Indian J. Phys. 66B(5 & 6), 499 – 504 (1992)

Nature of current termination in ADITYA discharges at low *q*

P K Atrey, S B Bhatt, D Bora, B N Buch, C N Gupta, K K Jain, R Jha, P I John, P K Kaw, A Kumar, V Kumar, S K Mattoo, C Natarajan, H A Pathak, H R Prabhakara, H D Pujara, C V S Rao, D C Reddy, K Sathyanarayana, Y C Saxena, G C Sethia, A Vardharajulu, P Vasu and N Venkataramani

Institute for Plasma Research, BHAT, Gandhinagar-382 424, Gujarat, India

Abstract : The observations of soft disruption like events in ADITYA discharges at $q_{limiter}$ between 2 and 3 are presented. The current termination at low q limit is characterised by a sequence of positive spike in plasma current and a negative spike in loop voltage. The voltage spike is delayed by 100-200 μs from the corresponding spike in plasma current. The hard x-ray bursts and increase in optical signals are coincident with the current spike and voltage spike respectively. The current termination scenario is discussed in light of existing models for soft disruptions.

Keywords : Tokamak, disruption, low q.

PACS No. : 52.55. Fa

1. Introduction

The abrupt termination of plasma current, known as a major disruption, has been observed in tokamak ever since the begining of tokamak research. The typical diagnostic signatures of the current termination are : (i) negative spike in loop voltage with a corresponding positive spike in plasma current, (ii) increase in m/n = 2/1 MHD oscillation amplitude as a precursor signal to the negative loop voltage spike, (iii) increase in the Hard X-ray signal coinciding with the increase in MHD activity and (iv) abrupt fall of central plasma temperature preceding or during the negative voltage spike. If the magnitude of negative voltage spike is 1 to 10 volts and the current increases again, the disruption is termed as soft while hard disruption has loop voltage spike of 100 to 500 volts and the plasma current always terminates [1]. Typically, a sequence of soft disruptions is followed by a hard disruption. If sufficient volt-second is available in the Ohmic transformer, the plasma can recover from soft disruptions. Several models have been proposed to explain the observed features of current disruption [2]. The importance of the 2/1 MHD oscillation has been well recognized in these models. The growth rate of 2/1 oscillation increases rapidly when q=2 surface moves towards the limiter (current limit disruption) or the gaseous boundary moves towards the q=2 surface (density limit disruption). The growing 2/1 perturbation moves towards the plasma core and couple with 1/1 or 3/2 helical mode. The growth rate of the coupled mode increases rapidly and leads to expansion and ultimate loss of the hot plasma core. The central plasma temperature decreases abruptly. The consequent decrease in β_p (poloidal beta) causes loss of plasma equilibrium and crashing of the current channel to the inboard side of the vacuum vessel.

Recently, a definite time delay (δt) between positive spike in plasma current (I_p) and corresponding negative spike in loop voltage (V_l) has been observed in JET disruption [3]. The value of δt is found to be 1-2 ms in JET. Wesson *et al.* [4] explain this observation in terms of an initial trapping of ejected poloidal flux and its subsequent release which is triggered by a sudden cooling of the plasma. In this paper, we report the observation of soft disruption-like features in ADITYA and discuss a possible disruption scenario in the light of the above model.

2. Observation

The operational parameters of ADITYA for the experiments reported here are : B = 0.25 Tesla, R_0 = 0.75 m, a = 0.25 m I_p = 30 to 50 KA hydrogen fill pressure $\cong 5 \times 10^{-5}$ Torr and chord averaged electron density n_e in the range of 2×10^{12} cm^{-3} to 8×10^{12} cm^{-3}.

