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MHD instabilities observed in extremely reversed shear discharges on JT-60U

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A reversed shear (RS) plasma is expected as a discharge of advanced scenario of ITER because it has good confinement and large bootstrap current fraction. It is understood that disruption at q_{min} ~ 2 β_N ~ 2 is caused by stability limit of n=1 ideal kink ballooning mode. However RS plasma with strong ITB disrupts frequently even at lower β_N . By now, low beta disruption is explained by double tearing mode [1] or resistive interchange mode [2], and these are MHD instabilities at q_{min} and around ITB. However these cannot explain all of observed low beta disruption. Figure 1 shows two typical wave forms of these RS plasmas. The shot of E39387 (a red solid line in Fig. 1) reached to Q_{DT}~1, H_{89}~3 and b_N=1.44 with Bt=4.05T and Ip=2.56MA just before disruption at t~6.85s. Typically pressure gradient of these type of RS plasma is very large at r~0.6 (ITB layer) and flat in the region around ρ < 0.5 (Fig. 2(a)). The current profile is characterized by the current hole and two peaks around the ITB layer and the peripheral region (Fig. 2 (b)). The current peak at peripheral region is formed by current ramping up for producing the RS profile because the

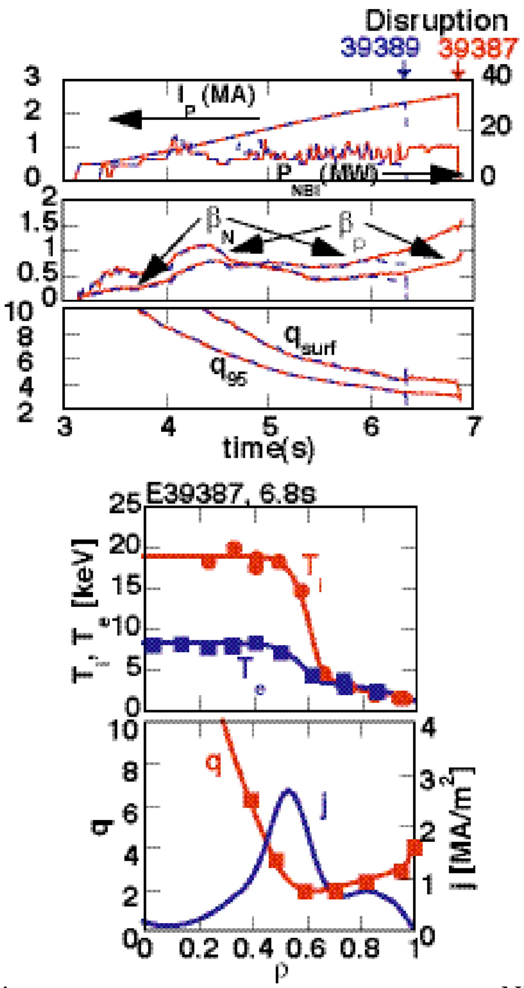

Fig. 1 Time evolution of (a) Ip and NB power, (b) normalized beta and poloidal beta, (c) q_{surf} and q_{95}. Radial profiles of Ti and Te (c) and q and j(d) just before disruption of E39387at t~6.8s.

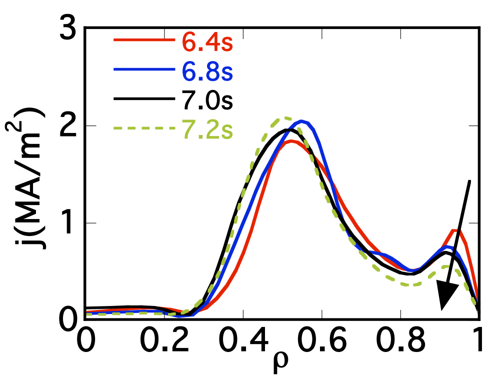

Fig. 2 Temporal evolution of plasma current. The peripheral plasma current decreases after stopping current ramping up

