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Characteristics of Low-q Discharge in the IR-T1 (Iran-Tokamak 1)

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Abstract

This paper presents an experimental study on the hard disruption instability in low-$q_\psi(a)$ discharge on the Iran-tokamak 1 (IR-T1), that limits the accessible operation plasma parameters. Reproducible major disruptions are triggered by contact of a large m/n = 2/1 magnetic island with the limiter. The growth of m/n = 2/1 mode is precipitated by a thermal collapse of the plasma periphery during the current decay phase.

Keywords:

hard disruption instability, locked mode, critical error field

1. Introduction

Operation at low-edge safety factor ($q_\psi(a) < 3$) and the corresponding magnetohydrodynamic (MHD) characteristics have been investigated in the IR-T1 tokamak. It is necessary, for a tokamak operating at low-$q_\psi(a)$ values without a conductive shell and using a material limiter, to make a careful adjustment of the plasma parameters and have an appropriate ramp-up rate of plasma current in the startup phase and low effective ion charge ($Z_{\rm eff}$). In lower-$q_\psi(a)$ discharges ($q_\psi(a) < 4$), locked modes are often followed by a disruption, and also observed in many tokamaks [1,2]. Locked modes are usually n = 1 and m = 2 or 3 modes which can either grow in a stationary position in the torus or evolve from an oscillating mode whose rotation frequency slows down to zero. Here m (n) is the poloidal (toroidal) mode number. Characteristics of discharges with locked modes include cessation of soft x-ray (SXR) sawteeth, reduced energy confinement and cessation of the plasma mode rotation at safety factor q = 2, etc. [1]. In the present work we have studied characteristics of such fluctuations in lower and higher edge $q_\psi(a)$-discharges. In particular, we investigate effects of m = 2 mode instability on confinement. Diagnostics and operational region of the IR-T1 tokamak have already been presented [3,4].

2. Description and Discussion of the Experimental Results

The IR-T1 is a conventional tokamak with aspect ratio (R/a = 45 cm/12.5 cm) and a circular poloidal limiter of minor radius 0.115 m. This has allowed current operation (I_p < 60 kA) at low toroidal fields (B_ϕ < 0.9 tesla). This work draws on previous experiences [4,5], over a significant range of parameters which showed that the MHD behavior can be characterized by the single parameter $q_\psi(a)$. The starting point for this study occurs for $2 < q_\psi(a) < 3$ and is typified by strong oscillatory signals on both soft x-ray and magnetic coils and dominated by m/n = 2/1 spatial harmonic. A typical major disruption on the IR-T1 tokamak is shown in Fig. 1, where toroidal field $B_\phi \approx 0.64$ tesla and mean electron density $\bar{n}_e \cong 1.4 \times 10^{13}\ \mathrm{cm}^{-3}$. The characteristics of the discharge are summarized in Table (I). As the current is increased, instabilities occur which degrade confinement

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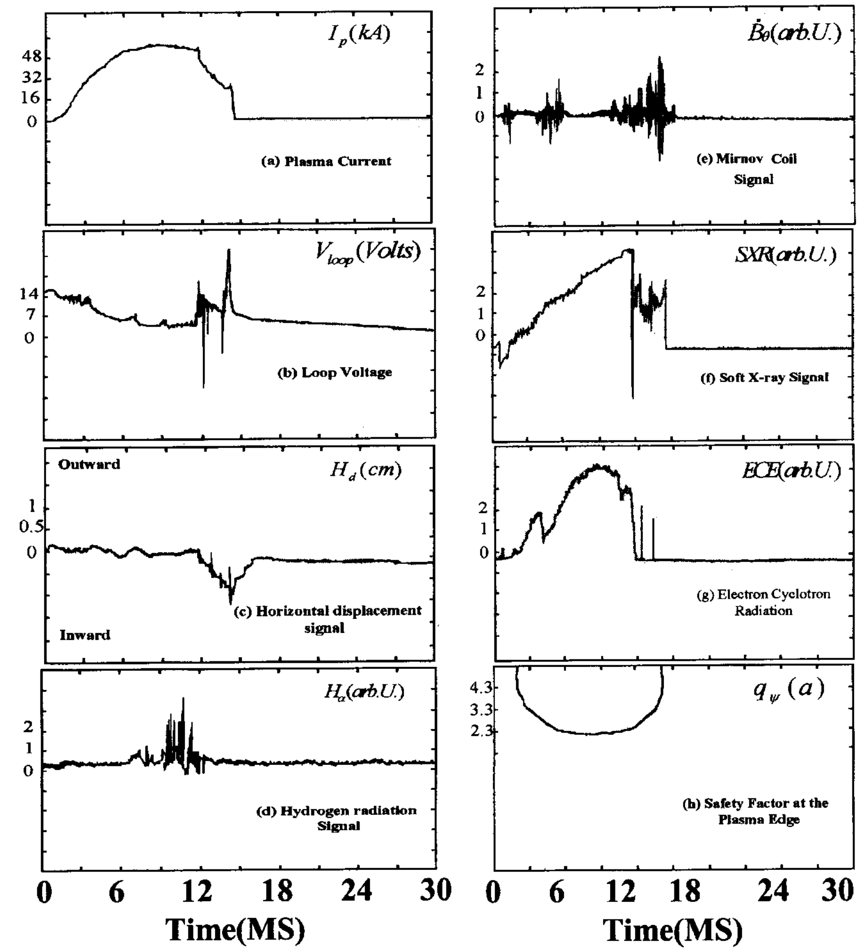

