Alfvén wave excitation by magnetic field perturbations at TEXTOR

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Abstract

A class of MHD instabilities characterized as Alfvén waves has been observed in plasmas with a strong radial magnetic perturbation induced either by large m/n=2/1 tearing modes or an external rotating perturbation field at TEXTOR ($R = 1.75$ m, $a = 0.46$ m). The experimental results show that the Alfvén wave appears even in ohmic plasmas where no population of fast particles exists. A detailed experimental investigation of the Alfvén waves shows, that the 2/1 tearing mode, which was deemed to be necessary for their excitation described in former publications [1,2,3] is not the only way these Alfvén waves can be excited. In previous publications the dependence on the magnetic and density were described. For the first time the dependency on the isotope mass will be presented in this paper, proving the Alfvén wave characteristics.

Experimental Results

At TEXTOR the Dynamic Ergodic Divertor(DED) can be used to apply external rotating perturbation fields to the plasma. The results in this paper are obtained in the 3/1 configuration of the DED. Above a threshold these perturbation fields excite a 2/1 tearing mode in a controlled and reproducible way [4], [5]. The frequency of the rotating perturbation field for this publication was chosen to be 1 kHz and 3.75 kHz.

By studying the 2/1 tearing mode onset, excited by the perturbation field, additional modes have been detected, accompanying the 2/1 tearing mode. Later on also natural tearing modes, where found, accompanied by these new modes. These modes were identified as Alfvén-like wave [1,2,3]. Figure 1, shows a typical plasma, chosen to study the Alfvén waves. At $t = 1.8$ s a reduction of the temperature at $R = 2.05$ m can be seen, which is approximately the localization of the q=2 surface. SXR measurements show, that at this time a 2/1 tearing mode is excited (lower part of fig.2). The 2/1 tearing mode stays phase locked to the rotating external perturbation field. The spectrogram from magnetic pick-up coils (top part of figure 2) shows the appearance of secondary high frequency modes in the frequency range of $16-24$ kHz. The frequency of these Alfvén waves is well above the typical tearing modes frequency and well below the typical TAE frequency. Several bands appear after the DED is switched off. During the DED phase higher frequencies between $f = 14 - 24$ kHz from $t = 1.3 - 2.8$ s can be seen. The frequency of the Alfvén waves can not be a harmonic of the 2/1 tearing mode, as their frequency e.g. increases while the 2/1 frequency decreases as shown in figure 2 at $t = 4.3$ s. This excludes also the possibility, that the Alfvén wave are driven by a magnetic field ripple due to large rotating 2/1 tearing mode, as the Alfvén wave frequency would then be proportional to the 2/1 tearing mode frequency. In this discharge at $t = 2.2$ s ECCD is switched on, leading

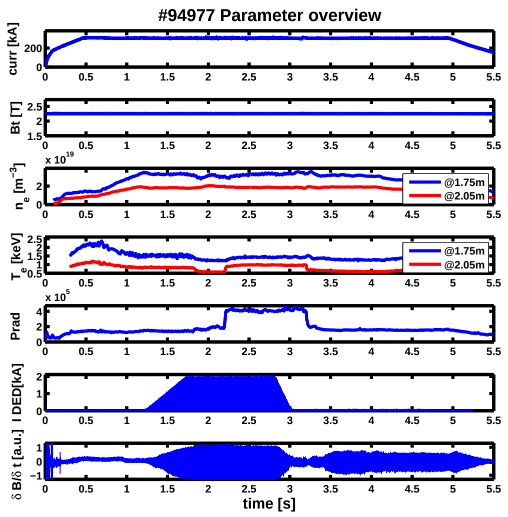

Figure 1: This figure shows the main plasma parameter chosen for a series of discharges. In this discharge the DED was used in 3/1 configuration. The frequency of the perturbation field was set to 1 kHz. The temperature traces show at $t = 1.8$ s a reduction of the temperature at $R = 2.05$ m, which is approximately the $q = 2$ surface. At $t = 2.2$ s ECRH-heating was applied.

