EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(04)03-08

C. Boswell, A. Fasoli, J. Snipes, D. Testa and JET EFDA Contributors

Comparison between TAE and EAE Properties using MHD Spectroscopy

Comparison between TAE and EAE Properties using MHD Spectroscopy

C. Boswell[1], A. Fasoli[2], J. Snipes[1], D. Testa[2] and JET EFDA Contributors*

[1]Plasma Science and Fusion Center, MIT, Cambridge, MA 02139, USA
[2]CRPP-EPFL, Association EURATOM-Confederation Suisse, 1015 Lausanne, Switzerland
** See annex of J. Pamela et al, "Overview of Recent JET Results and Future Perspectives",*
Fusion Energy 2002 (Proc. 19th IAEAFusion Energy Conference, Lyon (2002).

Preprint of Paper to be submitted for publication in Proceedings of the
31st EPS Conference,
(London, UK. 28th June - 2nd July 2004)

ABSTRACT

Alfvén waves can be driven unstable and reach amplitudes at which they cause radial transport of fast particles [1]. In a tokamak, the coupling of different poloidal harmonics of the Alfvén wave spectrum produces global wave fields known as Alfvén Eigenmodes (AEs) [2], of which two are discussed here: Toroidal Alfvén Eigenmodes (TAEs) [3] and Elliptical Alfvén Eigenmodes (EAEs) [4]. Knowing the mechanisms for the damping of the AEs can help con-trol the impact they have on the radial transport of the fast particles. In the absence of direct charge exchange measurements and if TAEs and EAEs are driven unstable, their measured frequencies can yield an estimate of the bulk plasma rotation.

1. COMPARISON OF TAE AND EAE DAMPING RATES

On JET, MHD modes can be excited by a pair of saddle coils used as external antennas and programmed to sweep in frequency [5]. By measuring the response of the plasma at the driven frequencies, the frequency and the damping rate of a stable mode can be determined.

To compare the damping rates of the $n = 1$ TAEs and EAEs, a pair of nearly identical, limited, Ohmic, low elongation ($k = 1.34$), low triangularity ($\langle\delta\rangle = 0.004$) discharges with a constant electron density ($n_{e0} = 2.5 \times 10^{19}\ \mathrm{m}^{-3}$), electron temperature ($T_{e0} = 3$keV), current ($I_p = 2.25$MA), and toroidal magnetic field ($B_T = 2$ Tesla) were used. Figure 1 shows the sweep in the driving frequency for the two discharges as well as the mode frequency and damping rate for the TAE and EAE observed. The average frequency of the $n = 1$ TAE in figure 1 is $f_{TAE} = 165$kHz, with a damping of $\gamma_{TAE} = 2.86 \times 10^4\ \mathrm{s}^{-1}$, and the average frequency of the $n = 1$ EAE is $f_{EAE} = 333$kHz, with a damping of $\gamma_{EAE} = 3.10 \times 10^4\ \mathrm{s}^{-1}$.

Identification and determination of the mode structure of the observed TAE and EAE were done by using the MISHKA-1 [6] ideal MHD normal-mode analysis code. This code was used to find an $n = 1$ TAE near the normalized frequency of $\omega_{TAE} = 2\pi f_{TAE} R/v_A(0) = 0.5$, where R is the major radius of the plasma, $v_A(0)$ is the Alfvén speed on axis, and an $n = 1$ EAE near the normalized frequency of $\omega_{EAE} = 1.02$. Figure 1(right) shows the radial localization as calculated from MISHKA-1 for an $n = 1$ TAE and for an $n = 1$ EAE within 10% of the measured frequencies.

The fact that the radially extended TAE and edge localised EAE have similar damping provides a test for theoretical predictions of AE damping rates. A possible mechanism for the damping of AEs is mode conversion to short wavelength waves which are then damped by Landau damping [7]. This mode conversion occurs in regions of low magnetic shear (plasma core) and high magnetic shear (plasma edge). For the modes shown here, we conjecture that the TAE experiences mode conversion in both regions, whereas the EAE only experiences mode conversion at the plasma edge. This is consistent with the EAE damping rate to be lower than the TAE damping rate, as reported here.

2. ROTATION MEASUREMENTS OF TAES AND EAES

Using calibrated [8], toroidally spaced, fast (< 500kHz) magnetic pickup coils, one can determine the toroidal mode number (n) of magnetic perturbations [9]. Due to rotation of the plasma, a Doppler effect shifts the measured frequency of the magnetic perturbation: $f_{meas} = f_{plasma} + nf_{tor} + mf_{pol} + f_{dia}$, where f_{meas} is the measured frequency, f_{plasma} is the frequency of the perturbation in the plasma frame, f_{tor} is the toroidal rotation frequency of the plasma, f_{pol} is the poloidal rotation frequency of the plasma, f_{dia} is the diamagnetic drift frequency, and m is the poloidal mode number. Using neoclassical calculations, as in reference [10], the f_{pol} for the discharge shown in figure 2 is ~100Hz, and f_{dia} at the expected mode locations was estimated to be ~300Hz. Both are small when compared to the measured toroidal rotation of 1-9kHz and thus are neglected in this analysis. The Doppler shift of the frequency of radially localised TAEs and EAEs can provide an alternative method of determining the bulk plasma rotation in the absence of direct charge exchange measurements [10,11]. If the source is sufficiently strong, many harmonics of the same mode will be excited at the same radial location, having different mode numbers but the same f_{plasma}. Therefore, the toroidal rotation and rest frame frequency at the modes' radial position can be determined by a linear fit of the measured frequency as a function of the toroidal mode number. The assumption that the TAEs (or EAEs) exist at the same radial location is not known *a priori* and must be confirmed either through modelling (as done here), or through measurements of the location of the AEs by reflectometry, Electron Cyclotron Emission (ECE), or interferometry.

