EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(07)03/71

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** See annex of M.L. Watkins et al, "Overview of JET Results ", (Proc. 21st IAEA Fusion Energy Conference, Chengdu, China (2006)).*

Preprint of Paper to be submitted for publication in Proceedings of the 34th EPS Conference on Plasma Physics, (Warsaw, Poland 2nd - 6th July 2007)

ABSTRACT

Alfvénic modes, as determined by their frequency scaling, have been detected in ohmic discharges at TEXTOR [1][2] and FTU [3]. Recently they have also been observed in limiter plasmas at JET. They appear in the presence of large 2/1 tearing modes or strong resonant magnetic perturbations. Their drive by thermal ions distinguishes the from other Alfvénic modes, such as Toroidal Alfvén Eigenmodes (TAE). A consistent cross-machine scaling indicates a robust frequency dependence on plasma parameters.

1. EXPERIMENTAL OBSERVATIONS

As previously reported from TEXTOR [1][2] and FTU [3], these Alfvén-like modes display several branches on a time-frequency spectrogram in the frequency range 10–50 kHz. Measurements of the toroidal mode number reveal both positive and negative mode numbers. In addition to the observations on TEXTOR and FTU, on JET a further frequency branch between the two primary branches is observed. A toroidal mode number calculation of this branch indicates that it is an $n = 0$ mode (figure 1). These Alfvén-like $n = 0$ modes are distinguished from other recent $n = 0$ mode observations at JET [4], since in the latter case they are driven by highly energetic ions, accelerated by ion cyclotron heating or NBI heating. Figure 2 shows the raw signal of several toroidally distributed Mirnov Coils. A band pass filter of $f = 12.9–13.5$ kHz was used to show, that there isno phase shift seen, if one compares all available coils. There are two possible reasons why these $n = 0$ modes are not seen on TEXTOR and FTU: Either the magnetic diagnostics at JET are more sensitive or, because of the higher plasma current on JET, the amplitude of the poloidal magnetic ¯field perturbations are correspondingly larger.

In figure 3 the scaling of the measured frequency with the Alfvén speed is shown. A linear dependency is seen. In addition a further linear dependency is found, if one compares the measured frequency with the frequency scaling of GAMs (eqn. 1) and BAEs (eqn. 2):

$$f_{GAM} = \frac{k}{2\pi R_0} \cdot \sqrt{\frac{T_e + T_i}{T_i}} \tag{1}$$

$$f_{GAM} = \frac{k}{2\pi R} \sqrt{\frac{2T_i}{A}\left(\frac{7}{4} + \frac{T_e}{T_i}\right)} \tag{2}$$

Due to the low variation in normalized pressure (β) in these Ohmic plasmas on TEXTOR, FTU and JET, it is not possible to isolate whether the mode frequencies observed scale with the sound speed or the Alfvén speed. Nevertheless, the mode frequencies have been shown to consistently vary with magnetic field (B_t), density ($1/\sqrt{n_e}$), ion mass ($1/\sqrt{m_i}$) and electron temperature ($\sqrt{T_e}$) across all three machines.

Figure 3 indicates, that the data of all three machines show a linear dependency of the measured

frequency with the Alfvén velocity. The data from TEXTOR are separated into discharges with different operating gases like Hydrogen, Deuterium and Helium4. The ion masses are different up to a factor of 4 leading to a change of the measured frequency by a factor of 2. As the Alfvén velocity is depending on the ion mass, the discrepancy of the JET data to the linear scaling, could be explained, by the fact, that the ion mass in these discharges is unknown, and set to 2 for the used Deuterium operation gas. A higher average ion mass, resulting e.g. from impurities, would shift the JET points nearer to the straight line.

