Plasma response to $n = 1$ and $n = 2$ 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 have been applied to TEXTOR plasmas using the Dynamic Ergodic Divertor (DED) [2]. TEXTOR was also equipped with a fast movable magnetic probe (FMMP) capable of measuring the magnetic field in the edge of TEXTOR plasmas with applied RMPs. By subtracting the vacuum field, direct measurements of the plasma response to RMPs have been obtained.

Experimental set-up

TEXTOR's DED consisted of sixteen helical coils on the high-field side (HFS) of TEXTOR. It could be configured to produce fields with mode number $m/n = 3/1, 6/2$ or $12/4$. The results presented here were obtained in $3/1$ and $6/2$ configurations. The DED frequencies available were $\pm 1\,\mathrm{kHz}$ and $\pm 5\,\mathrm{kHz}$ for the $3/1$ configuration and $\pm 1.4\,\mathrm{kHz}$ for the $6/2$ configuration, 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 was located at the midplane on the low-field side (LFS) of TEXTOR and could be plunged into the plasma edge in order to obtain radial profiles of the magnetic field. The probe contains three groups of three 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.

When the probe was plunged into the plasma, radial profiles of the magnetic field were obtained. The measured field is correlated with the DED signal, and the Fourier component corresponding to the DED frequency is selected in order to distinguish the effect of the DED field from the background equilibrium plasma. This fluctuating part of the magnetic field is labelled δB. The same procedure is carried out for the magnetic field measured in a vacuum shot. This

vacuum field is then subtracted from the data, and the remaining field is considered to be generated by the plasma as a response to the RMPs. This process is outlined in more detail in [3].

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 shows three examples of such plots. An example for a vacuum shot is shown in figure 1 (*a*). In this case, there is no measureable radial variation in the DED field. Figure 1 (*b*) and (*c*) show similar plots but with the addition of a TEXTOR plasma. In figure 1 (*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 1 (*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.
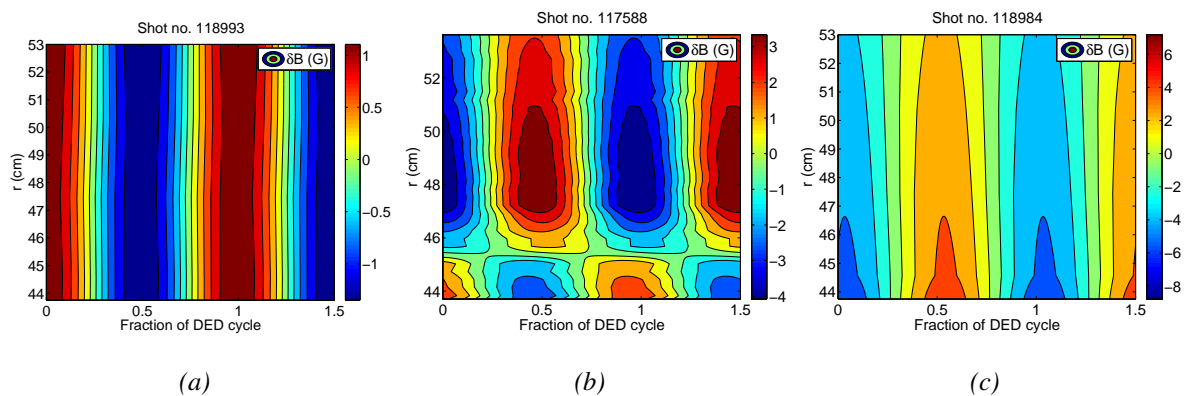

Figure 1: Example contour plots for (*a*) a vacuum shot, (*b*) screening and (*c*) field penetration.

Screening currents on multiple resonant surfaces

The first observations of screening currents on multiple resonant surfaces in the same probe plunge were reported in [3]. These results were repeated for DED frequencies of $\pm 1\,\mathrm{kHz}$ and $\pm 5\,\mathrm{kHz}$. The observation of multiple resonant surfaces raised the possibility of observing overlapping surfaces or the formation of a stochastic region between surfaces. It was hoped that 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.

For the 3/1 configuration, the clearest examples of multiple screening currents were observed for $5 < q_a < 6$ because the close proximity of the $q = 4$ and $q = 5$ surfaces in the plasma edge enabled them both to be well within range of the FMMP, while the $m/n = 4/1$ and $m/n = 5/1$ harmonics of the perturbation field were strong enough to have an observable effect on the plasma. However, as seen in figure 2,

(a) *(b)*

Figure 2: Perturbation spectra for *(a)* the 3/1 configuration with $I_{DED} = 0.8\,\text{kA}$ and *(b)* the 6/2 configuration with $I_{DED} = 1.8\,\text{kA}$. Despite having more than double the DED current, the $n = 2$ perturbation is weaker, and it is very localized at the plasma edge with a narrow resonant window.

the perturbation spectrum for the 6/2 configuration is weaker than for the 3/1 configuration and is very localized at the plasma edge with a narrow resonant window. As a result, no effect on the plasma was observed for $q_a \gtrsim 4.25$, and the clearest examples of multiple screening currents were on the $q = 7/2$ and $q = 4$ surfaces (figure 3). Owing to the lower magnetic shear at lower q_a, the proximity of these surfaces was only similar to that of the $q = 4$ and $q = 5$ surfaces with $5 < q_a < 6$, so no overlapping surfaces or stochastic regions were observed.

