

Testing the modes coupling effect on flux pumping in plasmas

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Introduction

Some recent results claiming the sawtooth suppression via flux pumping at HBT-EP have been presented [1], due to the magnetic coupling between the central 1/1 mode and its more positive poloidal neighboring high amplitude modes. The strength of the coupling with larger edge modes is found to favor the plasma current broadening associated with the flux pumping mechanism. It has been also found that, conversely, an intense sawtooth activity is related to the coupling with the stabilized lower amplitude neighboring modes. In order to check these assumptions, a theoretical multimode perturbations model [2] is proposed.

The perturbed solution

In this regard, the following perturbed solution for the m/n magnetic flux [2]

$$\Psi_s^{mn}(t) = i(m/q_s - n) \times \left[\frac{\Delta^l}{(\tau + i\Omega_{MP})\Delta} \Big|_{\tau=0} + \frac{\Delta^l}{\tau\Delta} \Big|_{\tau=-i\Omega_{MP}} \exp(-i\Omega_{MP}t) + \sum_{p=1}^{7L} \frac{(\tau - \tau_p)\Delta^l}{\tau(\tau + i\Omega_{MP})\Delta} \Big|_{\tau=\tau_p} \exp(\tau_p t) \right] \quad (1)$$

is used to derive the perturbations amplitude $b_{\theta f}^{mn} = (mr_s^m/r_f^{m+1})|\Psi_s^{mn}|$ and frequency $f^{mn} = \text{Im}[(\partial\Psi_s^{mn}/\partial t)/\Psi_s^{mn}]$ to be compared to their experimental values [3], to test and validate the model. Furthermore, our modes localization technique [4] is used to either check the single mode model validity or to isolate the 1/1 sideband mode coupling effect on the central mode location. The latter plainly delivers the central mode safety factor profile $q = 1$. Subsequently, the magnetic axis profile q_0 is calculated using the simple Wesson type safety factor formula $q_0 = q_a \ln(1 - r^2/a^2)/\ln[1 - q_a r^2/q(r)a^2]$, where a and q_a are the minor radius and the plasma boundary safety factor, respectively. Δ is the determinant of the Laplace transformed system of linearized perturbed plasma and outer plasma equations having Ψ_s^{mn} and its radial derivative at the m/n magnetic surface radial coordinate r_s as unknowns. τ_p are the roots of $\Delta(\tau) = 0$ with τ the Laplace transform variable. Δ^l is simply the numerator determinant according to

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the Cramer's rule applied to the mentioned system of equations in order to find the solution associated to every mode. $l = m - m_1 + 1 + (n - n_1)(m_2 - m_1 + 1)$ where m and n span $m_1, n_1 \leq m, n \leq m_2, n_2$ and $L = \max_{m,n}(l)$. q_s and Ω_{MP} are the safety factor at r_s and the outer coils signal rotation frequency, respectively. Δ and Δ^l enclose the mode coupling effect. The mode amplitude is derived at the JET Fast Magnetic Acquisition System diagnostic coils, disposed at r_f .

Modelled vs experimental results

Shots performed during JET flux pumping campaigns have been chosen to test our code and evaluate the mode coupling effect. In the figure 1(a) is depicted the spectrogram of the perturbations from the shot no. 102438, showing a clear profile of the central 1/1 mode between 5 s and 7 s. Another $n = 1$ has been reported between 5.9 s and 6.6 s, at a lower frequency. A short 2/1 mode is also shown in the shot final phase. As a first step our model single mode approach

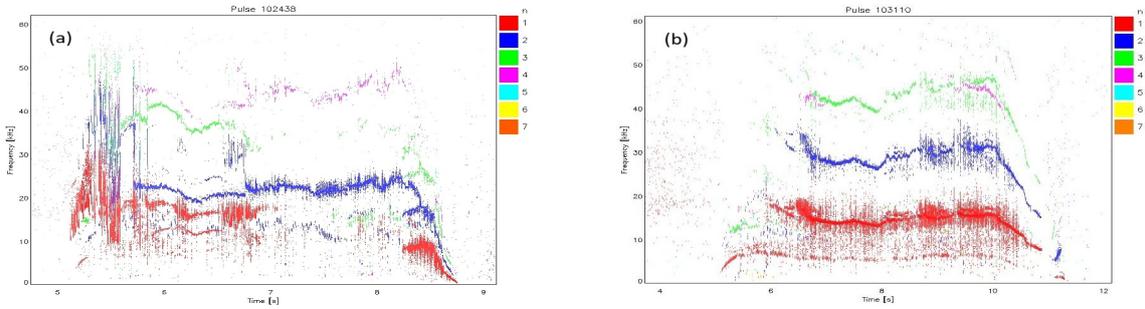


Figure 1: JET shot no. (a) 102438 and (b) 103110 modes spectrogram of frequencies.

