Fast ion wall loads in ASDEX Upgrade in the presence of magnetic perturbations due to ELM mitigation coils

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Introduction

Mitigation of edge localized modes (ELMs) is vital for successful high-confinement mode (H-mode) operation of ITER [1]. To investigate the effect of magnetic perturbations on the behaviour of ELMs, 24 in-vessel saddle coils will be installed on ASDEX Upgrade (AUG) [2]. So far, eight coils have been installed and their locations are shown in Figs. 1(b) and 2. Running a current in the coils in the positive (negative) direction creates a magnetic field mainly in outward (inward) radial direction. First experiments using the coils showed clear mitigation of ELMs, but left plasma performance (e.g. stored energy and pedestal top density) unaffected [3].

While the magnetic perturbation created by the in-vessel coils has been found to have the desirable effect on ELMs, it might be harmful for the fast ion confinement. Indeed, the local perturbation due to tritium breeding test blanket modules (TBMs) projected for ITER has been found to cause increased and more localized fast ion losses [4].

In this work, the effect of the magnetic perturbation created by the in-vessel coils on the confinement and losses of fast particles was studied. Neutral beam injected (NBI) particles were simulated in AUG discharge #26476 plasma in the presence and absence of the said magnetic perturbation. The simulations were done with the test particle orbit following Monte Carlo code ASCOT [4, 5] and the results were compared with those of the fast ion loss detector (FILD) [6].

ASCOT simulations

ASCOT [4, 5] is able to take into account the full 3D structures of both the magnetic field and the first wall of the device, which makes it an ideal tool for modelling fast ion wall loads, particularly in non-axisymmetric magnetic fields. In this work, the most recent 3D wall structure of AUG, updated to include the modifications for the 2010–2011 experimental campaign, and the magnetic fields from AUG discharge #26476 (B_t = 1.8 T, I_p=0.8 MA), were used. Six different cases were studied; three neutral beams Q5, Q6, and Q8 (all 93 keV and 2.5 MW) were simulated individually, each with both I_{coil}=0.0 kA, and $I_{coil} = \pm 0.95$ kA current in the in-vessel coils. The coils were used in the odd parity configuration creating an n=2 perturbation (cf. Fig. 2). The effect of the in-vessel coils on the magnetic field can be seen on the ripple maps shown in Fig. 1.

In the simulations, the guiding centres of ∼260000 test particles were followed until they either hit a material surface or had cooled down to twice the energy of the thermal ions. For wall hits, full-orbit collision model was used, i.e. close to material surface the particles' full orbits, instead of their guiding-centre orbits were followed [7].

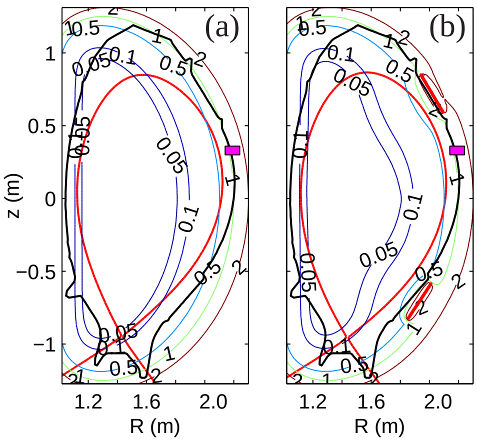

Figure 1: Ripple maps depicting $\delta = \frac{B_{\max}-B_{\min}}{B_{\max}+B_{\min}}$ in #26476 with (a) I_{coil}=0.0 kA, and (b) I_{coil}=0.95 kA current in the in-vessel coils (indicated by red bars on the outboard side of (b)). The magenta square marks FILD location.

Simulated wall loads due to in-vessel coils

The simulated NBI wall loads for the three neutral beams (Q5, Q6, and Q8) are plotted in Fig. 2; on the left-hand column without the magnetic perturbation, and on the right-hand column with the perturbation. The effect of the perturbation seems to vary strongly for different beams; for the more normal beams the perturbation increases the losses only a little (Q5 in Figs. 2(a) and (b)), or even reduces them (Q8, Figs. 2(e) and (f)), whereas for the tangential current drive beam (Q6, Figs. 2(c) and (d)), that has the least losses to begin with, the losses increase drastically. The total losses with (without) the perturbation are approximately 8% (5%), 9% (2%) and 5% (5%) of the total beam power for the beams Q5, Q6, and Q8, respectively.

