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Shielding of Resonant Magnetic Perturbations in the Long Mean-free-path Regime

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The resonant response of a plasma in a layer where the wavefront is parallel to the magnetic field is of interest in many contexts. In axisymmetric systems, it influences the dynamics of wall modes,[1] the interaction between the various internal modes, and the effect of externally imposed perturbations such as feedback corrections and error fields.[2] In helical systems, the resonant response governs the extent to which flux surfaces are destroyed by magnetic islands.

In a static plasma resonant perturbations give rise, through magnetic reconnection, to islands of widths proportional to the square root of the transverse displacement at a large distance from the island. Magnetic reconnection is strongly inhibited, however, in the presence of even modest levels of plasma motion.[3] The primary effect of the perturbations is then to exert a braking force on the plasma. When the perturbation exceeds a threshold amplitude, the plasma is abruptly stopped and reconnection proceeds to saturation.

Although both existing and planned fusion experiments operate in the long mean-free-path regime, previous calculations of the braking force and mode penetration threshold, both analytic and numerical, have used a low beta Magnetohydrodynamics (MHD) model in slab geometry. In principle, however, the validity of this model is restricted to the collisional regime. In order to improve the reliability of extrapolations to burning plasma experiments, we have investigated the effect of long electron mean free path on the resonant response of a plasma to magnetic perturbations. We find that the scaling with machine size of the threshold for mode penetration in Ohmic discharges for the long mean-free-path model ($\Psi_{\text{pen}} \sim R_0^{-1.76}$) is almost identical to that obtained with short mean-free-path MHD ($\Psi_{\text{pen}} \sim R_0^{-1.71}$). The nature of the force exerted on a moving plasma by a resonant perturbation is qualitatively altered, however, by both drift and long mean-free-path effects. The force is found to have three minima, each of which is a possible locus for discontinuous transitions in plasma velocity. Between these minima are two points where the force exerted by the perturbation vanishes. These points describe locked states where shielding is ineffective and a magnetic island will grow. They correspond to rotation velocities such that either the electrons or the ions are at rest in the frame of the perturbation. The ion root, however, is unstable. The model thus predicts that during the growth of low-density locked modes the plasma will rotate so as to bring the electrons to rest in the frame of the perturbation.

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References

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