

Investigation of Some MHD Events in the SUNIST Spherical Tokamak*

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Abstract Internal reconnection event (IRE), which is characterized by a perturbation in plasma current I_p , loop voltage V_{loop} , H_α radiation and magnetic perturbation dB_p , was observed in the SUNIST experiment. It is found that, the fluctuation before IREs is characterized by a structure of $m = 2/n = 1$, then changes to $m = 4/n = 1$ during the IREs; and, after IREs, the mode number changes to $m = 3/n = 1$. An analysis in the evolution of equilibrium parameters during IREs shows that a positive spike appears in the evolution of the plasma's elongation and a negative spike in the poloidal beta of plasma. A collapse in the pressure profile, corresponding to the occurrence of IREs, is also found.

Keywords: IREs, SUNIST, singular value decomposition, poloidal mode

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1 Introduction

In spherical tokamaks (STs), MHD instabilities exhibit different characteristics against those in conventional tokamaks. The internal reconnection event (IRE) is one of several unique features observed in STs^[1~3]. IREs are known to cause energy and particle losses, without a termination of the plasma current^[4~6]. Such phenomenon is observed with a spike in plasma current, and in irregular intervals. IREs are studied experimentally on START^[1], MAST^[2], TST-2^[3,7] and other ST devices^[8]. The Sino-United Spherical Tokamak (SUNIST) is a spherical tokamak with a small aspect-ratio A/a of about 1.3 and a high elongation κ of about 1.6^[9]. Investigation of IREs in SUNIST should be necessary. The motivation of this paper is to expound the features of IREs and to identify the source of the instability in SUNIST.

This article is organized as follows. In section 2, a conventional diagnostics system in SUNIST is presented, and then the methods of using singular value decomposition (SVD) to analyze MHD mode and using EFIT code to obtain plasma parameters are briefly described. Analysis results, including the evolution of both MHD mode number and plasma parameters, are shown in section 3, and the observed impact of toroidal field on IREs is also discussed. Section 4 is devoted to conclusion and summary.

2 Experimental setup

2.1 Magnetic diagnostics system in SUNIST

All experimental data in SUNIST is obtained from a conventional diagnostics system, which includes a Rogowski coil measuring the total toroidal plasma current, thirteen flux loops, fifteen poloidal pick-up coils and six toroidal pick-up coils. Partial locations of the sensors are shown in Fig. 1.

Magnetic fluctuations are measured by magnetic pick-up coils with a frequency response of up to 20 kHz. Especially, the coils to detect toroidal mode number are located at toroidal angles of $\theta = 0^\circ, 30^\circ, 120^\circ, 180^\circ, 240^\circ$, and 300° . Reconstructions in SUNIST utilize data from a Rogowski coil, thirteen loop voltage monitors and fifteen integrated poloidal pick-up coils.

2.2 Mode analysis by singular value decomposition

The SVD scheme^[10] is used to analyze mode structures in many fusion experiments^[11,12]. Consider a matrix S of $M \times N$, expressed as

$$S = U \sum V^T, \quad (1)$$

where U of $M \times M$ and V of $N \times N$ are orthogonal matrices and \sum of $M \times N$ is a diagonal matrix. $\sum, U,$

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and V are called the singular value, chrono and topo, respectively. Both chrono and topo exhibit common waveforms for temporal eigenmodes and spatial eigenmodes, respectively. Time evolutions of each decomposed mode (i.e., chrono) and its spatial distribution (i.e., topo) can be extracted in this way.

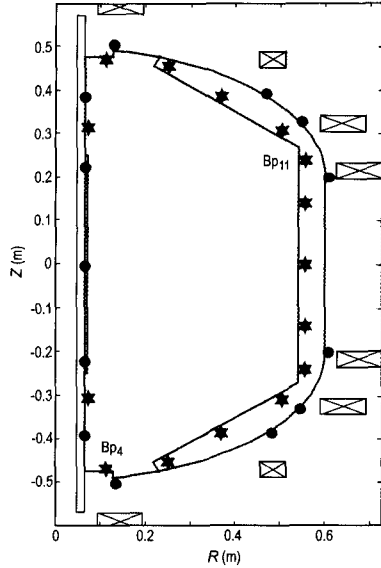


Fig.1 Flux loops (●) and poloidal magnetic coils (★) in SUNIST

2.3 Plasma parameters fitted by EFIT model

The EFIT code has been applied to many tokamaks, e.g., DIII-D, JET and JT-60U, details of which can be found in Ref. [13]. Each implementation has the specific features required to properly model a particular configuration.

For the SUNIST plasma, a reliable set for p' and ff' can be written as

$$p'(\psi) = \alpha_0 + \alpha_1\psi_N - (\alpha_0 + \alpha_1)\psi_N^2, \quad (2)$$

$$ff'(\psi) = \beta_0 + \beta_1\psi_N - (\beta_0 + \beta_1)\psi_N^2, \quad (3)$$

with p' and $(f^2)'$ the gradients of pressure and poloidal current of plasma, respectively. ψ_N is the normalized poloidal flux.

