Impact of resonant magnetic perturbations on the L-H Transition

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Introduction The power loading to the divertor during type I ELMs is a concern for large fusion machines. One proposed method to reduce this power loading is the application of resonant magnetic perturbations (RMPs). RMPs have been used to suppress type I ELMs [1-3], however, not all devices with RMPs have achieved this suppression. A second possibility is mitigation, which reduces the power loading due to the ELMs, typically by increasing ELM frequency and hence reducing the energy loss per ELM event [4-6]. One observed side effect of the application of RMPs is that it makes H-mode access more difficult, increasing the L-H Power threshold ($P_{L\text{-}H}$) and hence the requirement for external heating power. Although this increased power requirement is small in absolute terms on current devices, the predicted power threshold scales with plasma surface area and B_T [7] and is predicted to be ~52MW on ITER [8].

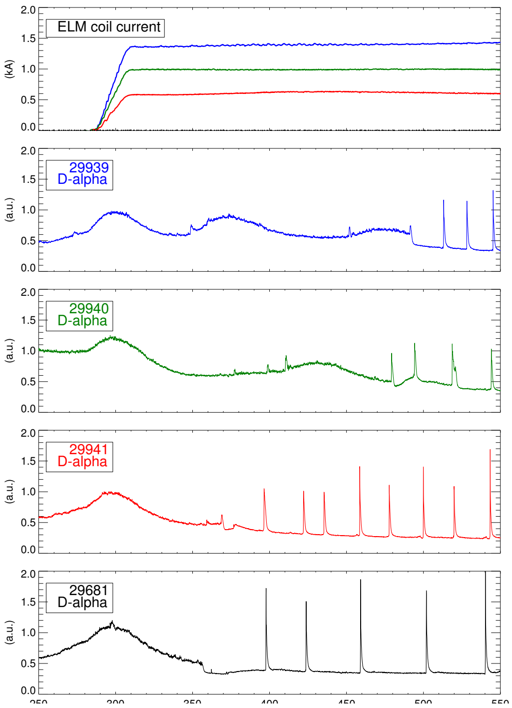

Figure 1 – Varying RMP coil current in n=6.

On DIII-D [9] increases in power threshold of up to 100% have been observed at large $\delta B/B_T$. On ASDEX Upgrade [10] a density dependence of the impact of RMPs on $P_{L\text{-}H}$ is observed, with an ~20% increase in $P_{L\text{-}H}$ for $0.45*n_{GW}<n_e<0.65n_{GW}$ and complete suppression of the transition for $n_e>0.65n_{GW}$. At NSTX [11] an increase in $P_{L\text{-}H}$ of at least 50% is observed on application of RMP. In previous results from MAST [12] an applied n=3 RMP to a 900kA double null discharge resulted in an increase of injected beam power from 1.8MW to 3.3MW to achieve a H-mode transition at the same time as a no applied RMP discharge. Of the observations on existing devices, a number have cited changes in radial electric field by the RMP as a potential source of the impact on the L-H transition. This paper presents the results of systematically varying intensity and toroidal configuration of RMP on the L-H transition in lower single null 400kA discharges.

Applying varying intensity RMP in n=6 The impact of varying RMP coil current on a typical discharge is shown in figure 1. This discharge has 1.5MW of injected neutral beam power and is at least a factor of 2.5 above the injected power required for an L-H transition, separately measured to be < 0.6MW. RMPs are applied in an n=6 configuration, with coil currents of 0.5kA, 1.0kA and 1.4kA. The line integral density is held constant from 300ms and the L-H transition for all discharges occur at a line integral density of $N_e = 1.25x10^{21}m^{-3}$. Similar density profiles from TS are observed for all discharges before the transition. A particle 'pump out' caused by the RMPs is evidenced by increased gas refuelling rate with increasing I_{RMP} to maintain the constant N_e. Once in H-mode the gas fuelling is turned off by the feedback system and eventual line integral density and plasma energy are both observed to be lower with higher applied RMP. A strong increase in ELM frequency (~doubling) is observed in the discharges with applied RMP although the marginal increase from 0.5kA to 1.4kA is relatively small. However, the impact on the timing of the L-H transition is very large with delays of ~13,120,130ms with 0.5kA, 1.0kA and 1.4kA of RMP coil current respectively corresponding to $0.5\text{-}5\tau_E$.

