NBI ion losses at energy $E_0/2$ driven by NTMs.

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Introduction

The (2,1) neoclassical tearing mode (NTM) has been proposed as a candidate to explain the larger than expected losses of high energy ions produced during neutral beam injection in ASDEX-U [1]. We studied the ions injected at E_0 = 93 keV and at $E_0/2$. We Although the numerical simulations performed so far to study the effect of NTMs on energetic ions have reproduced several features observed in experiments, the agreement is not completely satisfactory. In this work we study the effect of NTMs on the confinement of energetic ions produced by NBI injection using FOCUS [2], a full orbit code that runs in Graphical Processing Units. This allows us to follow the evolution of a large number of particles with modest resources. A reconstruction technique that includes the experimental information available [3,4] is employed to calculate the perturbed magnetic and electric fields.

Magnetic Field

For simplicity, we use an analytical expression for the equilibrium magnetic flux derived by McCarthy [5] to fit a series of Asdex U discharges. The major and minor radii are $R = 1.71$ m and $a = 0.51$ m respectively and the vacuum toroidal field at $r = R$ is $B_0=2\ T$. The ion cyclotron frequency is used to normalize time and frequencies. The perturbed magnetic flux produced by the NTM, Ψ_{pert}, is calculated employing the reconstruction technique proposed by Igochine [5], where a J_{pert} is reconstructed and can be written as $J_{pert} = h\ J_1(\rho)$, where h is a free parameter. Ψ_{pert} is obtained by solving Ampere's law with the perturbed current density (J_{pert}). This calculation is performed in cylindrical coordinates so a mapping method is required. We use the method proposed by Jardin [6] and find that no spurious islands appear in the total magnetic flux provided that only one mode is included. In our case, the (2,1) dependence is taken to be $exp(i\ 2\ \theta - i\ \phi + \omega\ t)$. We adjust the parameter h to match the island size. In Fig. 1, we show Poincare plots of the equilibrium (left) and perturbed (right) magnetic fields.

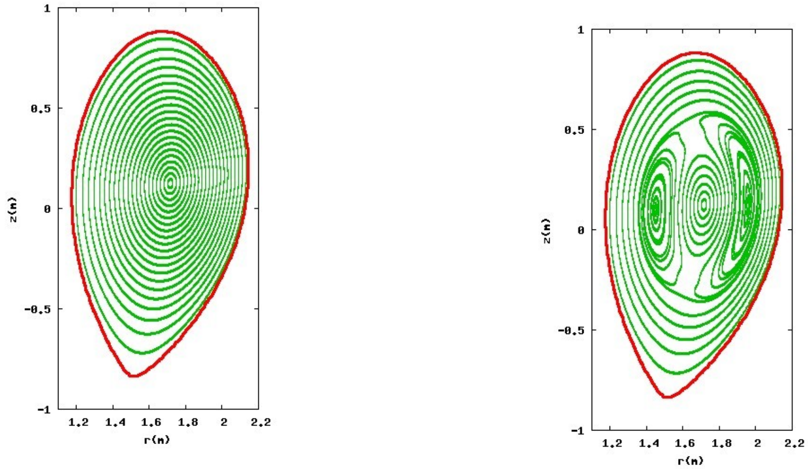


Figure 1.

Initial Particle distribution

In the experiment described in [1] the energetic ions are generated by NBI. We emulate the NBI distribution by a collection of particles distributed as shown in the figure with the same energy and pitch uniformly distributed between 0.2 and 0.9. In a typical run 250000 particles are evolved during 4.17 ms for each set of parameters using the code FOCUS that runs in GPUs [2]. When a particle reaches the last closed flux surface (LCFS) it is considered lost. as discussed above.

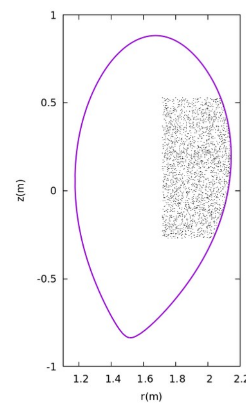


Figure 2.

Results

Figure 3a shows the poloidal projection of the guiding center of an ion with $E_0 = 93$ keV, this ion is lost when an NTM with $\omega = 8 \times 10^{-4}$ is active. In Figure 3b detailed view of the displacement of the upper bouncing point, and in Figure 3c a zoom of the lost point, where the full orbit touches the LCFS.

