Coupling of Alfvén-like Modes and large 2/1 Tearing Modes at TEXTOR

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Abstract

A new class of MHD modes has been observed at TEXTOR($R = 1.75$ m, $a = 0.46$ m). The excitation of intensive 2/1 tearing modes is accompanied with the excitation of high frequency modes. These modes are found for different plasma conditions and appear only in pairs, with slightly different frequencies. A similar observation is reported from FTU [1].

There are several ways to excite 2/1 tearing modes at TEXTOR. The first way is to use the error field scaling for the excitation of 2/1 tearing modes. It was shown [2], that 2/1 tearing modes can easily be excited in low density and high co-NBI-power discharges. The second way of 2/1 tearing mode excitation is to use of the Dynamic Ergodic Divertor(DED). The perturbation field of the DED in its 3/1 configuration excites a 2/1 tearing mode in a controlled and reproducible way [2].

MHD spectroscopy of high frequency modes

Discharges with strong 2/1 tearing mode activity often show secondary high frequency modes. MHD spectroscopy show the 2/1 tearing with a frequency of $f \approx 2$ kHz and some weak harmonics with a frequency up to $f \approx 10$ kHz. The rotating 2/1 tearing mode is than accompanied by pairs of high frequency (HF) ($f \approx 20-25$ kHz) modes. The frequency of these HF-modes is well above the typical tearing modes frequency and well below the typical TAE frequency. Figure 1 shows a spectrogram a Mirnov coils signal. In this discharge a low density ($n_e \approx 5 \cdot 10^{18}$ m^3) start-up with a high power ($P_{NBI} = 1.3$ MW) neutral beam injection ($t = 0.3 - 2.8$ s) in current direction, was chosen to excite a 2/1 tearing mode. This unlocks first at $t = 0.55$ s and later again $t = 1.85$ s. The modes to be discussed can be seen at $t = 0.55 - 0.7$ s in the frequency range of $f \approx 25$ kHz and $f \approx 42$ kHz and starting from $t = 2.2$ s. There is a relationship between the large 2/1 tearing mode and the excitation of the HF-modes. First the 2/1 tearing mode unlocks a $t = 1.85$ s and later the HF appear at $t = 2.2$ s. At this time the signal intensity of the 2/1 tearing mode increases and an additional harmonic appears. The appearance of an additional harmonic indicates, that the signal modulation due to this 2/1 tearing modes becomes more non-sinusoidal, e.g. because of a non-uniform rotation.

An additional feature of this mode is, that a critical 2/1 island size is needed to excite the HF-modes.The island size can be influenced by ECRH or ECCD [3]. It can be seen in figure 3, that there seems to be a linear dependence of the 2/1 tearing mode width for the change of the HF-modes frequency. With increasing island width the HF-modes frequency increases, either. The island width in arbitrary units in these figure is estimated from the magnetic field amplitude of the 2/1 tearing mode measured by Mirnov coils, divided by its frequency.
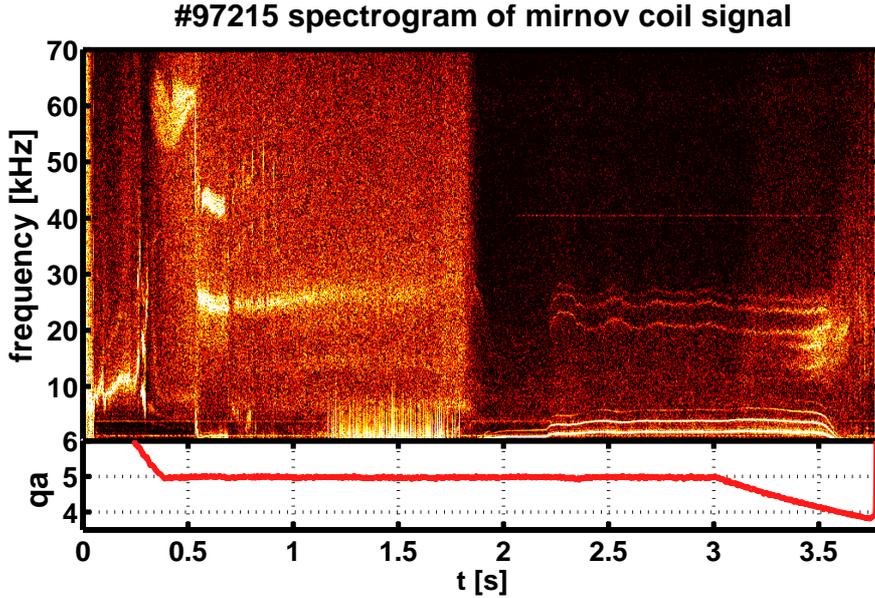
Figure 1: The upper figure shows a spectrogram of a Mirnov Coil signal. At $t = 0.55 - 0.7$ s mode activity in the frequency range of $f \approx 25$ kHz and $f \approx 42$ kHz can be seen. Additional mode activity can be seen starting at $t = 2.2$ s in the frequency range $f = 15 - 25$ kHz. The lower figure shows the edge safety factor in cylindrical approximation. Starting from $t = 3$ s the plasma current was constantly increased, by keeping the magnetic field constant.

