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NTM avoidance through control of island rotation by external torque exploring the role of the polarisation current

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Introduction

In tokamak operation at high β_p the Neoclassical Tearing Modes (NTMs), destabilized by the loss of bootstrap current over magnetic islands at low q=m/n surfaces, can degrade the plasma energy confinement and cause disruptions. These modes can grow when β_p is above a critical value and are triggered when an initial perturbation has an amplitude above a certain threshold. Various triggering mechanisms have been proposed, but here we show that an intrinsic destabilizing mechanism can drive the mode even in undercritical conditions. Testing this mechanism, associated with the NTM rotation regime, gives suggestion for strategies to avoid the mode onset.

An important mechanism for NTM threshold is related to the role of the ion polarisation current either stabilizing or destabilizing depending on island rotating in the ion or electron diamagnetic drift; it is also related to the collisionality and viscous effects on the structure of the shear flow perturbation around and within the island [1]. Therefore, the control of island rotation can be considered as a mean to probe the destabilization of NTM thus offering a strategy of NTM avoidance. Our target is to explore how an initially marginally stable NTM in rotating plasma can be triggered by an intrinsic mechanism by suitably varying the difference between the frequency of the mode rotation and the toroidal plasma rotation. An electromagnetic torque, imposed by a resonant external static error field correction coils (EFCC), can decelerate the island and drive reconnection at β_p slightly above the critical value for onset of the mode. A parametric study is performed for JET-like rotating plasmas in order to investigate the mode onset in typical hybrid scenarios (sawteeth free), taking into account also viscous effects deforming the island, and to establish the braking rotation limits by external field coils for understanding NTM stability and avoidance. The dynamics of the island evolution is discussed by an analysis of the region of metastability in the phase space (W, dW/dt).

Intrinsic mechanism of NTM trigger

The NTM island evolution, W(t), is described by a new form of the generalized Rutherford equation (G.R.E.) [2] including terms characterizing the dynamic of these metastable modes, stable at low β_p and growing when the island width becomes larger than a critical width W_{cr}. and including a new inertial coefficient g_1 taking into account the island deformation by viscous effects (for symmetric island g_1 =0.82). The mode stability depends on a number of effects coming from stabilizing terms as the Δ'_0 usual stability parameter, Δ'_{GGJ} ($\propto 1/W$) related to the favourable toroidal curvature, Δ'_{wall} due to the action of the resistive wall and destabilizing terms as Δ'_{BS} ($\propto 1/W$) associated to the bootstrap current; the contribution Δ'_{pol} ($\propto 1/W^3$) , related to the ion polarization current proportional to the difference between the island rotation and the ion diamagnetic frequency (ω_T) can be stabilizing or destabilizing depending on the island rotating in co-/counter- direction w.r.t. the ion or electron diamagnetic drift direction. We assume that the plasma rotates in positive direction as the ions. The competition among the terms in G.R.E. provides the stability conditions: they are favourable if the dominant bootstrap term is balanced by the other ones, unfavourable if the ion polarization term change sign from negative to positive, meaning that the island decelerate with respect the plasma bulk by the braking effect of an external magnetic torque. An initial perturbation of amplitude less than the critical threshold width becomes unstable if Δ'_{pol} change sign. The investigation of this trigger due to an inertial intrinsic mechanism is essential for the understanding of NTM stability and avoidance.

Onset of the mode by EFCC

Interaction between mode and resonant external magnetic field is investigated for NTM in a JET-like plasma hybrid scenario, sawteeth free, thus avoiding the possible onset by sawteeth crash. To probe the stabilizing/destabilizing role of the polarisation current acting on the frequency difference, we consider a braking force driven by external magnetic perturbations, generated by coils, with (m,n) helical components; this external field, resonant at q=m/n, can alter the island rotation decelerating the mode and changing the sign of the ion polarisation term inside the narrow region with $W<W_{cr}$ (**Fig.1**). For our analysis, we choose a (4,1) magnetic external perturbation resonant at q=4/1 to explore the possibility to destabilize one of the most stable mode. The plasma rotates at moderate frequency (2 ω_T) via neutral beam injection (NBI). In **Fig.2** phase space diagrams (W, dW/dt) are shown for 2 values of EFCC intensity and β_p: **Fig.2(a)** shows that the Δ'_{pol} change sign and goes up destabilising the mode for $W<W_{cr}$ an $\beta_p< \beta_{cr}$, **Fig.2(b)** shows as in **Fig.2(a)** the mode triggering for $W<W_{cr}$ an $\beta_p> \beta_{cr}$. It is worth noting that the plasma rotation fully stabilizes the mode with larger effect as β_p increasing.

