Measuring the plasma response to applied RMPs on TEXTOR

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Introduction

In order to avoid damage to plasma-facing components on ITER, type-I edge-localized modes (ELMs) must be either mitigated or suppressed [1]. The application of resonant magnetic perturbations (RMPs) to the plasma provides a promising method of ELM mitigation or suppression. However, in order to understand the mechanism by which RMPs mitigate or suppress ELMs, it is necessary to understand the plasma response to the application of RMPs.

RMPs can be applied to TEXTOR plasmas using the Dynamic Ergodic Divertor (DED) [2]. TEXTOR is also equipped with a fast movable Mirnov probe (FMMP) capable of measuring the magnetic field structure in the edge of TEXTOR plasmas with applied RMPs. By subtracting the vacuum magnetic field, direct measurements of the plasma response to RMPs can be obtained.

Experimental setup

TEXTOR's DED consists of sixteen helical coils on the high-field side (HFS) of TEXTOR. It can be configured to produce fields with mode number $m/n = 3/1$ or $6/2$. The results presented here were obtained with the DED in $3/1$ configuration. The DED frequencies that are available in this configuration are $\pm 1\,\text{kHz}$ and $\pm 5\,\text{kHz}$, where positive frequencies represent a rotation of the field in the counter-current (electron diamagnetic drift) direction and negative frequencies correspond to the co-current direction.

The FMMP is located at the midplane on the low-field side (LFS) of TEXTOR and can be plunged into the plasma edge in order to obtain radial profiles of the magnetic field. The probe contains three groups of three Mirnov coils. Within every group, one coil is oriented in each of the radial, toroidal and poloidal directions so that every component of the magnetic field can be measured at three locations simultaneously.

An example of the measurements taken by the FMMP can be seen in figure 1. This example shows data from the coil in the group closest to the plasma that measures the poloidal component of the magnetic field, B_θ. The vacuum field is subtracted from the data, and the remaining field is considered to be generated by the plasma as a response to the applied RMPs.

When the probe is plunged into the plasma, radial profiles of the amplitude and phase of the plasma response are obtained. The duration of the probe plunge is much longer than the DED time period, so many DED cycles occur during a single plunge. If probe measurements taken at different radial locations but at the same point in the DED cycle are compared, then any difference in the amplitude or phase of these measurements is most likely due to radial variation in δB. Therefore, if δB is plotted as a function of radius and time point in the DED cycle, radial variations in the amplitude or phase of δB should appear.

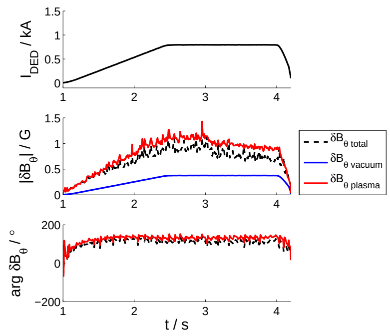
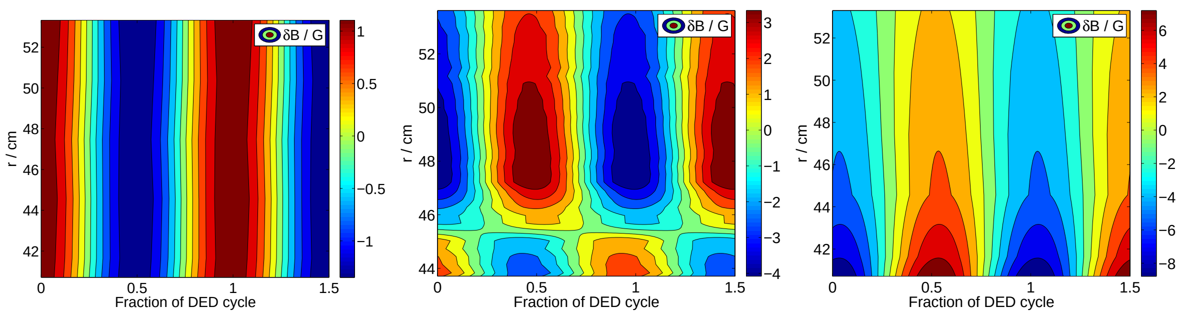


Figure 1: Measurements of the amplitude (middle) and phase (bottom) of $\delta B_{\theta\,\mathrm{plasma}}$, $\delta B_{\theta\,\mathrm{vacuum}}$ and $\delta B_{\theta\,\mathrm{total}}$ as the DED current (top) is ramped up, maintained at a constant value and then ramped down.