For beams Q5 and Q8, protruding wall structures, such as the limiters, collect the majority of the heat load both with and without the magnetic perturbation. For the current drive beam Q6, in addition to the divertor loads that are prominent in all the cases, the majority of the loads are located close to the upper set of coils where the plasma is closest to the wall. This is particularly the case in the presence of the magnetic perturbation.

Another interesting feature on the wall load plots is the n=2 structure with peaks between the coils at around 125° and at 315°, seen in Figs. 2(b), (d), and (f). It seems like the magnetic perturbation does indeed cause some additional losses of fast particles in these regions.

Experimental vs. simulated FILD

FILD measurements and the results from a synthetic FILD diagnostic in ASCOT are shown in Fig. 3. There is a good correspondence in the particle pitch angle between the measured and the

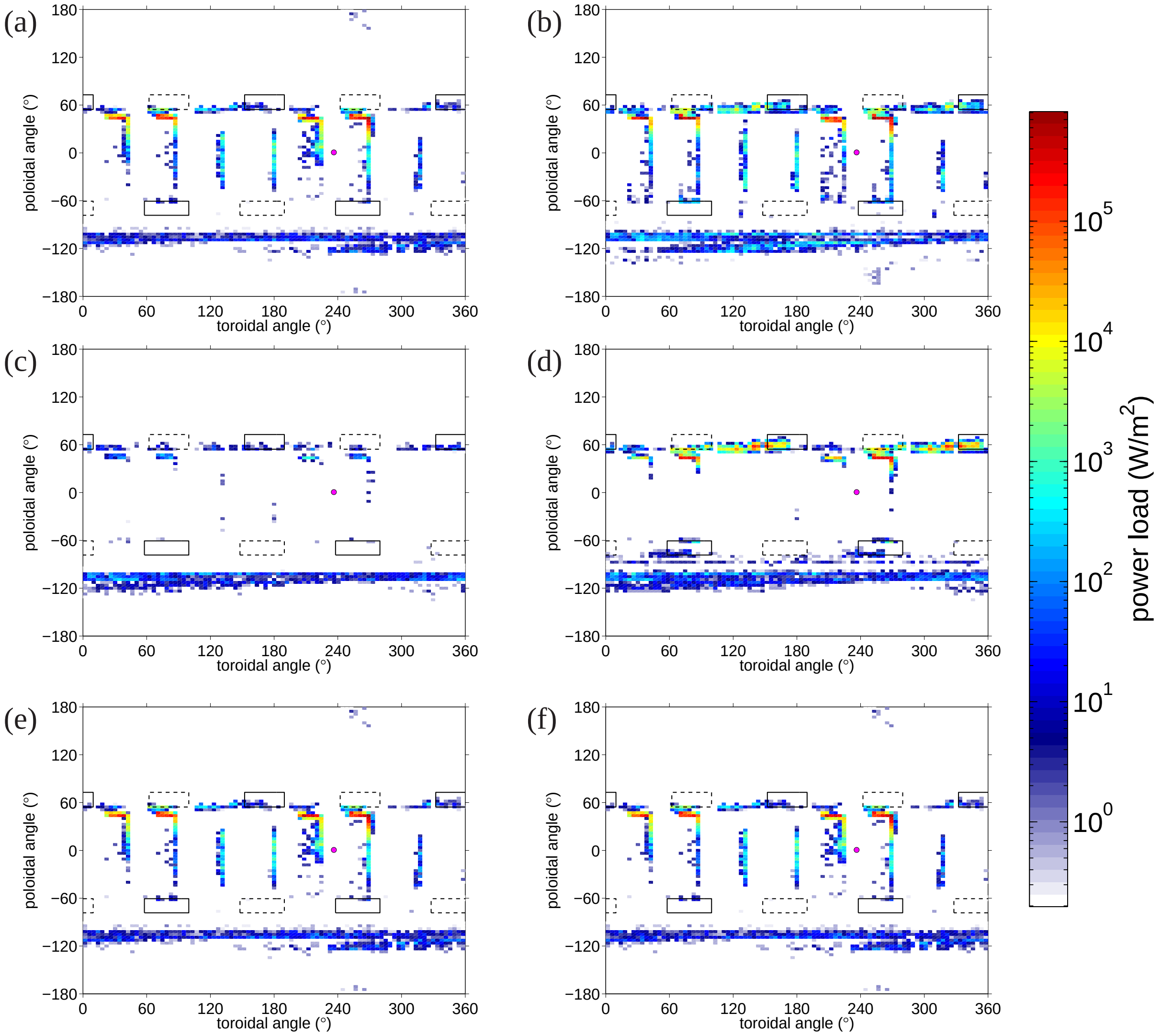

Figure 2: Simulated fast ion wall loads for: (a) Q5 with I_{coil}=0.0 A (b) Q5 with I_{coil}=0.95 kA (c) Q6 with I_{coil}=0.0 A (d) Q6 with I_{coil}=0.95 kA (e) Q8 with I_{coil}=0.0 A (f) Q8 with I_{coil}=0.95 kA. The location of the FILD is marked with a filled magenta circle, and the in-vessel coils are drawn as squares with solid (negative current) and dashed (positive current) black line.

