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Poloidal Magnetic Field Fluctuations in Low-q(a) in Iran-Tokamak1(IR-T1)

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Abstract

In the present paper, an attempt is made to explain the behavior of the magneto-hydro-dynamic (MHD) instabilities observed at low values of the edge safety factor on the basis of experimental results obtained on the Iran Tokamak 1 (IR-T1). The major disruption studied here consist of three phases: 1) thermal instability, 2) growth of the magnetic island, 3) trigger mechanism. Estimates are given for the rate of island growth and the characteristic growth time of the m = 2 / n = 1 mode, τ_g, and the experimentally and theoretically deduced values are found to be in reasonable agreement with each other.

Keywords:

IR-T1 Tokamak, low edge safety factor, poloidal magnetic-field fluctuations, rate of island growth.

1. Introduction

The present paper reports on detailed investigations into the confinement properties of low-q(a) discharges (i.e., discharges with 2 < q(a) < 3) and the MHD characteristics of these discharges. Tearing modes are known to play an important role in confinement degradation and disruptions in tokamaks [1,2]. They are resistive instabilities driven by the free energy contained in the poloidal magnetic field. Due to their resonant character, they are localized around flux surfaces and change the topology of the magnetic flux distribution through the formation of magnetic islands. At present, there are several distinct MHD models of tokamak disruptions. According to the first model, the interaction of a single magnetic island of helicity m = 2/n = 1 with the limiter or cold-gas region ruins energy confinement [3]. In a second scenario, disruptions are believed to be triggered by the nonlinear coupling of modes of different helicities. In cases where both the m = 2/n = 1 and the m = 3/n = 2 modes are unstable, a broad spectrum of waves is excited which destroy magnetic surfaces and therefore strongly enhance cross-field thermal collapse in the region of the stochastic magnetic field [4]. In the third model of disruptions, a nonlinear interaction between the m = 1/n = 1 and the m = 2/n = 1 modes, taking place through the intermediary of the current profile, was proposed [5,6]. Understanding in detail the various mechanisms that can lead to disruption is important for achieving tokamak confinement, and especially so with a view to suppressing disruptions [7]. The purpose of this paper is to further investigate the major disruptions occurring in low-q(a) discharges in IR-T1, and to compare the theoretical and experimental results for the rate of island growth. Experimental evidence has shown that disruptions are connected with MHD activity and that the time scale involved is intermediate between the resistive and the ideal MHD time scales [8]. Diagnostics and operational region of the IR-T1 have already been presented [9,10].

2. Experimental Results and Discussion

The IR-T1 is a conventional tokamak with a major and minor radii of 45 cm and 12.5 cm, respectively, and

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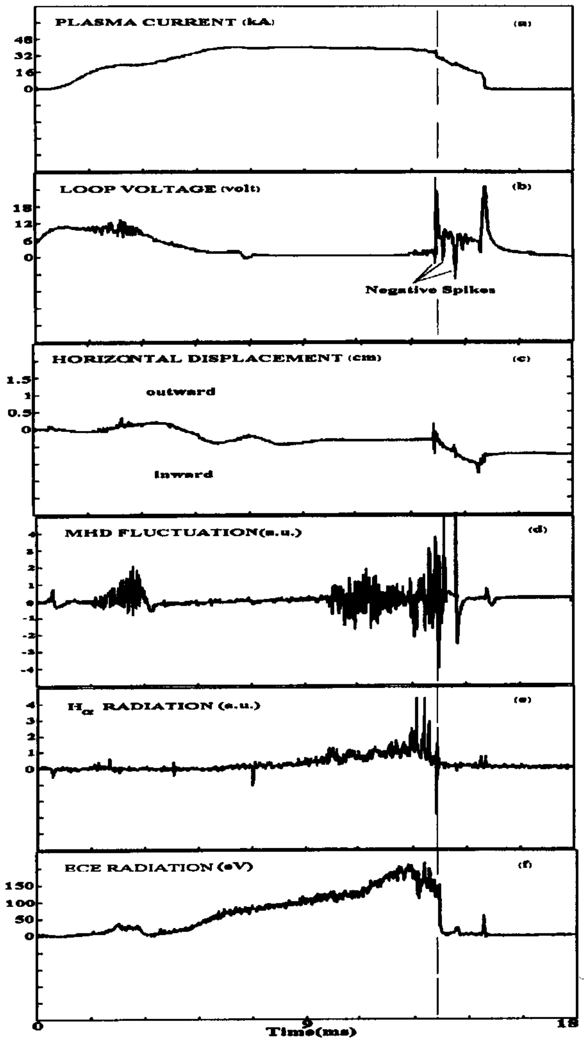