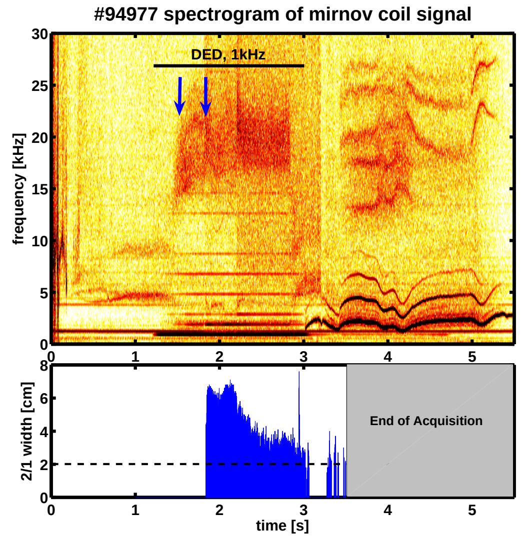

Figure 2: The upper figure shows the spectrogram of a magnetic pick-up coil. Between $t = 1.5 - 2.8$ s and $t = 3.2 - 5.2$ s signals with a frequency in the range of $f = 14 - 29$ kHz can be seen. The frequencies below 10 kHz belong a 2/1 tearing mode with harmonics. The lower figure shows the width of the 2/1 tearing mode obtained by SXR-measurements. The dashed line shows minimum islands width detectable by SXR.

to a decrease of the island width. The frequency of the Alfvén waves is not influenced by this. This result is contradictory to earlier publications, where a significant dependence of the Alfvén waves frequency to the 2/1 mode width was shown[1,2,3]. At $t = 3$ s the 2/1 tearing modes unlocks from the external perturbation field, which is ramped down in amplitude. At $t = 3.2$ s several harmonic of the 2/1 tearing mode frequency can be seen on the spectrogram. The appearance of an additional harmonics indicates, that the signal modulation due to this 2/1 tearing modes becomes more non-sinusoidal, e.g. because of a non-uniform rotation, or because of an unsymmetric island topology. In this phase several branches of Alfvén waves appear with a frequency between $f = 13 - 27$ kHz from $t = 3.2 - 5.8$ s can be seen.

Mode number calculations show, that the Alfvén waves appear in pairs rotating in opposite directions. The toroidal mode numbers presented in figure 3 show that they are $n = \pm 1$. The poloidal mode number calculation gives $m \leq |3|$. The frequency splitting of the bands is twice the 2/1 mode frequency [1,2,3].

Up to now, it is not clear, why the frequency bandwidth of the high Alfvén waves differs during the DED phase at $t = 1.5 - 2.8$ to the natural rotating mode at $t = 3.2 - 5.2$ s. Operating the DED with a frequency of 3.75 kHz clearly shows (figure 4), that there seems to be in principle no difference. In the DED phase at $t = 1.8 - 3$ s of this discharge several bands of the Alfvén waves can be seen, and remain, when the 2/1 tearing modes unlocks from external perturbation field and rotates freely. In this phase, several harmonics of the 2/1 mode frequency can be seen either.

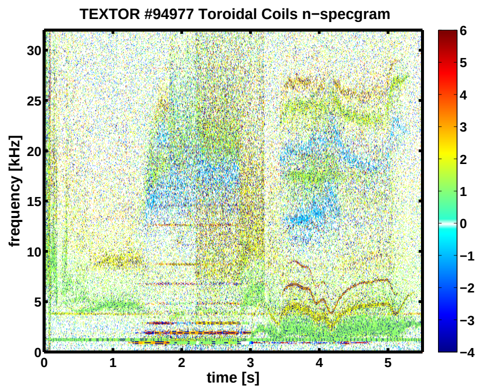

Figure 3: The toroidal mode number calculation shows, that the branches of the Alfvén wave rotate in different directions and have a toroidal mode number of $n = \pm 1$.

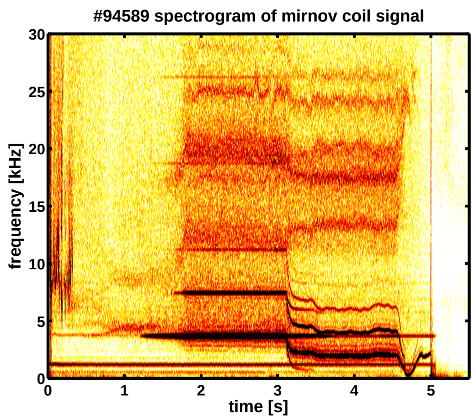

Figure 4: Spectrogram of magnetic signal, showing the excitation of the Alfvén waves in the DED phase at $t = 1.8$ s, and remain, when the 2/1 tearing mode unlocks from the external perturbation field at $t = 3.1$ s.

A striking new characteristic of the Alfvén waves compared to earlier publications is, that a 2/1 tearing mode , which was deemed to be necessary for their excitation described in former publications [1,2,3] is not the only way these Alfvén waves can be excited. Figure 2 clearly shows, that the Alfvén waves are excited 300 ms ($t = 1.5$ s) before 2/1 tearing mode onset ($t = 1.8$ s). The onset of the 2/1 mode can be seen in the lowewr part of figure 2. This is contradictory to earlier report from TEXTOR[1] and FTU[2]. Figure 5 shows this even more impressive. At $t = 1.8$ s a 2/1 tearing mode is excited by the external perturbation field, which suppresses the Alfvén waves, which appeared already 400 ms before. At $t = 2.2$ s the 2/1 tearing mode is suppressed by ECCD. Directly afterwards the Alfvén waves reappear with an smaller frequency bandwidth.

