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# Alpha particle orbits in a locally perturbed ITER 3D magnetic field

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**Introduction.** Simulation of high-energy fusion alphas is time-consuming and susceptible to numerical drifts because it takes long time before collisions have any other significant effect than slowing down the particle. However, due to the periodicity of the orbits, the reduction of drifts and CPU time consumption is possible by acceleration of interaction time scales. In the presence of toroidal ripple, the banana orbits become non-periodic, but selective acceleration of passing orbits is still possible. This approach has been used in ASCOT simulations of fast ion losses in ITER [1].

When, in addition to the periodic ripple, the magnetic field is perturbed by a test blanket module (TBM) that is localized both toroidally and poloidally, all the remaining symmetry from the magnetic field is removed. This raises the question whether any periodic orbits survive.

We have investigated both the field line behavior and the orbits of strongly passing 3.5 MeV alphas in ITER 3D magnetic geometry that includes the effects of not only the 18 toroidal field coils but also the ferritic inserts introduced to reduce the field ripple and, most importantly, the TBMs.

The mixed use of 2D equilibrium and 3D vacuum field in the simulations may also play a role. The local perturbation induces an island structure in the magnetic field, which has been found to lead to an increased particle drift. It is currently under investigation whether the increased drift is physical or just numerical drift amplified by the rapid movement across the forbidden zones. A physical drift would be important in itself, and in either case the choice of correct simulation procedure is affected by this phenomenon.

**TBMs and island structures.** The single particle orbits were studied as Poincare plots, taken at the outer midplane crossing. Figure 1 shows a Poincare plot of the outer midplane crossings of a 3.5 MeV alpha particle, launched at $\rho = 0.7$, with $v_{\parallel} = 0.9v$ so that it is strongly passing, in the absence of collisions as a function of the toroidal angle. The plot displays a regular

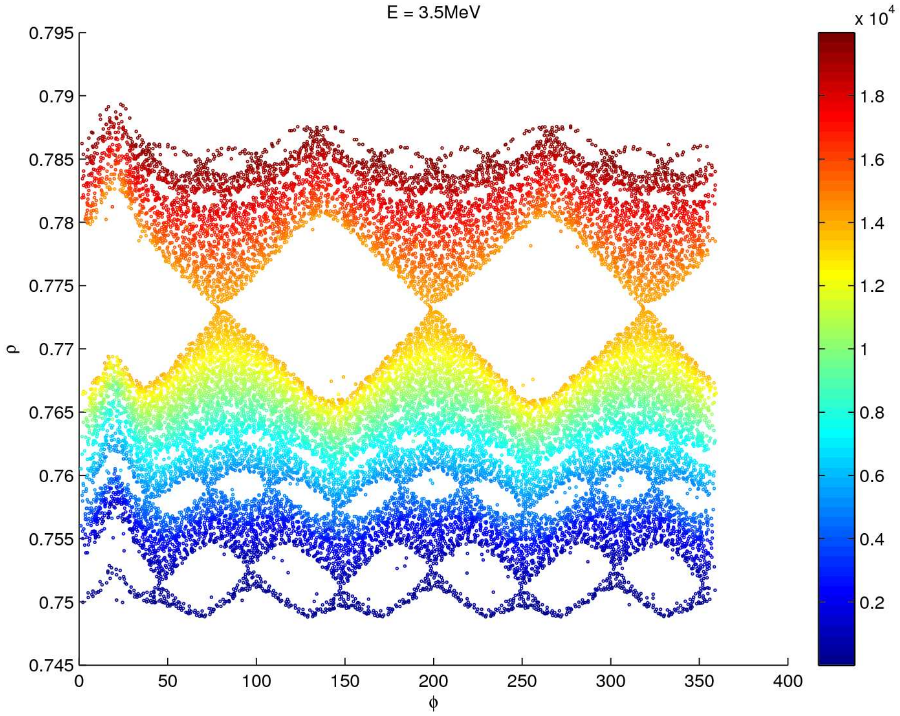
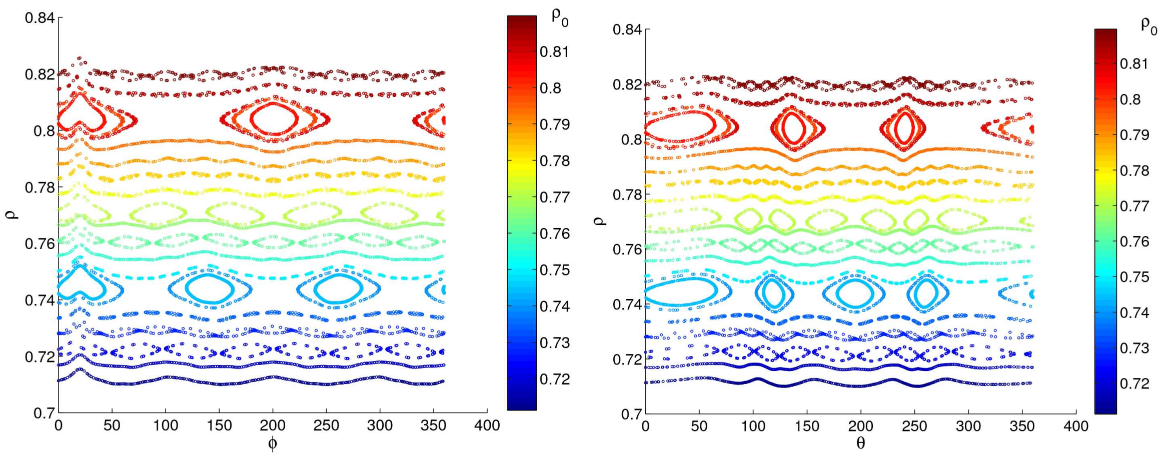


Figure 1: *A Poincare plot of a 3.5MeV alpha's outer midplane crossings as a function of the toroidal angle $\phi$ in the presence of a TBM. The particle has been followed for 20 000 poloidal orbits and the color tells the orbit number.*

structure of "forbidden zones" which is found to be related to rational values of the safety factor $q$. Figures 2(a) and 2(b) displays corresponding plots for field lines that have been followed from several starting points in $\rho$. The plots against poloidal and toroidal angle reveal that the structures have distinct mode numbers which, furthermore, are that of the local rational surface. The effect of the TBM is thus to widen the rational surfaces into helical tubes with finite radius, which manifest themselves as islands.