Screening and field penetration

For the 3/1 configuration, a transition from screening of the applied perturbation to field penetration as the DED current increases has previously been reported and described in detail in [3]. However, for the 6/2 configuration, only screening was observed, even at high values of I_{DED} (figure 3). One possible explanation is that the $n = 2$ perturbation was simply not strong enough for field penetration to occur.
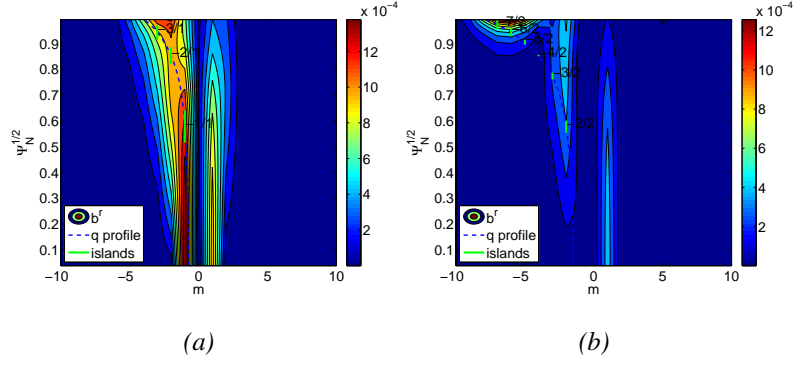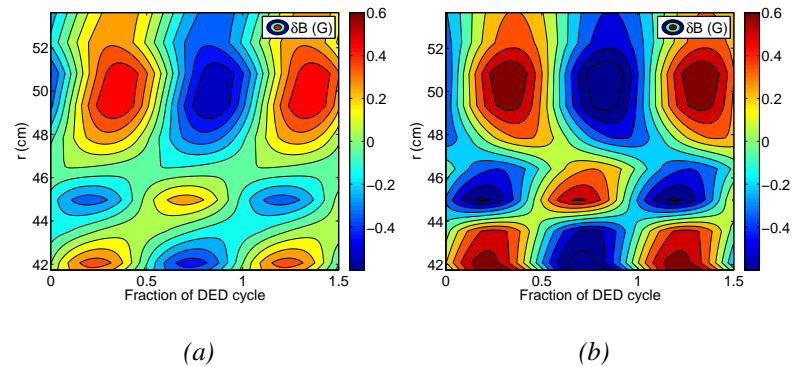

(a) *(b)*

Figure 3: Screening currents on the $q = 7/2$ and $q = 4$ surfaces with $n = 2$ RMPs for *(a)* $I_{DED} = 1.2\,\text{kA}$ and *(b)* $I_{DED} = 2.3\,\text{kA}$.

An analysis of the data from an array of in-vessel Mirnov coils revealed that field penetration in the 3/1 configuration was accompanied by the appearance of an $m/n = 2/1$ mode that locked to the DED frequency [3]. Therefore, another possible explanation is that this 2/1 mode, which is absent in the case of $n = 2$ perturbations, is required for field penetration. On the other hand, it could be that the field penetration causes or at least enables the growth of the 2/1 mode.

Dependence of δB on q_a

With the FMMP outside of the plasma, the effect of q_a on the amplitude and phase of δB with $n = 2$ RMPs was investigated. Figure 4 shows peaks in the amplitude of δB where q_a is near a resonant value, i.e. there is a resonant surface at the very edge of the plasma. This represents the minimum distance between the outermost resonant surface and the FMMP. This effect can be explained by the radial decay of the field created by screening currents on the resonant surface. The strongest peak occurs for $q_a \approx 3$ because the strongest harmonic is $m/n = 6/2$.
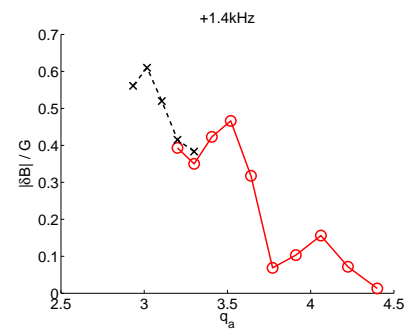

Figure 4: Amplitude of δB_θ with $n = 2$ RMPs. The dashed line represents data taken on a different day.

Summary and conclusions

Screening currents on multiple surfaces that had previously been observed for $n = 1$ perturbation fields have now also been observed for $n = 2$ perturbations. However, no evidence of overlapping surfaces or stochastic regions was found, nor could the field penetration previously observed for $n = 1$ perturbations be reproduced with $n = 2$. This is possibly due to the fact that the $n = 2$ perturbations are weaker and have a narrower resonant window. It was found that the amplitude of the plasma response measured outside of the plasma was greatest when the outermost resonant surface was at the very edge of the plasma.

The FMMP will now be deployed on other tokamaks.

Acknowledgments

References

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