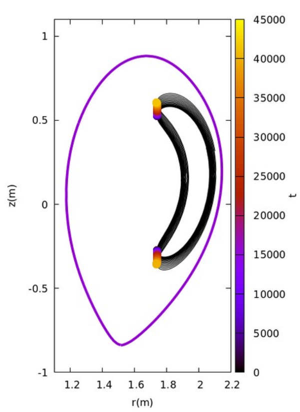
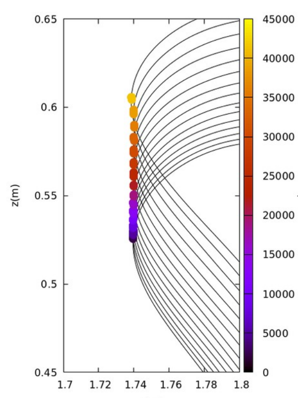
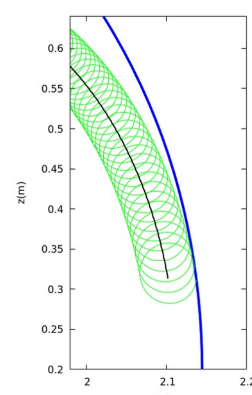


Fig. 3a



3b



3c

Figure 4 shows ion losses vs NTM frequency for different ion energies. The histogram bars show the toroidal precession frequency of the trapped particles of 46.5 keV (cyan) and 93 keV (light red). When the frequency of the NTM matches the toroidal precession frequency of the trapped particles the losses increases significantly. The losses of passing particles show a mild dependence on the NTM frequency. The measured frequency of the NTM is plotted as a vertical black line. There is a maximum of losses for ions with $E_0/2$ (E = 46.5 keV) at the measured NTM frequency.

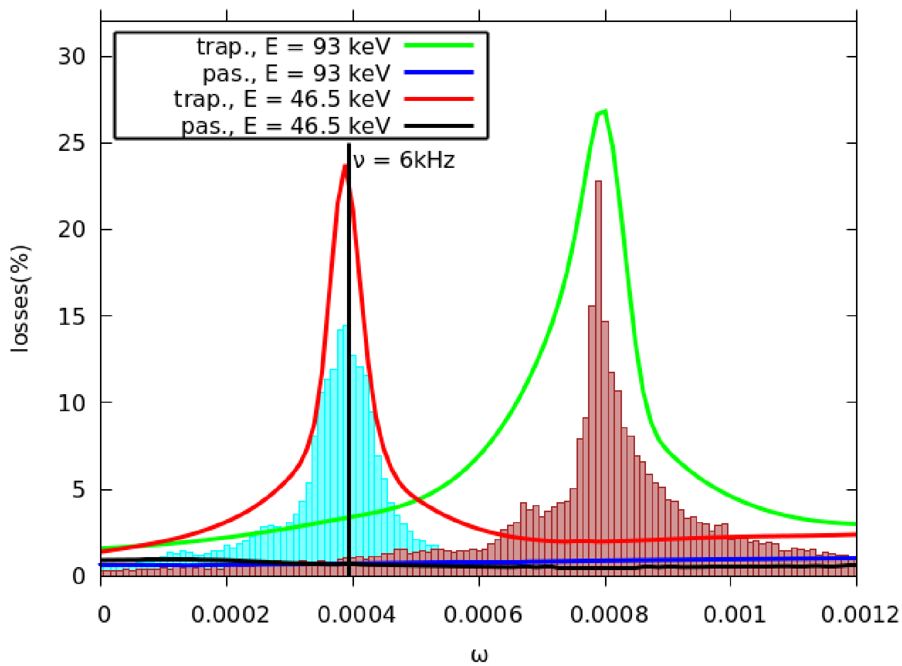


Figure 4

Conclusions

The main result of this study is that when the frequency of the NTM matches the toroidal precession frequency of the trapped particles, the losses of these particles increases significantly.

Significant increases in the losses of trapped ions (when compared with the static case) can occur for mode frequencies that are relatively far from the value corresponding to the maximum.

Since NBI systems usually produce ions with one half and one third of the maximum energy, the possibility of having at least a fraction of the injected ions with precession frequencies close to the mode frequency increases. In the experiments reported in [1], the 93 keV ions have a precession frequency that is approximately twice the mode frequency but the 46.5 keV ions have a precession frequency that matches the mode frequency. This indicates that a large fraction of the trapped 46.5 keV ions could be lost.

References

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