Topics: TH.W

# Critical gradient and kick models for fast ion profile relaxation in fusion plasmas and their validations*

N.N. Gorelenkov[1], M. Podesta[1], W.W. Heidbrink[2], R. B. White[1]

[1]*Princeton Plasma Physics Laboratory, Princeton University;* [2]*University of California, Irvine*

A redistribution and potential loss of energetic particles (EP) due to MHD modes limit the performance of fusion plasmas. We report on two models for EP profile relaxation due to Alfvénic modes that are based on the linear instability theory of Alfvénic eigenmodes (AE).

The first model is the critical gradient model (CGM) [1]. It is based on linear AE stability calculations of the EP pressure critical gradient that is sufficient to overcome damping in order to drive AEs. CGM predicts EP velocity distribution higher moments such as the density or pressure profiles.

The second model we report on is the recently developed kick model [2]. The kick model provides important insights on the underlying velocity space dependence of the AE induced EP transport. It also allows realistic calculations of the neutron deficit in the presence of measured and observed low frequency Alfvénic modes. This model relies on measured mode structures and their frequencies supported by more accurate AE poloidal structures computed by the ideal MHD codes such as NOVA. Fast ions are advanced by the ORBIT guiding center code in order to compute the ion probability function response to the Alfvénic modes. Found probabilities then are used evolving EP distribution function in the integrated plasma modeling.

The CGM is applicable when the effective pitch angle scattering of beam ions near the resonances is large, i.e., when the amplitudes of the modes are sufficiently small for scattering to dominate ion dynamics near the phase space resonant island. In addition CGM assumes that the number of unstable modes is large and the diffusion of fast ions is fast. Two versions of CGM are developed based on perturbative, pCGM, and non-perturbative, nCGM, computations of TAE growth and damping rates. In pCGM TAE growth rates are computed using the linear perturbative code NOVA-K [3]. For nCGM in DIII-D we use a fully kinetic non-perturbative code HINST [4] where AEs show strong instability drive, $\gamma/\omega \sim 20-30\%$, violating NOVA-K perturbative assumptions. The non-perturbative approach computes the corresponding mode structure and its frequency by solving the eigenmode equations which accounts for EP kinetic effects, their resonances as well as the kinetic effects from thermal ions and electrons. In both CGM it is assumed that all fast ions

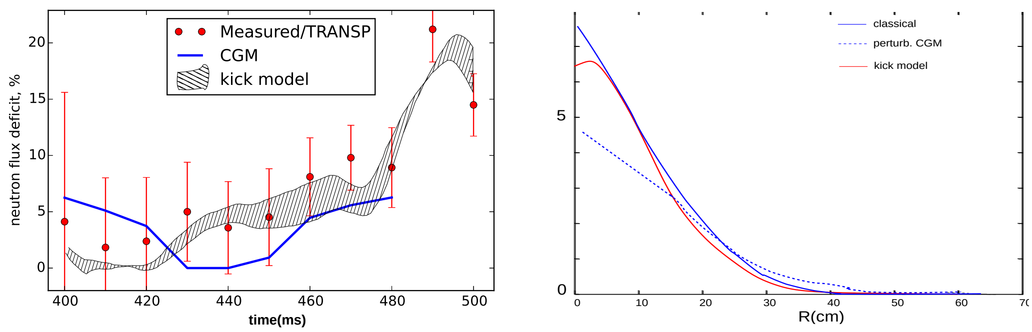


Figure 1. Neutron deficits computed by the TRANSP code (denoted as classical) and by pCGM for NSTX shot #141711 are shown on the left figure. Shown on the right figure are the fast ion beta profiles obtained by TRANSP, pCGM and kick model at $t = 470msec$.

are affected even when they are not in resonance with the eigenmodes. This situation is expected for a plasma with strong collisions or strong AE overlapping.

In the NSTX discharge #141711, only pCGM version can be applied because of typically much broader radial TAE mode structures, so that the HINST computations need higher order corrections not implemented at the moment. pCGM and the kick model have similar predictions for NSTX shot #141711 as well. Both models agree with the experimentally measured neutron deficit within the error bars, Fig. 1 (left). We show the pCGM, classical (TRANSP) and kick model computed EP profiles in Fig. 1 (right).

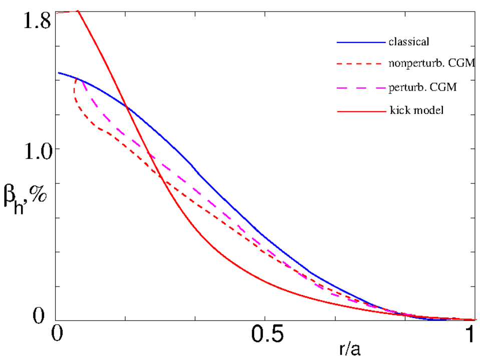


Figure 2. Beam ion radial beta profiles computed by the TRANSP code (denoted as classical) and by pCGM and nCGM for DIII-D shot #153072, $t = 3.7sec$, shown in the left figure. In addition the kick model computed fast ion beta profiles is also shown as more peaked in the center.

We apply pCGM, nCGM and the kick model to DIII-D shot #153072 to compute EP beta profiles and the neutron deficit. The applied models find the neutron deficit smaller than the measured deficit by approximately a factor of two as computed by the TRANSP code. It does not evolve and at $t = 3.7sec$ has a value 21% according to pCGM and nCGM models whereas the kick model finds it to be 19%. On the other hand TRANSP finds the deficit to be 40%. This points out some additional mechanism in used modeling which is not accounted for. Fig. 2 shows an example of the relaxed and initial fast ion beta profiles in the DIII-D. CGM profiles are close to each other whereas the kick model predicts the more peaked EP pressure.

We also attempt to understand these results with the help of the kick model which gives an insight into the underlying velocity space dependence of the AE induced EP transport. The discrepancy present in DIII-D modeling indicates that both CGM and kick models equally underestimate the neutron deficit by neglecting the low frequency part of the Alfvénic spectrum. This part of the spectrum is populated by the Alfvén-acoustic modes studied in Ref. [5]. However the ideal MHD code NOVA did not find these modes in DIII-D discharge of interest.

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