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Impact of the Resonant Magnetic Perturbations (RMP) on Edge Turbulence and Turbulent Transport on TEXTOR

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1. Introduction

In recent years, the edge resonant magnetic perturbation (RMP) and its effect on the control of the edge plasma transport have been of increasing interest. The experimental results in several machines have shown the importance of an ergodized magnetic boundary in mitigating ELMs [1] and also in optimizing the plasma-wall interaction [2,3]. With RMP, considerable changes in edge turbulence have been observed [4-6]. In this paper, we report the results about the impact of the RMP on edge turbulence and turbulent transport in the TEXTOR-DED (Dynamic Ergodic Divertor) operation.

2. Experimental setup

The experiments were performed at TEXTOR under various DED scenarios [3, 7]. The edge RMP was created by 16 DED coils, helically winding around the torus with a pitch parallel to field lines with a safety factor $q \cong 3$. The base poloidal/toroidal modes, *m/n*, can be adjusted as 12/4, 6/2 and 3/1. At the outer plasma layer, DED induces stochastization of magnetic field lines, including an ergodic zone (*EZ*) with long and a laminar zone (*LZ*) with short connection lengths to the wall [8]. In this study, we focus on the static DEDs (*dc* DED current) under following ohmic discharge conditions: For *m/n*=12/4, I_p=250 kA, B_T=1.4 T, R/*a* ≅1.73/0.46 [m/m], *dc* DED current I_{DED}=12 kA; for 6/2, I_p=270 kA, B_T=1.9 T, R/*a* ≅1.73/0.46, I_{DED}=6 kA; and for 3/1 I_p=250 kA, B_T=1.9 T, R/*a* ≅1.75/0.48, I_{DED}=1 kA. The plasma density $\langle n_e \rangle = (1.5\text{-}3.5)\times 10^{19}$ m^{-3}. The I_{DED} is applied in the stationary phase of the discharge. In all cases no tearing modes are excited externally by DED and the global confinement is nearly unaffected. In this investigation, two Langmuir probe arrays were used. One array is stationary while the other is fast reciprocating. The probe measurements cover both the *EZ* and *LZ*. The local electron temperature T_e, density n_e, plasma potential and the radial electric field E_r were measured by a triple probe [7]. The turbulent particle flux is calculated from the fluctuating density ($\tilde{n}$) and poloidal electric field ($\tilde{E}_\theta$) by $\tilde{\Gamma}_r = \langle \tilde{n}\tilde{E}_\theta \rangle$/B. The fluctuation spectra, S(k, f), are computed by the two-point cross correlation technique [9]. The fluctuation data were digitized at a rate of 500 kHz. In the experiment, the turbulence properties display similar features in various DED scenarios.

3. Results and discussion

Figure 1 depicts the impact of the RMP on edge equilibrium profiles, where the radial dependences of T_e, n_e and E_r before and during the static 6/2 DED are shown. With

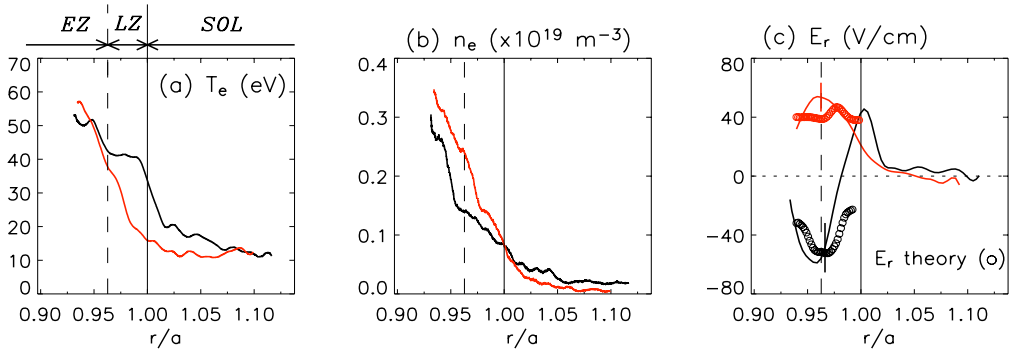

Fig. 1 Radial profiles of (a) electron temperature; (b) plasma density and (c) radial electric field before (black solid curves, w/o RMP) and during (red solid curves, with RMP) the static 6/2 DED measured by fast reciprocating probes at TEXTOR (# 99626). The radial locations are normalized by *a*. The vertical dashed line roughly separates the ergodic zone (EZ, left side) and the laminar zone (LZ, right side). The open circles in (c) show the simulated E_r .