Recently a β-scan was performed at TEXTOR. Figure 4 shows the toroidal mode numbers of one of the discharges. The DED[5] in its 3=1 configuration in AC mode with 1 kHz was used to excite a 2/1 tearing mode[6], which is accompanied by Alfvén like modes, seen as a pair of n = ¡1 and n = 1 modes at t = 2.7–3.7s. The frequency splitting of these modes is twice the 2/1 mode frequency, driven by the external perturbation ¯field with 1 kHz. To exclude the effect of toroidal rotation and fast ions on the excitation of the Alfvén like modes, β was changed in the series of discharges by ICRH heating only. The ion sound speed and the ion thermal velocity are proportional to both, the square root of β as well as the Alfvén velocity as described in eqn. 3 and eqn.4:

$$\frac{c_s^2}{v_A^2} = \frac{\gamma Z}{2} \cdot \frac{8\pi n_i k T_e}{B} = \frac{\gamma Z}{2} \beta \tag{3}$$

$$\frac{v_i^2}{v_A^2} = \frac{1}{2} \cdot \frac{8\pi n_i k T_i}{B} = \frac{1}{2} \beta \tag{4}$$

Here $c_s^2 = \frac{\gamma Z k T_e}{m_i}$ is the ion sound speed, $v_A^2 = \frac{B}{4\pi n_i m_i}$ the Alfvén velocity, $v_i^2 = \frac{kT_i}{m_i}$ the ion thermal velocity and $\beta = \frac{8\pi n k T}{B}$.

Figure 5 shows, that the frequency of the Alfvén like modes scales like the Alfvén speed if β is changed. For standard ohmic discharges at TEXTOR $\beta_N \approx 0.4$. During the β scan, β was changed to $\beta_N \approx 0.8$. Referring to eqn. 3 and eqn. 4 $c_s/\sqrt{\beta_N} \sim v_A$. In figure 6 the measured mode frequency is used to determine v_A. The linear dependency proves that these modes scale with the Aflvén speed and not with the sound speed.

CONCLUSIONS

Alfvénic modes have been detected at FTU, TEXTOR and JET in L-mode, or ohmic limiter discharges in the presence of a large 2/1 tearing mode or external resonant perturbation field. A cross-machine scaling shows that the observed mode frequencies scale with the sound speed or the Alfvén speed. It has been shown by a ¯ scan at TEXTOR, that the observed modes scale linearly with the Alfvén speed and not with the sound speed. How the presence of large 2/1 tearing modes

or a strong magnetic perturbation leads to the observation of these Alfvénic modes is still unclear. Possible explanations are that the distribution of thermal ions is modified in such a way that they are able to destabilize these Alfvénic modes, or the distortion of the equilibrium magnetic field leads to a state which now supports these new modes.

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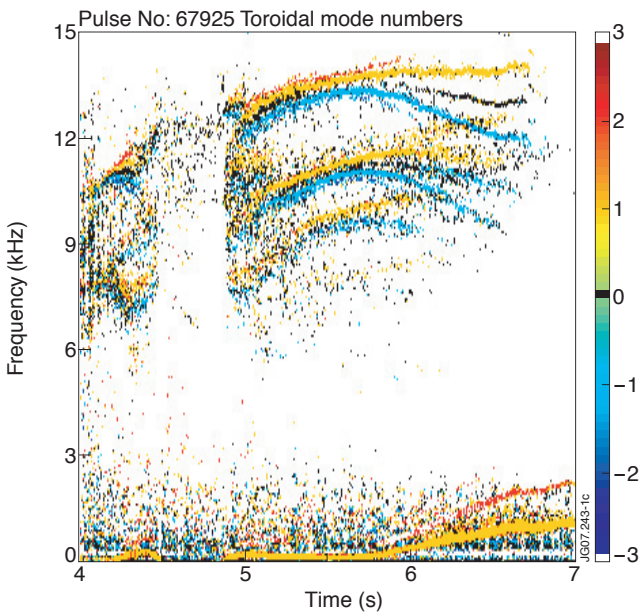

Figure 1: The toroidal mode number estimation of a JET discharge shows a slowly rotating n=1 mode below 1kHz, which accelerates at 5.5s. In the frequency range of 7–15kHz several pairs of n=1 and n=–1 modes are seen. Between these modes a n=0 mode is seen.