To check the toroidal rotation measurements of the TAEs and EAEs, a sawtoothing dis- charge that had toroidal rotation measurements of the carbon impurity from Charge Exchange Recombination Spectroscopy (CXRS) was chosen. Figure 2 shows the behaviour of the TAEs and EAEs and the calculated toroidal rotation frequencies during a single sawtooth oscillation. The CXRS measurements of the rotation profile show a peak in rotation on axis (R = 3m) of 9kHz decreasing monotonically to 1.5kHz at R = 3.75 m. This profile varied by less than 1kHz over an entire sawtooth period. Using neoclassical calculations [10] and the carbon impurity rotation measurements, the bulk plasma rotation profile was calculated to be typically 500Hz faster than the carbon rotation and no more than 1kHz across the entire profile.

To determine locations of the modes using MISHKA-1 [6], an accurate magnetic topology must be known. For this discharge, the magnetic configuration obtained from the magnetic equilibrium code EFIT [11] is known to be incorrect because here, $q > 1$ everywhere, yet the plasma had sawtooth oscillations. A q profile was reconstructed using information from observed MHD phenomena and the measured rotation profile from CXRS. The sawtooth inversion radius, and hence the $q = 1$ surface, was found from electron temperature profiles measured by ECE to be at 3.33m. An $n = 2$, $m = 4$ mode was observed to have a frequency of 3kHz and was assumed to have zero frequency in the plasma frame, implying that the $q = 2$ surface must be rotating at 1.5kHz. A comparison of this frequency to the toroidal rotation profile obtained by CXRS locates the $q = 2$ surface at 3.75m.

Using this reconstructed q profile, MISHKA-1 [6] was used to find the mode structure of the n = 4, 5, 6, and 7 TAEs and the n = 3 and 4 EAEs. The mode structure of the TAEs was found to consist of many poloidal harmonics at R > 3.4m, peaking in magnitude between R = 3.75m and R =

3.8m. This multiple mode structure makes it difficult to assign a single location to the TAEs. An added complication is the possibility that these TAEs may not all have the same frequency in the plasma frame, and MISHKA-1 [6] predicts a frequency offset between the modes of different *n* of several kHz. From the model, the EAEs have a simpler structure, are localised around $R = 3.3$m, and dominated by the poloidal harmonics $m = n - 1, n, n + 1$. Since these mode structures were calculated from the reconstructed q profile shortly before the sawtooth crash, a comparison of the rotation as measured by CXRS at $R = 3.3$m (4.7kHz) and EAEs at this time (3kHz) can be done. There is a 1.7kHz discrepancy in these measurements, implying an error in the assumptions made in the EAE rotation measurement analysis. A possible explanation could be in the density profile, which was not modified in this analysis. Were the density made to be more peaked, the location of the EAEs may move to a region of lower rotation. Work is ongoing to find the cause of this inconsistency.

CONCLUSIONS

The measurements of the damping rate of the radially extended $n = 1$ TAE and the edge localised $n = 1$ EAE for the same discharge conditions provide a test for theoretical predictions of AE damping rates. Using information from observed MHD phenomena and toroidal rota-tion measurements from CXRS, the *q* profile from equilibrium codes has been checked and corrected. Using this corrected *q* profile and determining the mode structure of the TAEs and EAEs does not produce rotation measurements consistent with the directly measured toroidal rotation frequency.

ACKNOWLEDGEMENT

This work has been conducted under the European Fusion Development Agreement and was funded partly by US DoE contract DE-FG02-99ER54563.

REFERENCES

[1]. Wong K. 1999 Plasma Phys. Control. Fusion **41**, R1

[2]. Kieras C.E. and Tataronis 1982 J. Plasma Phys. **41**, 395

[3]. Cheng C.Z., Chen L, and Chance M.S., 1985 Ann. Phys. (N. Y.) 161, 21

[4]. Betti R. and Freidberg J P 1991 Phys. Fluids B**3**, 1865

[5]. Fasoli A., Borba D., Bosia G., Campbell D.J. et al. 1995 Phys. Rev. Lett. **75**, 645

[6]. Mikhailovskii A.B., Huysmans G.T.A., Kerner W.O.K. and Sharapov S.E. 1997 Plasma Phys. Rep. 23, 844

[7]. Jaun A., Fasoli A. and Heidbrink W.W. 1998 Phys. Plasmas **5**, 2952

[8]. Heeter R.F., Fasoli A.F., Ali-Arshad S. and Moret J.M. 2000 Rev. Sci. Instrum. **71**, 4092

