SOME FEATURES OF THE DISRUPTION INSTABILITY IN REVERSED SHEAR TFTR PLASMAS

I.Semenov[1], S. Mirnov[1], K. McGuire, M. Bell, E. Fredrickson,
M. Okabayashi, P. Savrukhin[2], G. Taylor, V. Vershkov[2], L. Zakharov.

Princeton University, Plasma Physics Laboratory, Princeton, NJ 08543, USA
[1]TRINITI, Troitsk, 142092, Moscow Reg., Russia
[2]RRC “Kurchatov Institute” 123182, Moscow, Russia.

Abstract

The behaviour of MHD perturbations before and during disruptions in the TFTR Reversed Shear (RS) plasma with q_{min}~2 was analysed. In the q_{min} region tearing modes, wave-like modes, and mixed tearing plus wave-like modes are followed by disruption. Sometimes a helical snake (helix) appears at the X-point of the q_{min} island. The local outward electron energy transport near the X-point can be explained by the development of “positive” magnetic islands . It is proposed that the disruption is initiated when the X-point of the magnetic islands coincides in one toroidal position near torus equator.

1. INTRODUCTION

Today the enhanced interest in RS plasmas exists because the experiments show the promising improvement of the confinement. However, this is unfortunately accompanied by an enhanced rate of disruptions. This stimulates the study of the perturbations in RS plasmas in the hope to find ways for disruption suppression. The most interesting features of the MHD perturbations are discussed.

2. DIAGNOSTICS

In TFTR, arrays of Mirnov coils allow identification of external perturbations with poloidal/toroidal modes up to m=6,7/n=2,3. ECE emission in two cross sections (labelled GPC1 and GPC2) separated by 126^o in the toroidal direction was used to measure internal MHD-perturbations. These two main diagnostics have a time resolution of 2 µs. Motional Stark Effect (MSE) and TRANSP code were used in analysis to find the q-profile. Soft X-Ray (SXR) channels were used to monitor cut-off of the ECE signals. In addition to the earlier visualisation method [1], we have developed a code which allows representation of the large data arrays as 3D stereo images although in this paper we show mono images. This open the possibility for faster analysis of complicated phenomena.

3. COMPARISON OF THE RS and SS DISRUPTIONS

Analysis shows that the disruption instability in SS (in positi ve shear) and RS has the same sequence of events - minor disruption (first fast thermal quench), slow thermal quench, second fast electron and ion thermal quenches, positive current spike, and current quench [2, 3]. The fast electron thermal quenches have the same time scale ~ 50-200 µs. The same time scales of the current quenches ~ 4000-5000 µs. Slow thermal quench is shorter. The main difference is in the value of the current spike. In RS disruptions δIp ~ two times less than in SS disruptions (RS(δIp~4-5%), SS(δIp~6-8%)). Probably the reason for this difference is the relatively small magnetic energy inside the plasma column ($l_iI^2/2$) and resulting shorter time l_i/R for current density flattening. As in the SS plasmas [2] the probable J(r) flattening decreases the MHD-stability of ideal modes and the major disruption could be the result of the ideal instability. The key event of the RS minor disruption is the relaxation-like phenomenon and the resonance between q_{min} and q(a) modes.

4. MODE DYNAMICS IN RS DISRUPTIONS

Strong wave-like, mono-tearing, double-tearing and mixed modes are observed in the q_{min} region.
A. In high power NBI shots wave-like perturbations develop as separate fishbone-like bursts in a frequency range of 10-70 kHz (m=even(4)/n=2 or m=even(2)/n=1) and in some cases produce enormously strong deformation of the electron temperature profile without visible tearing structure. As the perturbation increases, the initial wave-like structure can transform into a mixed structure with a single tearing mode in the normal shear and a wave-like perturbation in the reversed shear region. Fig. 1a shows evolution of the electron temperature profile in two toroidal cross-sections separated by 126^0. Figs. 1b, c show 3D images of the electron temperature profile. A clearly visible hot island (double-tearing mode) has formed only ~1 ms before the minor disruption . In the mixed case the X-point has increased size (t2, t4) and the perturbation pushes to outside through X-point. It looks like a deformed Waelbroeck's ribbon-like X- point which was discussed in [4].

