ITER fusion alpha particle confinement in the presence of the European TBMs and ELM coils

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A commercial fusion power plant will need tritium breeding to provide its fuel. Tritium is expected to be bred from lithium blankets, and one of the key things to demonstrate in ITER is the successful breeding of tritium during the fusion burn. To this end, ITER is equipped with three test blanket modules (TBM) that are placed very close to the plasma to maximize neutron irradiation. The massive modules are made of demo relevant ferromagnetic martensitic steel and will thus produce a field of their own that perturbs the nominal field produced by the TF and PF coils as well as the plasma current. Collisionless particles, such as alpha particles born in fusion reactions, are particularly sensitive to field perturbations, and if their confinement is significantly compromised, the integrity of the first wall could be jeopardized. For these reasons it is very important to carefully calculate the perturbations introduced by various ferromagnetic components in ITER, and use the resulting total field to assess the confinement of fusion alphas.

In this contribution we report on the magnetic field structure and wall power loads in the ITER 15MA scenario when both the European TBM design and the ferritic inserts (FIs) are included in the calculation at varying degree of detail. As a reference, we shall use the ITER nominal field where ripple mitigation by the FIs inside the ITER double wall structure is not included. In addition, also the effect of the ELM coils (ECs) on the field structure and on fusion alpha confinement is addressed.

Field calculation

The magnetic field was calculated using the COMSOL Multiphysics FEM platform. For a device of ITER scale in spatial dimensions and in field strength, a two-step process was found to be the most robust in giving detailed field structures: first, the total magnetic field of the coils and the magnetization were calculated. In the second step, the magnetized components were modelled as permanent magnets, and the perturbation field was evaluated. This was then added to the unperturbed field obtained from a Biot-Savart law integrator. It should thus be emphasized that the field was calculated in vacuum approximation, with no plasma shielding included.

The perturbations were calculated for a number of models for the ferritic components, illustrated in Fig. 1. Typically, ferritic components have been included as solid blocks, but in this

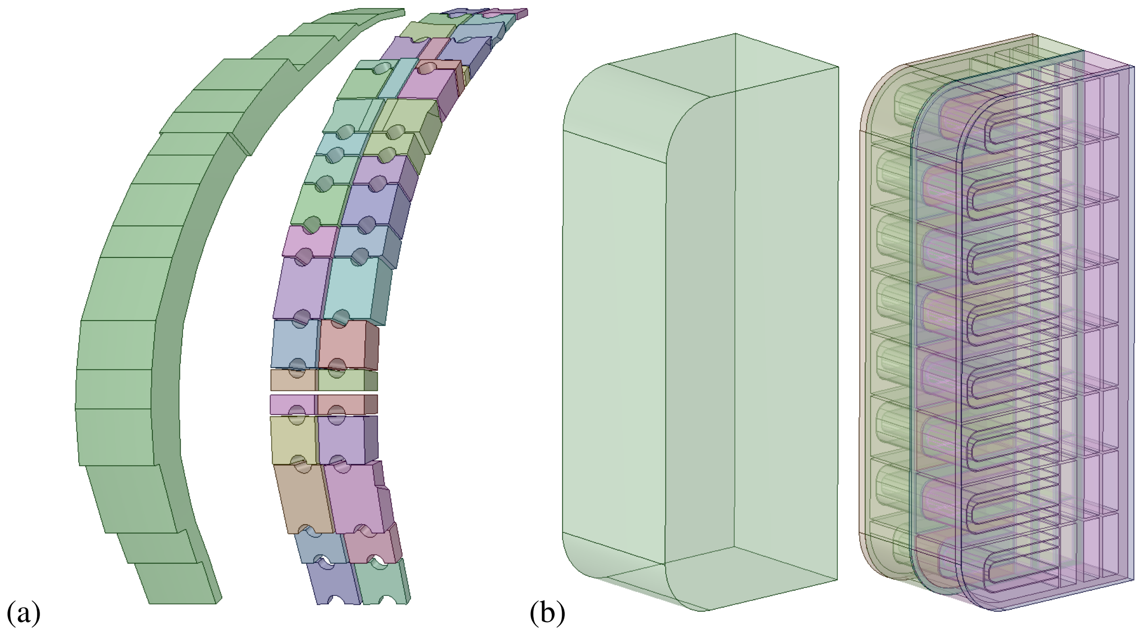

Figure 1: *The FI (a) and TBM (b) models, showing the two levels of detail used in the simulations.*