In several discharges it is clearly seen, that the frequency of the HF-mode 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. This excludes also the possibility, that the HF modes are driven by a magnetic field ripple due to large rotating 2/1 tearing mode, as the HF-mode frequency would than be proportional to the 2/1 tearing mode frequency.

An additional evidence for the direct coupling of the tearing mode and HF-mode is obtained, if one compare the frequency of the 2/1 tearing mode with the frequency difference of the two HF-modes. It was found that the two branches of the high frequency mode differ exactly by twice the 2/1 tearing mode frequency, as can be seen in figure 4:

$$2 * f_{2/1\ TM} = f_{2.\ HF-mode} - f_{1.\ HF-mode}. \tag{1}$$

The dependency of the frequencies on the evolution of the 2/1 tearing mode frequency indicates, that the modes are rotating within a 2/1 island rest frame.

Mode number analysis

The mode number analysis yields a rotation in the electron drift direction (negative number) for one high frequency signal and in the ion drift direction for the other one. The different algebraic signs of the toroidal mode number indicates that the high frequency modes propagate in opposite direction. The poloidal mode number determination gives $m = \pm 2$. Together with the toroidal mode number one yields $-2/-1$ and $2/1$ modes. Figure 6 shows, that the HF-modes at $t = 2.2 - 3.5$ s have a toroidal number of $n \pm 1$ and figure 7 shows a poloidal mode number of $m \pm 2$. The additional pair, which appears at $t = 3.2$ s, when the edge safty safety
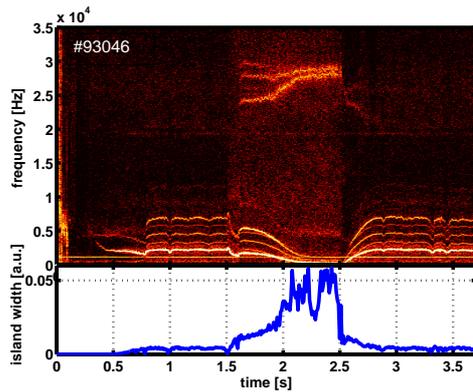
Figure 2: In the upper figure a discharge with a natural 2/1 tearing mode is shown. At t = 1.5 − 2.5 s ECRH is applied. The HF-modes appear and their frequency increases while the 2/1 tearing mode frequency decreases. The lower time trace shows a rough estimation of the island width, obtained from magnetic signals.
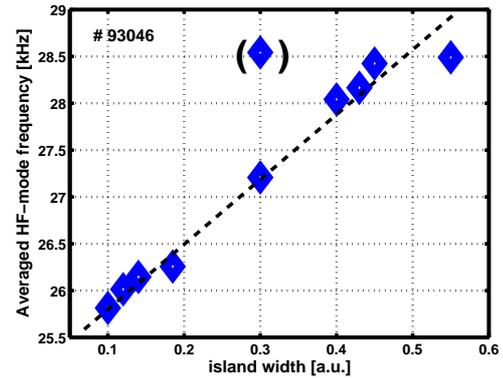
Figure 3: The averaged HF-mode depends linearly on the 2/1 tearing mode width, obtained from magnetic signals. The data point in brackets belongs to t = 2.3 s in figure 2, where the 2/1 width estimation fails.

factor is reduced from $q_a = 5$ to $q_a \approx 4$ has a different symmetry. Here the mode numbers are $n \pm 1$ and $m \pm 3$.

In both cases the positive mode number corresponds to the mode with the higher frequency. This property is depending on the rotation direction. By using a rotating perturbation field the rotation direction of 2/1 tearing mode can be chosen. Mode number determinations show the dependence of the high frequency modes on the rotation direction of the 2/1 tearing modes. Mode number calculations show, that the signs of the high frequency modes changes their sign if the 2/1 tearing mode changes its rotation direction.