B. Fig. 2 shows relaxation type of MHD activity which is typical for the negative shear region near q_{min}. The development of this perturbation causes a fast (~ 100 μs) changes in the electron temperature profile in a narrow region adjacent to the negative shear region. It looks like a sawtooth relaxation (fragment (a) of Fig. 2), but the nature of the precursor is not clear because the precursor is not visible in the frequency range f<250-500 kHz and in the space range δr>3-5 cm. (The size of the relaxation region is 2-3 cm, estimated according to [5]). This activity precedes the disruption and probably plays the trigger role of the disruption (t3 in Fig. 2)

C. Helical snake perturbations (helix) could be observed in the RS shots before and during disruption. Fig. 3a shows the evolution of the ECE perturbations in the q_{min} region, which leads to the minor disruption. The TRANSP q(R) profile is shown in Fig. 3c. Sawtooth-like phenomenon, (type as discussed above) at the time t~3.482s preceded by fishbone-like perturbations, develops in the q_{min} region (R~310-314 cm). A magnetic island suddenly appears 3 msec later at t=3.485 s, probably as a result of some relaxation processes. The analysis of ECE signals shows that this perturbation is an even(2)/1 single island tearing mode. The helix has appeared in the X-point of this island 0.5 ms before the disruption and propagated through the external magnetic surfaces leading to the minor disruption. A ballooning-like mode at the edge of the helical bulge sometimes can accompany this type of MHD activity. Fig. 3b shows the 3D top view image of the electron temperature profile for the time interval ~ 2 ms.

Sometimes a fast helical "Bridge" between hot and cold regions of the plasma can be observed during a minor disruption in the q_{min} region. Fig. 4 shows the development of the "bridge" in a discharge with q_{min}=2. In this discharge, the tearing mode starts at t=3.068628 s. 16 μsec later the hot "bridge" at the X-point of the (even(2)/1) island reaches the external(3)/1 mode region. At this moment the first non-thermal ECE appears at the position of 3/1 island. 14 μsec later we can see the flattening of the electron temperature in the toroidal position of GPC1 between q=3(int) and q=3(ext_ (q(r)-TRANSP). Only 18 μsec later the temperature along the torus becomes equal and the plasma shifts inwards (~ 9 cm) indicating a drop of plasma energy. This moment coincides with the beginning of the turbulent edge magnetic activity. During the next 300 μsec the central temperature drops slowly from 4 keV to 2 keV (slow thermal quench) and in 50 μsec it disappears during the second fast thermal quench. The plasma current spike, an indicator of global magnetic reconnection, starts at that time. One of the possible explanations of this phenomenon can be the development of the bulge-type perturbations [6], another one is the development of the "positive" magnetic islands in the X-point of the initial magnetic island in low shear region near q_{min} [7].

Thus, the RS disruption observed in TFTR discharges is the result of the non-linear development of the m/n=q_{min} perturbation. The scheme of the development is similar to the sawtooth development near $q(r_s)$=1 in SS discharges. A peculiarity is the development of the islands near q_{min} and subsequent appearance of the helical "bridge" from the hot plasma region to the periphery. This behaviour could be understood if we take into account that in low shear region there is a possibility for the development of an additional "positive magnetic island" in the region of positive current perturbation [7]. Such positive islands have radial orientation and as the perturbation increases it penetrates the magnetic surfaces connecting the hot and cold regions. The development of the "Bridge" in RS discharges is the analog of the "Hot spot" in a positive-shear sawtooth but with $m/n=q_{min}$. A possibility for avoidance of the disruption in this case could be the distortion of q_{min} and q(a) resonance, for example by rotational shear or local ECD in q_{min} region.

5. REFERENCES

[1] I. Semenov, S. Mirnov, et al., Proc. 22nd EPS , Bournemouth UK, 1995, 1, 114 (1995).
[2] S. Mirnov, I. Semenov, et al.Phys. Plasmas, to be published (1998).
[3] E. Fredrickson, S. Sabbagh, et al., Phys. Plasmas, 4 , 1589, (1998).
[4] L. Zakharov, B. Rogers, S. Migliuolo, Phys. Fluids B 5, 2498, (1993).
[5] Z. Chang, E. Fredrickson, et al., Phys. Plasmas, 5, 1076, (1998).
[6] W. Park, E. Fredrickson, et al., Phys. Rev. Lett., 75, 1763, (1995).
[7] S. Mirnov, I. Semenov, et al. Plasma Phys. Reports (Rus), 24, 813, (1998).

