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Kinetic profiles and plasma response during application of 3D magnetic perturbations fields

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Introduction

The H-mode is accompanied by edge localized modes (ELMs), which may imply intolerable power loads on first wall materials in large fusion devices. One method to suppress or to mitigate such ELMs is the application of external magnetic perturbation (MP)-fields. This technique has been demonstrated to suppress large ELMs in ASDEX Upgrade (AUG), DIII-D, KSTAR and to mitigate them in JET, MAST, NSTX [2].

Recent experiments demonstrated ELM mitigation at low collisionality $\nu^\star$ in AUG [1, 3]. Accompanied with ELM mitigation is a decrease of density, the so-called density pump-out, whereas the temperature is not strongly affected. Towards ELM mitigation, the ELM frequency can reach several 100 Hz making an analysis of inter-ELM kinetic profiles and their evolution very challenging. Additionally, the MP-fields introduce a toroidal asymmetry, which makes the analysis and its interpretation of toroidally localized measurements even more complicated. In this paper, we investigate changes in kinetic profiles towards ELM mitigation and the effect of toroidal asymmetry on the plasma using toroidally localized diagnostics and rotating MP-fields.

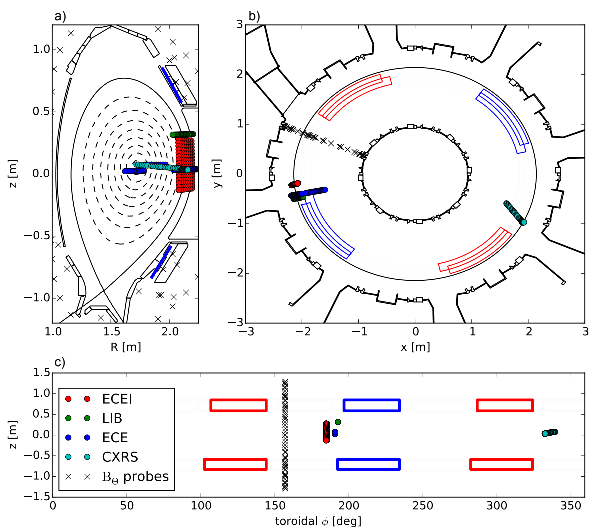

Figure 1: (a) poloidal plane, (b) toroidal plane, (c) toroidal angle versus z

Experimental setup

Recent diagnostic upgrades of electron cyclotron emission (ECE) (T_e), charge exchange recombination spectroscopy (CXRS) (T_i) and the lithium beam (LIB) (n_e) diagnostics allow us to resolve inter-ELM kinetic profiles during ELM mitigation, although the ELM frequency amounts to up to ~ 800 Hz. Figure 1 shows poloidal and toroidal positions of several used diagnostics at AUG. Additionally to the standard set of edge diagnostics for kinetic profiles, we also used ECE imaging (ECEI), which can resolve poloidal structures. ECEI and ECE was only used at medium q ($q_{95} \sim 5.2$) discharges due to the higher magnetic field ($|B_T| \sim 2.5$ T) and their limited frequency range.

The MP-field in AUG is generated by 16 perturbation coils and its versatile power supply allows rigid rotations of the MP-field using a coil configuration with a toroidal mode number n of one (n=1) or n=2 . Fig. 1 shows the position of the coils and the colors indicate an n=2 perturbation.

Kinetic profiles during ELM mitigation

Figure 2 shows ELM mitigation experiments at medium q. Time traces of Fig. 2(a) show two phases (labelled as MP I an II), when an n=1 MP-field was applied. These two phases differ only by the applied MP-field alignment caused by a toroidal phase shift between the upper and lower coil set. Although the strength of the currents were the same, only the second phase achieved ELM mitigation indicating the importance of the MP-field alignment on conditions for ELM mitigation (more details in [4]). Additionally, the ELM mitigation was induced by a radial sweep, which led to a larger perturbation field at the plasma edge due to the smaller distance between the plasma and the MP-coils.

