so was the change in radial electric field, see Fig.3, black curves, shot #05051928. In the last case radial electric field changes from $E_r^{L\text{-}mode}$~1.5kV/m to $E_r^{H\text{-}mode}$~0kV/m. If the ohmic H-mode transition was accompanied by a short burst of MHD-activity, the radial electric field experienced a noticeable positive perturbation - up to $E_r^{H\text{-}mode\ plus\ MHD}$ ~ +5kV/m, as compared to $E_r^{H\text{-}mode}$ ~ -2kV/m, see Fig.4 (red curves show traces for shot #05051922 with low level of MHD activity, black curves show traces for shot #05051924 with stronger MHD burst from t=51.7ms till 56.5ms.)

Discussion

Peripheral radial electric field evolution in a vicinity of rotating MHD-island (m=2 or 3, f~5-12 kHz, located at r~17-18cm, width Δ ~1.5-2.5cm) was measured on the TUMAN-3M tokamak in regular ohmic heating shots as well as in ohmic H-mode discharges. In initial stage of the island evolution, measured E_r is close to the theoretical predictions [2], later, as the island grows, it changes sign and becomes positive (directed to the plasma boundary). In the ohmic H-mode scenario, MHD-activity burst is accompanied by a positive perturbation of E_r and transient deterioration of the plasma confinement. At higher level of MHD oscillation the improvement in plasma confinement was weaker. A degree of MHD-caused degradation of the confinement depends strongly on level of the MHD oscillation. One may speculate, that, beside the electric field predicted in [2] $E_r^{island} \propto \omega$, which is directed inwards and dependent rather on mode frequency than on the island size, in a vicinity of the rotating island there should be a positive (directed outwards) $E_r(\Delta)$, which depends on the island's size Δ. The total radial electric field is then $E_r^{tot} = E_r^{island}(\omega) + E_r(\Delta)$ and may reverse from negative to a positive value when mode frequency ω decreases and island size Δ increases. As for the origin of this positive radial electric field component $E_r(\Delta)$, it is not clear yet and may be presumably attributed, for example, to the electron loses due to stochastical perturbation of the magnetic field lines in a vicinity of the island [5]. This point of view is supported by observation of non-thermal X-ray signal from peripheral plasma (r=12cm), see Fig.5. During the burst of MHD oscillation there is also a short burst of X-ray radiation, indicating electron losses from plasma to the wall.

References

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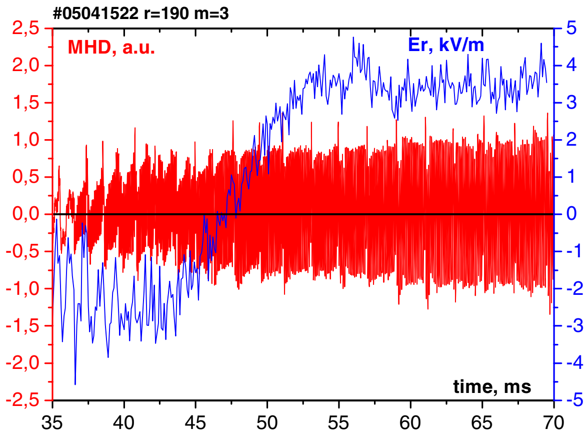

Figure 1. Measured radial electric field $E_r=-\nabla\Phi_{float}$ near the island (blue) and magnetic probe signal (red) as functions of time.

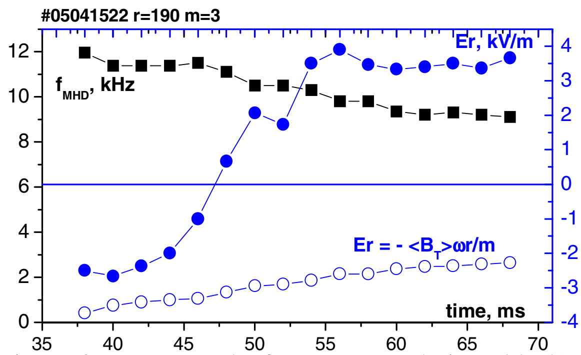

Figure 2. MHD mode frequency evolution (black), measured radial electric field $E_r=-\nabla\Phi_{float}$ near the island (closed blue circles) and theoretical value $E_r^{island}= - \langle B_T\rangle\omega r_s/m$ from [2] (open blue circles).

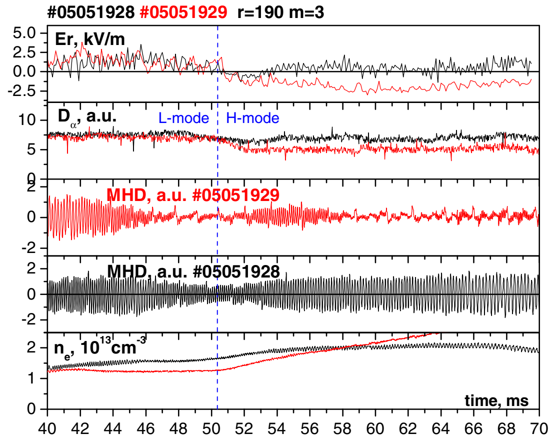

Figure 3. Radial electric field $E_r=-\nabla\Phi_{float}$ evolution during the H-mode transition with lower (red) and higher (black) level of MHD activity.

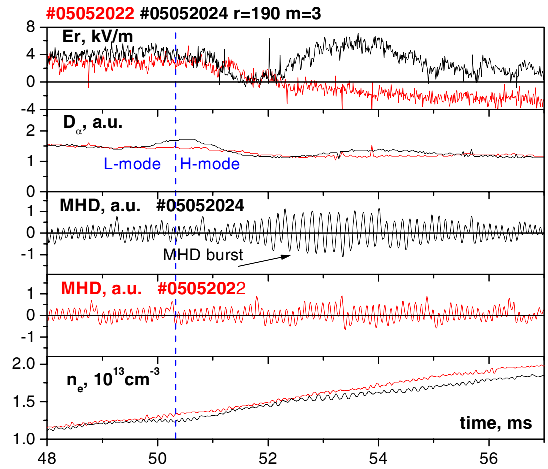

Figure 4. Radial electric field $E_r=-\nabla\Phi_{float}$ evolution during the H-mode transition with an MHD burst (black) as compared to a shot nearly without MHD (red).

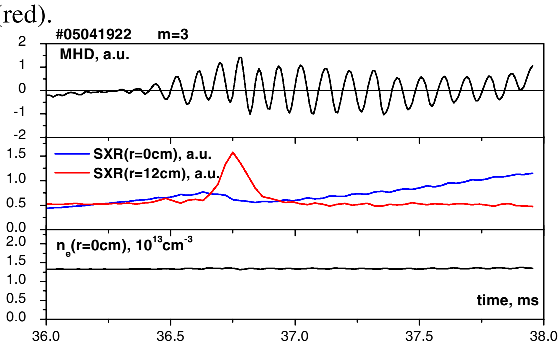

Figure 5. Non-thermal SXR burst (red) from peripheral region (r=12cm) during MHD oscillation burst.