Note that we can avoid the destabilization from Δ'_{pol} when EFCC are applyied by the rotation island control.

The polarisation term affects only the ion destabilization: the value of the saturation width is unaffected, as it depends on plasma equilibrium.

For the plasma parameters used in these calculations we find a Δ'_{GGJ} not negligible with respect the Δ'_{BS} due to large value of the ratio of pressure and q gradients.

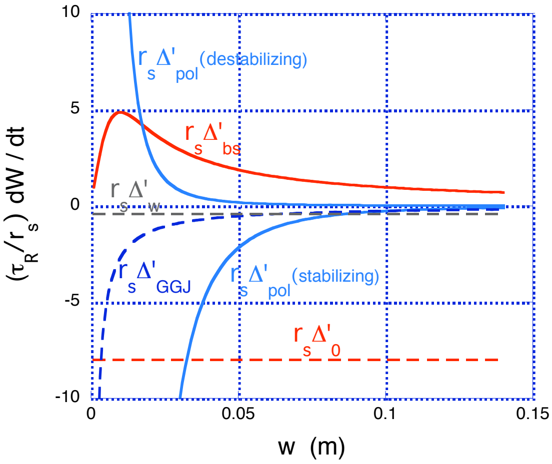

Fig.1 - G.R.E. terms with positive and negative Δ'_{pol}

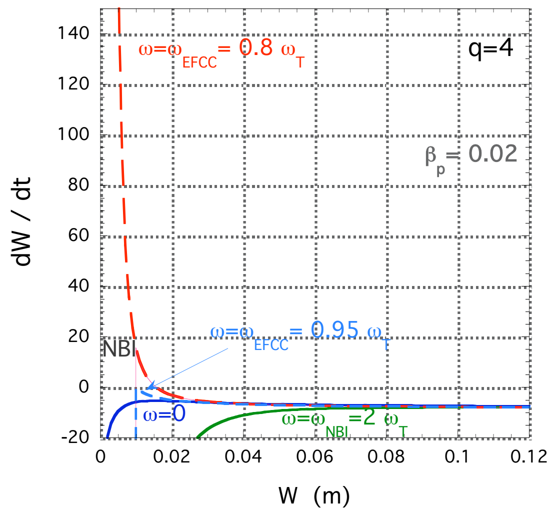

Fig.2(a) – Phase space for locked and rotating islands β_p=0.25

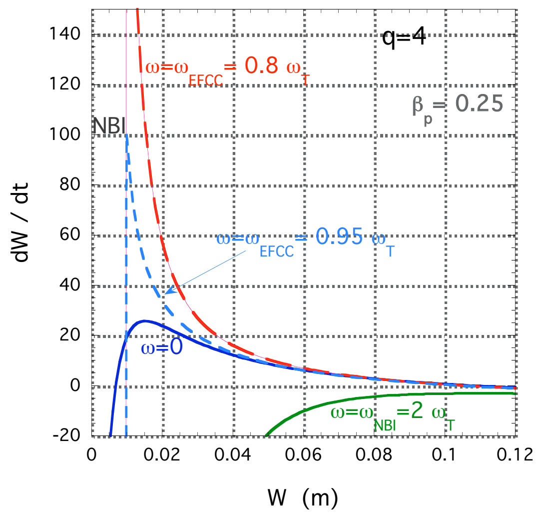

Fig.2(b) – As Fig.2(a) for β_p=0.25

Viscous effects deforming the magnetic island have been also taken into account by varying the inertial coefficient g_1 in the Rutherford equation (g_1 being < 0.82). We find a small variation in the amplitude evolution,