Figure 2 shows three examples of such plots. An example for a vacuum shot is shown in figure 2 (*a*). In this case, there is no measureable radial variation in the DED field. Figure 2 (*b*) and (*c*) show similar plots but with the addition of a TEXTOR plasma. In figure 2 (*b*), there is a clear $\sim 180°$ jump in the phase of δB_θ at $r \approx 45\,\mathrm{cm}$. This is interpreted as being caused by the presence of a screening current at this radial location, which should correspond to a resonant surface. Figure 2 (*c*) shows no such phase jump, but a resonant surface is expected to exist within the range of r covered by the probe. This is interpreted as penetration of the RMP field and destruction of the screening current on this resonant surface.



(*a*) (*b*) (*c*)

Figure 2: Example contour plots for (*a*) a vacuum shot, (*b*) screening and (*c*) field penetration.

Observation of screening currents

The first observations of screening currents on multiple resonant surfaces in the same probe plunge are reported. These observations have been repeated for DED frequencies of ± 1 kHz and ± 5 kHz. The observation of multiple resonant surfaces raises the possibility of observing overlapping surfaces or the formation of a stochastic region between surfaces. This would be more likely with the DED in 6/2 configuration since there would be more resonant surfaces and they would be closer together. Experiments in 6/2 configuration are included in future plans.

Figure 3 shows how the topology of the edge poloidal magnetic field changes as the DED current is increased with a frequency of $f_{DED} = -1$ kHz. This DED current scan was carried out with toroidal field $B_T = 1.6$ T, plasma current $I_P = 180$ kA and line-averaged electron density $n_e = 10^{19}\,\mathrm{m}^{-3}$. At $I_{DED} = 1.3$ kA, two $\sim 180°$ phase jumps are clearly visible, indicating screening on two resonant surfaces. Based on an equilibrium reconstruction using the DIVA code, the two outermost surfaces are identified as the $q = 4$ and $q = 5$ surfaces. As the DED current is increased, there is a gradual shift in the phase of δB_θ outside of the $q = 5$ surface such that the phase jump across the surface is reduced to $\sim 90°$ at $I_{DED} = 1.6$ kA. At this value of DED current, the amplitude of δB_θ begins to increase sharply inside the $q = 4$ surface.

