Fast ion effects on the magnetic islands in a tokamak

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It is known that the presence of helical perturbations that violate the axial symmetry of the magnetic field of a tokamak leads to the formation of magnetic islands with a width $w \sim \sqrt{\tilde{B}}$, as well as to a change in the drift trajectories of charged particles, coupled with their radial redistribution and/or additional losses. For a sufficiently large perturbation magnitude, the magnetic islands overlap, leading to stochastization of the magnetic field lines. Near the periphery of the plasma pinch, magnetic lines can cross the tokamak's camera, as a result, particles can escape to the wall. The configuration of the magnetic field lines constructed by a numerical simulation in the presence of a helical perturbation (magnetic islands) is shown in Figure 1.

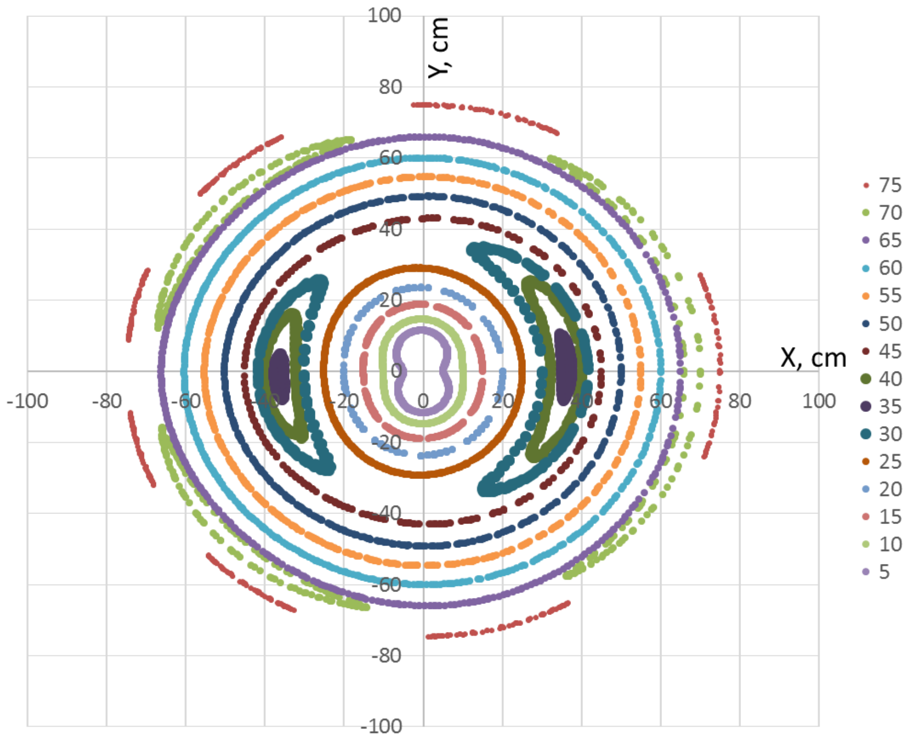

Figure 1 – The magnetic island m=2, n=1

In this case, according to [1], the drift trajectories of fast ions, characterized by a significant deviation from the magnetic surfaces, λ, are more stable to helical perturbations of the magnetic field than magnetic surfaces. Due to the fact that the passing particles, in contrast to the trapped particles, move mainly along the lines of the magnetic field, then the helical perturbation influences on the particles of this type stronger. The trapped particles practically do not feel perturbations of the field, continuing to move along the original trajectories. Because of this "selective" influence, an additional anisotropy of the distribution function of the injected particles appears. It is namely the perturbation of the drift motion of fast ions that leads to the appearance of a helical perturbation of the current, which can both contribute to and inhibit the growth of the magnetic islands.

The Poincaré sections of the drift trajectories for trapped and passing particles are shown in Figure 2.