based on (1) is tested for the 1/1 mode in figures 2(a-d), showing an excellent experimental mode amplitude and frequency retrieval by the calculated quantities. This retrieval is on par with the good experimental vs modelled location match, based our localization method. The modelled $q = 1$ profile is obtained from the EFTF equilibrium reconstruction safety factor data located at our modelled location. q_0 is calculated from the $q = 1$ profile. A good experimental vs modelled match is again obtained. The single mode approach is checked in figures 2(e-h) for the lower frequency $n = 1$ mode. It is clearly shown the good retrieval of all the involved experimental quantities by the calculated ones, no matter the $n = 1$ mode is chosen, each case having its peculiar initial conditions. At least according to the single mode mode, the sideband $n = 1$ can be any chosen mode. Starting with figures 2(i-l) the multimode approach is used in order to test the mode coupling mechanism effect. It is expected to be delivered all the coupled modes amplitudes and frequencies at the same time. The 2/1 mode has been chosen to play the role of the lower frequency poloidally coupled $n = 1$ mode in this case. Apart from an excellent double retrieval of the both modes frequencies, the choice was to best possible retrieve the central 1/1 mode amplitude at the cost of a reasonably good sideband mode amplitude retrieval. The latter

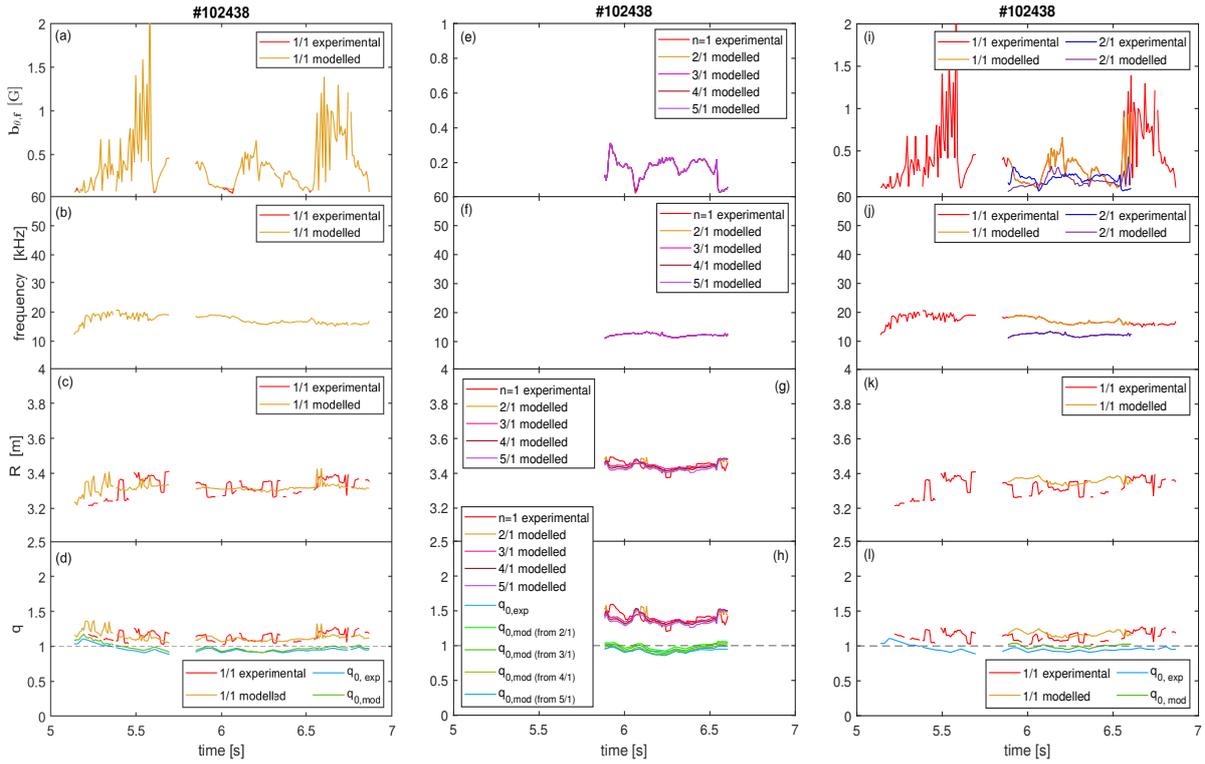


Figure 2: JET 102438 shot experimental vs single modelled 1/1 mode (a) amplitude, (b) frequency, (c) location, (d) $q = 1$ and q_0 profiles, experimental $n = 1$ vs single modelled 2/1, 3/1, 4/1, 5/1 modes (e) amplitudes, (f) frequencies, (g) locations, (h) $q = 1$ and q_0 , experimental vs coupled 1/1 and 2/1 modes (i) amplitudes, (j) frequencies, and experimental vs coupled 1/1 (k) location and (l) $q = 1$ and q_0 .

