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Infernal mode stability in negative-triangularity plasmas

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Tokamak plasma with negative-triangularity (NT) shape is an attractive operational configuration because this type of plasma has been found to be capable of achieving H-mode like confinement while operating in L-mode regime. The latter helps solve the plasma exhaust problems in future fusion reactors by avoiding the edge localized modes (ELMs). In recent experiments in DIII-D [1] and TCV [2], high-performance plasmas, with the normalized beta values of $\beta_N = 2.2\sim2.8$ have been achieved without ELMs in the NT configuration. This, combined with other technical advantages, renders the NT plasma a promising operational choice for future reactor design.

This work aims at numerical investigation of magneto-hydrodynamic (MHD) instabilities in NT plasmas. In particular, we consider the infernal mode stability in NT versus its positive-triangularity (PT) counterpart. Compared to other MHD modes such as the external kink and the resistive wall mode [3] and the tearing mode [4] which have recently been studied for NT plasmas, the infernal model is less exploited. This instability typically occurs in tokamak plasmas with reversed central magnetic shear, where the minimum safety factor (q_{min}) is close to a rational value [5]. In such a case, sufficiently high plasma pressure (which is achievable in NT experiments as mentioned earlier) can drive the infernal mode instability.

Utilizing the toroidal code MARS-F [6], this work systematically scans the plasma triangularity from negative to positive values while fixing the (non-monotonic) safety factor profile (Fig. 1(a-b)). Linear stability of the n=1 (n is the toroidal mode number) ideal infernal mode is then numerically computed, with examples of the results reported in Fig. 1(c).

For the q-profile considered here, we find that the infernal mode is more unstable in the NT plasma than that in the PT counterpart. Sufficiently high-beta drives instability within the whole range of the triangularity scan. However, the least unstable case occurs for the PT plasma. Moreover, at fixed q_{min}=2.01 and β_N=2, a stable window opens, again towards the positive triangularity value. The physical reason for the NT-destabilization is the less favorable curvature, when the mode is located towards the plasma edge where the triangularity effect is strong.

Other families of equilibria have also been considered, with varying q_{min} (near q=2) but fixed β_N and the triangularity value of 0.5. MARS-F modelling finds instability windows near q=2 as shown in Fig. 1(d). This, combined with the radially localized eigenmode structure (not shown here), confirms the infernal mode nature in these NT plasmas. The slight shift of the peak growth rate, with respect to the q=2 value, is due to the coupling of the infernal mode to the other (high-pressure driven) kink instability. This is different from the case of a pure infernal mode, with growth rate peaking at the rational-q location as e.g. reported in Ref. [7].

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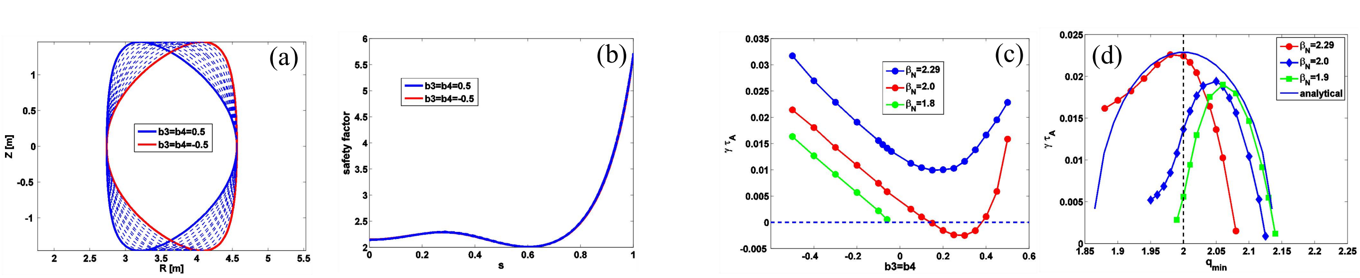

Figure 1. With scanning the plasma triangularity including both the NT plasmas and PT plasmas, (a) the plasma boundary shape, (b) the radial profiles of safety factor, and (c) the growth rate with different plasma pressure, $\beta_N = 2.29$, $\beta_N = 2$ and $\beta_N = 1.8$. (d) reports the growth rate versus q_{min} (near q=2) for the relative equilibrium with different plasma pressure, where the solid line denotes the analytic results from Ref. 7, and the value of the triangularity is 0.5.