Fig. 1 Time dependence of plasma parameters (Shot No. 151,96) in the major disruption event on the IR-T1 tokamak; (a) plasma current (kA), (b) loop voltage (volt), (c) horizontal displacement signal (cm), (d) Hα signal (arb. units), (e) pick-up coil signal (arb. units), (f) soft x-ray signal (arb. units), (g) ECE signal (arb. units) and (h) time evolution of the safety factor at the plasma edge $q_\psi(a)$. The disruptive instability is appeared close to 11.5 ms. Disruption occurs during ramp-down of plasma current, that is caused by the decrease of the safety factor at the plasma edge. Positive plasma current tips and negative loop voltage spikes are clearly observed.

Table (I) DISCHARGE CHARACTERISTICS

Quantity	Before disruption	After disruption
Toroidal field (tesla)	0.67	0.62
Plasma current (kA)	54	$54 \to 0$
Safety factor at the plasma edge ($q_\psi(a)$)	2.3	$2.3 \to \infty$
Loop voltage (V)	3.5	18
Plasma energy content (kJ)	0.89	0.02
Main ion species	H^+	
Limiter radius (cm)	11.5	
Major redius (cm)	45	
Minor radius (cm)	12.5	

and restrict the range of useful operating conditions. Instabilities have been observed on the plasma current, loop voltage, horizontal displacement, magnetic coil,electron cyclotron emission (ECE, 5-channels heterodyne radiometer) [5] , Hα signal (λ = 6563Å, 3–2) and an array of soft x-ray detectors. Several characteristic features of the disruptive instability are identified. The post-disruptive plasma is characterized by a very high level of magnetic turbulence, corresponding to relative large fluctuation of the poloidal field at location of the Mirnov coil, mainly at n = 1 toroidal wavenumber. The thermal quench occurs rapidly as evidenced in the sudden drop of the near central soft x-ray amplitude. The soft x-ray emissivity enhances suddenly before the disruption, and sawteeth were evident from 4 to 7 ms. The stored energy of the plasma also decreases from a maximum of about 0.89 kJ to 0.02 kJ by the end of the phase of the thermal quench. The increase of Hα radiation between one and two orders of magnitude during the post-disruptive is clearly associated with a thermal collapse of the plasma boundary. As is seen on horizontal displacement signal, the plasma moves inwards to interacts with the limiter, which is evident by pulsed increases in the emission of the Hα signal. This means a steadily increasing heat loading on the limiter, which could be the cause of the increase in Hα radiation. During the post-disruptive phase, the rate of current decrease is often –17 kA·ms^{-1} for typical shot considered. Analysis of MHD activity by means of magnetic coils shows that the only mode seen on IR-T1 during the plasma current plateau is usually specified by m/n = 2/1. Although all steady state low $q_\psi(a)$ discharges are sawtoothing, the m/n = 2/1 mode grows to a large value before disruption as observed on many tokamaks. This phenomenon occurs in the narrow window at high current limit in the Hugill plot of the IR-T1 [4]. The relative amplitude ($\delta B_\vartheta / B_\vartheta$) of the magnetic perturbations induced by this m = 2 mode is, under stable conditions, in the 10^{-4}–10^{-3} range and its frequency is in the 18 kHz < f < 22 kHz range. This frequency is quit in agreement with a scaling law of the critical relative intrinsic error field at the plasma surface for locked modes $f \approx R^{-9/5} B_\phi^{-1/5}$ [1], has been obtained in Ohmic discharges with safety factor $q_\psi(a)$ < 4. In this paper we have followed convention by defining $q_\psi(a)$ in its cylindrical approximation: $q_\psi(a) \equiv 2\pi B_\phi a^2 / \mu_0 I_p R$. The amplitude of the observed signal can be related to the half-width (δ) of the magnetic island at redius $r_{q=2}$ through the formula [6]: $\delta \approx [2r_{q=2}^{2-m} r_{coil}^{m} / m)(\delta B_\vartheta / B_\vartheta)]^{1/2}$, where r_{coil} is the redius at which the pick-up coil is located. For this shot and m = 2 mode, r_{coil} = 18 cm, $r_{q=2}$ = 8–10 cm and $(\delta B_\vartheta / B_\vartheta) \approx 0.007$ corresponds to $\delta \cong 1.5$ cm. So,the full island width of the m = 2 mode is $\Delta \cong 3$ cm, and therefore the disruption could be the result of a contact of the m = 2 magnetic island with the limiter.

