M3D-K Simulation of Beam-driven Alfven Modes in NSTX for Code Validation*

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*SciDAC Center CSEP: Center for Nonlinear Simulation of Energetic Particles in Burning Plasmas
Multiple beam-driven TAEs were observed in NSTX (shot #14711) at $t=470\text{ms}$. 

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Graphs showing frequency and power evolution with time, indicating the presence of TAE modes $n=2$, $n=3$, $n=4$, and $n=5$.
Outline

• Introduction
• SciDAC center CSEP
• M3D-K code
• M3D-K results of beam-driven Alfven modes in NSTX
• Discussions
Introduction

• In this work, we have carried out linear simulations of beam-driven Alfvén modes in NSTX using the kinetic/MHD hybrid code M3D-K;
• The main goal is validation of M3D-K code for modeling of fast ion-driven Alfvén instabilities and fast ion transport.
• This work was done as a part of the SciDAC project CSEP.
SciDAC CSEP: Center for Nonlinear Simulation of Energetic Particles in Burning Plasmas

• The mission is to develop tools for predictive simulations of energetic particle instabilities and transport in burning plasmas.

CSEP team

• PPPL: G.Y. Fu (PI), S. Ethier, J.Y. Lang, N. N. Gorelenkov;
• IFS: H. L. Berk (Co-PI), B. N. Breizman, E. Chen,
• J. W. Van Dam, G. Wang, L.J. Zheng,
• CU: Y. Chen (Co-PI), S.E. Parker;
• ORNL: S.A. Klasky (Co-PI)
CSEP Plan (2011 – 2015)

- Upgrade first principle hybrid codes GKM and GEM: electron physics;
- Develop reduced models: nonlinear chirping and quasilinear model;
- Simulation of alpha-driven Alfvén modes in ITER;
- Integrated simulations of energetic particle-driven instabilities with MHD modes and micro-turbulence.
CSEP TTF2011 Presentations

• G.Y. Fu: “M3D-K simulations of beam-driven Alfvén modes in NSTX”

• J. Lang: “M3D-K simulation of beam-driven Alfvén modes in DIII-D”

• Y. Chen: “Simulation of Reversed Shear Alfvén Eigenmodes using a gyrokinetic code GEM”

• G. Wang: “Model for spontaneous frequency sweeping of an Alfvén wave in a toroidal Plasma”

• B.N. Breizman: “Modeling of long-range frequency sweeping phenomena”

• E. Chen: “Free-boundary Toroidal Alfvén Eigenmodes”
M3D Kinetic/MHD Hybrid Code

\[ \rho \frac{dv}{dt} = -\nabla P - \nabla \cdot \mathbf{P}_h + \mathbf{J} \times \mathbf{B} \]

\[ \mathbf{J} = \nabla \times \mathbf{B}, \quad \frac{\partial \mathbf{B}}{\partial t} = -\nabla \times \mathbf{E} \]

\[ \mathbf{E} + \mathbf{v} \times \mathbf{B} = \eta \mathbf{J} \]

\[ \frac{\partial P}{\partial t} + \mathbf{v} \cdot \mathbf{P} = -\gamma P \nabla \cdot \mathbf{v} + \ldots. \]

\( \mathbf{P}_h \) is calculated using gyrokinetic/drift-kinetic equation (PIC method).
M3D-K Features

• Use realistic geometry (ST!);
• Use experimental parameters and profiles (interface with TRANSP);
• Global;
• Linear and Nonlinear;
• Non-perturbative fast ion effects (i.e., can model EPM);
• Plasma rotation is included;
• Interface with NUBEAM will soon be available.
M3D-K applications:

1. Alpha particle stabilization of n=1 kink in ITER;
2. Nonlinear frequency chirping of fishbone;
3. Beam-driven TAEs in DIII-D;
4. Beam-driven TAEs in NSTX;
5. Beam-driven GAM in DIII-D
6. Nonlinear simulation of TAE with energetic particle source and sink

G.Y. Fu, 2004 IAEA Fusion Energy Conference
G.Y. Fu, invited talk, the 2007 APS-DPP meeting
M3D-K Verification and Validation

• Good agreement between M3D and NIMROD for CDX-U sawteeth simulations;
• Good agreement between M3D-K and NOVA for RSAE and TAE;
• Good agreement between M3D-K and NOVA2 as well as M3D-K and NIMROD for energetic particle stabilization of internal kink and excitation of fishbone.
• In this work we will compare M3D-K results with NSTX data with respect to beam-driven TAE for code validation.
M3D-K results agree with NOVA for a n=2 RSAE in MHD limit.

J. Lang et al., this meeting.
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Multiple beam-driven TAEs were observed in NSTX (shot #14711) at $t=470$ ms.
Parameters and Profiles (#141711)

$B = 0.55 \text{T}$
$R = 0.85 \text{m}$
$a = 0.67 \text{m}$
$ne(0) = 4.4 \times 10^{13}/\text{cm}^3$
$Te(0) = 1.4 \text{ kev}$
$Ti(0) = 1.3 \text{ kev}$
$b(0) = 24\%$
$b_{\text{beam}}(0) = 10\%$

$q_{\text{min}} = 1.09$
$f_{\text{rot}} = 36 \text{ kHz}$
M3D-K results of n=1 mode (kink)

dn_e

f=36kHz
n=2 mode (TAE)

\[ \text{dn}_e \]

f=65kHz
$n=3$ mode (TAE)

dn$_e$  
f=97kHz
The M3D-K calculated TAE peaks just inside the continuum resonance.
Rotation has little effect on mode structure (n=3 TAE)

$f_{\text{rot}}=18\ \text{kHz}$

$f_{\text{rot}}=27\ \text{kHz}$

$f_{\text{rot}}=36\ \text{kHz}$
M3D-K’s mode structure is similar to the measurement. The main difference is a shift in mode location.

\[ f_{\text{exp}} = 94 \text{ kHz} \]

\[ f_{M3D-K} = 97 \text{ kHz} \]
Discussions

• M3D-K linear results are similar to the measurement with respect to mode frequency, core-localized radial structure, and phase shift.
• The main difference is a significant radial shift between the M3D-K’s mode structure and that of measurement.
• The difference in mode location could come from the difference in q profiles, fast ion profiles, or nonlinear modification of beam-driven modes. These possibilities will be investigated in near future.