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Effect of resonant magnetic perturbations on zonal flows and ambient turbulence

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Introduction

Resonant magnetic perturbations (RMPs) are used at TEXTOR, DIII-D and JET and discussed for ITER for an effective mitigation of edge localized modes [1]. A crucial point is the interaction of the RMP with the plasma and especially the consequences on plasma transport. The influence on the turbulence and the transport properties by the RMP at the plasma edge [2] and the gradient region can be studied in detail at TEXTOR, due to its unique turbulence diagnostic. The experimental findings at TEXTOR can have impact on RMP schemes at larger devices as JET and ITER.

The Dynamic Ergodic Divertor (DED) [3] generating the RMP, is operated in the $m/n = 6/2$ configuration. For characterization of the plasma standard diagnostic as HCN interferometry, Thomson scattering and a poloidal ring of Mirnov coils are used. For the turbulence characterization the O-mode heterodyne poloidal correlation reflectometer system is used with two antennae arrays on top and midplane, each consisting of one launching and four receiving antennae. Beside measurement of turbulence properties as density fluctuation level ($\delta n/n_c$), correlation length (l_c), turbulence wave length ($\lambda_\perp$) and decorrelation time (τ_{DC}) the perpendicular angular rotation ($\Omega_\perp$) of the plasma at the reflection layer is measured, assuming a negligible phase velocity of the turbulence with respect to the plasma. Furthermore the data of the poloidal Mirnov coils are analyzed. This paper describes the influence of the RMP on the ambient turbulence, the geodesic acoustic mode (GAM) and related zonal flows.

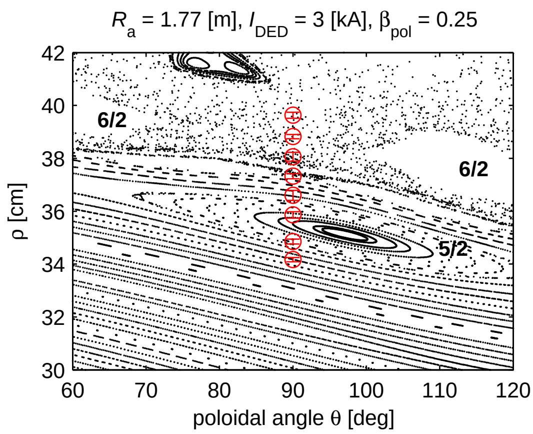

Figure 1: *Detail of a Poincare Plot with observation radii of reflectometry. The diagnostic covers the 6/2 and 5/2 island chains*

The investigated ohmic plasma scenario has the following parameters: $I_p = 350$ kA, $B_t = 2.25$ T, $R_0 = 1.75$ m and $a = 0.46$ m yielding $q_a = 3.7$. The line averaged density of $< n_e >= 2.5 \times 10^{19}$ m^{-3} was chosen that the reflection layer covers the plasma boundary and a part of the gradient region, where the effects of the RMP, regarding the ergodization, is expected to be large. The experiment is conducted by increasing the dc DED current for the generation of the RMP in steps of 1 kA on a shot to shot basis. The DED current is ramped up to its preprogrammed value within ≈ 50 ms and kept constant for 2.5 s until it is ramped down again. During the application of the RMP the frequency of the reflectometer system covers a range of 4 GHz to allow sufficient averaging for each frequency step. For all measurements the antennae array

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at $\theta = 90^o$ is used. A second discharge is performed at the same parameters to obtain data from additional 4 different reflection radii. In total 8 radii covering the range $0.75 \leq r/a \leq 0.90$. The reflection layer is estimated from the HCN interferometer system. For a comparison of the turbulence properties with the magnetic topology, Poincare plots for the above plasma parameter are calculated to identify relations between the degree of ergodization and the turbulence.

