Topic: EX-S

High Beta Plasmas Exceeding Dual Stability Thresholds in the MST RFP

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High-beta MST plasmas have been produced that exceed the stability thresholds for both local and global pressure-driven modes, but these plasmas also exhibit improved energy confinement [1]. Total beta, the average plasma pressure normalized to the total edge field pressure, reaches 26%, the largest value yet attained in the ohmically-heated RFP. Toroidal beta, normalizing to the edge toroidal field pressure, is about 100%. High beta is achieved by injecting deuterium pellets into MST plasmas with inductive current profile modification and improved confinement. The pressure gradient in these plasmas exceeds the Mercier criterion for local interchange, but there is no experimental indication of interchange modes affecting plasma performance. This is similar to recent results in helical devices such as LHD. The pressure gradient is also large enough to affect the stability of core-resonant tearing modes, representing a new regime for the RFP. These modes cause the bulk of energy transport in standard RFP plasmas and are normally driven entirely by a gradient in the current profile. This drive is reduced by current profile modification.

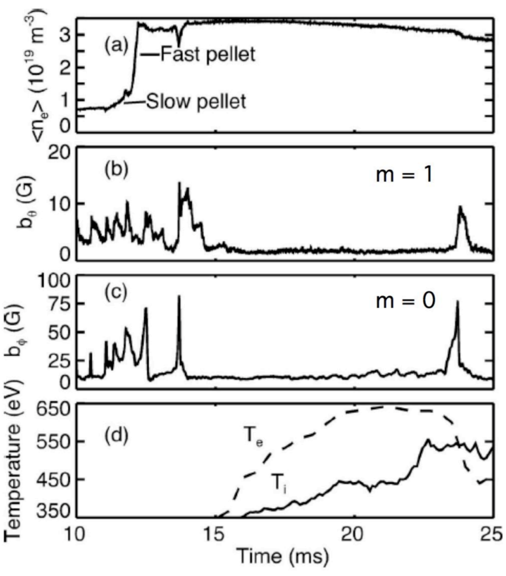

FIG. 1. Waveforms from a 0.5 MA improved confinement discharge with two pellets injected at about 11 ms, showing (a) central line-averaged density, (b) rms sum of core-resonant tearing modes, (c) rms sum of edge-resonant tearing modes, and (d) the electron and ion temperatures at r /a = 0.2. Current profile modification begins at 10 ms.

Due to the growth and spatial overlap of multiple internally resonant m = 1 tearing modes in standard RFP plasmas, the internal magnetic field is stochastic, and energy confinement is relatively poor. These modes are driven by a gradient in the current profile. With inductive modification of the current profile, these instabilities are reliably reduced, increasing Te threefold, improving energy confinement tenfold, and producing a total beta of 15%. The reduction of ohmic heating power accompanying the rise in Te prevented the pressure from approaching theoretical stability limits. In attempting to access higher density with gas puff fueling, edge-resonant m=0 modes are triggered when the average density exceeds about 1e19 m-3. This leads to confinement degradation. By depositing fuel directly in the plasma core with pellets, this edge instability is avoided, even up to a density of 4e19 m-3. Higher density increases the rate of energy transfer from electrons to ions, increasing ion thermal energy, but also reducing the increase in Te and the drop in the ohmic power. Beta is thereby increased.

