Clearing the road for high-fidelity fast ion simulations in full 3D

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High-energy ions, such as fusion alphas and ions from NNBI, can be very sensitive to any nonaxisymmetric features in the confining magnetic field due to their collisionless nature. Such nonaxisymmetries can be introduced externally by coils (ELM mitigation) or ferritic components (TBMs and ferritic inserts), and internally by various MHD modes. Since understanding the confinement properties of these ions is crucial for ITER and beyond, it is of ultimate importance that the predictive simulations are free of numerical distortions. Such can be produced by artificial features in the magnetic background and/or inaccuracies in the particle following. In this contribution we discuss both of these error sources and present some results on 3D effects.

When calculating the magnetic field, the contribution from discrete coils can be obtained very accurately using the Ampere's law. An approximate 3D field is usually obtained by combining this with a 2-dimensional equilibrium. As for the ferritic components, for large machines like ITER the problem doesn't render itself to using standard FEM solvers, but a multi-step procedure had to be devised in order to obtain the total field at desired accuracy.

Another source of uncertainty comes from including the plasma response. In the vacuum approximation described above, external perturbations are exaggerated. For ITER simulations, the plasma response has been evaluated by two different methods: with the fast, linear MARS-F code, and with the non-linear resistive MHD code JOREK.

When simulating energetic ions in large devices, typically the guiding-center (GC) approach is used. However, for high-energy ions the gyro orbits (GO) are substantial and, therefore, when calculating the power distribution on material structures, a hybrid GC-GO method has been developed. To check the validity of such simulations, complementary GO-simulations for the entire slowing-down time were carried out with somewhat surprising results: the power loads obtained with GO-following gave loads that were 25 – 50 % lower than those given by hybrid simulations. The validity of the guiding-center approach in non-axisymmetric magnetic fields thus calls for re-examination.

ASCOT simulations have been carried out not only for ITER and DEMO, but also for both regular-NBI and NNBI for JT-60SA, the device that will be paving the way for successful operation of ITER. With plasma response, none of the known 3D effects is found to jeopardize the fast ion confinement in these devices. The simulations address also the observed differences between GC and GO simulations. In the end, based on the simulation results, the role of the device size for the 3D effects is discussed.