[9]. Testa D., Fasoli A. and Solano E. 2003 Rev. Sci. Instrum. **74**, 1694

[10]. Testa D., Giroud C., Fasoli A. and Zastrow K-D. 2002 Phys. Plasmas **9**, 243

[11]. O'Brien D., Lao L.L., Solano E.R., Garriba M, et al. 1992 Nucl. Fusion **32**, 1351

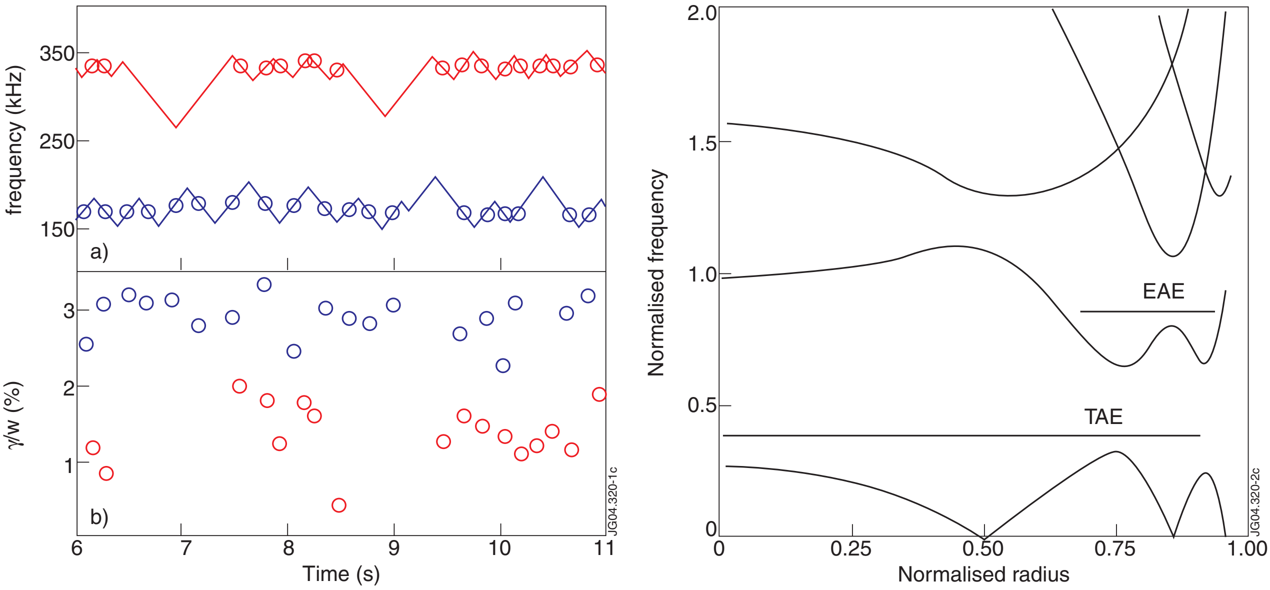

Figure 1: Plots of the TAE (blue) and EAE (red) mode frequency (a), damping rates (b), and location of the modes in the Alfvén continuum (c). The solid blue and red lines represent the frequency sweep of the active MHD spectroscopic system used to measure the mode frequencies and damping rates. The solid lines in the right hand plot represent the radial extent of the n = 1 TAE and EAE.

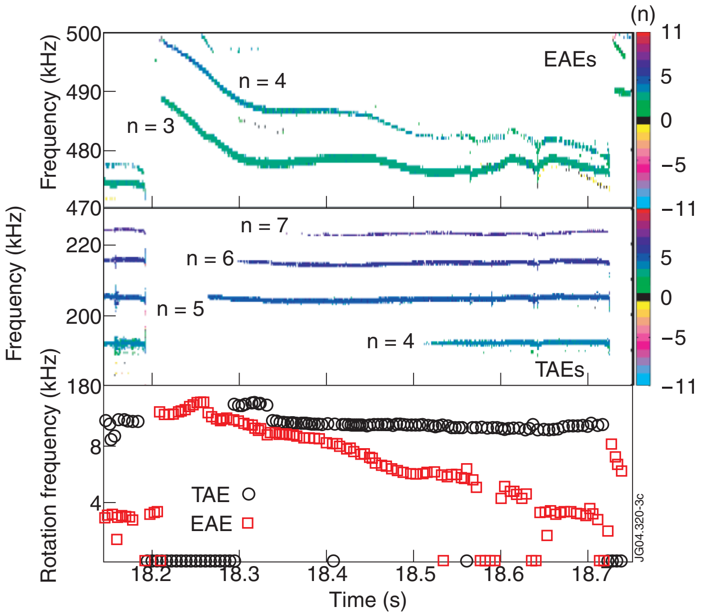

Figure 2: Plots of the mode frequency and toroidal mode numbers for TAEs (b) and EAEs (a) over a single sawtooth period, and of their rotation frequencies determined by the frequency separation of the modes. The sawtooth crashes are marked by solid vertical lines in plots (a) and (b).