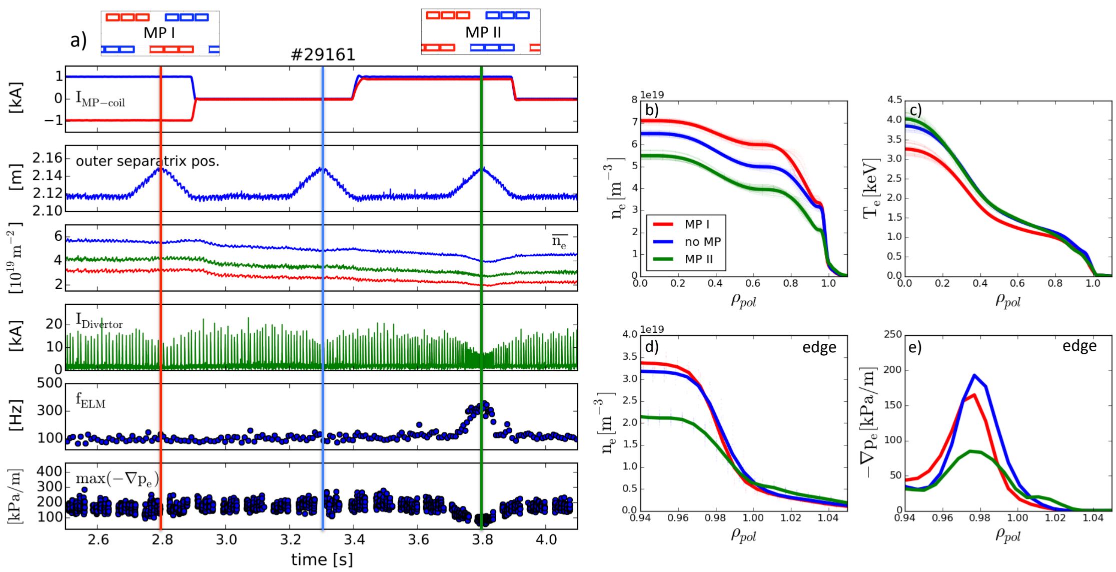

Figure 2: a) from top to bottom: MP coil current, outer separatrix position, line integrated density, divertor current, ELM frequency, maximum edge pressure gradient, (b) electron density profile, (c) electron temperature profile, d) edge electron profile, (e) electron pressure gradient. The color scaling of the vertical lines in (a) corresponds to the time windows used in (b-e).

Accompanied with ELM mitigation is a decrease of density, the so-called density pump-out (Fig. 2(b)), whereas the electron temperature is not strongly affected (Fig. 2(c)). Measurements indicate that the density pump-out comes along with smaller edge gradients within the pedestal region in the electron density profile (Fig. 2(d)) as well as electron pressure profile (Fig. 2(e)). The increase in ELM frequency and the lower critical electron pressure gradient indicate a change in ELM stability boundary, since a shallower pressure gradient is usually more stable to peeling-ballooning modes. Here, three dimensional effects caused by the MP could play a role, which are not considered in this analysis.

Toroidal asymmetry of kinetic profiles during MP field induced ELM mitigation

A three dimensional distortion of the plasma boundary is well documented [5, 6]. To analyze toroidal asymmetries of kinetic profiles, we rotated the MP field toroidally [5] and used toroidally localized diagnostics.

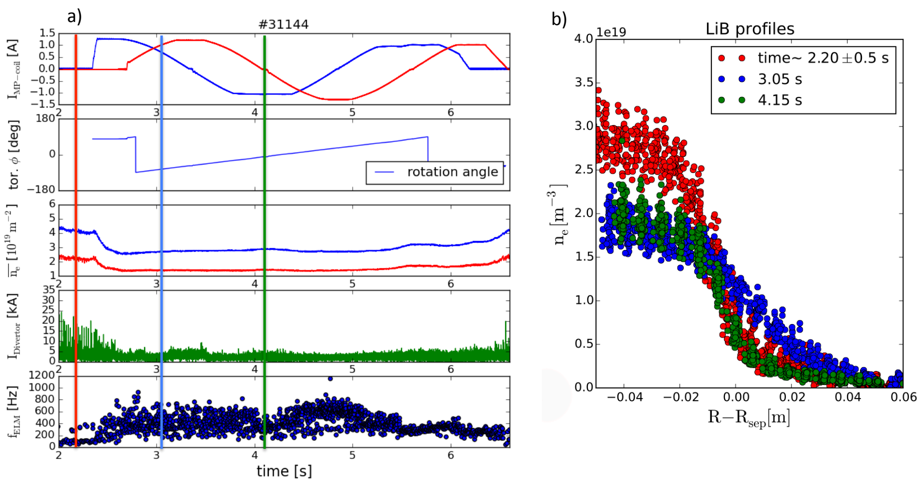

Figure 3: ELM mitigation experiment, (a) from top to bottom: MP coil currents, toroidal angle of rotation, line integrated density, divertor current, ELM frequency (b) edge electron density profile from LIB. LIB profiles are aligned with each other. The color scaling of the vertical lines in (a) corresponds to time windows used in (b).