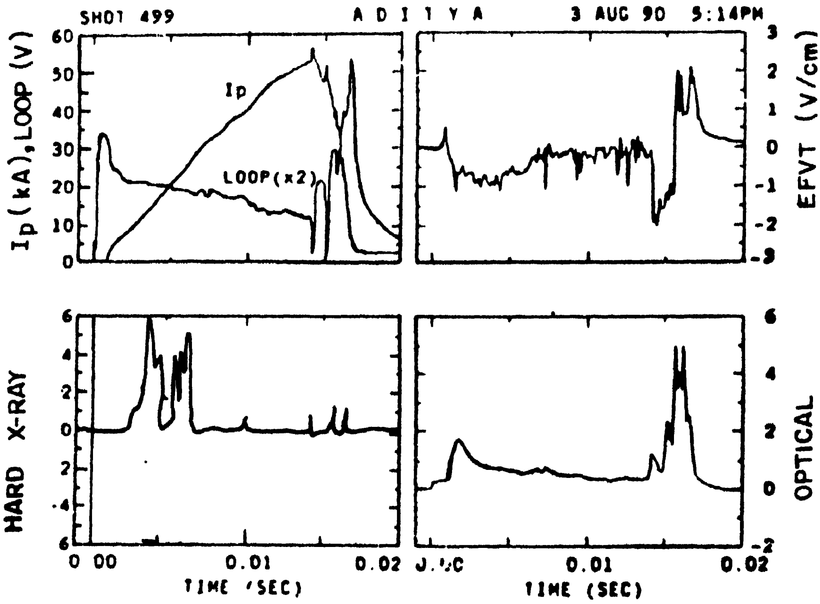

Figure 1. Plasma current and loop voltage (top left), vertical electirc field (EFVT) in the plasma column (top right), hard x-rays (bottom left; arb. units), and optical signals (bottom right), in a typical ADITYA discharge at low q.

The diagnostics used are Rogowskii coil, Voltage loop, Langmuir probes; Microwave Interferometer, Hard X-ray monitor [NaI(TI) Scintillator] pointing towards the limiter and Optical monitor (Photo-Transistors) viewing the central chord. The diagnostic signatures of a typical ADITYA discharge (shot 499) are shown in Figure 1. The diagnostic signatures of current termination (for time between 12 and 17 ms) are shown in Figure 2. A sharp positive current spike (PCS) is followed by a negative voltage spike (NVS). The sequence of PCS and NVS is repeated 2 to 4 times each separated by 0.5 ot 1 ms. The plasma current decreases continuously during this process. The vertical electric field measured by a pair of (Top and Bottom) Langmuir probes changes sign when the plasma current decreases by about 10 KA.

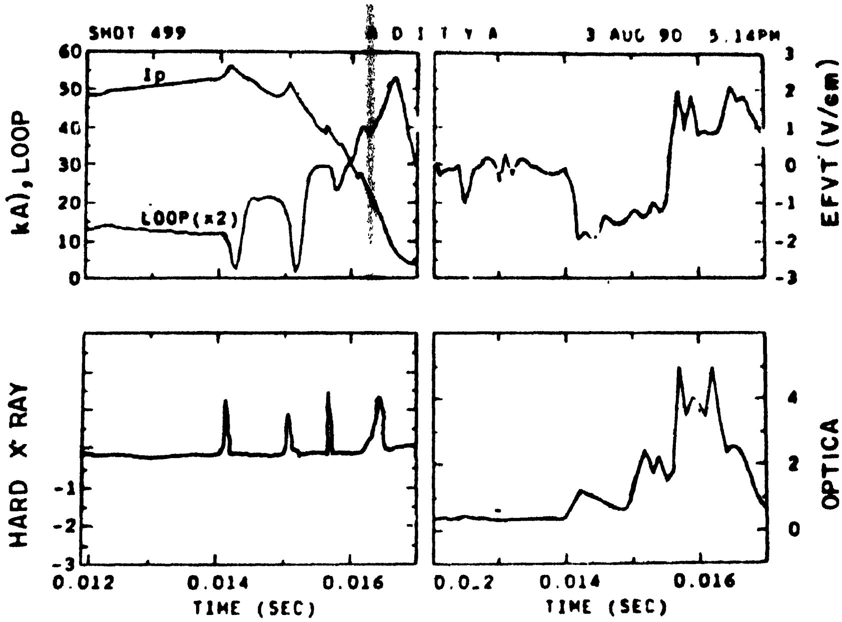

Figure 2. Same as Figure 1, but expanded for times between 12 and 17 ms.

The problem of the interpretation of Langmuir probe measurements of electric field in a tokamak is discussed separately [5]. During the current decay phase, bursts of hard X-ray (< 500 keV) are emitted coinciding with the positive spike in the plasma current. The optical signal shows large increase coinciding with negative spike in the loop voltage. The mean value of the loop voltage continuously increases after the first negative spike. There is a large increase in optical signal as well as the loop voltage after reversal in the vertical electric field.