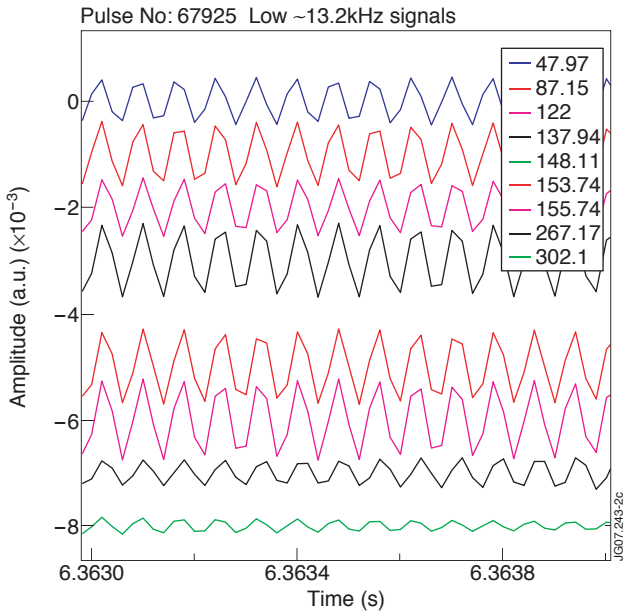

Figure 2: Band pass filtered signals from several toroidally separated Mirnov show no phase shift of the oscillation. The included legend presents the toroidal angle of the coil position.

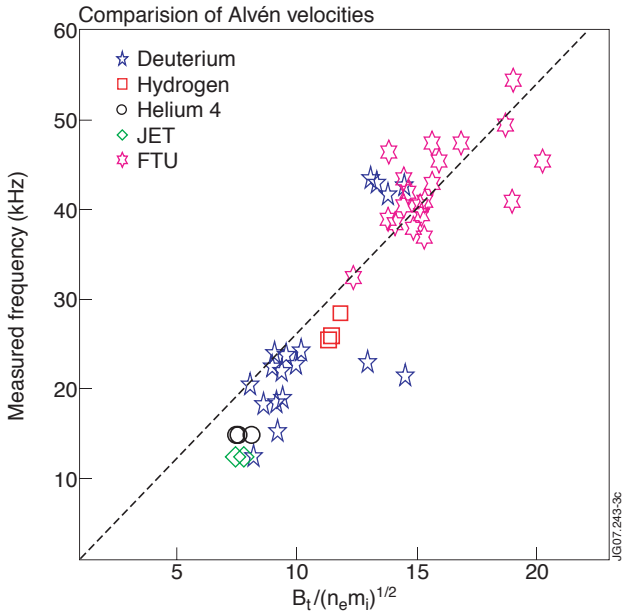

Figure 3: The measured mode frequency of JET, FTU and TEXTOR show its linear dependency on the Alfvén velocity. The TEXTOR discharges are distinguished into those with different operation gases: Hydrogen, Deuterium and Helium4.