Alfvén like scaling

As these modes were seen in various discharges, scalings on different plasma parameters were performed. A linear scaling on the toroidal magnetic field and density were found. The measured HF-mode frequency scale with the the Alfvén velocity $v_A = B_0/\sqrt{n_e}$, indicating an Alfvén-like mode. As the range of density and magnetic field values at TEXTOR are limited, values obtained from FTU were also included. Figure 5 shows the TEXTOR results together with data obtained at FTU. Additional values from FTU are presented in [1]. This figure shows the Alfvén-velocity of the HF-modes accompanying the 2/1 tearing modes. The blue rings show naturally excited 2/1 tearing modes. The red dots and magenta diamonds corresponds to DED excited 2/1 tearing modes. The values for a 2/1 tearing mode unlocking from a static perturbation field are indicated by red dots, tearing modes excited by rotating perturbation field by magenta diamonds. A larger amount of data points, especially from FTU, can be found in [1] stressing the scaling of the HF-mode frequency with the Alfvén velocity.
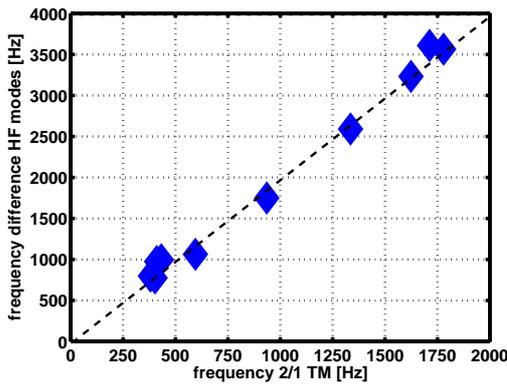
Figure 4: These figure shows, that the frequency difference of the two high frequency is twice the 2/1 tearing mode frequency.
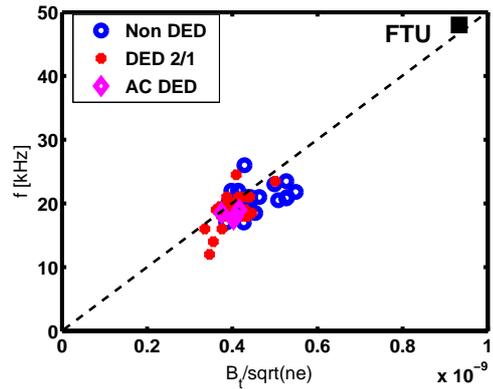

Figure 5: Values from TEXTOR and FTU show a linear scaling of the measured HF-mode frequency and Alfvén velocity.

Summary

A new class of MHD modes has been observed at TEXTOR and FTU. These modes are directly linked to the presence of large tearing modes. The HF-modes appear in pairs rotating in different direction in some kind 2/1 tearing mode rest frame. Their frequency lies well above the typical tearing mode frequency and well under the TAE frequency. The HF-mode frequency shows a Alfvén scaling, although all discharges are performed in ohmic conditions. At the moment the source of the energy needed for the excitation of the Alfvén like modes is under discussions.
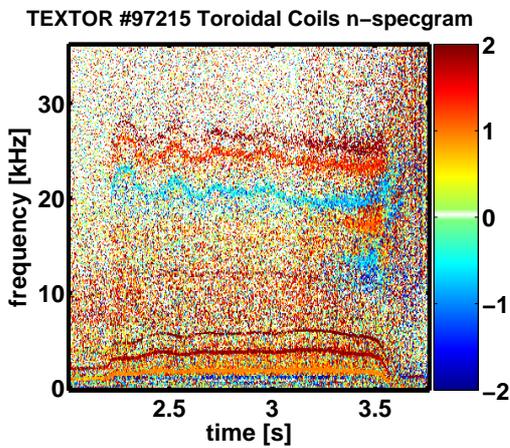
Figure 6: The toroidal mode numbers of the first pair of HF-mode are $n \pm 1$, as well as for the second pair (see figure 1). At $f \approx 2\ kHz$ a $n = 1$ mode is detected.
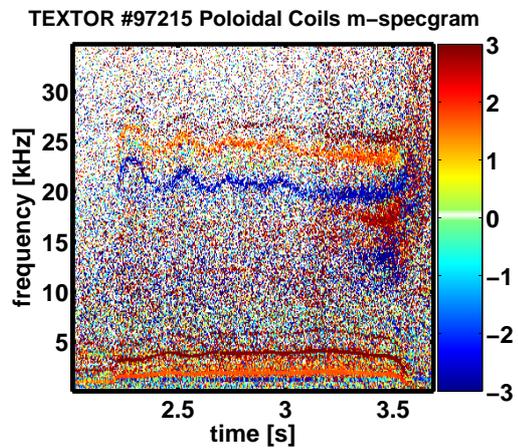

Figure 7: The poloidal mode numbers of the first pair of HF-mode are $m \pm 2$, and for the second pair $m \pm 3$ (see figure 1). At $f \approx 2\ kHz$ a $m = 2$ mode is detected.

References

[1] P. Buratti et al. *this conference* P5.055

[2] H.R. Koslowski et al., *31st EPS Conf. London 2004*, P1-124

[3] E. Westerhof et al., *this conference*, P4.071