27th EPS Conference on Contr. Fusion and Plasma Phys. Budapest, 12-16 June 2000 ECA Vol. **24B** *(2000) 1400 -1403*

Observation of internal reconnection events on TST-2

S. Shiraiwa, Y. Takase, A. Ejiri, K. Yamagishi[A], Y. Nagashima[A], N. Kasuya[A],
T. Mashiko[A], H. Nozato, M. Ushigome[A], L.M. Tozawa[A], S. Duorah[A]
T. Akiduki, H. Kasahara, H. Yamada, T. Yamada[A], H. Wada[A]
Graduate School of Frontier Sciences, University of Tokyo
Graduate School of Science, University of Tokyo[A]
Hongo 7-3-1, Bunkyo-ku, Tokyo, 113-0033, Japan

1, Introduction

The spherical tokamak (ST) is attracting attention worldwide as an alternative plasma confinement scheme with high efficiency and good stability[1]. Advantages of the ST include high plasma current capability at low toroidal field, high toroidal beta, naturally high shaping parameter and the existence of a nearly omnigeneous region in the bad curvature region at high beta regime. Concerning stability, early START experiments reported the disruption resilience[2]. Instead, the internal reconnection event (IRE) occurs. IREs have been observed on several STs[3] and are considered to be an MHD event peculiar to the ST regime.

The fact that a large fraction of the stored energy is lost during an IRE makes the understanding and control of this process an urgent issue. Numerical resistive MHD calculation[4] that successfully reproduces the overall distortion of the plasma shape and abrupt loss of stored energy during IRE indicates that the IRE is caused by a pressure driven instability. However, experimental evidence is still not sufficient.

In this paper, we report initial results from TST-2 (Tokyo Spherical Tokamak - 2)[5] which is a newly constructed spherical tokamak at the University of Tokyo.

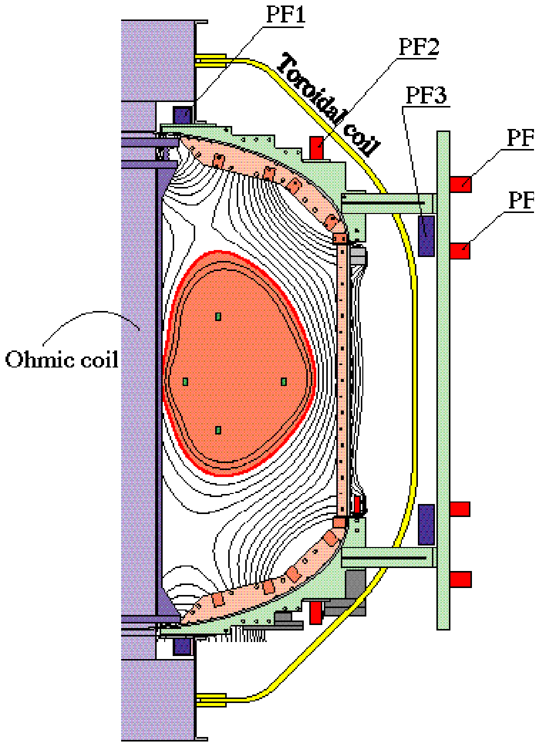

Fig. 1: Cross-sectional view of TST-2 with the plasma boundary shape overlaid.

2. TST-2 device

Figure 1 shows a cross-sectional view of TST-2. The geometrical parameters are major radius R=0.36 m, minor radius a=0.23 m, aspect ratio A~1.6 and elongation κ~1.3-1.8. Plasma current of 200 kA, discharge duration of 50 ms, electron temperature of several hundred eV and volume averaged beta of up to 10 % are expected by ohmic heating alone. The plasma boundary obtained using filamentary plasma model is also shown in Fig. 1. Detailed information on the design of TST-2 is found in Ref. 5. Research topics include study of MHD instabilities, fluctuation-induced transport, development of radio frequency heating and current drive scenarios, and development of new diagnostics suitable in the ST regime.