Earlier publications described these modes as Alfvén-like modes. Already there was shown, that the frequency scales like $f_a \propto B_0/\sqrt{n_e}$. For the first time, it was shown at TEXTOR, that the frequency of these mode also depends on the ion mass. Figure 6 clearly shows the dependence of the measured frequency on the ion mass. The measured frequency is reduced in discharges using an operating gas with an higher ion mass. For the discharges performed in pure hydrogen (#98810) or deuterium (#98790) operating gas, the H-D ratio give an Hydrogen content of 85% and 43% respectively, obtained by measurement of the HD-ratio. From this a Z_{eff} is estimated, yielding to a Z_{eff} of 1.15 and 1.6 respectively. Using these values as some kind of calibration of the measured frequency on the ion mass, one obtains from the measured frequency a reasonable Z_{eff} of 3.3 for the experiments performed in Helium4 discharges, confirming a Alfvén frequency scaling: $f_a \approx B_0/\sqrt{m_i n_i}$.

Summary

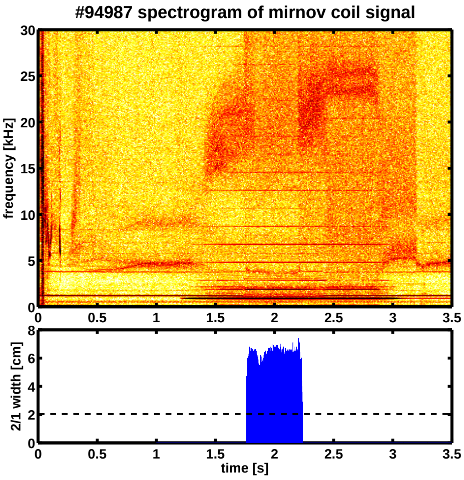

Figure 5: Spectrogram of magnetic signal and 2/1 island obtained from SXR, showing, that the Alfvén waves can be excited by the external perturbation field without 2/1 tearing mode. Contradictory to earlier publications, the 2/1 tearing mode even suppresses the Alfvén waves at $t = 1.8$ *s, destabilized again when the tearing mode is stabilized* $t = 2.25$ *s.*

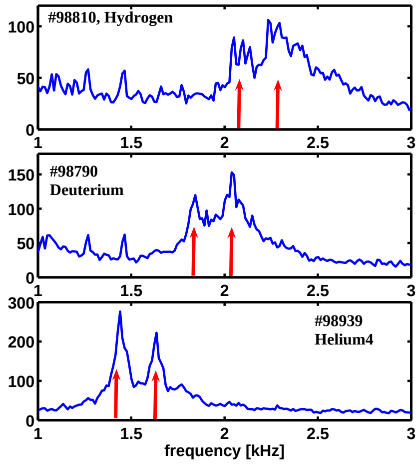

Figure 6: The influence of the ion mass on the measured frequency is shown in this figure. With increasing the ion mass by changing the operating gases from Hydrogen, to Deuterium and later Helium4 the frequency of the Alfvén waves is reduced.

A new class of Alfvén modes have been observed at TEXTOR and FTU. The Alfvén-modes appear in pairs rotating in different direction in some kind 2/1 tearing mode rest frame. It could be shown that the frequency of these modes scale like the Alfvén frequency. These Alfvén waves are excited, either by large tearing modes or a rotating perturbation field, which field has a strong fourier component resonant to the $q = 2$ surface. As the Alfvén modes are excited also in discharges without tearing mode, they can not be localized inside them, as it was published earlier[2]. The oscillation of the magnetic fields lines, which are needed for Alfvén waves, might be caused by the radial field superimposed of a large tearing mode and of the perturbation field in their vicinity. As already mentioned earlier, the frequency of the Alfvén waves do not scale linearly on the 2/1 tearing mode frequency. A linear excitation mechanism by a direct influence a field ripple causes by the tearing mode can be excluded. The magnetic field line oscillation caused by the external perturbation field could be a reason for the creation of the Alfvén waves before the 2/1 tearing mode is excited. The rotating perturbation field might already be deforming the flux surfaces, destabilizing the Alfvén waves, without an occurred reconnection. A detailed investigation of the vicinity of the q=2 surface by upgraded diagnostics is planned for the near future.

References

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