Contribution ID: **648** Type: **Regular Poster**

Trapped particle resonance effects on the NTM driven losses of energetic particles

Tuesday, 11 May 2021 12:10 (20 minutes)

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 by neutral beam injection observed in DIII-D and ASDEX-U [**1-4**]. Although the numerical simulations performed so far to study the effect of NTMs on energetic ions have reproduced some features of the experimental results, the situation is not completely satisfactory. In particular, it has been difficult to reproduce the total amount of losses, which are affected by the details of the perturbation in the edge region [**3-4**]. We are studying the effect of NTMs on the confinement of energetic ions produced by NBI injection using a full orbit code [**5**] that includes the time dependent perturbed electric and magnetic fields.

The main result of this study is that when the frequency of the NTM matches the precession frequency of the trapped particles (f ˜), the losses significantly increase. According to our simulations, the main losses correspond to trapped particles (with average pitch at the loss point of 0.53). This is in accordance with experiments performed in ASDEX U [**2**], where the lost ions had a defined energy and pitch. The perturbed electric field increases the losses of initially passing particles by changing the nature of their orbit, from passing to trapped and so on.

The fields employed to calculate the trajectories are the sum of a 2D equilibrium magnetic field plus the 3D electric and magnetic fields produced by the NTM. To calculate the perturbed fields we employ the experimental information available (i. e. width of the magnetic island, temperature profiles, etc) and the method proposed in [**6**]. The perturbed magnetic field is obtained from the perturbed poloidal flux, which is calculated by solving Ampere's equation with a parametrized perturbed current (see eq. (5) in Ref. [**6**]). The amplitude of the perturbed current is adjusted to obtain the desired island width. The perturbed electric field is calculated with the resistive Ohm's law, where the velocity is obtained from the displacement, which is parametrized as in eq. (2) of Ref. [6].

We simulate the NBI with a set of 250000 particles initially distributed uniformly inside the plasma, with fixed energy and uniformly distributed pitch between 0.2-0.9. Figure 1 shows the trajectory of the guiding center (calculated from the exact orbit) of a 70 keV D ion. The left frame shows the unperturbed case, the middle one the case with a static magnetic perturbation and the right one the case with time dependent electric and magnetic fields. In the las two cases the exact orbit crosses the last closed magnetic surface (green line).

Figure 2 shows the percentage of trapped and passing particles that are lost as a function of the normalized NTM frequency (Ω is the cyclotron frequency of the ions) for two energies (70 and 35 keVs). The precession frequency distribution of the trapped particles is also showed, with full boxes (70 keV in brown and for 35 keV in cyan). It is clear that the losses of trapped ions peak when the precession frequency of the trapped particles is similar to the mode frequency. Passing particle losses are lightly affected by the rotating mode. When the perturbation is reduced the losses are reduced.

Finally, figure 3 shows ion losses as a function of time in a narrow interval of toroidal angle (between 0 and 0.2) for an NTM with frequency 3.75 e-4 Ω. The losses produce a periodic signal with the frequency of the NTM mode.

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Session Classification: P1 Posters 1

Track Classification: Magnetic Fusion Theory and Modelling