Observations

An example of the vacuum calculation [4] for the magnetic field structure at a DED current of $I_{DED} = 3$ kA is shown in fig. 1. It is calculated for the toroidal position of the reflectometry system and the radial circles indicate the measurements positions. The island chains at $m/n = 6/2$ and $m/n = 5/2$ are clearly seen. Both islands are covered by the reflectometry. The dotted area outside the 6/2 island chain denotes the open stochastic boundary, where nested flux surface structure is perturbed and the connection length to the target is in the order of several 100 m.
The influence of the RMP on the plasma is clearly seen in the braking of the perpendicular plasma velocity ($v_\perp$) which is in the direction of the electron diamagnetic drift. In fig. 2 a decrease of $v_\perp$ by a factor of 2 is seen for $I_{DED} = 6$ kA compared to a case without RMP. The structure at $r \approx 0.37$ m for $2 \leq I_{DED} \leq 3$ kA is related to the region between the two island chains. With increasing RMP the 6/2 island chain is destroyed and the measured velocity decreases. Regarding the high frequency ambient turbulence spectrum (50 kHz – 500 kHz) a reduction in the amplitude is detected going along with a shape change of the spectrum. Especially the quasi coherent mode [5] located at $f \approx 60$ kHz decreases in frequency and vanishes for $I_{DED} > 3$ kA. Also the coherence spectrum between antennae signals is reduced, indicating a decrease of the perpendicular plasma rotation and/or a reduction in the turbulence lifetime.
During RMP operation the velocity shear deduced from fig. 2 is increased to $\omega' = 3 \times 10^4$ s^{-1} for $r \leq 0.36$ m and $I_{DED} \geq 2$ kA. The turbulence decorrelation time, estimated from the full width at half maximum from the maximum in the cross correlation function and for all antenna combinations, increases towards the plasma edge (see fig. 3). Values between 12 μs – 16 μs are obtained and an increase to 22 μs for $2 \leq I_{DED} \leq 3$ kA at $r \approx 0.4$ m is found. Comparing the mean shearing ω' with the decorrelation rate $1/\tau_{DC}$ confirms that the shearing due to the RMP is not enough to suppress the ambient turbulence. The estimation of $\lambda_\perp$ yields 0.03 m independent, within error bars, of the applied RMP. The level of density fluctuations ($\delta n/n_c$) increases from 1.5% at $r = 0.34$ m to 3.5% at the plasma edge. A reduction of 25% is observed for same DED current and radial position where an increase in τ_{DC} is found. A turbulent particle transport coefficient $D_{turb} = \lambda_r^2/\tau_{DC}$ assuming $\lambda_r \approx \lambda_\perp/2$ gives a mean values of 4.25 ± 0.6 m^2/s. A reduction of ≈ 25 % is found for $2 \leq I_{DED} \leq 3$ kA at the same region where τ_{DC} is increased.
Furthermore the influence of the RMP on GAMs [6] and related velocity oscillations is investigated. At TEXTOR the GAMs are located in a region $0.32 \leq r \leq 0.40$ m for the above plasma parameters [7]. The electron temperature profile in the GAM region is not much affected, so that the GAM frequency with and without RMP does not change. However the radial range of the GAMs shrinks with increasing I_{DED}. Already with small currents in the DED coils the GAMs at the edge are suppressed and vanish. This observation can be explained by the comparison of the GAM period ($50 \leq T_{GAM} \leq 70$ μs) with the propagation time of a particle on a field line hitting the target plate. Within T_{GAM} a thermal electron moves a distance of $420 \leq l \leq 500$ m, for an electron temperature in the range $100 \leq T_e \leq 300$ eV. The connection length to the target is in the order of $l_c = nq2\pi R_0$, where n denotes the poloidal turns and is in the order of 10–12 for $0.37 \leq r \leq 0.40$ m (see fig. 4). Typical values are 330–400 m. This is less than the distance traveled by a particle during one oscillation of the GAM and can explain the disappearance of the GAM. However, more deep in the plasma, in the gradient region, the number of poloidal turns increases and the amplitude A_{GAM}, deduced from the amplitude spectrum, even increases

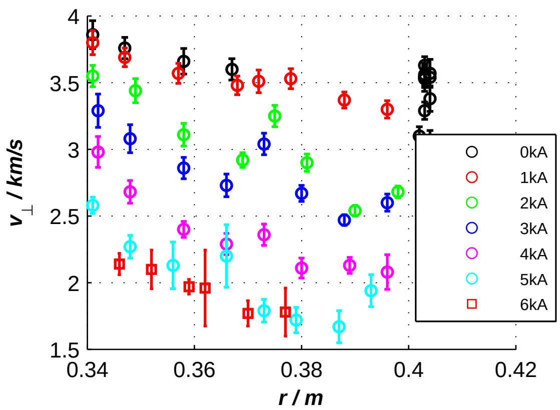

Figure 2: *Perpendicular velocity in the gradient region of TEXTOR for different I_{DED}. Note the strong braking due to the RMP*