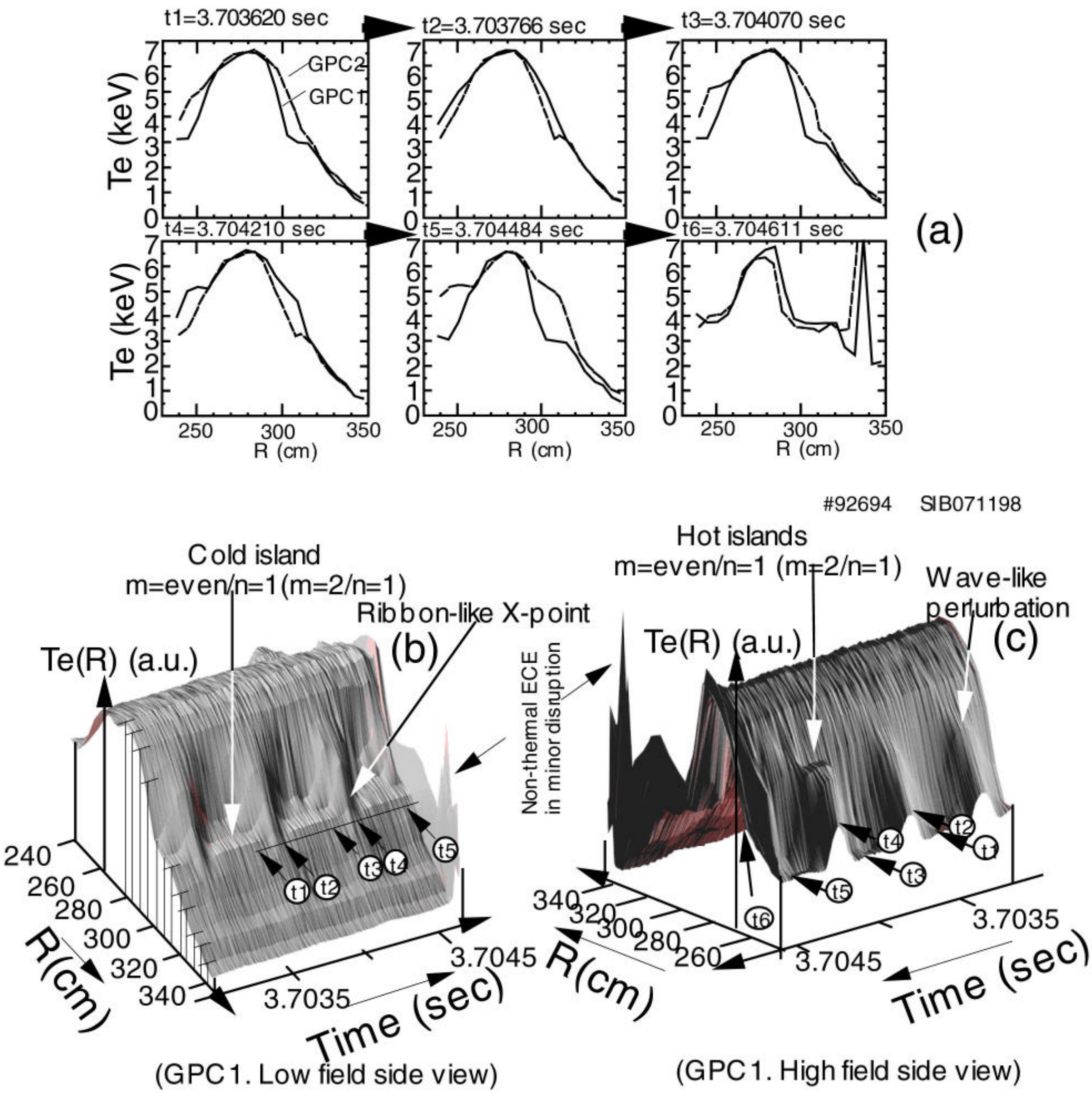

***Fig. 1** Mixed mode development in qmin region*

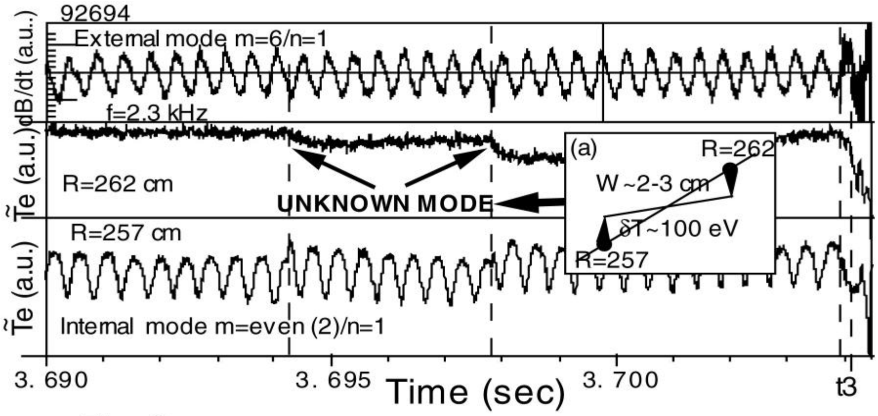

Fig. 2 Relaxation phenomena in the border between negative shear region and q_{min}