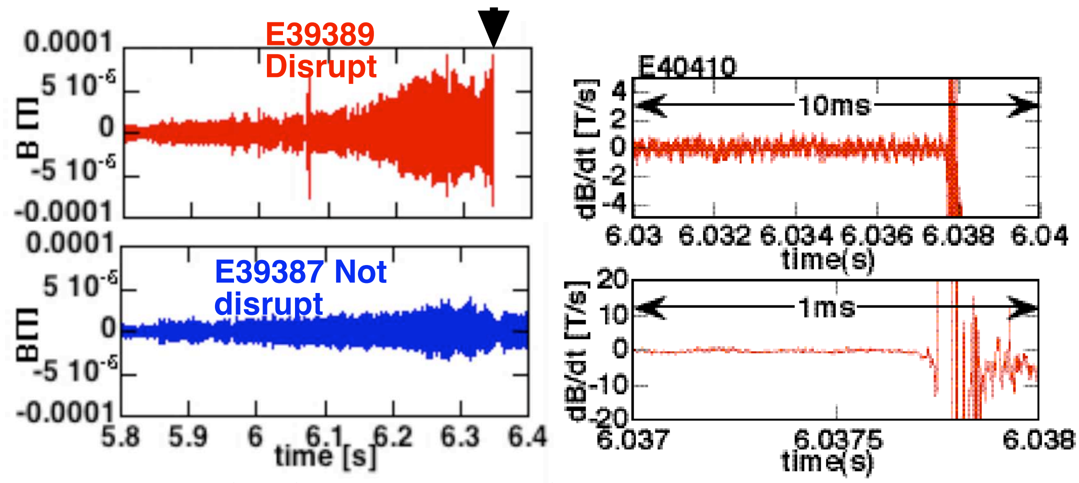

Fig. 4 (a) Temporal evolution of magnetic fluctuations in disruptive shot (upper) and no disruptive shot (lower). The m/n=4/1 mode start at t~6.1s. (b) Magnetic fluctuation before disruption of E40410. No precursor was detected.

peripheral plasma current decrease after stopping current ramping up (Fig. 3). The case of the early disruption is also plotted in Fig 1. The shot of E39389 (a blue dotted line in Fig. 1) disrupted whether b_N, b_p and also stored energy were decreasing and they are smaller than those of E39387 at same time. We mainly observed two type of disruptions. One is the disruption with n = 1 precursor of $1/\gamma$ > 100 ms. The m/n=4/1 magnetic fluctuation starts a*t t~6.1s* and grows before disruption in disruptive E039389 discharge and not in no disruptive E39387 (Fig. 4(a)). The other is the disruption without precursor at q_{surf} ~ integer. No growing magnetic fluctuation was detected before disruption as shown in Fig. 4 (b).

To explain observed low beta disruption of extreme reversed plasma, we introduce a simple model as below; "Disruption of RS plasma with strong ITB and central pressure plateau Disruption occurs when the both MHD instabilities at plasma surface and at safety factor being equal to surface mode are simultaneously unstable" [3]. By using this model, observed disruption can be explained by two processes, one is the discrete change of relative location of ITB and the rational surface in the RS region (surface mode triggered disruption) , the other is the continuous change of pressure gradient of the rational surface, which is determined by the surface mode (internal mode triggered disruption). This simple model can well the

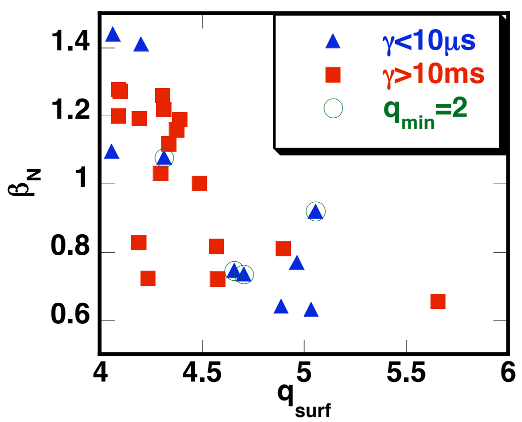

Fig. 5 β_N vs q_{eff} at disruptions with precursor (blue triangle) and without precursor (red square). The green open circles denote q_{min}=2.