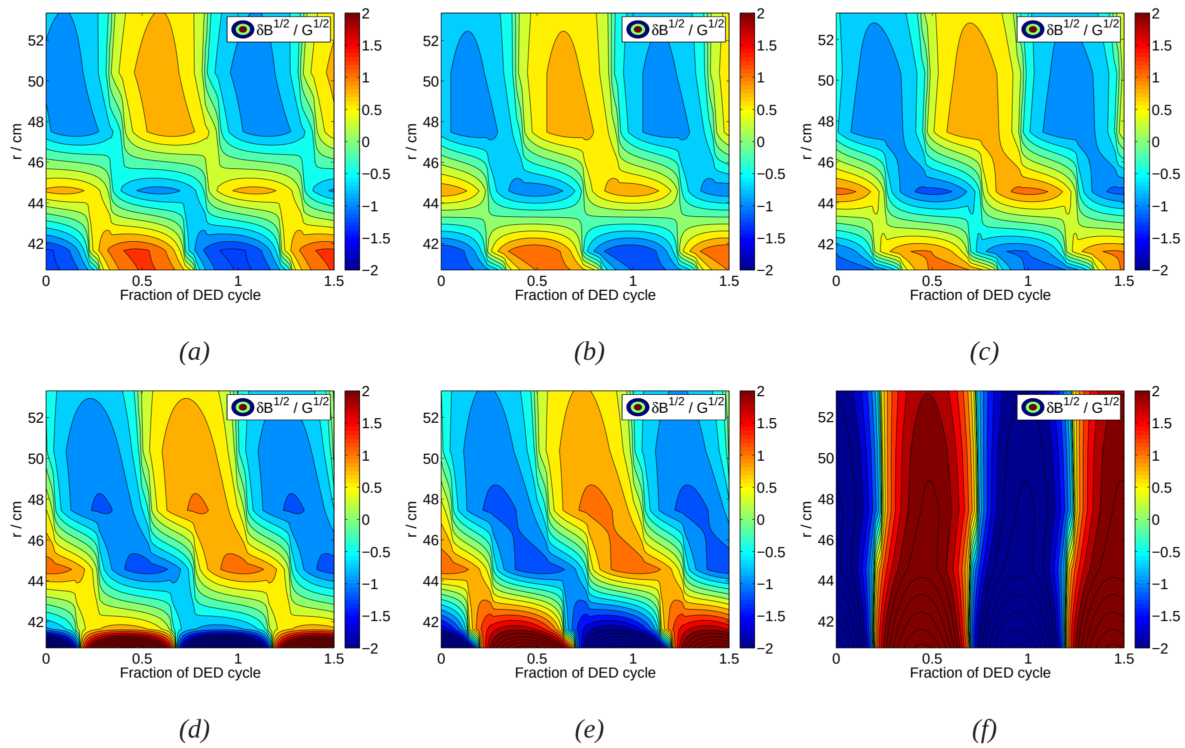


Figure 3: Topology of the edge poloidal magnetic field with a DED frequency of -1 kHz and current of (*a*) 1.3 kA, (*b*) 1.4 kA, (*c*) 1.5 kA, (*d*) 1.6 kA, (*e*) 1.7 kA and (*f*) 1.8 kA.

At $I_{DED} = 1.8\,kA$, the screening currents suddenly disappear and the amplitude of δB_θ suddenly increases throughout the plasma edge. An analysis of the data from an array of in-vessel Mirnov coils reveals that an $m/n = 2/1$ mode appears shortly after the DED current reaches its flat-top value of $I_{DED} = 1.8\,kA$. This $2/1$ mode becomes locked to the DED frequency and could be responsible for the sudden increase in the amplitude of δB_θ at $I_{DED} = 1.8\,kA$.

Another DED current scan was carried out for the same plasma parameters as above but with DED frequency $f_{DED} = +1\,kHz$. The results were similar except that field penetration occurred at just $1.2\,kA$. A lower threshold for field penetration is expected since there is less difference between the intrinsic plasma rotation and the rotation of the DED field.

Figure 4 shows the vacuum reference shot for the $-1\,kHz$ DED current scan. It can be seen that not only is the amplitude of the penetrated RMP field in figure 3 (f) significantly greater than the amplitude of the vacuum field but also that the phase differs by $\sim 180°$. This is possibly due to the $2/1$ mode. However, in the case of full screening on both resonant surfaces in figure 3 (a), the phase of the field outside of the $q = 5$ surface also differs from that of the vacuum field by $\sim 180°$.

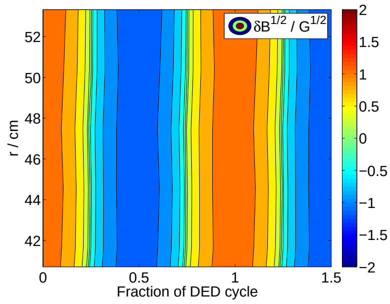


Figure 4: Vacuum reference shot for the DED current scan.

Summary and conclusions

The first observations of screening currents on multiple resonant surfaces have been made, and the transition from screening to field penetration has been measured. After RMP field penetration, the fluctuating part of the magnetic field has a significantly greater amplitude and a $\sim 180°$ phase difference compared to the vacuum case. This is possibly a result of the penetration of a $2/1$ mode. The threshold for RMP field penetration is found to be lower when the DED field rotates in the counter-current direction since there is less difference between the intrinsic plasma rotation and the rotation of the DED field.

Acknowledgments

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References

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