A scatter diagram of δt-values obtained from 76 disruption-like events in 44 ADITYA shots is shown in the top block of Figure 3. The δt-values are plotted as a function of the limiter q. The first and subsequent events in these shots are included. The δt-values vary between 50 and 200 μs with a mean value of 100 μs. The digitisation rate of data acquisition is 20 kHz. Bottom block of Figure 3 shows that these events are distributed in two broad groups at $q = 2.5 \pm 0.5$ and $q = 3.5 \pm 0.5$.

3. Discussion

We observe a sequence of PCS and NVS similar to the observation in Pulsator-I [6]. In case of Pulsator, hard X-rays are observed in bursts with the intensity increasing from burst to burst. If they are short enough, they are synchronized with the rotation of the helical mode occurring when the coupled (2/1 and 1/1) mode passes the limiter.

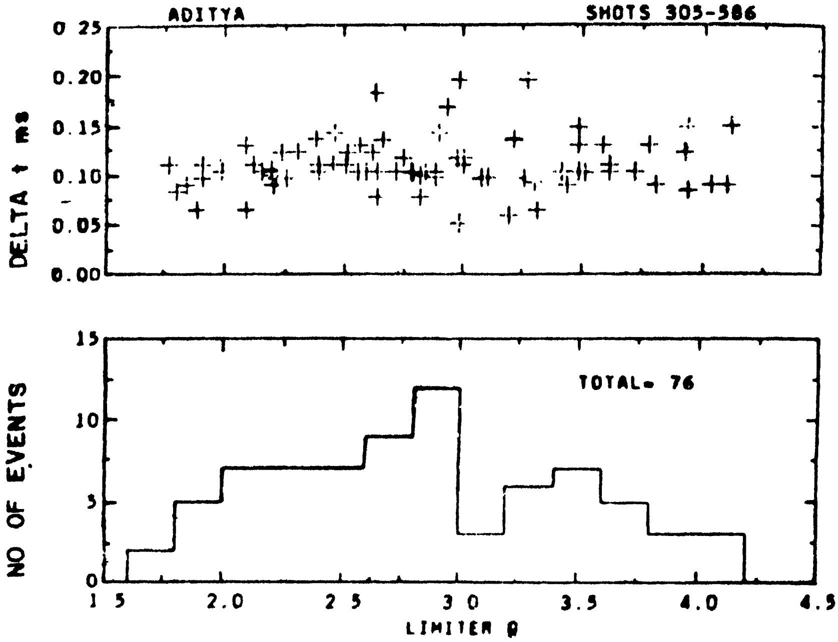

Figure 3. Top : Scatter diagram of time differences (δt) between PCS and NVS in 76 soft disruption like events; bottom : histrogram of number of events as a function of limiter q.

The most intensive burst occurs just before the large negative loop voltage spike (NVS) after which one never observes hard X-rays during subsequent NVS. Prior to the appearance of the first NVS the central plasma temperature decreases from 400 eV to less than 150 eV. The time difference between PCS and its corresponding NVS is less than 10 μs. According to [6], the NVS is triggered by the cooling of central plasma and the consequent decreases in β_p. Similar to the JET results [3] and unlike Pulsator, we observe a definite delay in the appearance of negative loop voltage spike. An important observation in ADITYA is the emission of Hard X-ray bursts coinciding with the PCS and optical signal coinciding with the NVS. The magnitude of NVS is typically 5-10 volts.

According to Wesson *et al.* [4] the appearence of positive spikes in I_p indicates flattening of current profile and ejection of poloidal flux. If the plasma temperature in the edge region (between q=2 surface and the limiter) is large, the ejected poloidal flux gets trapped in the conducting plasma. The subsequent appearance of negative voltage spike indicates detrapping of this flux and its expulsion outside the plasma. The time defference (δt) between I_p and V_t spikes is the time duration of trapping of the poloidal flux and depends on the plasma resistivity/temperature in the outer region,