work we started at the other end, from the detailed CAD drawings, and eliminated unimportant features, such as layered structures with narrow gaps. When doing so, it is very important to account for the change in the total mass. This is illustrated in Fig. 2 that shows the field due to FIs and TBMs with and without the mass correction along a path across the outer midplane.

Ripple mitigation by FIs and its effect on wall power loads from ASCOT

Figure 3 (a) shows the ripple map of the ITER nominal field. The maximum ripple along the separatrix is about 1.1%. This is to be compared to Figs. 3(b) and (c) that show, respectively, the effect that simple single-piece ferritic components and components containing significant internal structure have on the ripple. The FIs are found to mitigate the ripple very effectively:

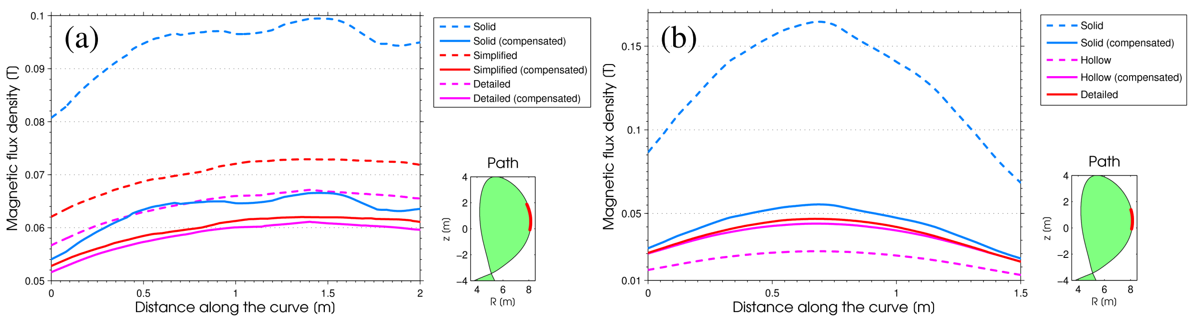

Figure 2: *The perturbation field produced by the FIs (a) and TBMs (b) with three different levels of sophistication showing the importance of mass compensation when the internal structure of the component is altered. The trajectory along which the field was evaluated is indicated on the right of the plots.*