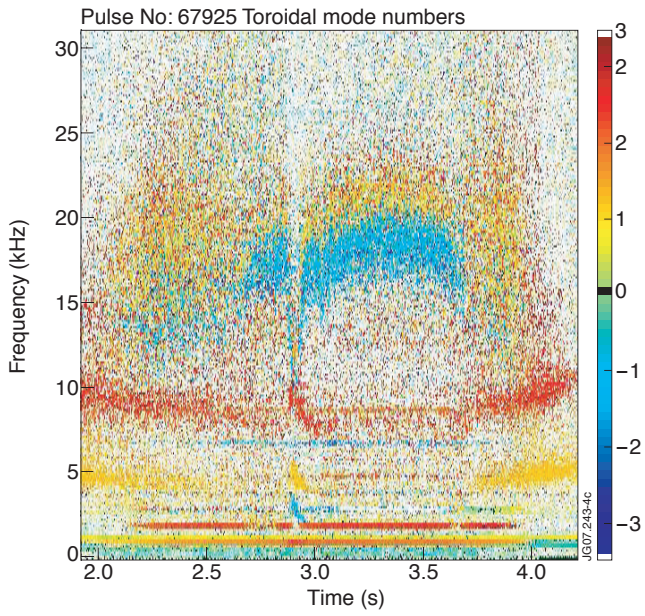

Figure 4: The toroidal mode number estimation of a TEXTOR discharge shows a rotating n=1 mode at 1kHz, which was excited by the DED in 3/1 configuration. From 2.1s in the frequency range of 13−20kHz n = 1 and n = −1 modes appear, which can be seen more clearly, when the 2/1 is excited at 2.7s. A rotating external perturbation field below the mode onset threshold is able to excite the Alfvén like modes [1].

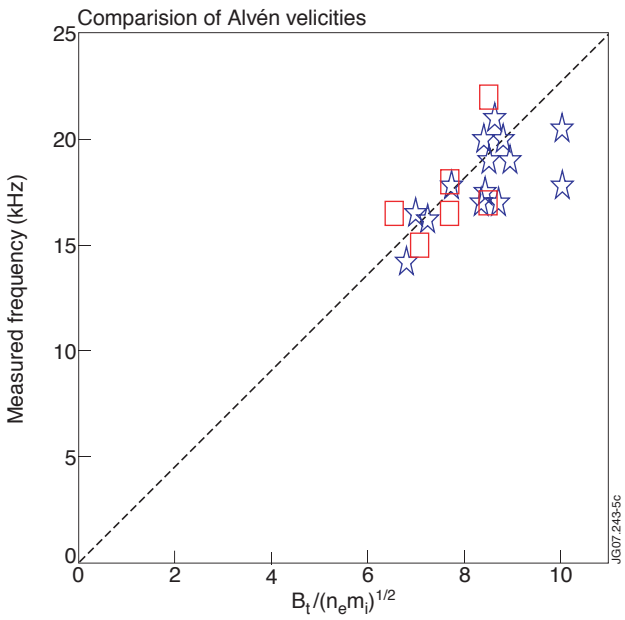

Figure 5: Two groups of discharges of the β scan are shown. The blue stars indicate discharges with slight NBI heating for diagnostic purpose and ICRH, the red squares show discharges with ICRH only. The Alfvén velocity scaling of the measured frequency is seen. The linear dependency is indicated by the dashed straight line.

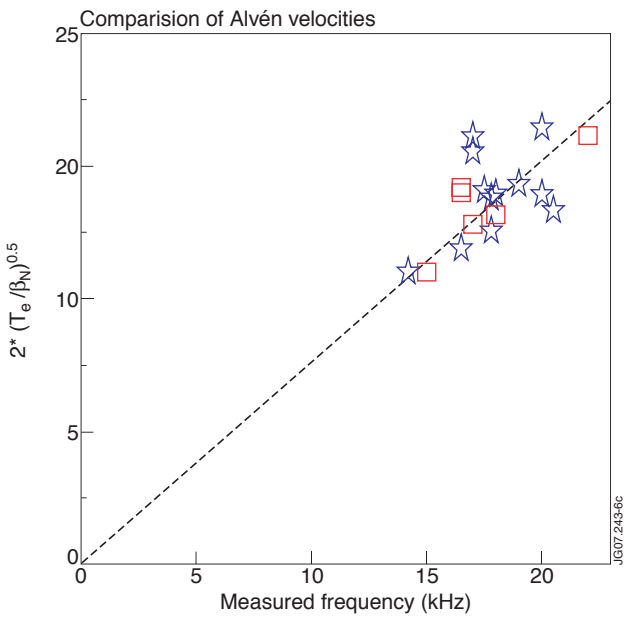

Figure 6: Referring to equ. 3 and equ. 4 $c_s/\sqrt{\beta} \sim v_A$. Here the measured mode frequency is used to determine v_A. The linear dependency indicates, that these modes scale with the Alfvén speed and not with the sound speed. Again the blue stars indicate discharges with slight NBI heating for diagnostic purpose and ICRH, the red squares show discharges with ICRH only.