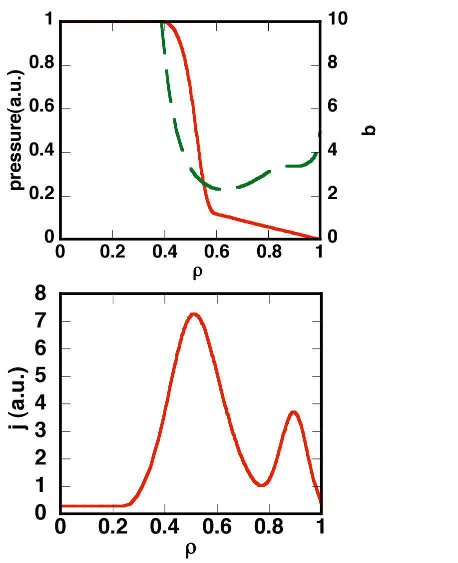

Fig. 6 The input profile for the ideal stability calculation . (a)Pressure and q, (b) toroidal current.

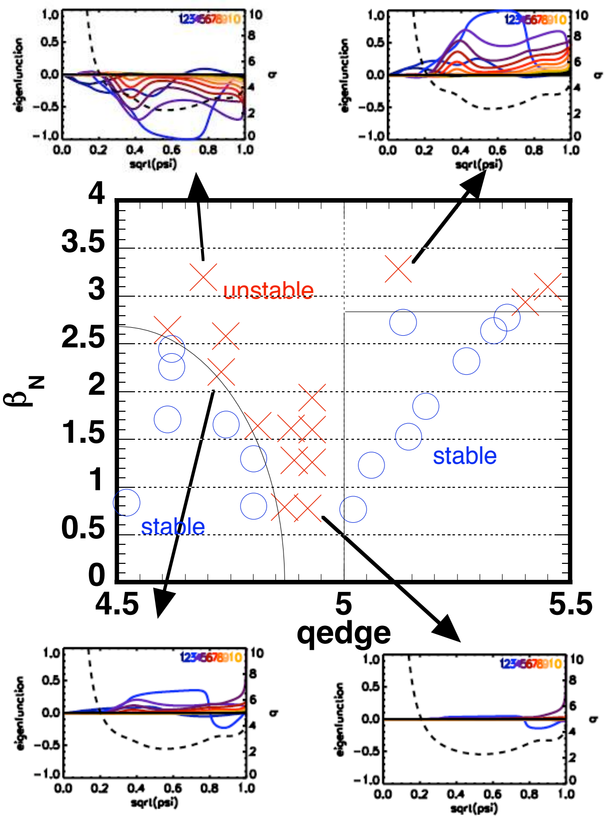

Fig. 7 The stability diagram for an extremely RS plasma with the profiles shown in Fig. 6.

explain experimental results. Figure 5 shows the β_N vs q_{eff} when disruption occurred. Almost all observed disruptions without precursor (blue triangle) and with precursor (red square) can be categorized into the surface mode triggered disruption and the internal mode disruption, respectively. The disruption without precursor observed when surface q is not integer cannot explain by the surface mode triggered disruption. A lot of them might disrupted due to double tearing mode, because q_{min} of them are ~2 (green open circle), however still future work remains.

It is reasonable to think the disruption without precausor caused by ideal MHD instability. However it is by now predicted that the ideal limit is larger than β_N>2. The actual plasma has a relatively large peripheral current and current hole. We have performed the ideal MHD stability calculation for the plasma with these characteristics by using the ERATO code. The input profile for the calculation is drawn in Fig. 6. The β_N-q_{edge} diagram of ideal MHD stability for changing edge safety factor from 4.5 to 5.5 derived from ERATO code is shown in (Fig. 1). Instability window exists from q_{edge} ~4.8 to ~5.0 at low β_N. However the eigenvalue is very low and marginal. The eigenfunction in this region shows external kink mode is destabilize. As the β_N increases the amplitude of internal modes increase and change to kink ballooning mode. Moreover, we check the eigenvalue on the peripheral plasma current. As the peripheral plasma current increase, the eigenvalue becomes larger. In the case of no peak of peripheral plasma current, the kink mode is stable. This calculation shows that it is reasonable that ideal disruption of this kind of plasma occurs. However many plasmas can survive in this region. We explain this survive and no-survive by the simple model described above. We also calculate the ideal stability by changing the pressure gradient at internal q=4 to know if the ideal stability can explain the our simple model. The eigenvalues are γ =-6.4e-4 for the plasma with q=4 at large pressure gradient and γ=-6.3e-4 for q=4 at pressure flat region. Eigenfunction for each plasma are also almost same as shown in Fig. 9. Ideal stability calculation cannot confirm our simple model. Other mechanism plays the role for the simple model.