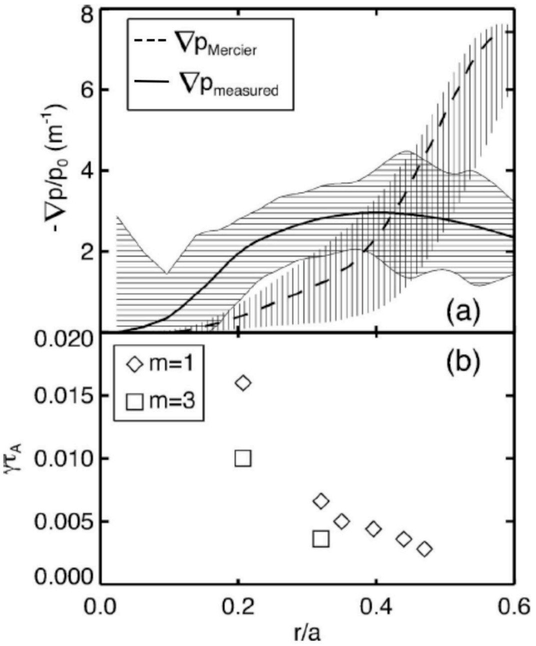

FIG. 2. (a) Measured pressure gradient profile from a 0.2 MA plasma plotted with the associated Mercier gradient limit and (b) calculated growth rates for m = 1 (tearing) and m = 3 (interchange) modes plotted at their respective locations of resonance. All modes are resistive and pressure driven.

The increase in density and temperature with pellet injection is illustrated in Fig. 1. Two pellets are injected near the beginning of current profile modification in a discharge with a toroidal plasma current of 0.5 MA. It is this current at which the largest density and temperature are produced. Once the m = 1 and m = 0 fluctuations are reduced, Te increases substantially. With the increased density, Ti increases as well.

While beta is substantially increased at 0.5 MA, the largest beta, 26%, has been achieved at 0.2 MA. The measured pressure gradient profile from a 0.2 MA plasma is shown in Fig. 2(a). In the same plot is the critical gradient defined by the Mercier criterion. Inside of r/a = 0.4, the Mercier criterion is surpassed, and m = 3 interchange modes are predicted to be linearly unstable. The growth rates of two such modes are shown in Fig. 2(b). This pressure gradient is also large enough to affect the stability of the m = 1 tearing modes. Growth rates for a few of these modes are also shown in Fig. 2(b). To our knowledge, this is the first time an RFP plasma has surpassed the Mercier criterion and been subject to core-resonant pressure-driven tearing.

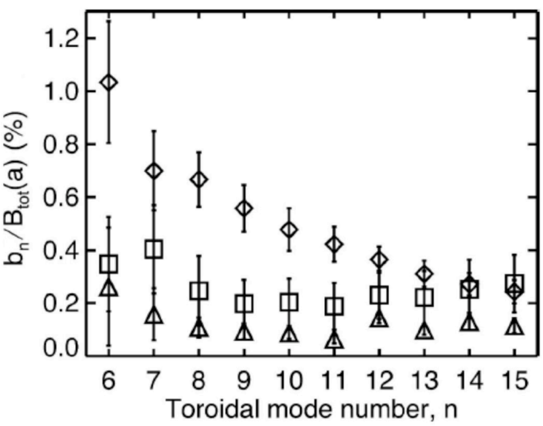

FIG. 3. m = 1 tearing mode spectra for three regimes at 0.2 MA, (◇) standard confinement at low density, (△) improved confinement (15% beta) at low density, and (□) improved confinement (26% beta) at high density.

As yet, there is no experimental evidence for interchange modes in these plasmas, but there is suggestive evidence for pressure-driven tearing, shown in Fig. 3, which contains spectra of the dominant m = 1 modes in three regimes. The modes are largest in the standard regime, without current profile modification, where they are solely current driven. The modes attain their lowest amplitude with current profile modification at low density. With high density and higher beta, the modes are still reduced, but not to the degree they are at lower density and lower beta. This suggests that the pressure gradient limits the tearing mode reduction. The improved energy confinement time (> 5 ms) in the high density case is also smaller than that (~ 10 ms) at low density, consistent with the somewhat larger mode amplitudes. The ultimate RFP beta limit is as yet unknown, but these data suggest that pressure-driven tearing may play an important role in determining the limit.

[1] M.D. Wyman, B.E. Chapman *et al.*, Phys. Plasmas **15**, 010701 (2008).