RMP, T_e reduces in the *LZ* and in the scrape-off layer (SOL), whereas n_e increases in the perturbed area and decreases in the SOL, respectively. It has been noticed that the influence of the RMP on edge T_e and n_e profiles can be varied under different DED configurations. With RMP, a typical change is the increase of plasma potential and the resultant variation on the ambipolar E_r. Because the electrons move faster than massive ions along the stochastic field lines onto the wall, the E_r is strongly enhanced or even reverses sign from negative to positive in most of the *LZ* and *EZ* region, as seen in Fig. 1(c). In that figure, a theoretic modeling [7] of E_r (circles) inside the limiter location has been shown for a comparison with the experimentally measured one (solid lines). The results show good agreement both before and during the DED.

For fluctuations, the influence of the RMP mainly occurs inside the *EZ*. As an example, Fig. 2 plots time traces of fluctuation signals measured in the *EZ* in a static 12/4 DED. With RMP the $\tilde{E}_\theta$ fluctuations are reduced considerably while for $\tilde{n}$ the modification is small. In Fig. 2(d), it is interesting to see that with RMP the $\tilde{\Gamma}_r$ changes remarkably and even reverses direction from radially outwards

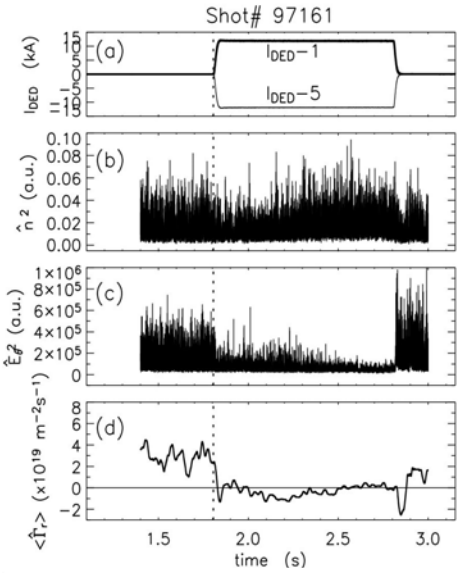

Fig. 2 Time traces of (a) DED currents; (b) power of density fluctuations; (c) power of poloidal electric field fluctuations and (d) ensemble-average of turbulent flux measured by a stationary probe in the ergodic region in static 12/4 DED. The vertical dotted lines denote the start time of the DED.

(>0) to inwards (<0). Similar results have been observed in the static 6/2 and 3/1 DEDs [7]. Figure 3(a) further shows the impact of RMP on fluctuation frequency spectrum

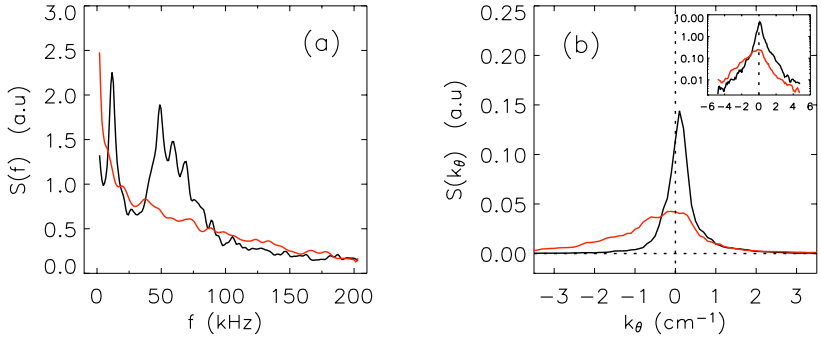

Fig. 3 Linear plot of (a) the frequency spectrum S(f) of density fluctuations and (b) the poloidal wave-number spectrum $S(k_\theta)$ of potential fluctuations measured in the ergodic region ($\rho\cong0.93$) before (black curves) and during (red curves) the static *m/n*=6/2 DED. The magnitudes of $S(k_\theta)$ are normalized by the total power before and during the DED, respectively. The semi-log plot in the inset of (b) displays their relative power. The $k_\theta>0$ (<0) is in the electron (ion) diamagnetic drift direction.

inside the *EZ*. Before DED, there exist coherent modes at the plasma edge. With RMP, the modes are all destroyed, suggesting an energy re-distribution by RMP on different frequency components. In Fig. 3(b), the poloidal wave-number spectra, $S(k_\theta)$, are plotted. Several features can be seen: (i) RMP reduces the power at small k_θ values,