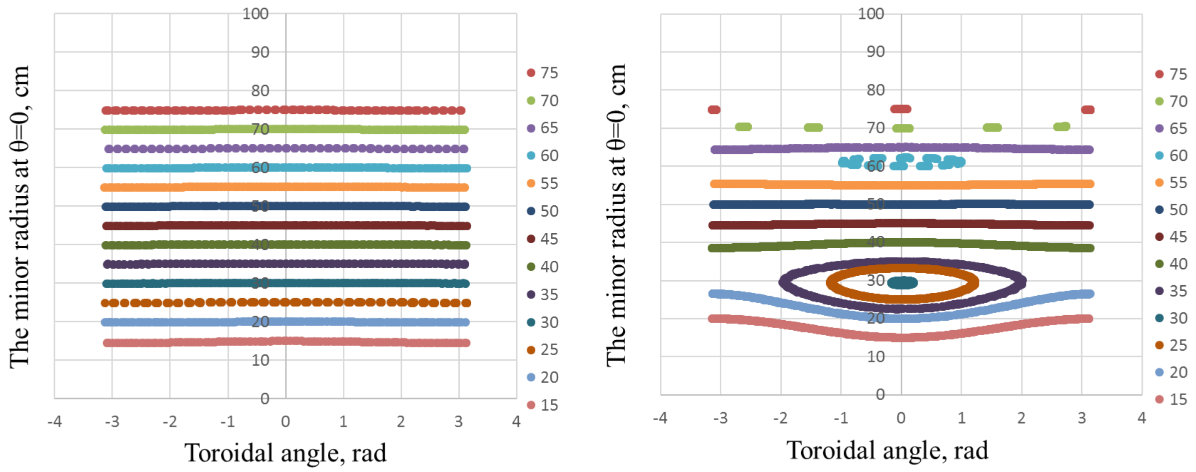

Figure 2 – The Poincaré sections of the drift trajectories for the trapped (left) and passing (right) particles

Until now, the effect of high-energy ions on sufficiently small islands has investigated, with an island width less than or of the order of the radial range of drift particle trajectories [2, 3]. These investigations were concerned with the problem of creating a seed island, rather than with an analysis of the possibility of suppressing NTM. Furthermore, the effect of the rotation of the magnetic island on the magnitude of the threshold of the tearing mode was investigated [4]. In the case where the helical perturbation of the current is due to the compensating electron drift $V_E \sim [\tilde{E} \times \boldsymbol{B}]$ ($\lambda > w$), the analytical calculations [5] show that the contribution from the fast ions to the generalized Rutherford equation for the evolution of the width of the magnetic island, in contrast to [6], is proportional to the difference $\Delta_h \sim (\omega - \omega_{*h})$, where ω is the island rotation frequency, and ω_{*h} is the drift diamagnetic frequency of the fast ions.

In this paper, we investigate the possibility of suppressing the growth of magnetic islands by injecting high-energy particles into the plasma in the case when the amplitude of the drift trajectory of ion motion is smaller than the width of the magnetic island. Figure 3 shows the model injection scheme.

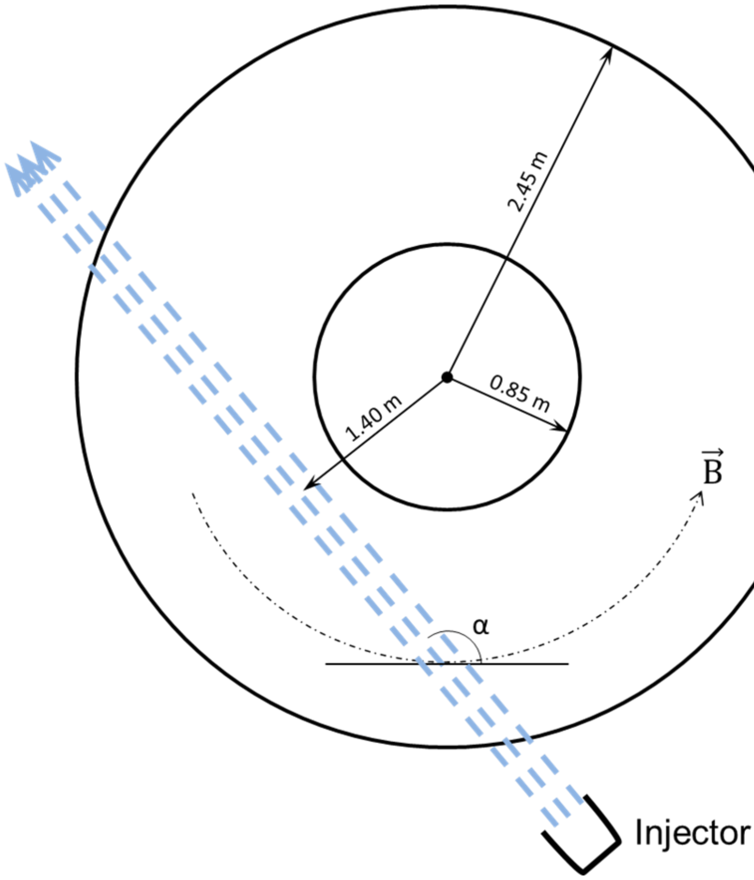

Figure 3 – The model scheme of particle injection

To determine the contribution of the injected fast ions current to the equation of the magnetic island evolution, Δ_{nb}:

