An investigation of 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 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

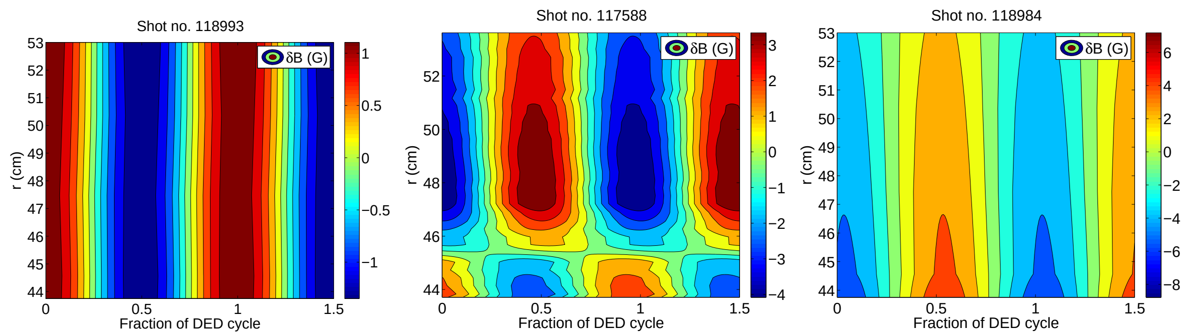
TEXTOR's DED consisted of sixteen helical coils on the high-field side of TEXTOR. It could be configured to produce fields with mode number $m/n = 3/1$, $6/2$ or $12/4$. The results presented here were obtained in $3/1$ and $6/2$ configurations. The DED frequencies available were ± 1 kHz and ± 5 kHz for the $3/1$ configuration and ± 1.4 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 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.



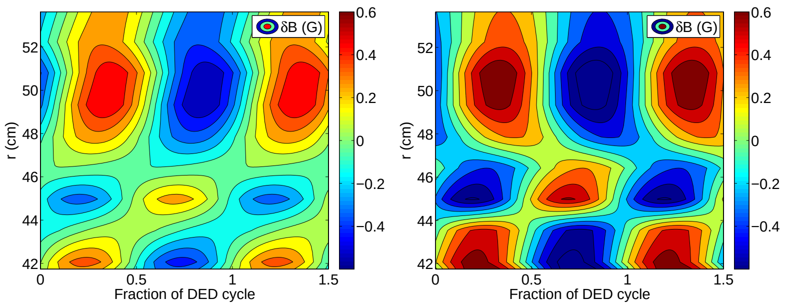
(*a*) (*b*) (*c*)

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

Screening and field penetration

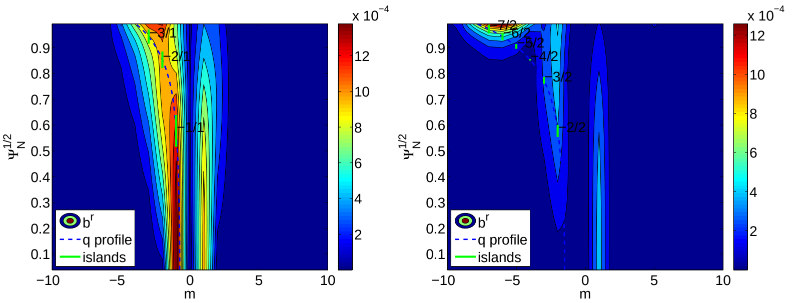
For the $3/1$ configuration, a transition from screening of the applied perturbation to field penetration as the DED current increases has previously been reported and described in detail in [3]. However, for the $6/2$ configuration, only screening has been observed, an example of which can be seen in figure 2. 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 can be seen in figure 3. As a result, for q_a values of 4.25 or above, $n = 2$ RMPs have not been observed to have any effect on the plasma that can be measured by the FMMP.

