Results from Real-time Open-loop Alfvén Eigenmode Excitation in Alcator C-Mod

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Abstract
The Active MHD diagnostic system excites Alfvén eigenmodes in Alcator C-Mod and measures their damping rates, or margin to instability. Resonant modes are stimulated with two moderate-n antennas positioned above and below the outboard midplane. The antennas are fed by power amplifiers equipped with automatically tuned capacitive networks capable of matching in the range of 30 kHz to 1 MHz. The driving frequency follows in real-time the center of the Toroidal Alfvén Eigenmode gap, \( \nu_{\text{MAX}} \approx 2 \times 10^4 \), making small excursions away from the gap to observe the modes’ damping characteristics. The effect of shear on mode damping rate was studied during elongation and triangularity scans of inner wall limited plasmas. The dependence on \( \rho_s \) was studied by varying plasma temperature; the destabilizing effect of ICRF-heated fast ions with energies above 1/3 the Alfvén speed, \( \nu_c > 10^4 \rho_s \), was also studied. Finally the diagnostic regularly records mode damping rates in plasmas tailored to other experiments. Results are presented.

Motivation
Toroidal Alfvén Eigenmodes of order \( n \approx 10 \) are expected to be unstable in ITER\(^2\). The Active MHD diagnostic could benefit fusion experiments like ITER by informing plasma control systems of approaching low-n instabilities and suggesting subtle changes in shape, heating and density to avoid rapidly growing modes. The C-Mod Active MHD program begins to address this role by studying the dependence of low-n mode damping rates on normalized parameters. The damping rate of these modes in JET is believed to depend on edge magnetic shear. Low \( n \) results on JET show increased damping with higher elongation and triangularity\(^3\) for monotonic q profiles. PENN code calculations indicate damping increases with edge shear. For very flat or reversed shear q profiles\(^4\) in the core, even low \( n \) TAEs on JET have low damping with high edge shear. For toroidal mode \( n \gg 1 \), results in C-Mod indicate that damping decreases with triangularity. Damping may also depend on normalized ion Larmor radius, \( \rho_i \), though C-Mod results presented here are not conclusive. Preliminary data on the effect of excited stable modes on fast particle loss are presented.

Background: Alfvén Eigenmode Diagnostics
Poloidal magnetic field probes, or pickup coils, are toroidally and poloidally arrayed around the C-Mod tokamak between centimeters of the last closed flux surface. The coils detect both core and edge magnetic disturbances that produce fluctuations on the order of 10mG at the coils’ position, including Toroidal Alfvén Eigenmodes (TAE)s and Alfvén Cascades. Toroidal and poloidal mode numbers are deduced from the spatial separation of the coils and the phase difference of their signals. The coils are toroidally separated by 158° for low \( n \) and by 2.4° for \( n \) up to 75. The sampling rate has been 2.5 MHz but new digitizers can sample up to 10 MHz.

System
The amplifier sweeps across the TAE frequency in real time to excite resonances repeatedly. Each time a resonance is crossed the damping rate of the excited mode is revealed. To achieve a high bandwidth in the antenna, the amplifier switches capacitors to optimize tuning as the frequency changes. Thus the antenna current is near peak at almost all frequencies of interest.

Investigation of TAE mode damping rate dependence on dimensionless parameters
The damping rate of TAE’s may depend on the dimensionless parameter \( \rho_s \), and the shape factors triangularity \( \chi \) and elongation \( \kappa \), which contribute to edge magnetic shear. We varied each parameter separately during a run of shots and excited TAE’s near the q=1.5 surface using the real-time open-loop system. The results of damping rate analysis for each parameter scan are presented below.

Ion gyroradius
\( \rho_i = (2m_iT_i^{3/2}nB^2) \) was scanned over ten shots by varying heating. Electron temperature was measured with the Thomson Scattering diagnostic and assumed to be similar to ion temperature. Toroidal modes \( n=3 \) and \( n=6 \) were predominant in the 350-650 kHz range of interest and appeared during every shot, but a clear trend in mode damping rate was not evident.

Triangularity
The shape factor triangularity \( \chi \) was varied from 2.9 to 5.2 over 17 shots. To isolate the effect of shaping, damping rate is compared to edge magnetic shear for the prevalent \( n=6 \) toroidal mode. A trend of decreasing damping rate with increasing shear is evident. In contrast, damping rate has been found to increase with shear for lower modes \( (n=1) \) in JET.

Elongation
In an elongation scan, the edge magnetic shear was varied by a factor of 2. Resonant toroidal modes detected were in the range 4 < \( n < 14 \). For these moderate \( n \) modes, there appears to be no collective trend on edge shear, better distinguishing of the modes could reveal a trend.

Preliminary studies on fast particle ejection due to TAE’s
The recently completed Compact Neutral Particle Analyzer measured fast particles ejected from the plasma during some Active MHD shots. We were able to observe resonances and measure damping rates during ICRF activity. Dedicated runs may be able to observe a decrease in damping rate due to fast particles driving the mode towards instability.

Future Work
• Improve capacitor switching strategy to leave resonances clear of blank spots.
• Install long wavelength pick-up coil arrays for better toroidal mode identification.
• Implement synchronous detection on ASIC chip – may make real time resonance detection feasible.
• Detect TAE resonances in real time to control the Active MHD driving frequency via feedback.
• Continue studies on fast particle ejection during lightly damped modes with the Neutral Particle Analyzer.

References
1 N N Goerlitz et al 2000 Nucl. Fusion 40 1311
2 A Ianus 1999 Nucl. Fus 39 2005
3 Tresta et al 2003 Nucl. Fus 43 479
4 D Tresta et al 2001 28th EPS Madeira 25A 1797
5 R F Hester et al 2000 Rev. Sci. Inst 71 4092
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