Experimental destabilization scheme

We describe now an experiment proposal to explore the destabilizing role of the ion polarisation current through braking rotation by EFCC. Our goal is to trigger a marginally stable NTM (4,1) both with Δ'_{pol} less than Δ'_{BS} in such a way that in absence of EFCC the mode amplitude evolution goes to zero (**Fig.3**) and in slightly overcritical conditions. We apply a small rotation (1.5 ω_T) to the plasma by using NBI: at this stage the difference between island and ion diamagnetic frequency is positive and Δ'_{pol} is stabilizing. For the mode (4,1) the critical width, below which the mode is stable and the ion polarization current is important, is about 1-1.4 cm. At this stage we apply EFCC for a short time (about 350 ms) decelerating the island up to 0.5 ω_T. No auxiliary heating, like ion cyclotron resonance heating (ICRH), is switched on: the aim is to maintain constant at a low level the poloiodal beta for avoiding the natural mode onset for $\beta_p > \beta_{cr}$. During the EFCC braking the mode amplitude grows up a value about 2 times the saturated one (in our example W_{sat}=0,036 m). It should be noted that this not negligible amplitude can be cover a few hundred msec before goes down to W_{sat}. In Fig.4 we show the phase space corresponding to **Fig.3**.

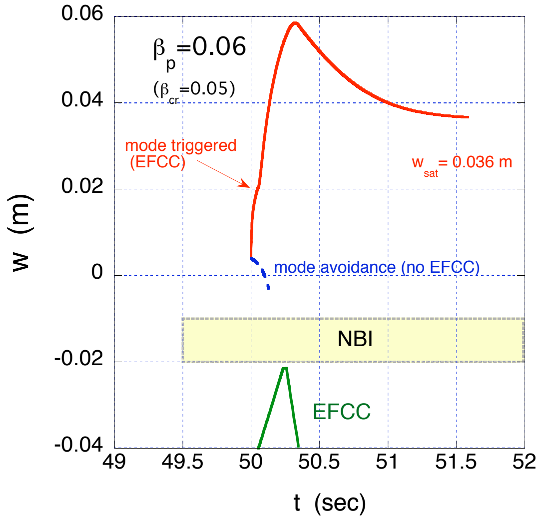

Fig.3 – (4,1) amplitude evolution for destabilization by EFCC

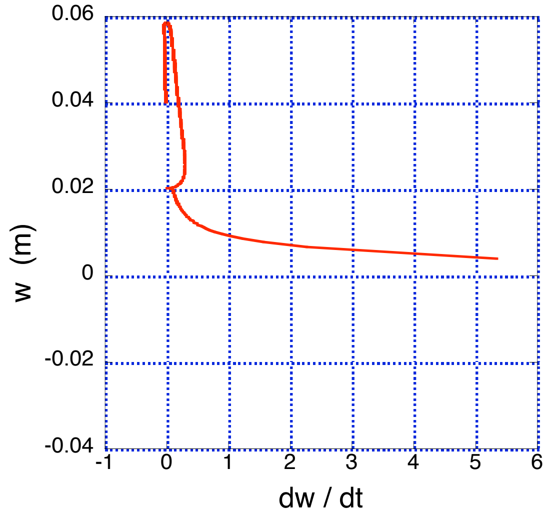

Fig.4 – Phase space for Fig.3

Conclusions

The probe of the stabilizing/destabilizing role of the ion polarization has been performed in order to give a strategy for avoiding NTM onset. The mode trigger by ion polarisation can be obtained by using external (error) magnetic field perturbations resonant at the q=m/n location of the mode. The EFCC effect is to brake the island rotation, initially greater than the ion diamagnetic frequency. The deceleration decreases the difference between island and natural mode frequency changing the negative sign of the Δ'_{pol} to positive thus triggering the mode. Onset by this intrinsic mechanism can be produced also for stable mode degrading the plasma energy confinement and causing disruptions. Understanding of this mechanism offers the avoidance strategy based on the control of the rotation: the growth of an NTM perturbation can be avoided by imposing an appropriate rotation.

References

[1] A.I. Smolyakov, A.Hirose, E. Lazzaro et al., Phys. Plasmas **2**, 1581 (1995)

[2] S. Nowak, E. Lazzaro, C. Marchetto, P4.077, 34th EPS, Warsaw, Poland 2007