Topics: TH.W

Developing and validating predictive models for fast ion relaxation in burning plasmas*

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Burning plasma performance is limited by the confinement of superalfvenic fusion products, alpha particles, resonating with the Alfvénic eigenmodes (AEs). Two techniques are developed to evaluate the AE induced fast ion relaxation. They rely on linear instability theory and are confirmed by experiments. The first technique is based on the NOVA-K linear theory computations of TAE (or RSAE) mode structures and stability. It takes mode amplitudes from the nonlinear theory predictions for fusion plasmas. This information is then used in the numerical runs by the guiding center code ORBIT to relax the fast particle profiles. The second method is the reduced quasilinear or critical gradient model that is also based on the calculations of the linear theory. The critical gradient is then computed for the Alfvénic modes and allows construct ion of the fast ion profiles and losses. We apply these models for NSTX and DIII-D plasmas with neutral beam injections for validations. Both methods are relatively rapid means to predict the fast ion profiles in burning plasmas and can be used for predictive modeling prior to building experimental devices such as ITER.

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Developing and validating predictive models for fast ion relaxation in burning plasmas*

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Redistribution and potential losses of energetic ions due to MHD modes are known to limit the performance of fusion plasmas by reducing the heating of the thermal plasma. These modes are important not only for planning self-sustained burning plasmas but they represent an area where the ideal MHD and kinetic theories are put to test with great accuracy. We report on two models for fast ion profile relaxation due to Alfvénic modes, based on linear instability theory of those modes.

In the first, hybrid model, the linear instability theory provides the basis for the subsequent guiding center (ORBIT) computations White and Chance [1], i.e. Alfvénic eigenmode structures and frequencies. Recent applications of the hybrid model to ITER employed TAE amplitudes computed by the NOVA code. The amplitudes follow from nonlinear perturbative theory. However the hybrid model in its initial application makes use of only the initially unstable Alfvénic eigenmodes [2] which is reasonable for near threshold driven instabilities. The results obtained for ITER predict relatively benign Alfvénic activity with weak losses of alphas on the order of 1% (shown in Fig. 1 with an arrow) in the advanced scenario (or reversed shear) plasma, which is below the loss limit, 5%, considered to be dangerous for ITER. To reach the limit level of losses requires five times the AE amplitude predicted by NOVA calculations.

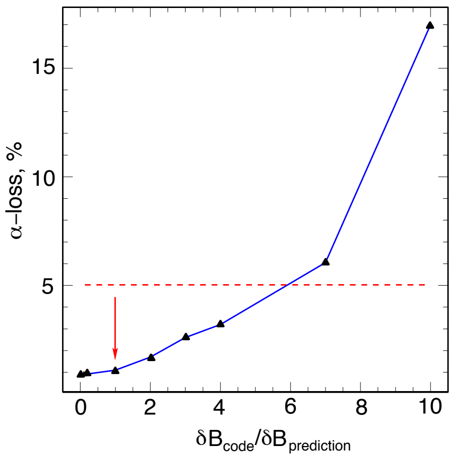

Figure 1: *Hybrid model predictions of alpha losses induced by TAE/RSAE instabilities as predicted by the ORBIT code for ITER plasma. The instability drive includes the tangentially injected beam ions.*

We extend the model to the case when not only unstable modes are included in the consideration but several stable TAEs as well. For all modes nonlinear theory connects the mode amplitude with the instantaneous value of the mode linear growth rate. The later is evaluated at each time during the simulations of the ORBIT code and the mode amplitude is evolved. We developed this technique for single TAE case and for multiple instabilities. The newly developed hybrid model technique is applied for validations with the neutral beam injection (NBI) driven AE instabilities in NSTX plasmas. In the considered plasmas several Alfvénic modes were observed which lowered the neutron fluxes. This implied a radial redistribution of the beam ions. The neutron flux signal evolution results are compared with the TRANSP, classical confinement expectations.

The second model we present is the reduced quasilinear or critical gradient model (CGM). It is based on linear instability theory of the critical fast ion pressure gradient in the presence of unstable Alfvénic modes [3]. The model relies on numerical calculations of TAE/RSAE growth and damping rates by the NOVA-K code [4]. The model does not resolve the velocity space dymanics of the EP distribution function. It is thus applicable when the effective scattering of the beam ions near the resonances is large. That is the amplitude of the modes is sufficiently small for the collisional scattering to be dominant near the phase space resonant island.

A validation exercise for CGM has been performed against the DIII-D experiments where the off-axis NBI was applied [5]. In those experiments the injection geometry of one of two beams was varied in order to modify the confined beam ion profiles. What was found is that independent on the injection geometry the beam ion profiles remained similar within the accuracy of the measurements. We found it important that the model was applied by averaging the predicted fast ion profiles over time comparable to the the slowing down time. This is physical since the instabilities are evolving rather quickly and the critical gradient changes accordingly.

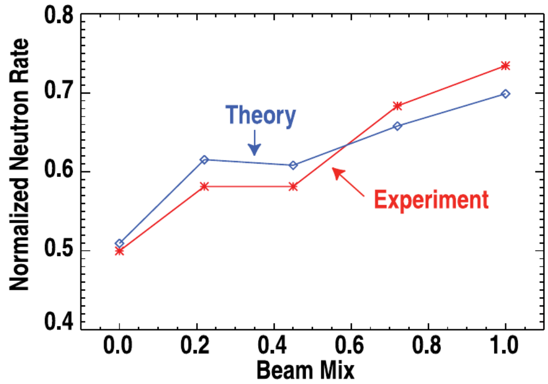

Figure 2: *DIII-D FIDA data using the tangenially-viewing channels for different beam injection mixing parameters. The value of the Beam Mix parameter equal zero corresponds to the on-axis injection whereas when it is equal to 1 the injection is aimed at the plasma edge.*

The applicability conditions for both models require that the unstable modes are evolving over the equilibrium time scale. Many unstable modes and resonances should exist and overlap to allow the expected fast ion stochastic transport to dominate. It is not clear whether the models should work for plasmas when the unstable modes exhibit bursting behaviour.

The developed methods capture correctly the radial dependencies of the fast ion density and pressure in conditions when the Alfvénic instabilities are likely to be excited. This follows from the model application to the DIII-D and NSTX experiments. The CGM is an efficient way to predict the fusion plasma operation points that include Alfvénic mode relaxation.

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* *Supported in part by the U.S. Department of Energy under the contract DE-AC02-76CH03073.*