3 Experimental results

3.1 Typical discharge

A typical discharge with IREs is shown in Fig. 2. A positive spike in plasma current and a negative spike in loop voltage are observed. During IREs, poloidal magnetic fluctuation increases significantly. The increase in H_α -emission indicates an enhanced interaction between the plasma and the vacuum vessel due to the loss of the plasma.

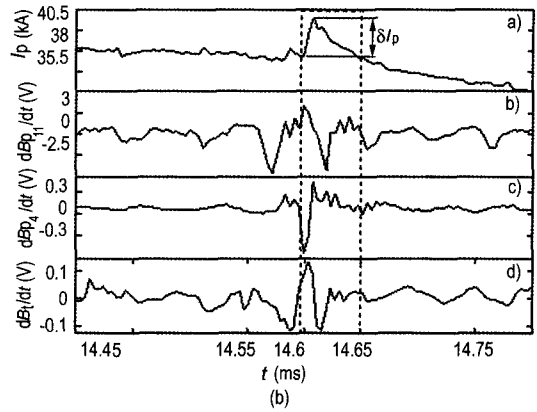
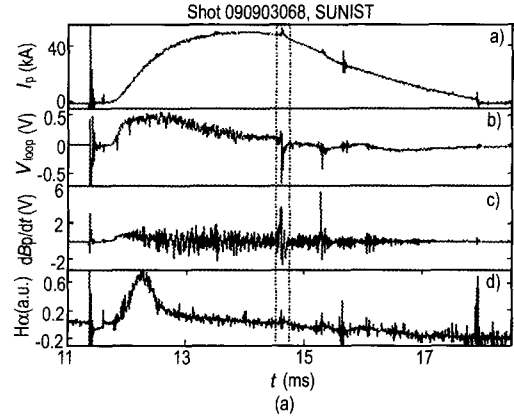


Fig.2 (a) Waveform of typical discharge with IREs: a) Plasma current, b) Loop voltage, c) Signal from a magnetic coil, d) H_α emission. Dot lines indicate the time intervals for the occurrence of IREs; (b) IREs in an expanded time scale: a) Plasma current, b) Signal from the 11th poloidal coil, c) Signal from the 4th poloidal coil, d) Signal from a toroidal coil. Dot lines indicate the time intervals for the occurrence of IREs

3.2 MHD analysis

Magnetic signals reflect mainly the mode behavior outer of the plasma. As mentioned earlier, both poloidal and toroidal magnetic fluctuations increase significantly during IREs, which are also shown in Fig. 2(b). SVD analysis including magnetic signals is useful for obtaining mode number. SVD was performed on shot 090903068 by using data from fifteen poloidal pick-up coils and six toroidal pick-up coils. The evolution is as follows. Before IREs, poloidal mode number is two, then it changes to four during IREs, and after IREs it decreases to three. Meanwhile, the toroidal mode number remains unchanged, $n = 1$. The results are shown in Fig. 3.

By varying the toroidal field, it is found that the toroidal field sets a threshold for IREs, as shown in Fig. 4. IREs occurs only when the toroidal field is lower than the threshold. In Fig. 4, it is shown that the change in I_p , i.e., δI_p in Fig. 2(b), during IREs, which defines the intensity of IRE, does not depend notably on the toroidal field B_T . So the relation between edge safety factor (q_a) and IREs in SUNIST is as follows.