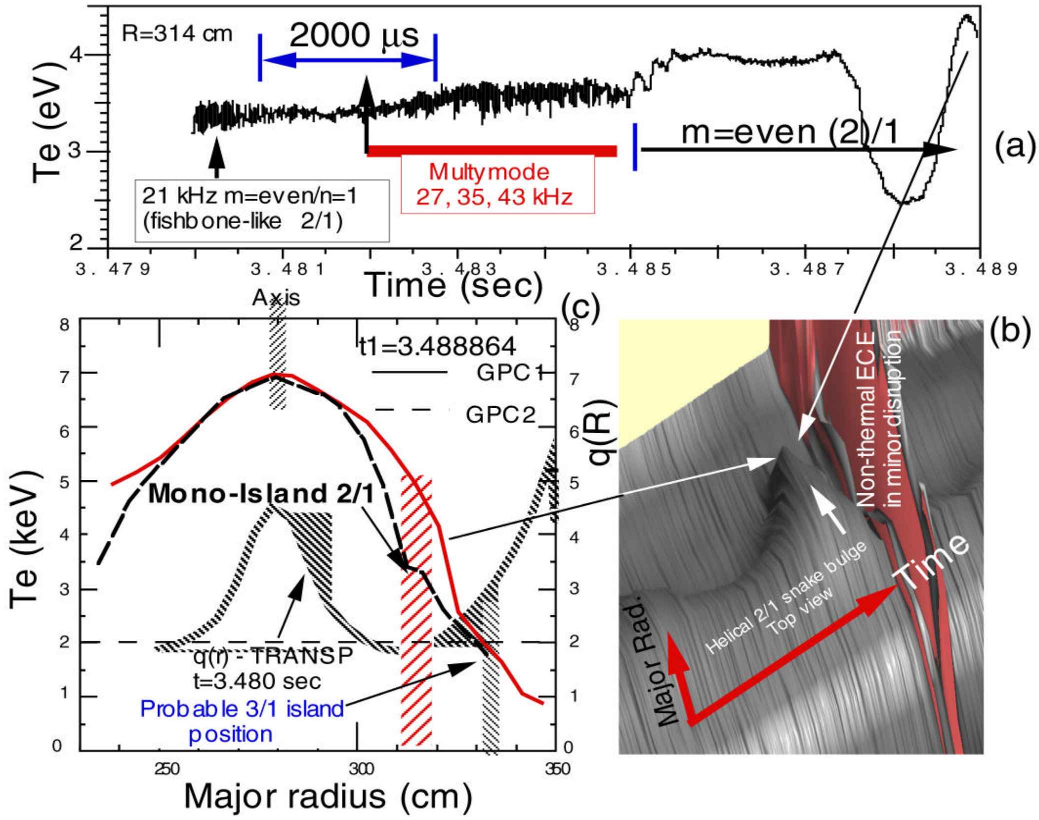

Fig. 3. Helical snake in the island X-point near q_{min} before minor disruption

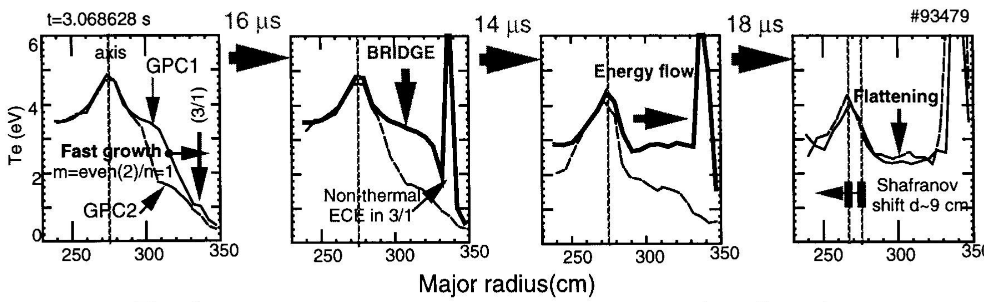

Fig. 4 Helical snake in the X-point near q_{min} during minor disruption