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Limits of RMP ELM Suppression in Double Null Plasmas

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New DIII-D results may explain why achieving ELM suppression by resonant magnetic fields (RMPs) remains elusive in double null (DN) diverted configurations: the lack of ELM suppression in DN correlates with a damped high-field side response of field-aligned structures that could be indicative of a missing resonant tearing needed to stop inward growth of pedestal. This is found despite favorable conditions for RMP suppression in lower single null (LSN): low $\Omega_{E\times B}$ aligned with a resonant surface at the pedestal top at low $n_{e,ped}$. The DN configuration is advantageous for future machine design as it allows improved divertor power handling and particle control, but still needs ELM handling solutions and may not be compatible traditional RMP ELM suppression driven from low-field side coils.

In experiments where the magnetic balance is varied from LSN toward DN, ELM suppression was obtained for $dR_{sep} < -1.7$ cm, where dR_{sep} is defined as the separation between the separatrices from the lower null and upper null at the outboard midplane. In discrete steps of dR_{sep}, q_{95} is scanned to find a window in ELM suppression under the model that aligning a resonant surface in a region of low $\Omega_{E\times B}$ results in resonant tearing inhibiting the inward growth of the pedestal otherwise leading to an ELM {1}. Results of these scans are shown in Figure 1a where the values of $\Omega_{E\times B}$ at resonant surfaces are within $\pm 2\%$ of $\psi_{ped,top}$ (to account for uncertainty in profile fitting). Figure 1b shows $n_{e,ped}$ where ELM suppression was achieved (with the largest value of $n_{e,ped} \sim 2.4{\times}10^{19} m^{-3}$). This shows for each ELM-suppressed discharge, a resonant surface is near the pedestal top with $|\Omega_{E\times B}| < 20$ krad/s.

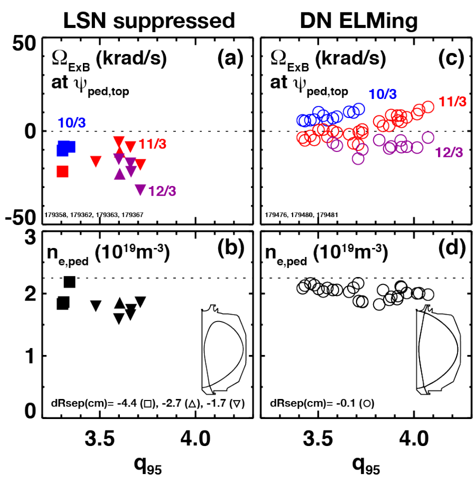

Figure 1: Demonstration of low $\Omega_{E\times B}$ at resonant surfaces co-aligned with the pedestal top: $\Omega_{E\times B}$ at resonant surfaces within $\pm 2\%$ of $\psi_{ped,top}$ (a,c), $n_{e,ped}$ (b,d) in lower-single null suppressed (a,b) vs. double null ELMing cases (c,d). $\psi_{ped,top}$ is defined by the $\tanh$ fit to T_e profile.

In near balanced DN ($dR_{sep} \sim -0.1$ cm), similar scans show that nominal ELM suppression conditions are demonstrated while still ELMing. ELM suppression is not achieved over a range of q_{95} from 3.4 to 4.1 where it was observed in LSN. This is shown in Figure 1c where $\Omega_{E\times B}$ at resonant surfaces aligned within $\pm 2\%$ pedestal top are $|\Omega_{E\times B}| < 10$ krad/s—a tighter range than in LSN. These discharges also achieve a lower value of $n_{e,ped}$ than the highest value suppressed in LSN. The pedestal temperature width is consistently wider in ELMing DN plasmas compared to the ELM suppressed LSN plasmas. This leads to a wider total pedestal pressure, consistent with lacking a mechanism inhibiting the pedestal inward growth.

The 3D plasma response to applied RMPs measured on the high-field side (HFS) drops in plasma shapes transitioning from LSN to DN and recovers in upper single null (USN) as shown in Figure 2. The plasma response on the low field side (LFS) remains relatively constant during the shape transition. The reduced HFS response is found similarly for $n = 2, 3$ over a range of q_{95} from 3.4 to 5. This feature is found broadly across a range of $|dR_{sep}0.1|$ cm indicating it is not restricted to exactly balanced DN or specific pedestal conditions.

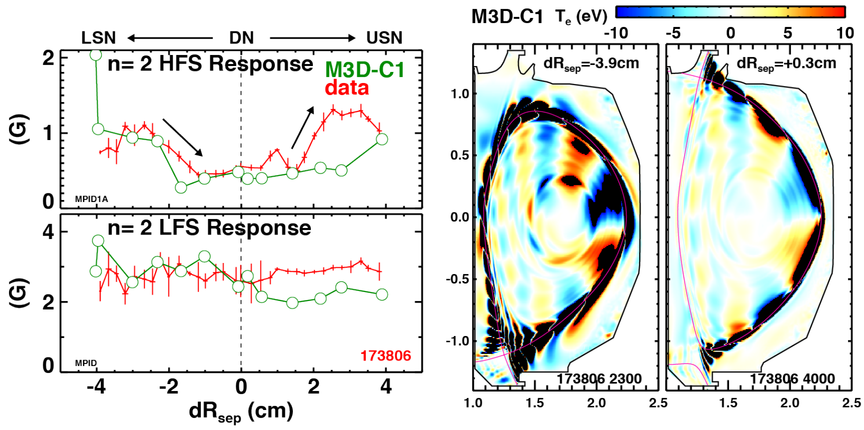

Figure 2: Measured high-field side (HFS) and low-field side (LFS) magnetics response compared linearized resistive single-fluid simulated response from lower single null to upper single null. Simulated T_e perturbations show damping along HFS in double null.

Linearized single-fluid resistive MHD modeling with M3D-C1 shows relatively good agreement with plasma response measurements transitioning from LSN to DN for both the HFS and LFS indicative of a strong damped of perturbations on the HFS in DN. This is further illustrated in the modeled T_e perturbations in Figure 2 where the perturbations are strongly damping on the HFS in DN. This can be partially understood using a simple geometric model assuming field-aligned resonant perturbations. Field-aligned modes driven from the LFS (as is the case with I-coils in DIII-D) are connected to the HFS through a region of low poloidal field in the presence of a secondary null. This can lead to interference of radially-separated resonant modes on the HFS. In balanced double null, this leads to the strongest interference on the HFS.

Results presented here are consistent with using HFS response as a proxy for local tearing drive responsible for ELM suppression by stopping inward growth of pedestal. This is consistent with previous results showing correlation of HFS response and tearing drive needed for ELM suppression {2}. The benefit of DN in power handling resides in a narrow region of dR_{sep} where exact splitting of the heat flux depends on cross-field drifts and has been shown to balance at $dR_{sep} \sim 0.25$ cm (near double null) with the ion ∇B drift directed to the lower divertor {3}. This region of dR_{sep} lies within the damped HFS response and lack of demonstrable ELM suppression. If this model is correct, we can use it to optimize shape and coil positions to better attempt ELM suppression.

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