This low beta disruption can be avoid by decreasing peripheral plasma current. The conducting wall near the plasma also stabilize this instability as shown in Fig. 10.

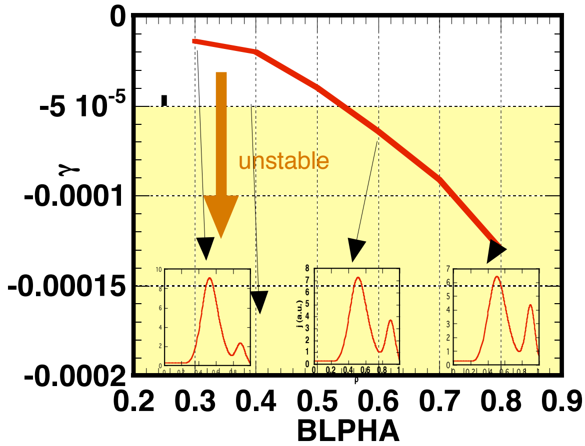

Fig. 8 The stability diagram for an extremely RS plasma with the profiles shown in Fig. 6.

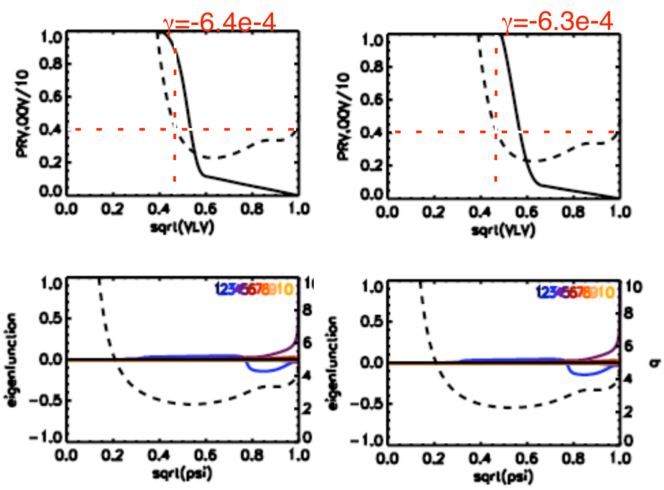

Fig. 9 The pressure and q profiles for the plasmas with q=4 in the ITB (a) and pressure flat region (b). Eigenvalue and eigenfuncttion are almost same for each profile.

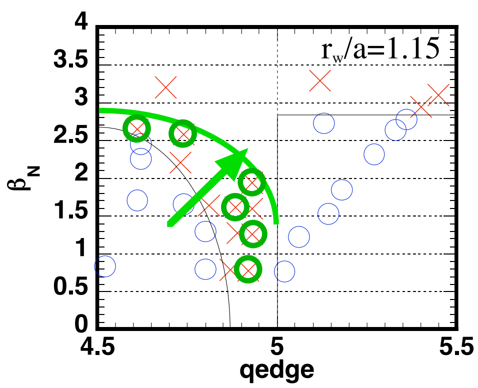

Fig. 10 The stability diagram for an extremely RS plasma with conducting wall at r_w/a=1.15 (green curve and circles).

References

[1] Y. Ishii, Physical Review Letters **89**, 205002(2002)

[2] S. Takeji *et al.*, Nucl. Fusion **42**, 5 (2002).

[3] M. Takechi et.al., Proceedings of the 20th International Conference, Vilamoura, 2004, IAEA-CN-116/EX/P2-32,(2004).