is more probably due to the multimode approach for two modes only. It is consistent to assume a higher number of modes to be considered, of more negative and more positive poloidal mode numbers, in order to balance and complete the influence of the single sideband mode taken into account. But this would alter the evaluation of the isolated sideband mode effect on the central 1/1 mode we expect to achieve. The modelled quantities are drawn during the common range of evolution of the both modes only. It seems that the coupled 2/1 has only a very slight effect on the 1/1 mode, as seen from the good location, $q = 1$ and q_0 retrievals. When the 4/1 or 5/1 modes are chosen (see figures 3(a-d) or 3(e-h)), the sideband mode effect is clearly stronger (and even more stronger in the 5/1 case) while keeping a very good/ reasonable amplitude/frequency retrieval. In the both cases q_0 is sensibly higher than unity, the usual prerequisite for the sawtooth suppression mechanism. No 3/1 sideband mode effect is shown due to the impossible amplitude and frequency retrievals. Hence, at least according to the multimode approach, the sideband $n = 1$ mode cannot be the 3/1 mode. The mode coupling effect has been also checked for JET shot no. 103110, depicted in figure 1(b), involving this time a notably high amplitude central 1/1 mode compared to its sideband lower frequency $n = 1$ mode, as seen from figures 3(i-l). The 4/1 sideband mode has been chosen, having a similar isolated effect as in the pre-

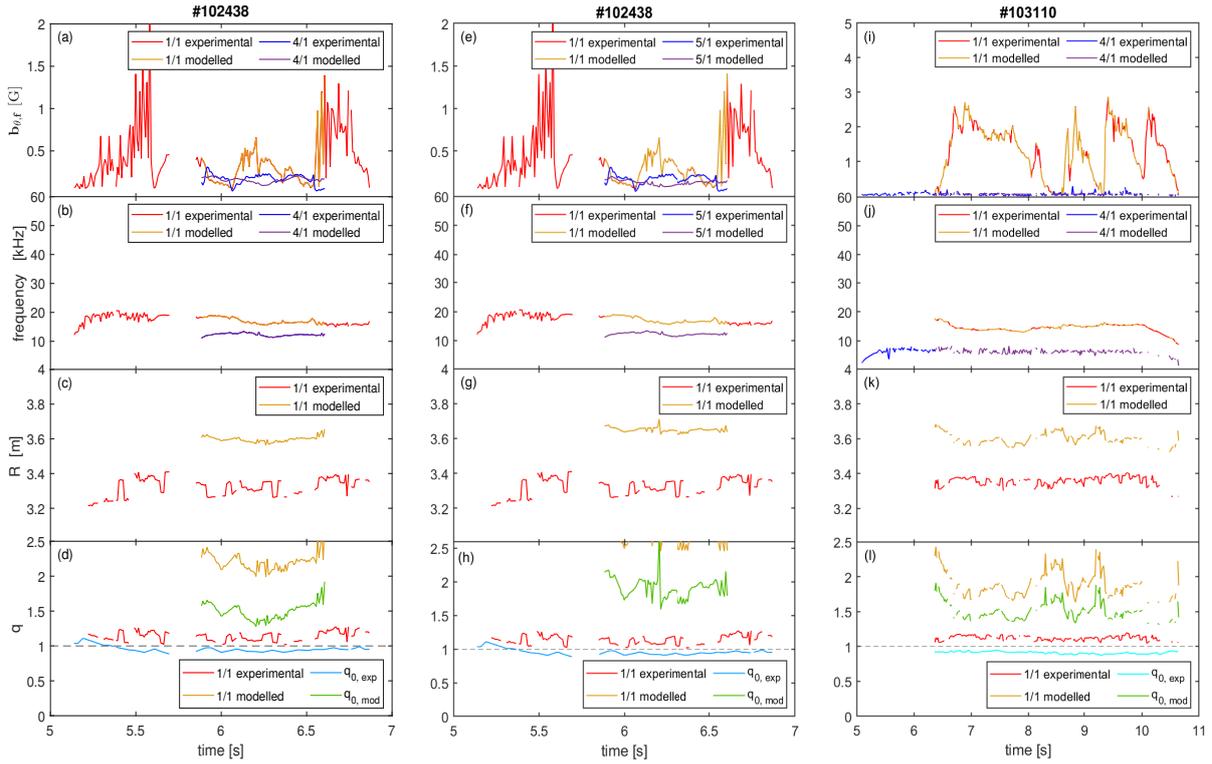


Figure 3: JET 102438 shot experimental vs modelled coupled 1/1 and 4/1 modes (a) amplitudes, (b) frequencies, experimental vs coupled 1/1 (c) location, (d) $q = 1$ and q_0 . The same quantities are shown (e-h) for the coupled 1/1 and 5/1 modes and (i-l) for shot no. 103110 coupled 1/1 and 4/1 modes case.

vous shot case, as well as the 2/1 or 5/1 modes, not depicted here. Despite the low sideband mode amplitude, the increase of q_0 is still significant. The assumed model plasma axisymmetry limits the physically relevant coupling to the poloidal case only. The toroidal coupling is only due to the model plasma inhomogeneously resistive plasma external structures.

Conclusions

It has been found that the core 1/1 mode isolated coupling with the edge modes of higher poloidal mode number increases the $q = 1$ safety factor, as well as q_0 , as a condition of the sawtooth suppression effect. It seems that the higher the sideband poloidal mode number is, the stronger the effect becomes. However, unlike the conclusions from [1], the closest sideband mode 2/1 has only a slight effect on the 1/1 mode and the association between the magnitude of the sideband mode amplitude and the sawtooth suppression or boost effect is not sustained.

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