Effect of edge localized modes and resonant magnetic perturbation on fusion reactions in MAST

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Introduction

Edge Localized Modes (ELMs) are a characteristic feature of a plasma in H-mode. ELMs are transient instabilities causing repetitive bursts of plasma energy and particles to be directed towards the in-vessel components of a fusion device. In order to reduce the energy and particle fluxes to the plasma facing components such as divertor plates, several mitigation techniques have been developed. Among others, the application of the external Resonant Magnetic Perturbations (RMPs) has resulted in the mitigation or suppression of ELMs [1]. However, it has been found in ASDEX Upgrade [2], DIII-D [3] and MAST [4] that RMPs might lead to degradation of the confinement of energetic ions.

In this paper, the impact of ELMs and ELM mitigation coils on the population of energetic ions in the Mega Ampere Spherical Tokamak (MAST) has been investigated. MAST is equipped with two sets of in-vessel ELM mitigation coils: the lower set consisted of twelve coils located below the midplane and the upper set consisted of six coils located above the plasma midplane. The coils could be configured to apply static magnetic perturbations with toroidal mode numbers $n = 2, 3, 4$ or 6. In MAST, the population of fast ions arises mainly from ionization of neutral deuterium atoms with initial energies of up to 70 keV injected by two Neutral Beam Injection systems which are capable of delivering a total power of 3.8 MW. The low thermal ion temperature ($T_\mathrm{i} \leq 2$ keV) along with a large energy difference between the fast and thermal ions give rise to the neutron emission from the plasma dominated by the fusion reactions occurring between fast and thermal ions (beam-thermal component) and among fast ions (beam-beam component). In such a case, the neutron emission is strongly linked to fast ions and therefore the effect of ELMs and ELM mitigation coils on fast ion population can be studied by measuring the global neutron emission using a fission chamber (FC) and the local one using a neutron camera (NC). In this study, NC observations only from the plasma core and edge are reported

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This study is based on a large database of plasma discharges with and without RMPs (294 and 397 discharges respectively) divided in six different scenarios. Scenarios 8 and 3 are in the so-called Lower Single-Null Diverted configuration with $I_p = 400$ kA and 600 kA respectively: scenario 8 consists of 93 and 27 plasma discharges with and without RMPs while for scenario 3 the corresponding figures are 124 and 59. The remaining four scenarios as in the Connected Double-Null configuration with $I_p = 750$ kA (Scenario 4, 25 and 61 discharges), 900 kA (Scenario 5, 6 and 118 discharges), 600 kA (Scenario 6, 45 and 75 discharges) and 800 kA (Scenario 7, 1 and 57 discharges).

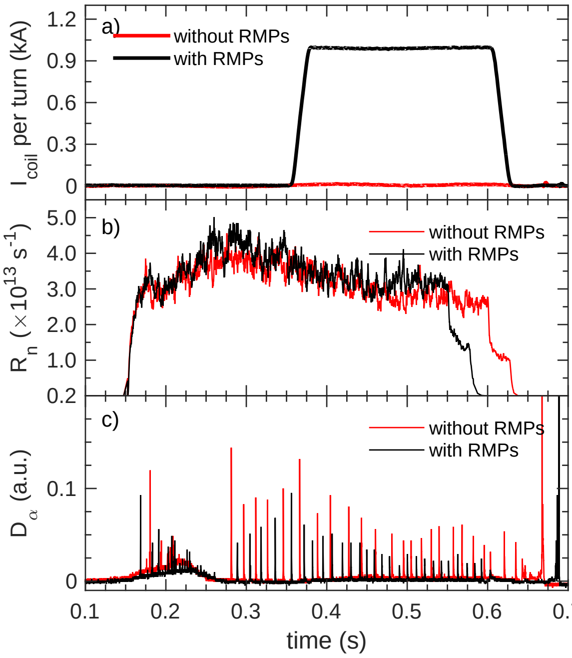

Figure 1: *MAST discharges* #30090 *(red) and* #30260 *(black) belonging to scenario 8: time traces of a) RMP coil current per turn, b) total neutron rate measured by the FC and c) D_α emission.*

The time evolution of the total neutron rate measured by the FC and thermal D_α emission from the plasma edge region for plasmas with and without RMPs belonging to scenario 8 are presented in figure 1. As can be seen in figure 1c) both discharges were in the H-mode from about 0.27 s where the short-lived bursts caused by ELMs are superimposed on relatively low steady-state D_α emission. The ELMs have slightly lower amplitude and occur more often during the application of RMP (see figure 1c)).