Figure 3(a) shows time traces of an experiment at low q ($q_{95} \sim 3.8$) using a rotating n=2 MP field. The application of this perturbation resulted in ELM mitigation, which is sustained throughout the rotation until the MP coils were switched off. A rigid rotation of the MP pattern was applied meaning a constant phase between the upper and lower coil set. The MP field was rotated by about one full turn, thus, by 180 degrees due to the n=2 configuration. As before, ELM mitigation, density pump-out and an increase of ELM frequency up to 600 Hz are observed. To resolve inter ELM profiles, we reconstructed LIB profiles with a temporal resolution of 100 μs. In Fig. 3(b), LIB electron density profiles prior to the MP onset (red) and at two different time-points i.e. toroidal rotation angles (blue and green) during the rotation of the MP-field are shown. The pedestal top values of the density profiles decrease, when the MP-field is turned on. Furthermore, the density gradients (in real space) vary with toroidal rotation angle within the steep gradient region, whereas the pedestal top values remain constant. The edge gradients change by 50%. The ion temperature profiles from CXRS also show alteration in the edge gradients, but less pronounced. This indicates a toroidal variation of the magnetic structure due to the MP-field e.g. flux surface compression/expansion.

Plasma response measurements

To measure the plasma response due to a MP-field, the electron temperature is the best quantity. Due to the high electron heat transport along the field lines, the electron temperature is assumed to be constant and therefore, changes in the electron temperature profile reflect changes in magnetic topology. We used ECEI measurements during one discharge applying rigid rotating MP-field with even parity and n=2 configuration at medium q to detect variations in the magnetic topology (shown in Fig. 4). An influence of the MP-field on the ELM behavior could not be observed. Figure 4(a) shows the ECEI channel array (crosses) and the color scaling indicates the mean temperature during the rotation. The time traces using inter ELM data of the analyzed channels, which are close to the rational $q \sim 5$ surface, are shown in Fig. 4(b). During one full turn, ECEI measurements reveal a poloidal propagating n=2 structure. From the poloidal velocity and the given toroidal velocity and mode number (n=2), one can determine the poloidal mode number m. Preliminary evaluation of the poloidal number m indicates a pitch aligned response. But due to the high uncertainties in the position of the ECEI radiation, forward modeling of ECE radiation transport is required and will be employed. Furthermore, the measurements show a poloidal asymmetry of the amplitude, which is not expected from ideal MHD codes. But amplitude measurements of radially and toroidally localized diagnostics could be compromised by the feedback of the plasma shape and position control due to the rotating MP-field. In principle, this could also cause a poloidal asymmetry and will be investigated in more detail.

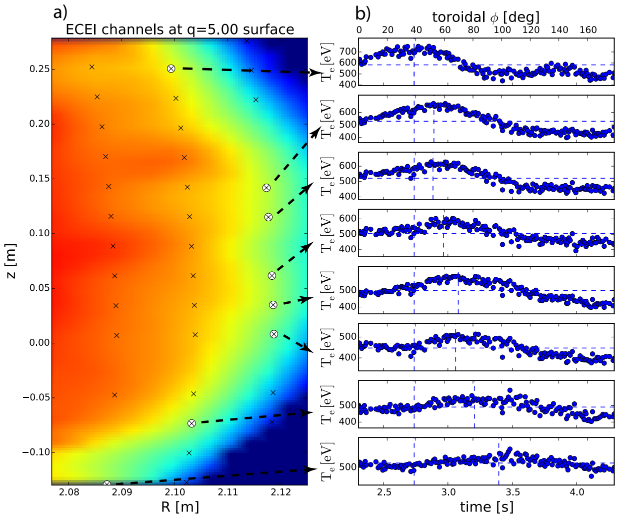

Figure 4: (a) The ECEI channel array is shown (cold resonance). The white circle indicate the ECEI channels around the $q \sim 5$ surface. (b) Time traces of the corresponding ECEI channels.

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