Effect of the European design of TBMs on ITER wall loads due to fast ions in the baseline (15MA), hybrid (12.5MA), steady-state (9MA) and half-field (7.5MA) scenarios

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The new physics introduced by ITER operation, of which there is very little prior experience, is related to the very energetic (3.5 MeV) alpha particles produced in large quantities in fusion reactions. These particles not only constitute a massive energy source inside the plasma, but also present a potential hazard to the material structures that provide the containment of the burning plasma. In addition, the negative neutral beam injection (NBI) produces 1 MeV deuterons which have to be well confined to ensure successful operation of ITER.

The almost perfect confinement of energetic ions, predicted for axisymmetric tokamak configurations, can be compromised by a variety of components breaking the axisymmetry: the finite number and limited toroidal extent of the toroidal field (TF) coils (18 in ITER) cause a periodic magnetic field perturbation with a magnitude exceeding 1% at the separatrix. This magnetic ripple can cause significant fast particle leakage, leading to localized power loads on the walls. Therefore, ferromagnetic inserts (FI) will be embedded in the double wall structure of the ITER vacuum vessel, reducing the ripple to 0.6% everywhere else except near the NBI ports, where the ports interfere with the FI structures. The ITER magnetic field at the edge is further perturbed by the test blanket modules (TBM), made of ferromagnetic material and installed to test tritium breeding. TBMs cause poloidally and toroidally localized perturbations to the magnetic field. Consequently, the ITER field structure at the edge is quite complex, and studying its effect on fast ion confinement analytically is impossible.

In this contribution, we calculated the ITER 3D magnetic field including the effects of the ferritic components (FIs and TBMs). The components were modelled with unprecedented detail as energetic ions are very sensitive to magnetic field structure and, therefore, even small details in the field could have a significant effect on fast ion losses. The FEM solver COMSOL was used to first calculate the magnetization of the ferromagnetic components due to plasma current and currents flowing in the field coils. The perturbation field due to the magnetization was then calculated and added to the unperturbed field integrated from the coils using the Biot-Savart law.

We simulate the fast ion wall power loads using the Monte Carlo orbit-following code ASCOT in the full 3D magnetic configuration. The first wall model also has full 3D features. The simulations are carried out for all the foreseen operating scenarios of ITER: the baseline 15 MA standard H-mode operation, the 12.5 MA hybrid scenario, the 9 MA advanced scenario, and the half-field scenario with helium plasma that will be ITER’s initial operating scenario. Both thermonuclear fusion alphas and NBI ions from ITER heating beams are addressed. The alpha population is generated according to the fusion reactivity, given by the density and temperature profiles corresponding to the stationary phases of the ITER plasmas, while the NBI population is generated from beamlets that correspond to the injector’s geometry. The ferritic components are found not to jeopardize the integrity of the first wall, but application of NBI in the ramp-up phases can lead to unacceptable shine-through.