

Rotating Directional Probe for the Study of RMP Effects on Fast Ion Losses in TEXTOR

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Introduction

A sufficiently high α -particle and fast ion confinement is of importance for the self-sustaining burning fusion plasma. One key aspect is the maintainability of a good fast ion confinement in the presence of non-axisymmetric fields, such as those found in stellarators [1, 2], and during the application of resonant magnetic perturbations (RMPs) on tokamaks [3, 4]. The application of RMPs is currently the most promising technique for edge localized mode (ELM) control [5] and heat load distribution on the plasma facing components. Therefore, an increasing focus is on the understanding of RMP effects on the fast ion losses. Theoretical and experimental work [3, 4, 6, 7, 8] is ongoing in this field, however, as of yet, final conclusions cannot be drawn. Knowledge of these effects allows optimization of the fast ion confinement in the presents of non-axisymmetric fields for the next generation fusion devices.

The focus of this work is the study of the influence of RMPs on fast ion losses using a rotating directional probe at the Tokamak Experiment for Technology Oriented Research (TEXTOR). In the following sections the experimental set-up, discussing the features of the rotating directional probe, is presented, as well as observations from fast ion losses without RMPs, and first results with RMPs. The last section summarizes the observations and gives an outlook for further studies.

Experimental set-up

TEXTOR is a medium sized tokamak with a cylindrical shape in a limiter design. Its major and minor radius are $R = 1.75$ m and $a \sim 48$ cm. For the performed fast ion losses studies the plasma currents were chosen in a range of $I_p = 180$ kA to 285 kA, and the magnetic fields from $B_t = 1.6$ T to 2.5 T. A tangential neutral beam injection (NBI) of up to 50 keV is used for

generate fast ions.

TEXTOR is equipped with a flexible perturbation coil system, the dynamic ergodic divertor (DED), allowing for the application of static and dynamic, e.g. rotating, perturbation fields of up to 5 kHz. The dominant toroidal mode number, n , used in the discussed experiments is 1.

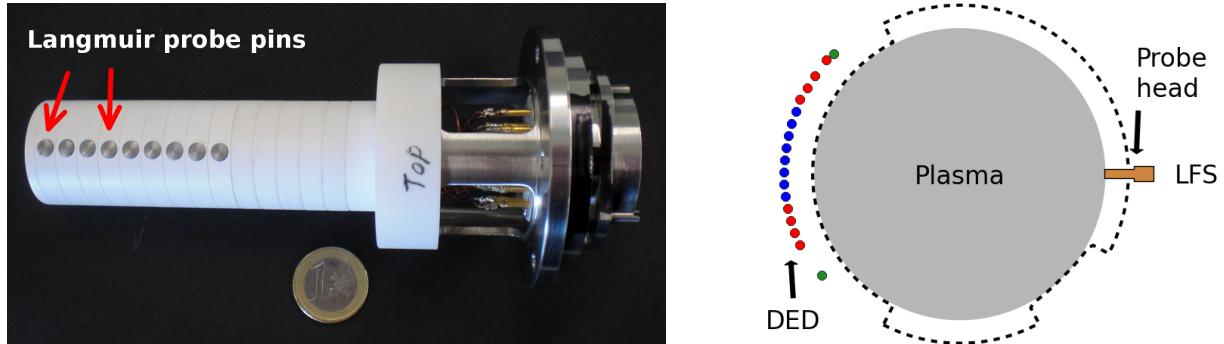


Figure 1: (left) Probe head of the rotating directional probe showing nine of the 18 Langmuir probe pins. The second array is facing in the opposite direction. (right) Geometrical set-up of the fast ion losses experiments showing the location of the probe with respect to the plasma and the DED.

A new fast ion losses diagnostic, the rotating directional probe, has been designed, for the purpose of the investigations. Figure 1 (left) shows the probe head, equipped with two arrays of nine Langmuir probe pins to measure the ion saturation current. A negative biasing (-160 V) is applied to the Langmuir probe pins in order to measure ion saturation currents. The probe rotates along its major axis during the measurements with a speed of about 4 Hz and acquired data at 0.5 MHz, allowing for a very high angular resolution. Radial profiles, with a resolution of $\Delta r = 6\text{ mm}$, are recorded during the measurement. For each of the radial positions, an angular resolved ion saturation current is measured which is a requirement for an accurate detection of the fast ion losses. The probe head is mounted on the fast reciprocating probe [9] located at the mid-plane of the low field side (LFS) at a toroidal angle of $\varphi \approx 346^\circ$. During the measurement the probe is moved close, but outside of the last closed flux surface (LCFS) (see fig. 1 (right)).

Analysis method

The measured angular dependent data is fitted with a sine curve to derive accurate values of the current density measured by the opposite facing probe pins. The fit formula is $I_{\text{sat}}(\theta)/A = (j_{\parallel} - j_{\perp}) \sin(\theta - \theta_0) + j_{\perp}$, with the ion saturation current I_{sat} , the Langmuir probe pin area A , the parallel and perpendicular current densities j_{\parallel} , j_{\perp} , the rotation angle θ , and the reference angle θ_0 at which the ion flux is normal to the probe pin area. The fraction of fast ion losses is determined by $j_{\text{loss}} = j_{\parallel,\text{Co}} - j_{\parallel,\text{Ctr}}$ [10].

Fast ion losses dependence on plasma position and current

Figure 2 (top) shows the dependence of fast ion losses on the plasma position. The plasma position, ΔR , was varied with respect to the geometrical centre while keeping all other plasma parameters the same. It is observed that a more outwards plasma position (red pentagons) causes higher losses, as the plasma is closer to the probe. It is also seen that the results are very reproducible. A general property of the ion losses is their radial decay for $r \leq 50$ cm and a vanishing of the losses at around $r \geq 51$ cm, due to the interception of the plasma facing components.