$$\Delta_{nb}\tilde{\Psi} = 2\mu_0 R \int_{-\infty}^{+\infty} dx \oint d\xi J_{\parallel} \cos(m\xi),$$

where $\tilde{\Psi}$ – the perturbation magnitude, R is the major radius of the tokamak, $J_{\parallel}$ is the helical perturbation of the beam ion current, $\xi = m\theta - n\varphi$ – the helical angle, direct simulation of the drift trajectories of energetic ions was used, as in [3].

Figure 4 shows the dependence of the resulting contribution to the evolution of the magnetic island on the time in bounce periods.

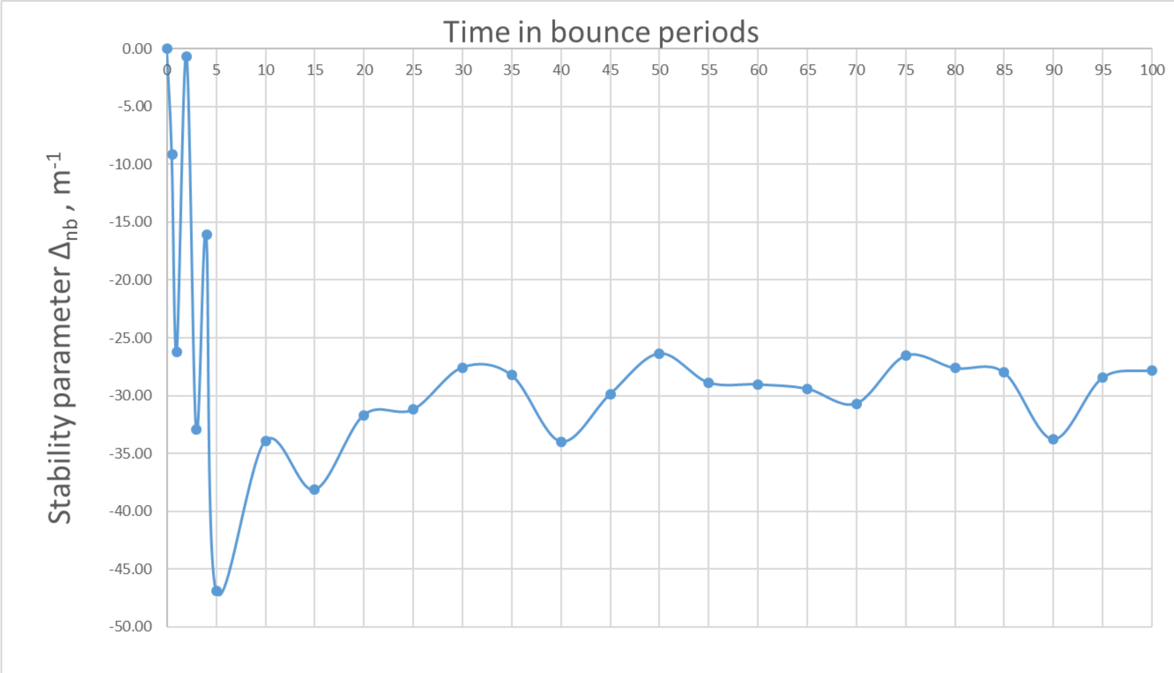

Figure 4 – The dependence of the stability parameter of the magnetic island on the time in bounce periods

An estimate of the stabilizing contribution of beam ions to the island evolution equation under conditions simulating the ASDEX Upgrade experiments [7] shows that Δ_{nb}/Δ_{bs} ~ 0.75 for an island width m/n = 2/1 of order w ~ 15 cm.

Thus, the effect of injected high-energy ions on magnetic islands in a tokamak is investigated in the case when $\lambda<w$. It is shown that the perturbation of the fast ion current can have a stabilizing effect on the growth of magnetic islands, and in the case of $\lambda<w$ the injection of high-energy ions can be used to suppress them.

References:

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