Fig. 1 Time behavior of principal parameters (shot No. 132) during the major disruption event in the IR-T1 tokamark; (a) plasma current (kA), (b) loop voltage (volt), (c) horizontal displacement signal (cm), (d) Mirnov coil signal (arb. units), (e) H_α signal (arb. units), (f) ECE signal (arb. units). The disruptive instability appears close to 13.5 ms.

a circular cross section without a copper shell and divertor and using a material limiter of minor radius 11.5 cm. A typical shot including a major disruption is illustrated in Fig. 1. In this shot, where toroidal field 0.6 tesla and mean electron density 1.1×10^{13} cm^{-3}, for which q(a) = 2.5, the relevant major disruption sets in at 13.5 ms. The main characteristics are : the major decrease of the plasma current after vertex close to 13:5 ms (Fig. 1a), negative spikes in the loop voltage signal (Fig. 1b), a displacement of the plasma column towards the inner part of the torus due to instability (Fig. 1c),

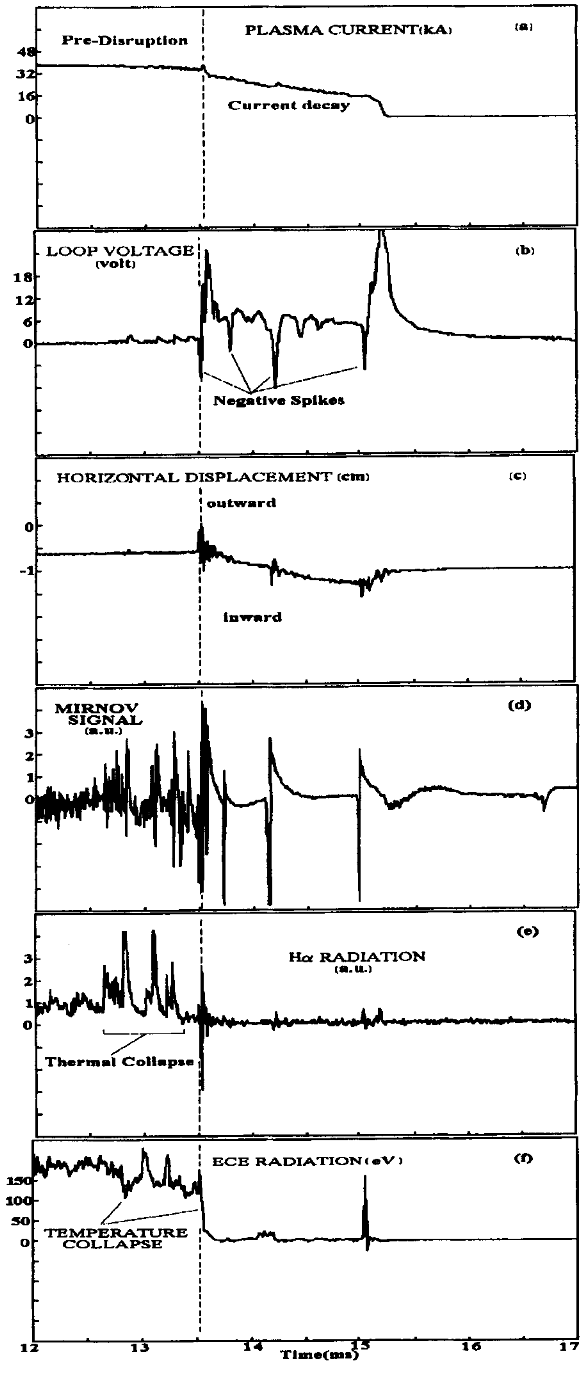

Fig. 2 Plasma current (a), loop voltage (b), horizontal displacement signal (c), Mirnov coil signal (d), H_α signal (e), ECE signal (f) in expanded time-scale 12–17 ms before and during the disruptive instability corresponding to the discharge shown in Fig. 1.

high level of magnetic turbulence corresponding to a relative large fluctuation of the poloidal field at location

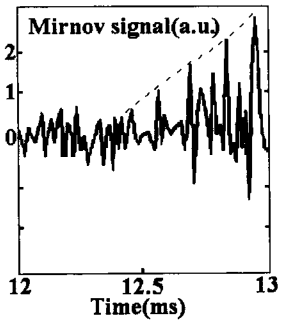

Fig. 3 Poloidal magnetic field fluctuation for a Shot No. 132 on an expanded time-scale 12–13 ms. This figure shows the final, approximately explosive growth of the disruption precursor mode. The dashed line ashematically indicates the approximate explosive groth of the oscillatio envelope.