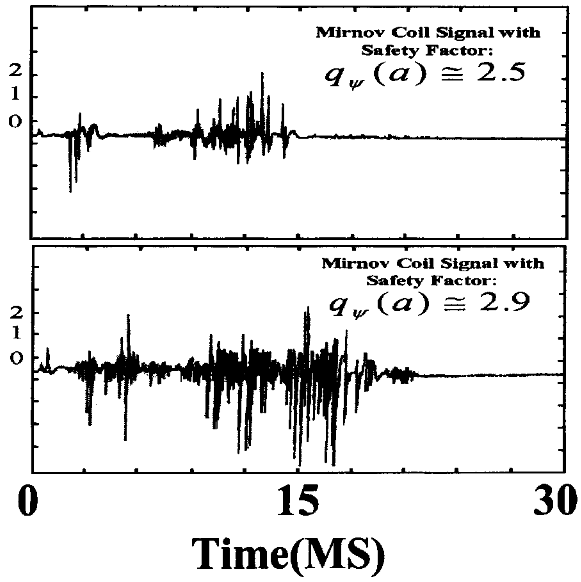

Fig. 2 Comparison of discharge evolution during the Ohmic heating phase for two discharges, one with $q_\psi(a) \cong 2.5$ (top panel), and one with $q_\psi(a) \cong 2.8$ (bottom panel) before the discharge disruptions.

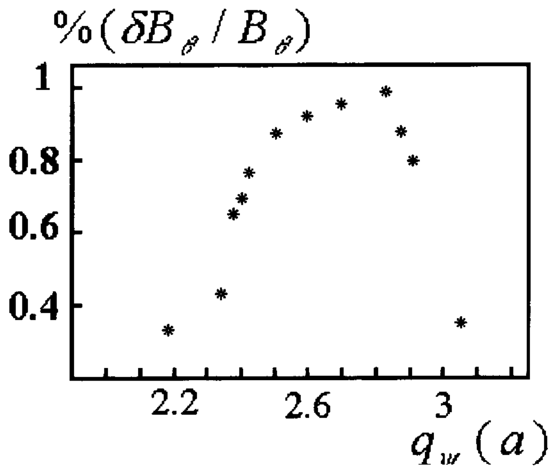

Fig. 3 Maximum MHD amplitude against $q_\psi(a)$. The flat top value was varied from shot to shot and the maximum amplitude was measured in each case.

An overview of the two types of low-$q_\psi(a)$ disruption scenarios is shown in Fig. (2). In contrast to the higher-$q_\psi(a)$ shot, the lower-$q_\psi(a)$ discharges exhibited relatively low level of MHD activity up until several of milliseconds before the disruption. This behavior is quite similar to the result presented by Kaye et al. [7], on the Princeton Beta Experiment (PBX).

The essential features of the results presented here are summarized graphically in Fig (3). This diagram is derived from data taken from twelve different discharges showing the relation between the amplitude of the externally measured poloidal field fluctuations against the value of the safety factor at the plasma edge.

3. Conclusion

To summarize, low-$q_\psi(a)$ operation in IR-T1 has indicated that disruptions always occur for discharges with $q_\psi(a) < 3$. The major disruption studied here consist of three phases. First, a thermal instability, secondly, growth of the $m = 2$ island to a large size and thirdly, the trigger mechanism, which is the contact of this large $m = 2$ island with the limiter. The other conclusion from this study is that in contrast to higher-$q_\psi(a)$ shot, the lower-$q_\psi(a)$ discharges exhibited relatively low level of MHD activity before the disruption.

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