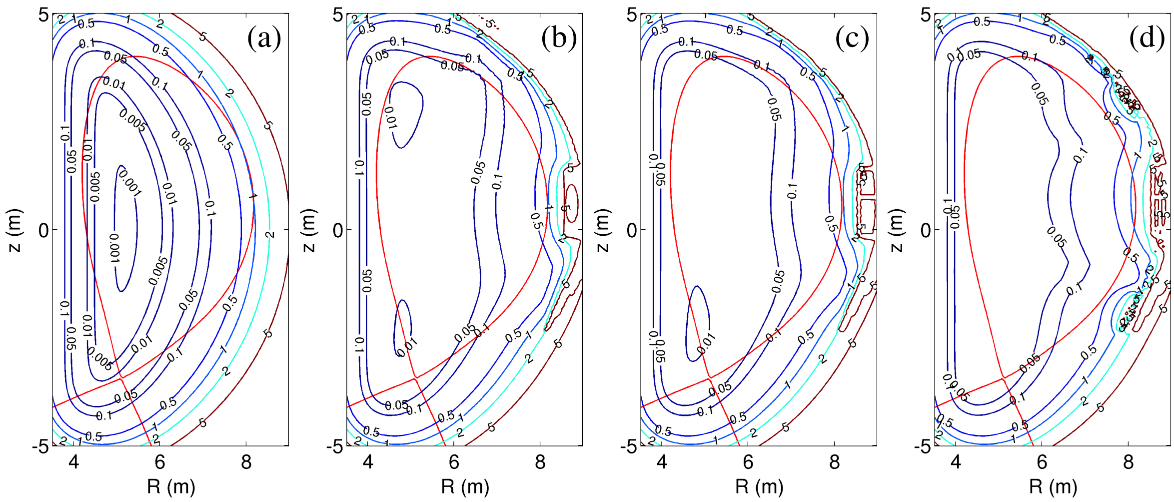

Figure 3: *Ripple maps for the 15MA ITER scenario with (a) no ferritic material, (b) FIs and TBMs modelled as solid blocks, (c) FIs and TBMs having sophisticated internal structure, and (d) with ferritic components and ECs operated at their nominal current values.*

the maximum ripple is reduced by about a factor of two, and in the upper hemisphere where the FIs are predominantly located, the ripple contours are pushed outward. Furthermore, the detail level at which the FIs are modelled in the field calculation does not appear to play a significant role except at the very periphery, as illustrated in Fig. 4. These conclusions are reflected also in the wall power loads, illustrated in Fig. 5. Only the introduction of ECs brings the loads back to the level of the unmitigated ripple, but the distribution is now different: most of the power is received by the *inner* divertor plate, which is quite beneficial.

Conclusions and future work

The European design of the TBMs does not seem to alter the confinement of fusion alphas in the 15MA scenario. NBI ions, however, have to be studied separately, and the study has to be repeated at least for the 9MA and 13.5MA cases. Furthermore, in this particular case, including all the details of the ferritic components in the field calculation does not appear to be crucial. When using simplified models, however, proper mass correction is essential.

Acknowledgements

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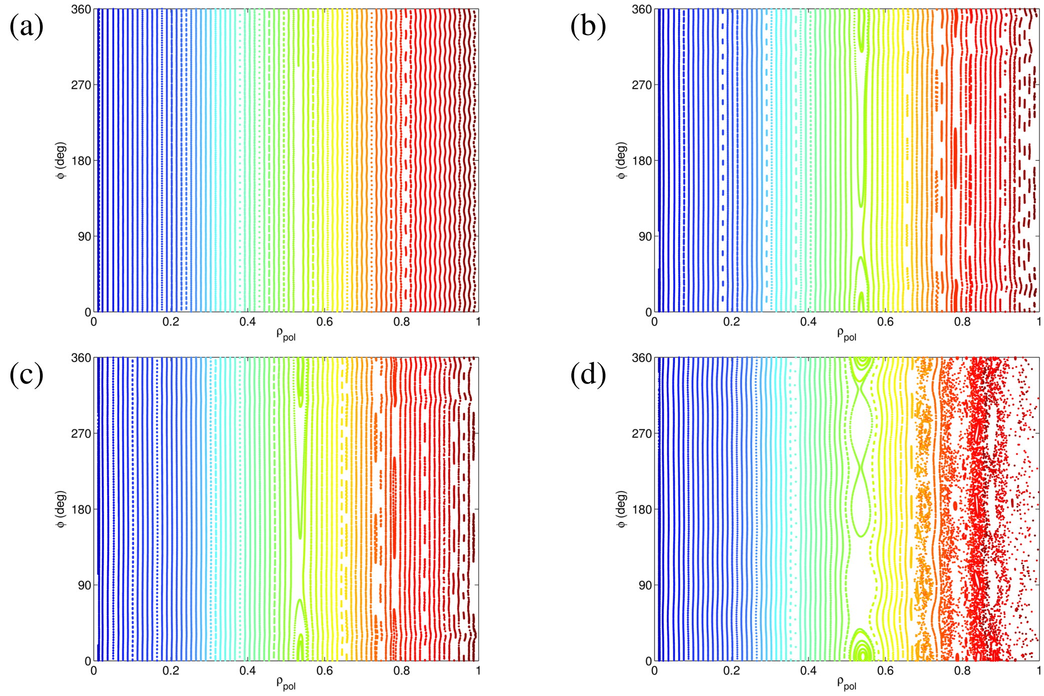