simulated diagnostic; both are centered around 70°. The gyroradii of the particles seen by FILD suggest that most of them are prompt losses. This might, however, not be the case since losses induced by the magnetic perturbation may have similar pitches and energies. ASCOT synthetic diagnostic on the other hand registers a broad distribution of energies. The most significant discrepancy between the two is the second blob in the ASCOT diagnostic (at around 30°). It could be due to the synthetic FILD (R=2.14–2.24 m, z=0.30–0.36 m) being deeper in the plasma than the real one. Also, losses with pitch angles between 0° and 30° can never be detected by FILD because they are blocked by the FILD collimator or by other protruding first wall structures. The most important result from the FILD comparison is that the in-vessel coils seem to have a negligible effect on the experimental and synthetic FILD signals for beams Q5 and

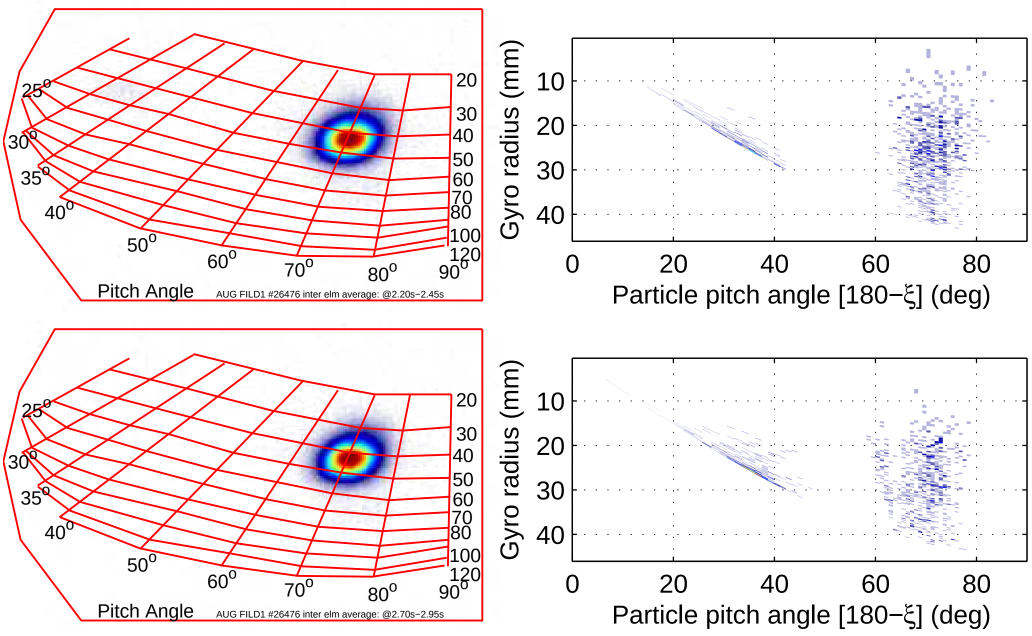

Figure 3: Comparison between experimental (left) and synthetic (right) FILD measurements for beam Q5 without (upper) and with magnetic perturbation (lower). Fast ion flux (indicated by color) is in arbitrary units in all the figures.

Q8. For the current drive beam Q6, however, the synthetic signal, as well as the wall loads, increases as the coils are turned on, while the experimental signal remains nearly constant. Further experiments are planned in order to isolate the effect of the coils on the FILD signal and, hence, enable drawing the final conclusions on their effect on fast ion confinement.

In the future, fast particles will be simulated in a similar discharge (#26475), including the observed β-driven neoclassical tearing mode islands. The islands are expected to increase the amount of lost particles and, therefore, the particles seen by the FILD, improving the statistics.

This work was partially funded by the Academy of Finland projects No. 121371 and 134924. This work, supported by the European Communities under the contract of Association between Euratom/Tekes, was carried out within the framework of the European Fusion Development Agreement. The views and opinions expressed herein do not necessarily reflect those of the European Commission. The supercomputing resources of CSC - IT center for science were utilized in the studies.

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