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Study of MHD activities in the plasma of SST-1

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HIGHLIGHTS

- An account of MHD activity in the plasma of SST-1
- Observation of MHD instabilities with mode m = 2, n = 1 in SST-1 plasma.
- MHD instabilities study of characteristic growth time, growth rate of island and island width etc. in SST-1 plasma.

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ABSTRACT

Steady State Superconducting Tokamak (SST-1) is a medium size Tokamak in operation at the Institute for Plasma Research, India. SST-1 has been consistently producing plasma currents in excess of 60 kA, with plasma durations above 400 ms and a central magnetic field of 1.5 T over last few experimental campaigns of 2014. Investigation of these experimental data suggests the presence of MHD activity in the SST-1 plasma. Further analysis clearly explains the behavior of MHD instabilities observed (i.e. tearing modes with m = 2, n = 1), estimating the growth rate and the island width in the SST-1 plasma. Poloidal magnetic field and Toroidal magnetic field fluctuations in SST-1 are observed using Mirnov coils. Onsets of disruptions in connection with MHD activities have been correlated with other diagnostics such as ECE, Density and Hα etc. The observations have been cross compared with the theoretical calculations and are found to be in good agreement.

1. Introduction

Steady State Tokamak (SST-1) is a medium size Tokamak (major radius = 1.1m, minor radius = 0.2 m) at Institute for Plasma Research, India.SST-1 has been consistently producing plasma currents in excess of 60 kA, with plasma durations above 400 ms and a central magnetic field of 1.5 T over last few experimental campaigns [1]. Investigation of these experimental data reveals the existence of magneto hydrodynamic (MHD) instabilities in operational regimes. For steady state operation of SST-1, stability of plasma is one of the primary focuses considering the disruptions due to operating limits. Disruptions are major concerns for operation of steady state Tokamak. During disruptions, large forces act on vacuum vessel with large amount of plasma energy getting deposited on plasma facing components. Generally, disruptions develop while approaching operating limits i.e. density limit, β limit, q limit and also may be initiated by fast density rise, fast current rise, geometry change from limiter to diverted configuration, by a mode activity localized at the plasma edge and penetration in plasma of fragment from first wall etc [2,8]. Tearing mode instabilities associated with formation of magnetic islands lead to degradation of plasma and eventually to disruption. Similar phenomena are routinely observed in other Superconducting Tokamak [3]. Stabilization of MHD activities or suppression of magnetic islands helps mitigate the disruptions.

This paper elaborates the MHD properties of SST-1 discharges at the values of edge safety factor q_a between 3 and 5 ($q_a \sim 3.8$ at ~70 kA and $q_a \sim 5.4$ at ~50 kA). Tearing mode as a current driven instability – accompanied by magnetic reconnection leads to confinement degradation and disruptions. It occurs when local resistivity is sufficiently high, so that energy can be dissipated during reconnection process- changing magnetic field topology. The drive for this instability is the radial gradient of Toroidal current density and poloidal asymmetry to some extent.

In SST-1, it is observed that m = 2, n = 1 mode often leads to minor and major disruptions. Currently studies are underway towards understanding different disruption scenarios present in SST-1 plasma, the factors leading to disruptions.

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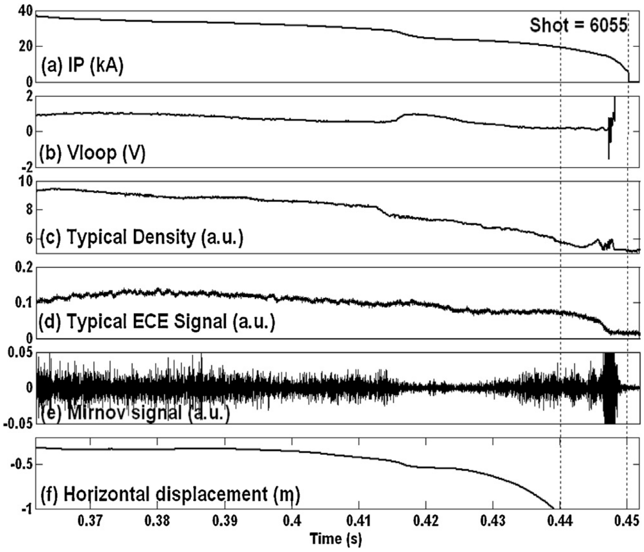

Fig. 1. SST-1 discharge with MHD disruption, (a) Plasma current, (b) Loop voltage (c) Typical Density signal (d) Typical ECE signal (e) Mirnov signal (f) Horizontal displacement.

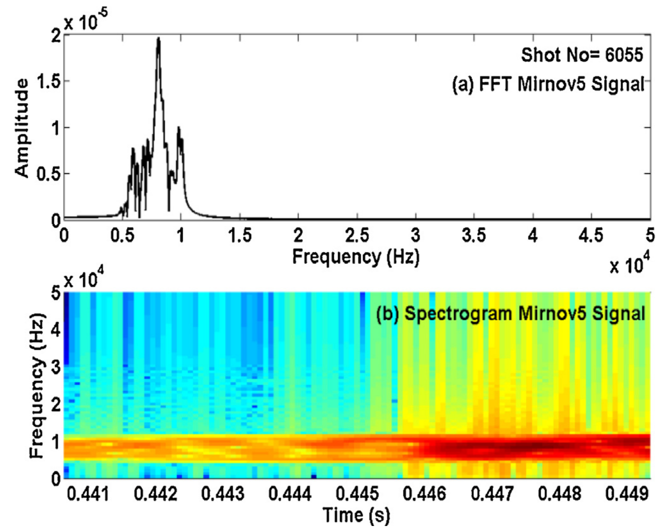

Fig. 2. (a) Fourier transformation of Mirnov signal, (b) Time-Frequency spectrum of Mirnov signal.