Figure 4: *Poincaré plots of the field lines with (a) no ferritic material, (b) single-piece FIs and TBMs, (c) detailed FIs and TBMs, and (d) ferritic components and ECs operated at their nominal currents.*

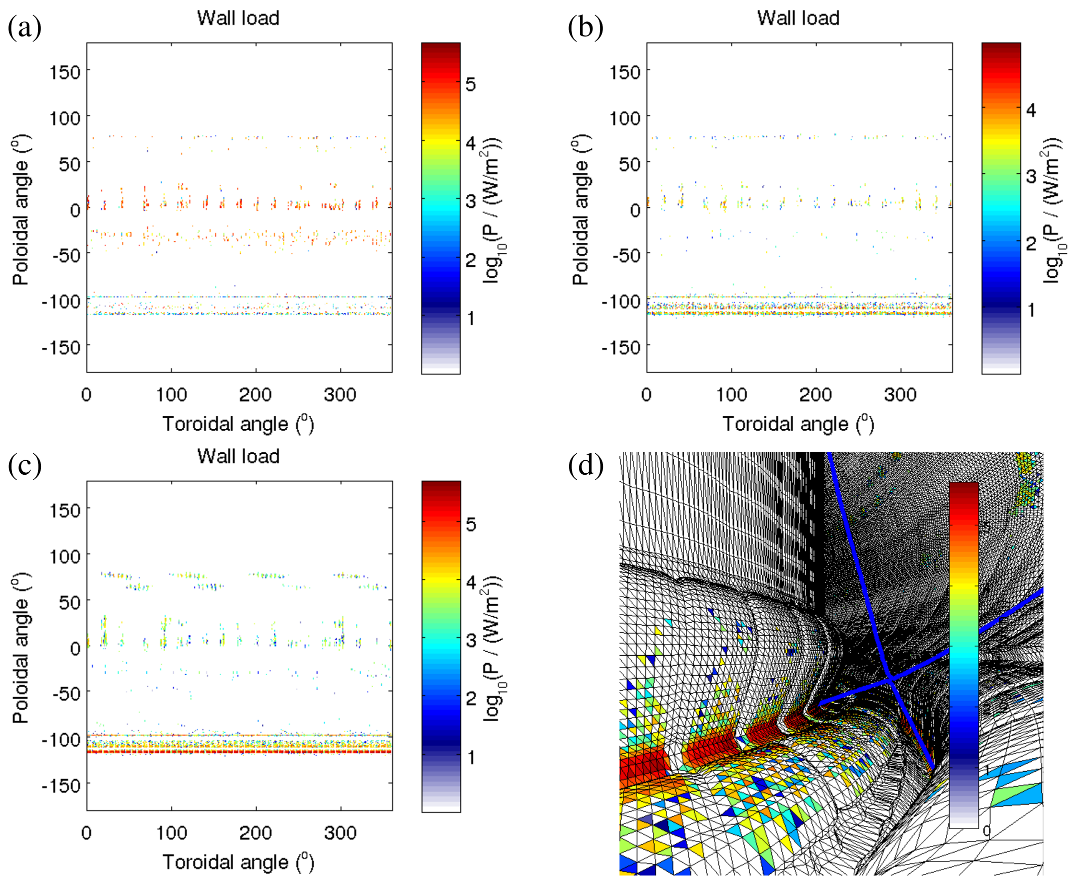

Figure 5: *Wall power loads from ASCOT. (a) and (b) are for the respective cases in Figs. 3 and 4. (c) and (d) correspond to the ELM coil case, (d) showing the power distribution in the divertor region in 3D.*