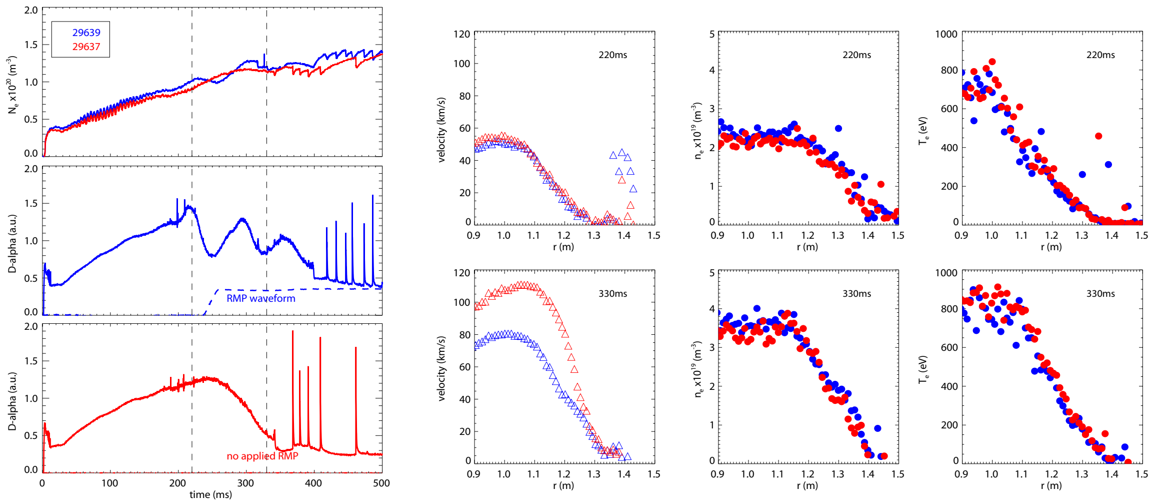

Figure 2 -Profiles of discharges before application of RMP and before L-H transition time of no RMP discharge.

Impact of RMPs on kinetic profiles The impact of n=4 RMP on a 400kA discharge are shown in figure 2. The profiles of n_e, T_e and v_ϕ are compared at two timeslices as indicated by the dashed vertical lines on the time traces figure 2. The first time at which the profiles are compared is at 220ms before the application of the RMP waveform. At this time the v_ϕ and n_e and T_e profiles of the two discharges are identical, verifying that the shots are good repeats. The second time at which the two discharges are compared is at 330ms, just before the 'natural' L-H transition in the no applied RMP shot. At this second timeslice, once again the

T_e and n_e profiles for the two discharges are identical, however the v_ϕ profile has been significantly decreased across the core of the plasma. Measurements of low v_ϕ at the edge of the plasma (r/a >~0.9) from charge exchange are not well resolved due to instrument function and strong background emission. However, it is likely that the v_ϕ at the separatrix is decreasing in line with the toroidal velocity in the core of the plasma. A change in edge velocity changes the edge radial electric field, which is widely theorised to be a strong determinant of the L-H transition due to its' impact on flow shear which in turn suppresses turbulence causing a build up of the pedestal [13].

Comparison of n=2,3,4 and 6 One of the goals of this experiment was to compare the impact of different RMP 'n' numbers on the L-H transition whilst maintaining effectiveness at mitigation. The results are shown in figure 3. Two sets of discharges are examined, with 1.2MW and 1.5MW of injected NBI power respectively. Application of n=2,3,4 and 6 perturbations, in all cases with 1.4kA of coil current, are then applied to these two discharges.

The results of these comparisons show that the n=2 has the greatest impact on the L-H, completely suppressing the transition in the 1.5MW discharge and delaying the transition by 200ms ($\sim 10\tau_E$) in the 1.2MW discharge.