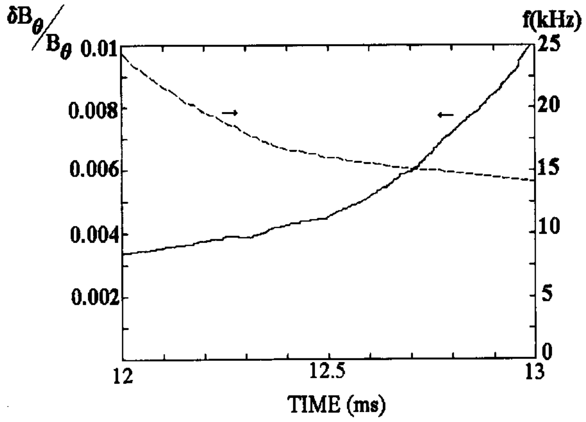

Fig. 4 The frequency and relative amplitude $\delta B_\theta/B_\theta$ as a function of time.

of the Mirnov coil (Fig. 1d), loss at the edge (Fig. 1e) and decrease temperature that observed in electron cyclotron emission (Fig. 1f).

As shown, when the plasma is pushed inwards in major radius it causes a positive spike on the loop voltage. The major disruption is preceded by a series of minor disruptions not resolvable in Fig. 1. In figure (2) we show the evolution of the plasma current, the loop voltage, the horizontal displacement, the MHD activity and the ECE signal in expanded time-scale 12–17 ms before and during the disruptive instability corresponding to the discharge shown in Fig. 1.

The approximately explosive growth of the precursor activity is presented at time 12.6 ms and appears to be correlated with a decrease in temperature observed in the ECE signal as shown in Fig. 2f, and increase H_α dradiation (Fig. 2e). The increase of H_α radiation between two and three orders of magnitude during the pre-disruption phase is clearly associated with a thermal collapse of the plasma boundary. The collapse phase is punctuated by a series of minor disruptions. The macroscopic effects of the minor disruptions are illustrated in Fig. 2. Each minor disruption is accompanied by a positive voltage spike, a burst in both MHD activity and H_α radiation and a dip in electron cyclotron harmonic emissions: however, the total plasma current remains unaffected (apart from a slight decrease accompanying the occurs minor disruption) until the major disruption. We now consider the characteristic time τ_g for the growth of the m = 2 mode from an amplitude $\delta B_\theta/B_\theta = 0.004$ to a large value > 0.01 at the onset of disruption. Figure (3) shows the oscillation in the poloidal magnetic field, $\dot{B}_\theta$, as measured by a Mirnov coil during the time interval 12–13 ms. It was observed to increase slowly at first and to then undergo rapid growth. Figure (4) shows as measured by integrated $\dot{B}_\theta$ and the measured frequency f of the m = 2 mode as a function of time at 12–13 ms. This figure shows that $\delta B_\theta/B_\theta$ grows and mode frequency decreases.

The average time scale of the final growth is about 60–100 μs. The time scale for ideal-mode growth is generally bounded from below by the ideal time scale and from above by the resistive time scale. Typical ideal time scales are given by the poloidal Alfvén time, $\tau_A \equiv a/V_A$ where V_A is the Alfvén velocity, and the resistive time scale [2],

$$\tau_S \cong \tau_R^{0.6} \times \tau_A^{0.4} \qquad (1)$$

where $\tau_A \equiv \mu_0 a^2/\eta(0)$ is the resistive skin time, with the resistivity at the plasma center. In the IR-T1 tokamak, the Alfvén velocity is about 1.15×10^6 m/s and $\eta(0) \approx 6 \times 10^{-7}$ Ωm so that $\tau_A \cong 0.11$ μs and $\tau_R \cong 31$ ms. By using formula (1) we find the resistive time scale to be about 200 μs. These growth time values span the range between those expected from ideal and resistive MHD time-scale.Therefore, we can estimate the rate of island growth, dW/dt, to lie in the range 3.6 – 6 × 10^4 cm/s. It is instructive to compare these with the predication of the Rutherford non-linear theory :

$$\frac{\mathrm{d}W}{\mathrm{d}t} \equiv \frac{\Delta' \times \eta(0)}{\mu_0} \qquad (2)$$

where η is the resistivity and Δ' is the jump in the logarithmic derivative of the perturbed helical flux function ψ across the resonant surface [11]. We assume that Δ' is of order 1 cm^{-1} [11] and take $\eta(0) \approx 6 \times 10^{-7}$ Ωm. If we

