Effect of externally-applied magnetic perturbations on fast-ion confinement in MAST-U

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Instabilities such as Edge Localised Modes (ELMs) can degrade confinement in tokamak plasmas, potentially leading to damaging heat fluxes on the first wall [1, 2]. Externally applied Magnetic Perturbations (MPs) are used to mitigate, and even suppress these instabilities [3]. This suppression technique is under investigation in many tokamaks, and its understanding is crucial for future fusion devices like ITER, as applying these perturbations can also have an effect on fast-ion confinement [4]. MAST-U is equipped with upper and lower sets of MP coils. Moreover, fast-ion losses are directly measured and analysed in the MAST-U spherical tokamak, using a scintillator-based Fast-Ion Loss Detector (FILD) [5]. This makes it possible to explore the effect of MPs on the fast-ion confinement in spherical tokamaks.

During the third and fourth MAST-U campaigns (2023-2025) several discharges using L-mode plasmas, with low MHD activity and constant densities in time, were dedicated to studying the effect on the fast-ion distribution of applying MPs. To this end, scans of the current applied in the coils, of the toroidal phase offset between the currents in the upper and lower coil sets ($\Delta\Phi_{ul}$), and of the absolute phase of the perturbation have been performed for an n=2 perturbation with on and off-axis beams separately. The results indicate a modulation of the FILD signal with the applied perturbation. Furthermore, the modulation is determined by the MPs' toroidal phase offset and the velocity-space of the losses, suggesting a resonant interaction between the MPs and the fast-ion orbits, as observed in previous work [6]. In order to study this resonant interaction, the linear single-fluid resistive magnetohydrodynamic stability code MARS-F [7] has been used to compute the resonant MP fields, both in the vacuum approximation and with the plasma response (PR). The resulting magnetic field has been used as input in the modelling of first-orbit losses performed with the orbit-following Monte-Carlo code ASCOT [8]. Simulations predict that the total losses are unaffected by the applied $\Delta\Phi_{ul}$, as this only results in a redistribution of the losses on the wall, which is confirmed by the neutron rate measured experimentally. The experimentally-measured modulation of the losses reaching the FILD is also observed in the ASCOT simulations, but with minima/maxima at opposite phases than seen experimentally, suggesting that all non-axisymmetric field components, such as intrinsic error fields, need to be included in the MARS-F modelling. Finally, the transport of passing fast ions is shown to be related to geometrical resonances between the fast-ions and the perturbed magnetic field.

** See author list of J. Harrison, et al. 2019 Nucl. Fusion 59 11201*
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