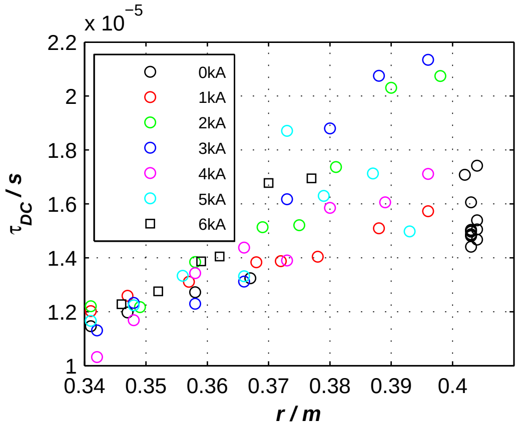

Figure 3: *Turbulence decorrelation is increasing towards the plasma edge. For low* $2 \leq I_{DED}$ 3 *kA a increase of 25% is measured at the plasma edge.*

as seen in fig 5, where A_{GAM} is shown as function of I_{DED}. It can be seen that A_{GAM} increases only in a narrow region of $0.345 \leq r \leq 0.360$ m and achieves a maximum at $I_{DED} = 4kA$. A further increase in I_{DED} causes a beginning ergodization in the vicinity of the $q = 5/2$ surface which as a consequence will decrease the connection length to the target and therefore A_{GAM}. Note that the amplitude at this particular radius starts to increase already for $I_{DED} > 1$ kA. At all other observation radii A_{GAM} decreases.

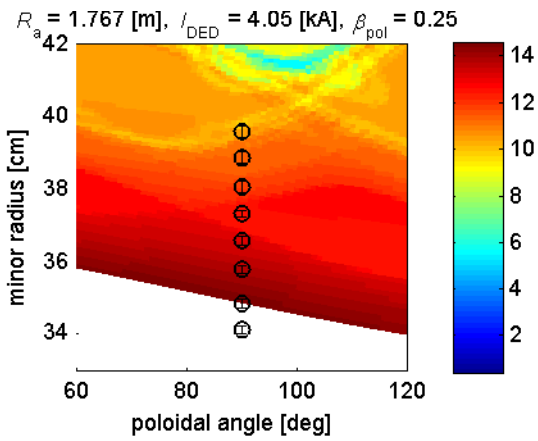

Figure 4: *Color coded connection length for a case with* $I_{DED} = 4$ *kA. The reflection layer of the reflectometer (black circles) are mostly in a region with short connection length*

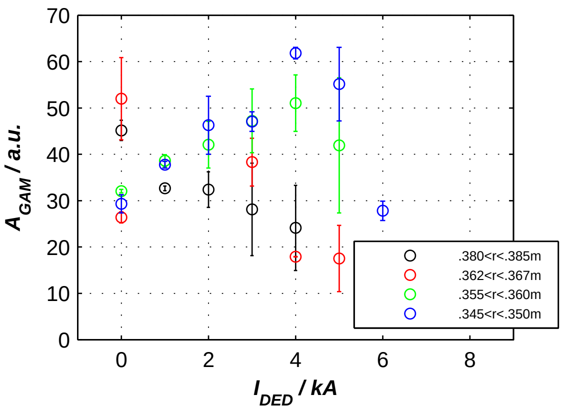

Figure 5: *Amplitude of the peak at* f_{GAM} *as obtained from the amplitude spectrum. Note the strong increase for* $0.345 \leq r \leq 0.360$ *m.*

The analysis of the phase fluctuation level from reflectometry $\delta\phi_{GAM} \propto \delta n_{GAM}/n_c$ at f_{GAM} yields an increase by a factor of 2 at $I_{DED} = 4$ kA for $0.345 \leq r \leq 0.360$ m compared with a case without RMP. In addition the magnitude of the GAM related velocity oscillations is analyzed. Here no increase in the δv_{GAM} with I_{DED} is observed. This indicates that the RMP affects only $\delta n_{GAM}/n_c$.