2. SST-1 experiments

In the current phase of experiments, SST-1 was operated in limiter configuration (Graphite inboard, outboard limiters) with a central field of 1.5 T assisted with ECRH pre-ionizations in Hydrogen gas.SST-1 has 16 Toroidal Field (TF) superconducting coils responsible for providing the required Toroidal field, and a pair of vertical field coils placed symmetric to Z = 0 plane providing the necessary equilibrium field to the plasma column formed. The breakdown of the plasma was initiated with ECH pre-ionization employing a 42 GHz Gyrotron in fundamental mode followed by the Ohmic transformer. In experimental campaigns of 2014, SST-1 was normally operated at plasma currents (I_P) ranging between 50 kA and 70 kA at B_T = 1.5 T with H_2 gas plasma and EC heating systems (< = 200 kW).

SST-1 is equipped with Electron Cyclotron Emission (ECE) diagnostics (Radiometer E-Band, 74-86 GHz), Spectroscopy system (for temporal evolution of Hα, Hβ, O_I, O_{II}, C_{II} etc. line emissions), Soft – X ray, Hard- X ray diagnostics (Nal(TI) Scintillator detector, 70 keV–10 MeV) and Density diagnostics (Heterodyne and Homodyne) etc. Poloidal magnetic fluctuations are measured using 12 Mirnov coils placed at different toroidal and poloidal locations. The Mirnov coil signals are acquired at 100 kHz sampling rate considering magnetic fluctuations of the order of tens of kHz. The Mirnov coil oscillations are largely analyzed in this study towards the MHD activities in SST-1 plasma.

3. Results and discussions

In a specimen shot 6055, with a plasma current in excess 50 kA at 1.5 T, we observed minor disruptions which were recovered and a major disruption leading to zero plasma current (Fig. 1). Disruptions are caused by a rapid broadening of the current profile with consequent decrease in Poloidal field, followed by loss of thermal energy from the plasma.

Disruption as observed for shot 6055 shows: decrease in electron temperature (approximately ~70%) as measured by ECE diagnostics, negative spike on Loop voltage. These indicate a sharp broadening of the current carrying zone accompanied by partial release of poloidal flux from the plasma [4]. Earlier in the shot, ECE diagnostics diagnoses the minor disruptions consisting of radial redistribution of plasma energy, which the plasma recovers and does not get disrupted completely.

For shot 6055, Fast Fourier Transform of Mirnov signals (Fig. 2a) and Wavelet spectrogram (Fig. 2b) are used to understand the temporal evolution and frequency components. Mirnov coil signal of ~8 kHz (Fig. 2a and b) is the dominant one associated with the tearing mode. In particular, the magnetic fluctuations analysis using Singular Value Decomposition method (SVD) [5–7]. for the discharge shows that the MHD activity consists dominantly of a m = 2 mode (Fig. 3b). The spatial structure represented by polar plot in Fig. 3b reveals m = 2 magnetic island structure and corresponding temporal evolution in Fig3.a shows that a m = 2 mode appears (grows and decays) in between 444 ms to 448 ms.

The external magnetic fluctuations detected by Mirnov coils present the evidence of magnetic islands. MHD instability observed is m/n = 2/1 resistive tearing mode, which is driven by the plasma current density gradient, and is characterized by reconnection of magnetic fluxes and development of magnetic islands.

The Poloidally asymmetric increase of plasma resistivity due to MARFE (Multifaceted asymmetric radiation from the edge) cooling leads to a global contraction of the current channel. Qualitatively, because of the equilibrium constraint, the Ohmic resistance of cold MARFE appears in series with the hot plasma resistance on each flux surface, resulting in substantial increase of the average edge resistivity. As a consequence of current contraction, instability parameter increases. This results in formation of quasi-stationary rotating islands, located near the corresponding rationale surface. MHD instability with Poloidal number m and Toroidal number n is located at the resonant surface $r_{q=m/n}$. Considering the current profile, $J \sim (1-(r/a)^2)^\alpha$, the q profile can be calculated by using formula

$$\boldsymbol{q}(\boldsymbol{r}) = \boldsymbol{q}(\boldsymbol{a}) \times \frac{(\boldsymbol{r}/\boldsymbol{a})^2}{1-\left(1-(\boldsymbol{r}/\boldsymbol{a})^2\right)^{\alpha+1}} \quad (1)$$

For shot no 6055, With q(a) ~5.4 and α = 3, the calculated q(r) profile is depicted in Fig. 4. The resonant layer where q = 2 is located at $r_s \sim 10.8$ cm.

A general relation between linear MHD-mode growth time τ_g, ideal timescale τ_A and resistive diffusion time τ_R is

$$\tau_A < \tau_g < \tau_R \quad (2)$$