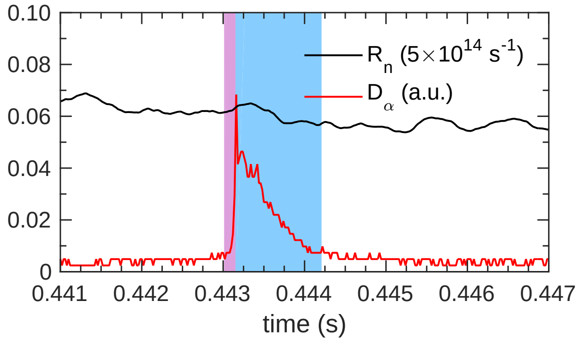

Figure 2: *MAST discharge* #30090*: a single ELM (red) and the neutron rate (black). The pink and blue regions indicate pre/post-ELM time averaging periods for the neutron rate, respectively.*

The time evolution of a single ELM and the measured neutron rate are presented in figure 2. The pink and blue regions indicate the pre/post-ELM time periods in which the pre/post mean neutron rates denoted as $R_{\rm pre}$ and $R_{\rm post}$ are used to calculate the relative change in the neutron rate $\Delta R = (R_{\rm pre} - R_{\rm post})/R_{\rm pre}$. The distributions of ΔR as a function of the amplitude of D_α emission for discharges with and without RMPs for both scenarios are shown in figures 3a) and 3b): no clear difference is observed. Histograms constructed from the distributions of ΔR, shown in figures 3a) and 3b), are depicted in figures 3c) and 3d). Only in scenario 3 histograms have means with clearly positive values, i.e. that the neutron rates clearly drop on average following the ELM. The discharges with the RMPs have been further