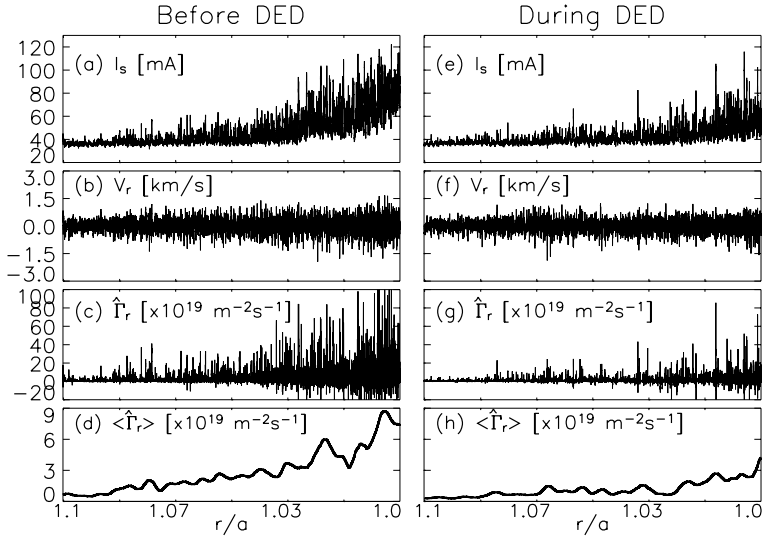

Fig. 4 Comparison of the I_s, V_r and $\tilde{\Gamma}_r$ signals (versus normalized radial position) measured in the SOL before (left column) and during (right column) the static 6/2 DED (# 101795). Plotted in (d) and (h) are the ensemble-averaged turbulent flux. Corresponding parameters in the two columns are drawn in the same scale.

indicating a suppression of large scale structures; (ii) with RMP, the spectrum becomes broadened, implying a reduction in the poloidal correlation length. Similar characters are also seen in $S(k_r)$ spectra. In Fig. 3(b), one can see that the $S(k_\theta)$ is power weighted in electron (ion) diamagnetic drift direction before (during) DED, revealing a change of the propagating direction. Further studies show that the alteration of the poloidal

propagation of turbulence is consistent with the reversal of $E_r \times B$ rotation by the RMP. Before DED the Reynolds stress displays a large radial gradient at the plasma edge while with RMP the Reynolds stress profile is suppressed, suggesting a re-arrangement by the RMP of the flow momentum profile [7].

Moreover, in the static 6/2 DED, a suppression effect by the RMP on the SOL blob transport has been observed [10]. The results are illustrated in Fig. 4. Comparing the left and right column, one can see that with RMP the amplitudes of blob bursts in I_s are decreased. The corresponding V_r is also reduced. The intermittency degree in turbulent flux $\tilde{\Gamma}_r$ is largely depressed by the RMP, at the same time as the time-averaged $\tilde{\Gamma}_r$ reduces. The results are in agreement with simulations [11].

4. Conclusion

The impact of the RMP on edge turbulence and turbulent transport has been investigated in TEXTOR under various DED configurations. Common features are observed. With RMP, the edge equilibrium profiles are modified and the resultant E_r is consistent with modelling. In the *ergodic zone,* the local turbulent flux reverses direction from radially outwards to inwards; the turbulence properties are profoundly modified by energy re-distribution in frequency spectra, suppression of large-scale eddies and reduction of correlation lengths; the fluctuation poloidal propagation changes sign, consistent with the $E_r \times B$ rotation. With RMP, the Reynolds stress profile is altered and the poloidal momentum is thus re-arranged. In the SOL, the intermittent blob-type transport is reduced by the RMP. The results suggest a controlling role by the RMP on edge turbulence, and thus, possible implications for the optimization of the plasma-wall interaction in ITER.

Reference:

[1] T. E. Evans et al., Phys. Rev. Lett. 92, 235003 (2004); Y. Liang et al., *ibid*. 98, 265004 (2007).

[2] Ph. Ghendrich *et al*., *ibid*. 42, 1221 (2002); S. C. McCool *et al*., Nucl. Fusion 29, 547 (1989).

[3] K. H. Finken et al., Plasma Phys. Control. Fusion 46, B143 (2004);

M. Lehnen et al., *ibid*. 47, B237 (2005).

[4] J. Payan *et al*., Nucl. Fusion 35, 1357 (1995); P. Devynck *et al*., Nucl. Fusion 42, 697 (2002).

[5] A. Krämer-Flecken *et al*., this conference, P2. 016.

[6] J. A. Boedo et al., Report GA-A25852 (2007); R. Moyer et al., Phys. Plasmas 12, 056119(2005).

[7] Y. Xu et al., Phys. Rev. Lett. 97, 165003 (2006); Y. Xu et al., Nucl. Fusion 47, 1696 (2007).

[8] M. W. Jakubowski et al., Phys. Rev. Lett. 96, 035004 (2006);

O. Schmitz et al., Nucl. Fusion 48, 024009 (18pp) (2008).

[9] J. M. Beall, Y. C. Kim, and E. J. Powers, J. Appl. Phys. 53, 3933 (1982).

[10] Y. Xu et al., submitted to Phys. Rev. Lett.

[11] D. Reiser, Phys. Plasmas 14, 082314 (2007).