One possible explanation for why field penetration has not been observed with $n = 2$ RMPs – even at lower values of q_a and high values of I_{DED} – is that the perturbation field was simply not strong enough for field penetration to occur. However, 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 a $2/1$ 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 $n = 2$ RMPs, is required for field penetration. On the other hand, it could well be that the field penetration causes or at least enables the growth of the $2/1$ mode.



(a) *(b)*

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



(a) *(b)*

Figure 3: Perturbation spectra for (a) the $3/1$ configuration with I_{DED} =0.8 kA and (b) the $6/2$ configuration with I_{DED} =1.8 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.

Hodographs

A hodograph is the locus of one end of a variable vector, with the other end at the origin. Hodographs enable us to combine measurements of two or all three components of the magnetic field in one plot and provide a new way of looking at the data.

The example shown in figure 4 shows a phase change in the plasma response to $n = 1$ RMPs that occurs for DED currents above a certain value when there is a large difference in rotation between the plasma and the perturbation field but not when there is a smaller difference in rotation. This phase change indicates that screening currents are formed on rational surfaces in the plasma edge. The fact that the phase change is not observed when there is a smaller difference between the rotation of the plasma and that of the perturbation field suggests that the

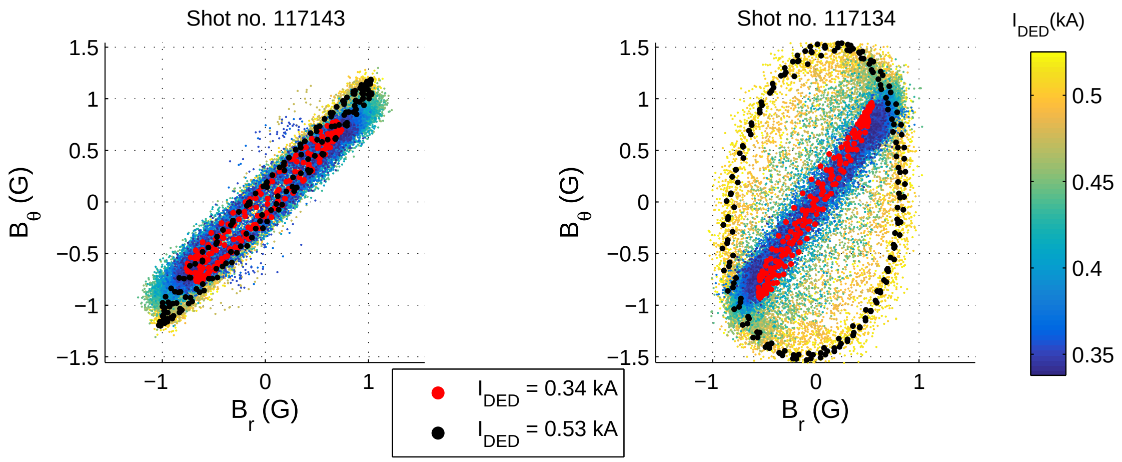


Figure 4: Hodographs of the plasma response with different values of plasma rotation, showing a constant phase (left) and a phase change (right) as I_{DED} exceeds a certain value.

RMPs are not screened when their rotation is close to that of the electron fluid, i.e. when the perturbation is almost static in the reference frame of the electron fluid.

Summary and conclusions

Screening currents on multiple surfaces have been observed for both $n=1$ and $n=2$ perturbation fields. Furthermore, a transition from screening to field penetration at higher values of I_{DED} has been observed for $n=1$ perturbations. However, this field penetration has not been reproduced with $n=2$ RMPs. This is possibly due to the fact that the $n=2$ perturbations are weaker and have a narrower resonant window, or possibly because the field penetration requires the presence of a $2/1$ mode.

Hodographs represent a promising new method of analysing the data that can combine two or all three components of the magnetic field in one plot. A systematic analysis of the magnetic topology using hodographs is currently ongoing.

The FMMP has now been deployed on other tokamaks.

Acknowledgments

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