$$\delta t = 4\pi d^2 / \varepsilon^2 \eta_\perp$$

where d is the width of the outer region and $\eta_{\perp}$ is the Spitzer resistivity. In ADITYA, most of the soft disruption like events have δt-values in the range of 100 to 200 μs (Figure 2b). For the ejection of poloidal flux in a time of 100 to 200 μs, the plasma temperature in the outer region should be ≈ 8 to 13 eV if the width of the outer region is assumed to be 10 cm. The plasma temperature at limiter measured using Langmuir probe is found to be about 10 eV for peak plasma current of 25 kA. For the discharges considered here, the plasma temperature in the outer region can be assumed to be 10 to 30 eV at the time of peak plasma current. If the plasma temperature in the outer region decreases to 5 to 10 eV during the first PCS and NVS sequence and remain to that value subsequently, it is possible to explain the ADITYA results using the model proposed by Wesson *et al* [4]. The ADITYA current termination shows a sequence of flattening and decrease in plasma current until the externally applied magnetic field over-compensates the hoop force and causes crashing of current channel towards the inboard side of the vacuum vessel. This can be inferred from the observation of reversal of sign and large increase in the vertical electric field from a very small value before the crash. The appearance of hard X-ray bursts coinciding with the PCS indicates re-organization of current profile by overlaps of magnetic islands and consequent deconfinement of runaway electrons. The decrease in the self inductance of the current channel (due to flattening of current profile) causes ejection of poloidal flux. The appearance of NVS after 100 to 200 μs indicates the diffusion time of the poloidal flux through the resistive plasma (Te = 8–13 eV). This feature is similar to a sequence of soft disruption. However, plasma current is unable to recover from soft disruption because the volt-seconds remaining in Ohmic transformer (5 to 10 mVs) is insufficient to reheat the plasma.

The ADITYA result can be explained most satisfactorily by Sykes and Wesson [7] model. The soft disruptions are caused by growth of 2/1 island and its contact with the limiter. At plasma current in the range of 30 to 50 kA, the value of q at limiter is in the range of 3 to 2. Hence in these discharges, the island width at q = 2 surface grows and touches the limiter, leading to loss of plasma current and consequent redistribution of current profile. If sufficient volt-second is available in the Ohmic transformer and equilibrium of the current channel can be maintained, the plasma can recover from soft disruptions. In ADITYA, very small amount of volt-second (5 to 10 mVs) is remaining in the Ohmic transformer when the soft disruption features appear. After the soft disruption, a cold region gets formed in the plasma. The Ohmic transformer is unable to reheat the cold region and restore the current profile, the q=2 surface moves inward and the growth of island restarts. The growth time is about 1 ms. Thus the sequence of event is repeated until the current channel crashes due to over-compensation of hoop force by the vertical magnetic field.

4. Conclusions

We have reported the observation of soft disruption-like. features during the current termination in ADITYA discharges at q between 2 to 3. The current termination at low q is characterized by a sequence of PCS and NVS. The NVS is delayed by 100-200 us from the corresponding PCS. The hard X-ray bursts and increase in optical signals are coincident with the PCS and NVS respectively. These features can be explained most satisfactorily by Sykes and Wesson [7] model of soft disruption. However, in ADITYA, the plasma current is unable to rise after the soft disruption because of the paucity of stored volt-seconds in the Ohmic transformer. Hence, a sequence of PCS and NVS is observed.

References

[1] S V Mirnov and I B Semanov 1977 *Proc 6th Int Conf Plasma Physics and Controlled Nuclear Fusion Research, Berchtesgaden 1976* (IAEA, Vienna) Vol. I p 291

[2] T F R Equipe 1985 *Proc 10th Int Conf. Plasma Physics & Controlled Nuclear Fusion Research, Lausanne 1984* (IAEA, Vienna) Vol. I p 97

[3] J A Wesson, R D Gill, M Hugon, F C Schüller, J A Snipes, D J Ward, D V Bartlett, D J Campbell, P A Duperrex, A W Edwards *et al* 1989 *Nucl Fusion* **29** 641

[4] J A Wesson D J Ward and M N Rosenbluth 1990 *Nucl. Fusion* **30** 1101

[5] ADITYA Team 1990 *Indian J Phys.* **66B**

[6] F Karger, K Lackner, G Fussmann, B Cannici, W Engelhardt, J Gernhardt, E Glock, D E Groening, O Klüber, G Lisitano *et al Proc Sixth Int Conf Plasma Physics & Controlled Nuclear Fusion Research, Berchtesgaden* 1976 (IAEA Vienna, 1977) Vol I, p. 267

[7] A Sykes and J A Wesson 1980 *Phys. Rev Lett* **44** 1215.