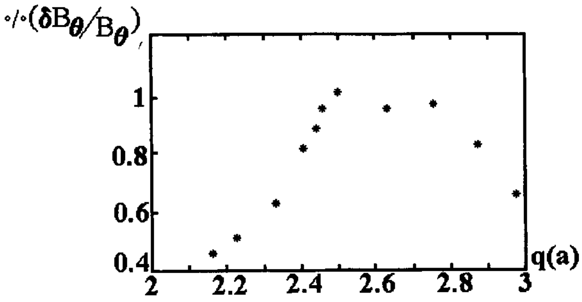

Fig. 5 The measured amplitude $\delta B_\theta/B_\theta$ of the 2/1 mode as a function of q(a).

make the further assumption that Δ' does not change significantly during the rapid growth phase then (2) predicts $dW/dt \approx 5.2 \times 10^4$ cm/s. Despite the considerable uncertainties involved in both the experimentally and the theoretically deduced values of dW/dt, they appear to be in reasonable agreement. We determined the ratio of the amplitude of the poloidal magnetic field fluctuation over the equilibrium poloidal magnetic field by using Mirnov coil signals in several shots with different q(a), the results being plotted in Fig. (5) [12]. It is clear from the figure that $\delta B_\theta/B_\theta$ exhibits a peak as a function of q(a). The peak in question corresponds to q(a) = 2.5 and is accompanied by a large amount of MHD activity. In Fig. 6, a Mirnov oscillation is observed at q(a) = 2.3. In contrast to the higher-q(a) shot, the lower-q(a) discharges exhibited a relatively low level of MHD activity up to several milliseconds before the disruption. This behavior is quite similar to the result presented by Kaye *et al.* [13] for the Princeton Beta Experiment (PBX).

3. Conclusion

In this work we have described detailed measurements of disrupting hydrogen plasmas in the ohmic-heating regime. The major disruption studied here consist of three phases: 1) thermal instability, 2) growth of the magnetic island, 3) trigger mechanism. The corresponding islands grow so rapidly, at rates consistent with the Rutherford non-linear tearing mode theory, that they reach size sufficient to cause disruption. The rate of island growth is about $3.6 - 6 \times 10^4$ cm/s, corresponding to a characteristic growth time τ_g of 60–100 μs. These values are in reasonable agreement with theory. The other conclusion from this study is that the magnitude of τ_g poloidal fluctuations (Mirnov oscillations) depends on the value of the safety factor at the limiter, q(a).

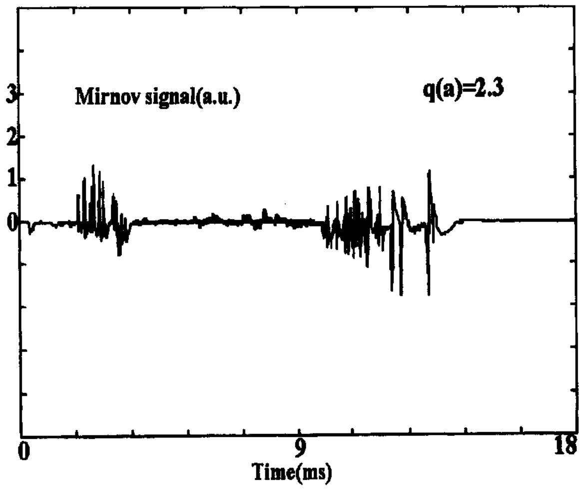

Fig. 6 Mirnov oscillation at q(a) = 2.3 in another shot.

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References

[1] Wesson, J.A. *et al.*, Nucl. Fusion **29**, 641 (1989).
[2] Schuller, F.C., Plasma Phys. Contr. Fusion **37**, A135 (1995).
[3] Sykes, A. and Wesson, J.A., Phys. Rev. Lett. **44**, 1215 (1980).
[4] Hicks, H.R. *et al.*, Nucl. Fusion **22**, 117 (1982).
[5] Turner, M.B. and Wesson, J.A., Nucl. Fusion **22**, 1069 (1982).
[6] White, R.B. *et al.*, Phys. Rev. Lett. **39**, 1618 (1977).
[7] Vannucci, A. *et al.*, Nucl. Fusion **31**, 1127 (1991).
[8] Jahns, G.L. *et al.*, Nucl. Fusion, **28**, 881 (1988).
[9] Ghoranneviss, M., Masnavi, M. *et al.*, Scientia Iranica **4**, 71 (1997).
[10] Ghoranneviss, M., Masnavi, M. *et al.*, J. Sciences I.R.Iran, **10**, 73 (1999).
[11] Rutherford, R.H., Phys. Fluids **16**, 1903 (1973).
[12] Ghoranneviss, M., Masnavi, M. *et al.*, J. Plasma Fusion Res., Series Vol. **2**, 67 (1999).
[13] Kaye, S.M. *et al.*, Nucl. Fusion, **28**, 1963 (1988).