To obtain more information on the GAM properties during RMP operation Mirnov data are analyzed. During RMP operation $I_{DED} > 1$ kA strong magnetic fluctuations show up in a range 18 kHz$\leq f_{GAM} \leq$ 22 kHz. This peak becomes broader with increasing I_{DED} (see fig. 6a). It shows the amplitude of the Minrov coil for different I_{DED}. In fig. 6b two amplitude spectra from reflectometry are shown. The spectrum at $r = 0.40$ m, represented by a black line, corresponds to the case without RMP and it correlates at $f_{GAM} = 14$ kHz with the Mirnov signal (black curve) in fig. 6a. The spectrum (magenta curve) at $r = 0.35$ m and $I_{DED} = 4$ kA shows the enhanced amplitude at $f_{GAM} = 20$ kHz which correlates with the enhanced magnetic fluctuations at this frequency and the same DED current. Note that both diagnostics are 112 ^{o} toroidally apart from each other. A significant correlation between them is found for $\Delta\phi = 112\ ^o$ and $\Delta\theta = 0, 30, 45, 90\ ^o$, indicating the global character of the mode and that both observations are caused by the same physical mechanism, and driven by the RMP. For $I_{DED} \geq 4$ kA the mode analysis of the of the Mirnov coil data suggests a $m/n = 5/2$ structure.

Conclusions

At TEXTOR for ohmic plasmas a strong braking of the plasma rotation is observed during RMP operation. The turbulence investigations at the same time demonstrates that the turbulent transport in the gradient region is not much changed. Only for weak RMPs a decrease in the turbulent particle transport is observed. Concerning turbulent instabilities which need long or infinite connection length a strong suppression is observed as it is shown for the GAMs. The increase of the density fluctuation level at the GAM frequency at a particular radius, the vicinity of the $m/n = 5/2$ surface, is not caused by a change in the ambient turbulence as it is predicted by the paradigm of drift wave zonal flow turbulence [8]. Also the missing increase in the amplitude of the related velocity oscillations rule out any interaction between drift wave turbulence and GAMs. The observation allows only one solution. The observed increase of the peak at f_{GAM} is driven directly by parallel currents on the rational surface caused by the RMP. [9]
As a side effect of the investigations the magnetic fluctuations at f_{GAM} at the plasma edge and without RMP are detected at TEXTOR for the first time.

References

[1] Y. Liang et al., Phys. Rev. Lett., **98**, (2007), 265004

[2] Y. Xu et al., Nucl. Fusion, **47**, (2007), 1696

[3] K.H. Finken et al., Fusion Eng. Des., **37**, (1997), 335

[4] M.W. Jakubowski et al., Nucl. Fusion **44**, (2004), S1-S11

[5] V.A. Vershkov et al.,Nucl. Fusion, **39**, (1999), 1775

[6] A.Krämer-Flecken et al., Phys. Rev. Lett., **97**, (2006), 045006

[7] A.Krämer-Flecken et al., submitted to Plasma Phys. and Contr. Fus.

[8] K. Itoh et al., Physics of Plasmas **13**, 055502 (2006)

[9] D. Reiser et al., *this conference*, P2.031

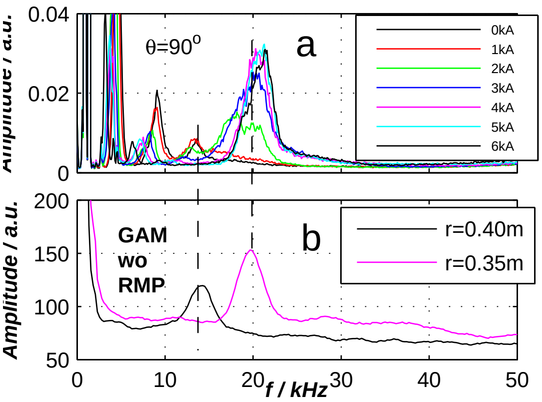

Figure 6: *Amplitude spectrum of Mirnov coil **(a)** and reflectometry **(b)** showing the correlation between both diagnostics for a case without RMP and with RMP.*