The formation of the island structure due to the TBM can be seen in Fig. 3 that displays the flux surface coordinate of a fixed field line near the 4,3 rational surface as a function of poloidal revolutions. The effect of the toroidal coils is visible as small wiggles every time the field line traverses the low field side of the torus. An abrupt step in the radial location takes place when the field line crosses the region in front of the TBM, which does not happen at every poloidal revolution.

Stationary magnetic islands, if present in ITER, would be extremely bad news and not only for the fusion alphas: the islands could serve as seeds to a multitude of MHD modes. Therefore their presence was put under scrutiny and it was discovered that, while probably present even in ITER, the magnitude of these island structures would be significantly less than in the magnetic



(a) (b)

Figure 2: *Field lines of the optimized inserts with 1 TBM background in the neighborhood of* $\rho = 0.75$ *as a function of (a) toroidal angle and (b) poloidal angle. Color gives the original* $\rho$*-value.*

backgrounds used in the simulations of this task.

The reason why such large islands emerged in our magnetic backgrounds is the way the equilibrium field was constructed: the 3D vacuum field was calculated from the currents in the toroidal field coils, taking into account the ferritic inserts. The 2D equilibrium field was then added on top of it. The effect of the TBMs was evaluated on the vacuum field, the field lines of which are practically toroidal. However, any ferritic insert will affect the field in the *direction of the field line* only. The real equilibrium field consists of the vacuum field and the field generated by the plasma current and, thus, the field lines in front of the TBM are not toroidal but have a significant poloidal component as well. It is these slanted field lines along which the effect of the TBM ought to be evaluated. Now that the TBM effect was evaluated before adding the plasma contribution to the field, the effect got magnified by changing also the field line direction.

**To drift or not to drift?** The qualitative difference between the Poincare plots of the field lines and the alpha particle is that, while the field lines remain radially confined, the particles are found to drift slowly, in the matter of thousands of toroidal revolutions, due to these islands. At this point it is still unclear if the drift is physical or not. Any simulation produces finite numerical error which, when combined with the island structures, can cause some artificial drift. On the other hand, a Hamiltonian with a broken symmetry can lead to a physical drift as well. It is possible that when a particle enters the perturbation, it receives a kick that is not completely compensated when exiting the perturbation. The difference between the field line and the particle orbit behavior is the gradient drift experienced by the particles, and this could

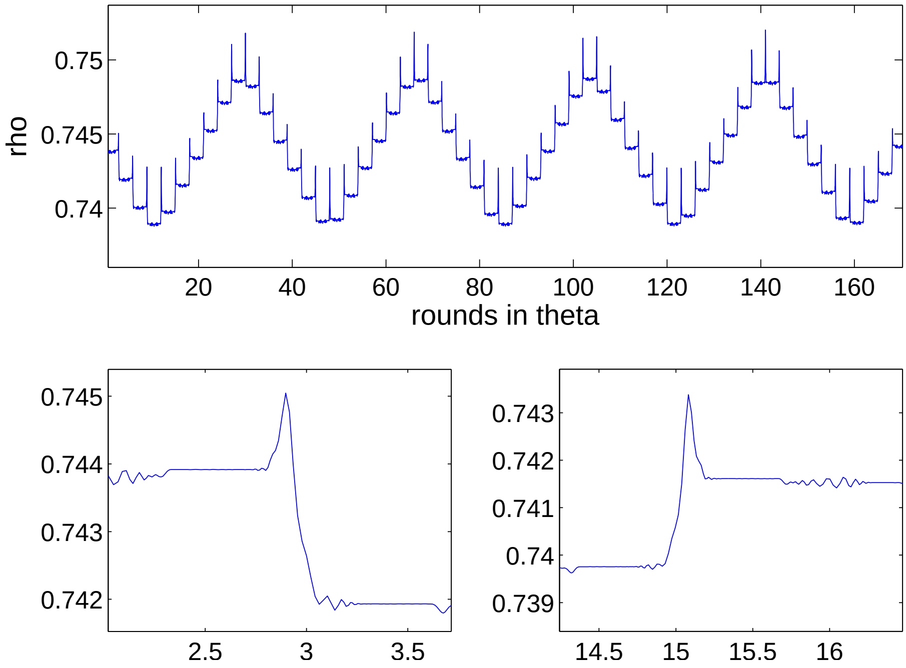


Figure 3: *A single field line in the vicinity of the 4,3 island, followed over 170 poloidal turns. The lower figures show two blow-ups of the top figure, both at the location of a radial kick.*

provide the means for a small but cumulating imbalance in the changes before and after the TBM.

The quantitative question of how large a physical drift the island structures can produce is currently under formal investigation with Dr. Dumbrajs using the Hamiltonian formalism. The discrete map has already been created, but the determination of the parameter giving the perturbation strength has to wait for a more appropriate calculation of the TBM effect on the field lines.

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## References

[1] T. Kurki-Suonio et al, Fast Particle Losses in ITER, submitted to 35th European Physical Society Conference on Plasma Physics, Hersonissos, Crete, Greece, 913 June 2008