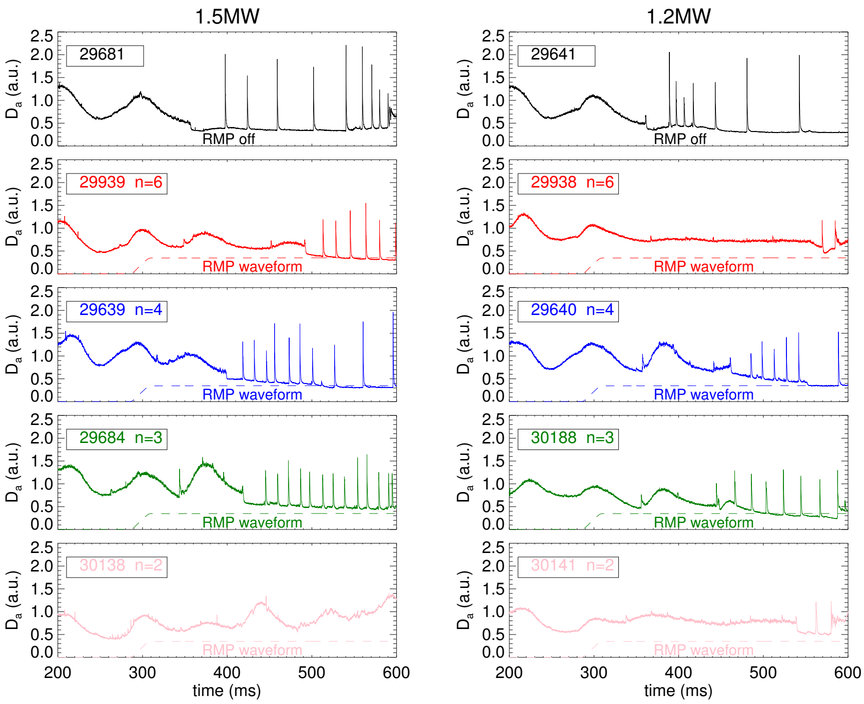

Figure 3 - Varying applied RMP n number and beam power.

The transition occurring more readily with decreased beam power is unexpected behaviour but this has been shown to be repeatable with subsequent discharges. The reason for this unexpected behaviour is due to strong braking of the plasma with application of RMP field in n=2 configuration, as shown in figure 4, and interaction of this braking with modes in the plasma.

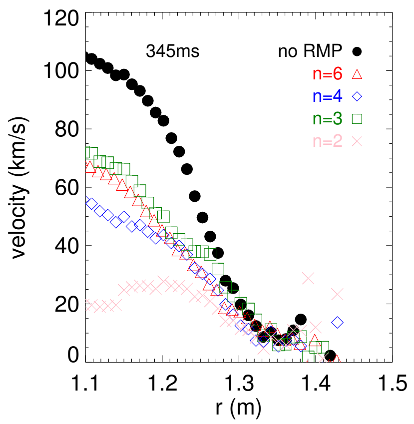

Figure 4 - Velocity profiles before L-H transition for 1.5MW discharges in fig 3.

The impact of n=3,4 and 6 RMP on the timing of the L-H transition can be compared directly without the complication of locking to internal modes. It can be seen that for the n=3 and 4 cases with 1.5MW of injected power there is a delay in the L-H transition time of ~2τ_E, even though the injected power is at least a factor of 2.5 above the injected power required for an L-H transition with no applied RMP. Decreasing the beam power to 1.2MW, such that the discharges are at least a factor of 2 above this power threshold, the timing of the L-H transition is delayed ~4τ_E. Although not shown here, complete suppression of H-mode is observed for shots in n=3 and n=4 (both 1.4kA) at injected NBI powers of 0.9MW.

Application of RMP with the same coil current in an n=6 configuration causes a larger impact on the L-H transition. For the 1.5MW discharge the timing of the L-H transition is delayed by ~4.5τ_E, although once the transition occurs the H-mode is stable. For the 1.2MW discharge a short H-mode period is obtained followed closely by a back transition, indicating that for this level of applied RMP the plasma is close to its L-H power threshold.

A comparison of the ELM mitigation and impact on plasma energy is shows that application of 1.4kA of RMP coil currents in these configurations results in mitigation of $f_{ELM,mitigated}/f_{ELM,natural}$ ~2-3. Since the power threshold for H-mode is increased by >~50%, this allows a comparison of the achieved mitigation with increased threshold. The same discharges show a reduction in plasma energy of ~20% due to the RMP. If a higher mitigated ELM frequency is required for future devices, a further increase in power above the no applied RMP power threshold would be required for H-mode access.

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