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Linear stability analysis of Tearing Modes on FTU by means of MARS code

G. Pucella[1], V. Fusco[1], P. Buratti[1], E. Giovannozzi[1], M. Marinucci[1], G. Vlad[1]
[1]ENEA, Fusion and Nuclear Safety Department, C. R. Frascati (Roma), Italy

In tokamak fusion devices it is of great interest, for the goal of practical fusion power, to operate at high plasma densities, but the maximum density achievable is limited by the appearance of events causing a rapid loss of plasma confinement, so defining an operational density limit. Dedicated density limit experiments were performed in recent years on the Frascati Tokamak Upgrade ($R_0 = 0.935$ m, $a = 0.30$ m, circular poloidal cross section, B_T up to 8 T, I_p up to 1.6 MA) [1].

For different (B_T, I_p) configurations the gas injection was tailored to produce an increasing density up to disruption for density limit. All the investigated pulses present a very similar MHD phenomenology, with the development of a (2, 1) tearing mode, as it is possible to see in Figure 1, where the time traces of some relevant quantities are reported for a specific pulse. The standard tearing mode is driven by the radial gradient of the current density profile. For our analysis, the temporal evolution of the current density and safety factor profiles has been obtained from the JETTO transport code considering the electron temperature profile from Electron Cyclotron Emission diagnostics and assuming Spitzer resistivity. During the density ramp-up, as a consequence of the increasing radiation losses in the peripheral region of the plasma, there is a contraction of the temperature profile leading to a clear shrinkage of the current profile, and in this phase we observe the onset of the tearing mode [2].

In this work, the linear stability analysis of the tearing mode has been performed by means of the MARS code [3], which is a global, full, resistive, compressible linear MHD code written in general curvilinear geometry. In particular, for the tearing mode, it can solve the MHD equations in toroidal equilibria without separating ideal and resistive regions. The output of this code for the specific pulse of Figure 1 is reported in Figure 2, where the solid lines represent, for each time, the growth rate γ (times the Alfvén time τ_A) as a function of the inverse of the Lundquist number S (times the square of the normalized resonance radius ρ_s^2), showing that for low values of S the standard relation for a tearing mode, $\gamma\tau_A \propto S^{-3/5}$, obtained by matching ideal and resistive regions, is recovered. Clearly, in the FTU pulse, for each time we have a specific value of the Lundquist number, so that, along the solid lines, the solid circles represent for each time the effective growth rate (times the Alfvén time) corresponding to the actual value of the Lundquist number for that time. From this analysis the tearing mode results to be stable before 0.85 s (because we have not the intersection between the solid lines and the corresponding vertical dashed lines), whilst the mode is clearly unstable after 1.05 s, which is in good agreement with the experimental observation from the pick-up coil signals, showing a stable phase before 0.88 s and an unstable phase after 0.96 s (see Figure 1). A systematic study of the linear stability of tearing modes on FTU has been performed, exploring the high density domain in a wide range of values of plasma current and toroidal magnetic field.

References

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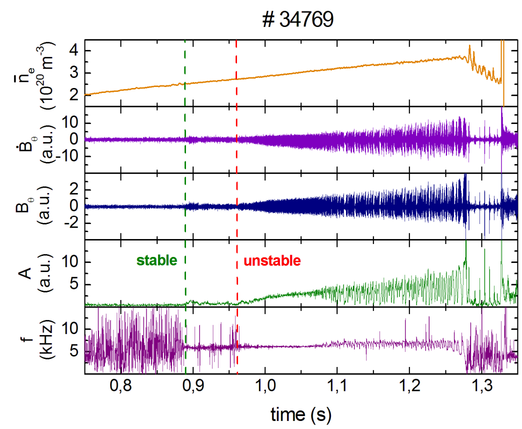

Figure 1. Time traces of some relevant quantities for a specific pulse on FTU ($B_T = 8$ T, $I_p = 0.9$ MA). From top to bottom: central line-averaged density, output from the magnetic pick-up coils, poloidal magnetic perturbation, mode amplitude and mode frequency.

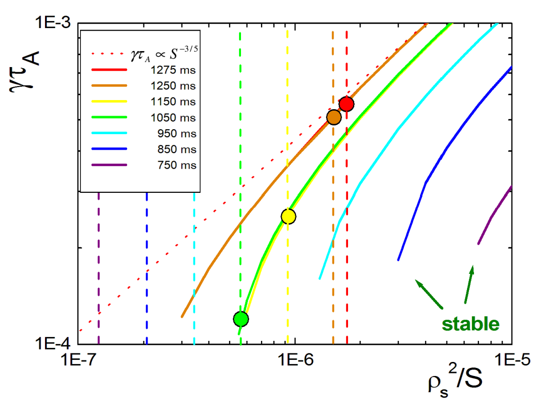

Figure 2. Growth rate times the Alfvén time as a function of the inverse of the Lundquist number times the square of the normalized resonance radius. Solid circles represent for each time the effective growth rate corresponding to the actual value of the Lundquist number for that time (vertical dashed lines).