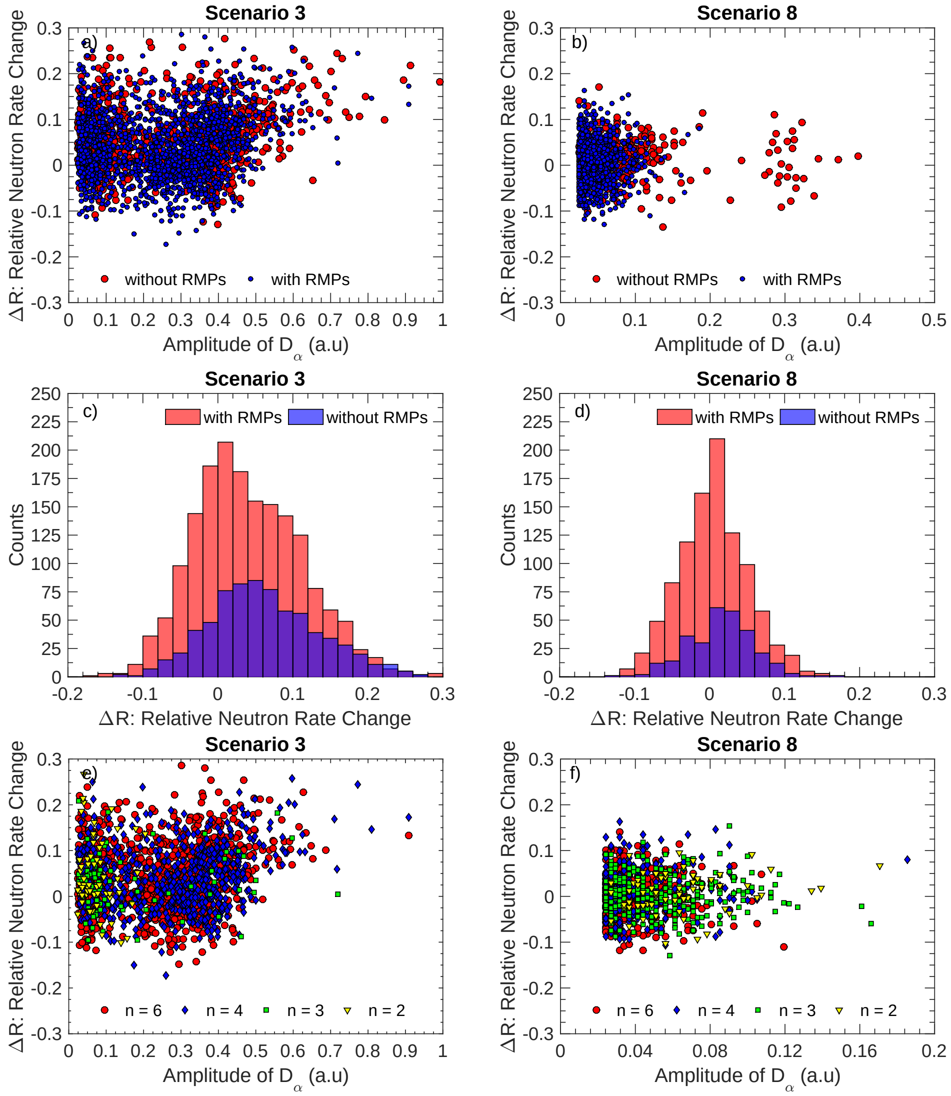

Figure 3: *Scenarios 3 and 8: a) and b) distributions of relative changes in the neutron rate as a function of the amplitude of D_α emission for discharges without and with RMPs; c) and d) histograms formed from the distributions shown in panels a) and b); e) and f) distributions for discharges with RMPs shown in panels a) and b) classified according to the toroidal mode number of the applied RMP.*

classified according to the toroidal mode number of the applied RMP. There are 5, 9, 41 and 63 discharges belonging to scenario 3, while 6, 26, 14 and 35 discharges belonging to scenario 8 with the RMP toroidal mode number $n = 2,3,4$ and 6 respectively. The results of such separations are presented in figures 3e) and 3f). No clear dependence of the ΔR on the toroidal mode number can be identified.

Since no change in the global ΔR was observed, the effect of ELMs and ELM mitigation coils on fast ions in the plasma core and at the plasma edge have been investigated by means of the local neutron count rate provided by the NC. The histograms of the relative changes in the local neutron count rate due to ELMs in discharges with (8 discharges) and without RMPs (26 discharges) are shown in figure 4 for scenario 8: no clear difference is observed neither in the plasma core nor at the plasma edge.

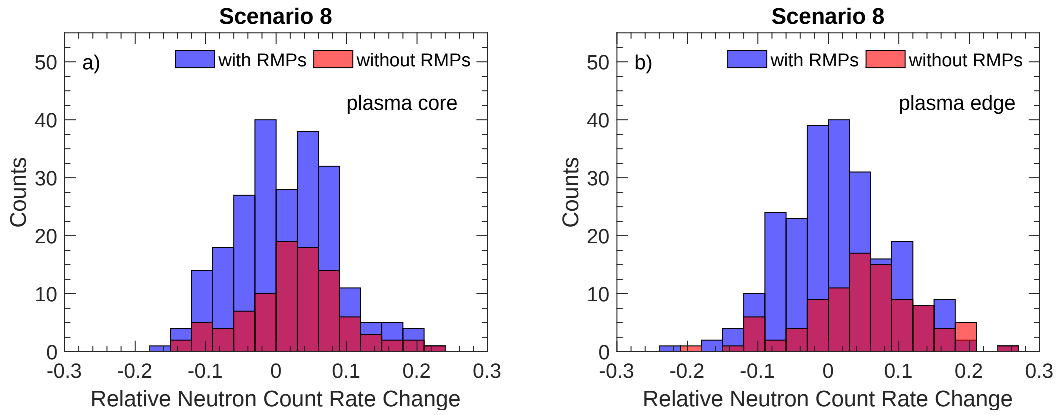

Figure 4: *Histograms formed from the distributions of the relative changes in local neutron count rates measured by the NC in the plasma core a) and at the plasma edge b).*

Summary and Conclusions

The effect of ELMs and ELM mitigation coils on fast ion confinement in MAST have been studied in as systematic way in two Single-Null Diverted and two Connected Double-Null Diverted plasma scenarios using global and local neutron rates. While unmitigated ELMs in these MAST scenarios are correlated weakly with a reduction in neutron emission, and hence in fast ion confinement; there is no clear effect of mitigated ELMs on neutron emission or fast ion confinement. The sawtooth activity was found to be present in both Lower Single-Null Diverted plasma scenarios, hence a correlation between the changes in the total neutron rate and the sawtooth/non-sawtooth triggered ELMs will be investigated in the future work.

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