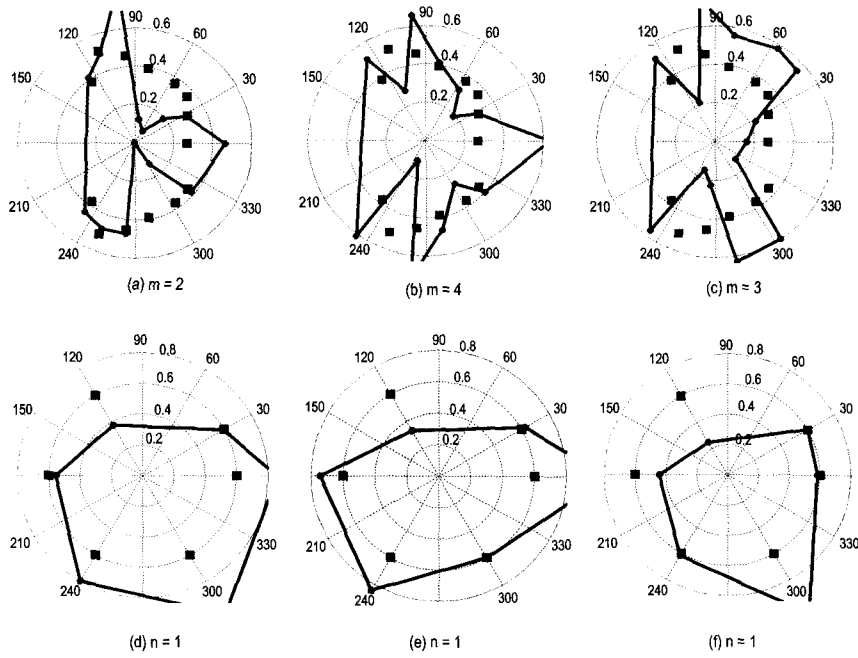


Fig.3 Temporal variation in the mode structure of (a)~(c) the poloidal mode and of (d)~(f) the toroidal mode. The fluctuation before the occurrence of IREs is characterized by a structure of $m = 2/n = 1$, then it changes to $m = 4/n = 1$ during IREs, and, after IREs, the mode number changes to $m = 3/n = 1$. Line represents spatial structure and ■ represents the positions of probes

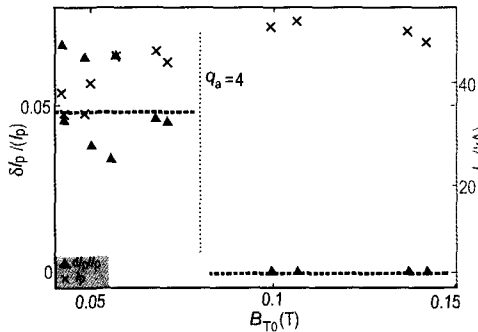


Fig.4 Relation between IREs and B_T . When q_a is below four, IREs are found during the discharges. The intensity of IREs doesn't change clearly with a further decrease in q_a

When q_a is below four, IREs occur during the discharges. The intensity of IREs doesn't change clearly when q_a decreases further.

3.3 Evolution of plasma parameters

Evolution of plasma parameters in SUNIST during IREs is studied by using EFIT. The results show that a positive spike appears in the elongation of plasma corresponding to the spike in plasma current, as shown in Fig. 5. The elongation during IREs increases from 1.80 to 1.86, then decreases to 1.78.

A negative spike is found in the poloidal beta of plasma, as shown in Fig. 5. Pressure profiles at different moments (t_1 , t_2 , t_3 , t_4 and t_5) are shown in Fig. 6. Before the occurrence of IREs (from t_1 to t_2), the pressure profile peaks and the pressure gradient increases.

During the IREs the pressure profile gets smooth (from t_2 to t_4). Finally the pressure profile peaks again after IREs (from t_4 to t_5). These results show that a collapse in the pressure profile is correlated to the occurrence of IREs.

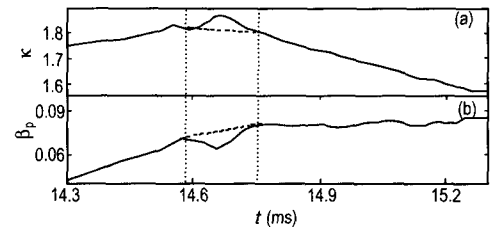


Fig.5 Evolution of the plasma parameters during IREs. (a) A positive spike in κ (plasma elongation) appears. (b) A negative spike in β_p (poloidal beta). Dot lines indicate the time intervals for the occurrence of IREs

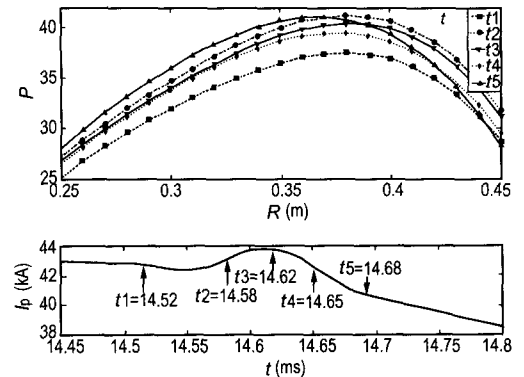


Fig.6 Pressure profile during IREs. (a) Pressure profile at different moments, (b) Evolution of plasma current with different moments during IREs indicated

4 Conclusion and summary

IRE, characterized by a perturbation in plasma current I_p , loop voltage V_{loop} , H_α emission and magnetic perturbation δB_p , is confirmed in the SUNIST experiment. Results of MHD analysis show a significantly change in mode number. It is found that, the structure of fluctuation before the occurrence of IREs is characterized by $m = 2/n = 1$, then it changes to $m = 4/n = 1$ during IREs, and after IREs, it changes to $m = 3/n = 1$. An analysis of the evolution in equilibrium parameters during IREs shows that a positive spike appears in the evolution of the plasma elongation while a negative spike in the plasma poloidal beta. A collapse in the pressure profile is also found to correspond to the occurrence of IREs.

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