The bottom panel of fig. 2 presents the important role of the plasma current in the fast ion confinement. The triangles shows a reference case without NBI at a low plasma current. From the other four cases one can see that at a higher I_p the fast ion confinement strongly increase. This dependence is well known [11] and understood as an impact of the plasma current on the loss energy of fast ions: $E_{\text{loss}} \sim I_p^2$. These experiments were performed at a fixed magnetic field, however the resulting changes in the edge safety factor, q_a , only weakly affected the losses, the major effects are due to the changes in I_p .

Impact of RMPs on the fast ion losses

For the study of RMP effects on fast ion losses, the DED is applied in both static and dynamic modes. Figure 3 (top) shows the stepwise scan of different perturbation strengths for a static perturbation field that covers the whole range available. Even at the maximum perturbation no locked mode are observed. A clear difference on fast ion losses is not seen.

In fig. 3 (bottom) the results of a DED rotation direction dependence are shown. At the same rotation frequency the perturbation is once applied to rotate in co- I_p direction (circles), and in the opposite direction (pentagons). No difference between the rotation directions is found for the chosen plasma parameters. However, a high edge safety factor, $q_a \sim 8$, has been chosen which leads to weak resonances in the plasma edge and could be the reason.

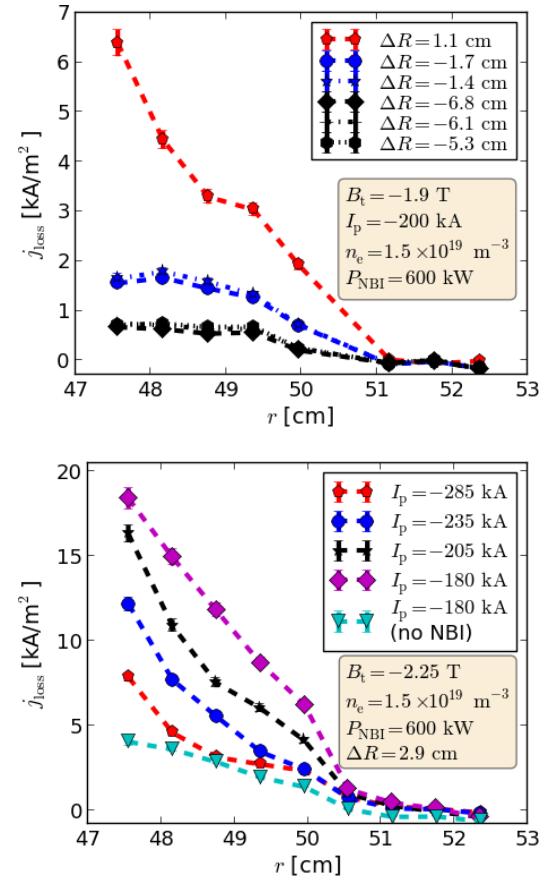


Figure 2: Radial profiles of the fast ion losses: (top) dependence on the plasma position given as the displacement of the magnetic axis ΔR , and (bottom) influence of the plasma current on the fast ion confinement.

Summary and Outlook

The measurement technique of a new fast ion losses diagnostic and first results, stating dependencies on fast ion losses with and without RMPs, have been discussed. The comparison of established theories with the results of the presented experiments shows that the rotating directional probe is a feasible diagnostic for fast ion losses detection. During this work, clear RMP effects on the fast ion losses have not been seen when investigating the dependence of the perturbation strength and RMP rotation direction. However, the studies were performed with a low toroidal mode number $n = 1$, compared to the high n perturbations of magnetic field ripple, which are known to have a strong impact on fast ion losses [3]. Theoretical studies by tracing the fast ions are required to understand the impact of $n = 1$ RMPs on the losses. Future studies with $n = 2$ fields at TEXTOR are in preparation.

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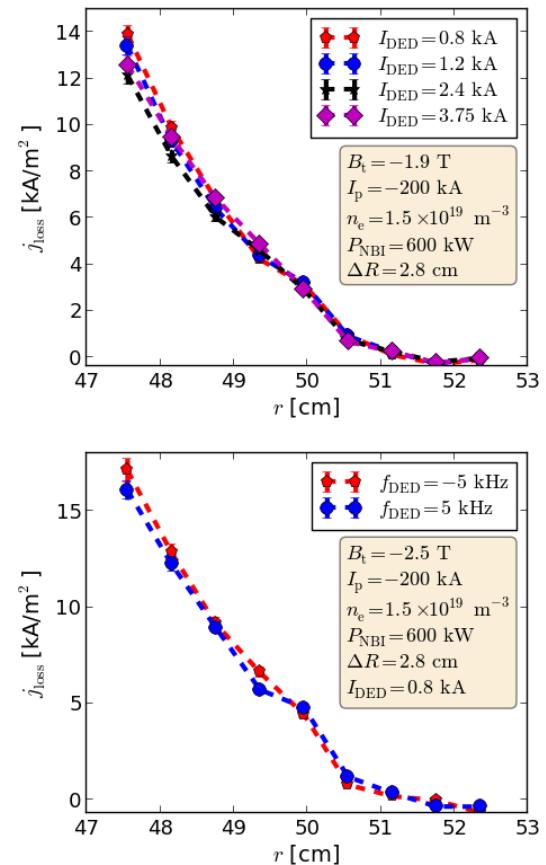


Figure 3: (top) Ion losses dependence on the perturbation strength of a static $n = 1$ perturbation field, and (bottom) impact of the rotation direction with a dynamic perturbation.