The first plasma discharge was obtained in September 1999. Presently optimization studies of plasma start-up are being carried out. So far, plasmas with plasma currents of up to 90 kA and with a typical discharge duration of about 10ms have been achieved with less than a half of the ohmic solenoid Volt-second capability.

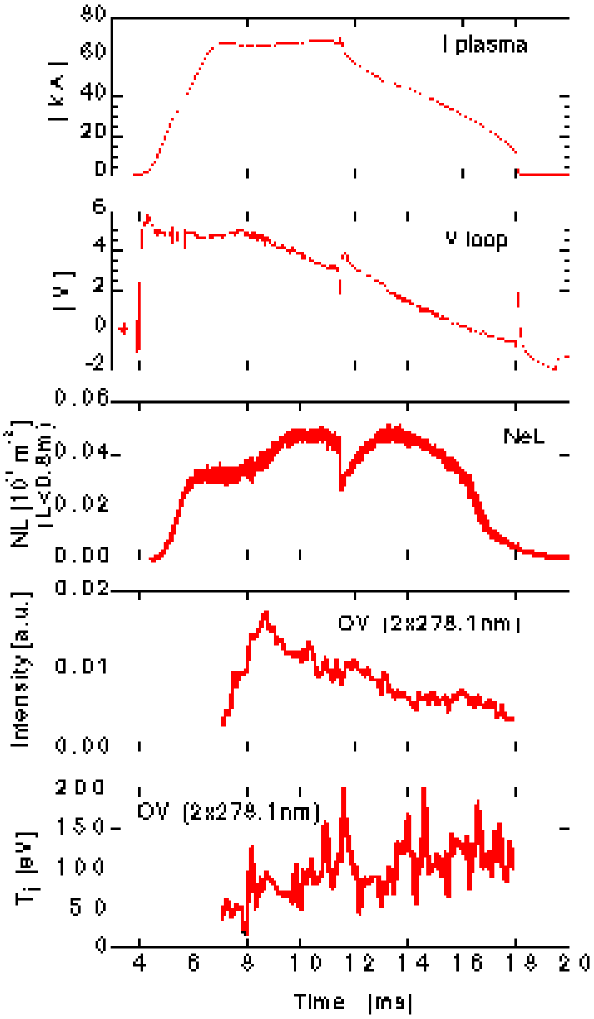

Fig. 2 A TST-2 discharge with IRE.

3. IRE on TST-2

Figure 2 shows a discharge with an IRE. Plasma is initiated by a loop voltage of about 5V induced by the ohmic solenoid, assisted by 2kW 2.45GHz ECH pre-ionization. Plasma current ramps up at a rate of 25 MA/s and becomes steady at 70 kA. At 11.5 ms, an abrupt increase of the plasma current and decrease of the loop voltage are observed. These are probably caused by a flattening of the current density profile and a resultant decrease of the internal inductance. The line averaged density measured by a 104GHz microwave interferometer along the vertical chord through the plasma center drops by roughly 40 %, while the ion temperature measured by Doppler broadening of OV emission is approximately 100 eV and does not show a drastic change at IRE.

In the discharge shown in Fig. 2, a coherent magnetic fluctuation around 10 kHz is observed when the plasma current saturates. A fluctuation in the line averaged electron density coherent with the magnetic fluctuation is also observed. The RMS fluctuation level of the line-averaged density is 2-4 %. The Mirnov coil array located outside the vacuum vessel shows that the 10kHz mode has a dominant toroidal mode number of one. Currently the number of poloidal Mirnov coils is insufficient to determine the poloidal mode number. The fluctuation amplitude is larger on the outboard (low field) side than on the inboard side, which suggests that this mode may be localized in the low field side.

In discharges with plasma currents of over 50kA, a 10-20kHz n=1 mode activity usually observed. However, in some discharges saturated mode become stabilized and the plasma current ramps up again (Fig. 3).

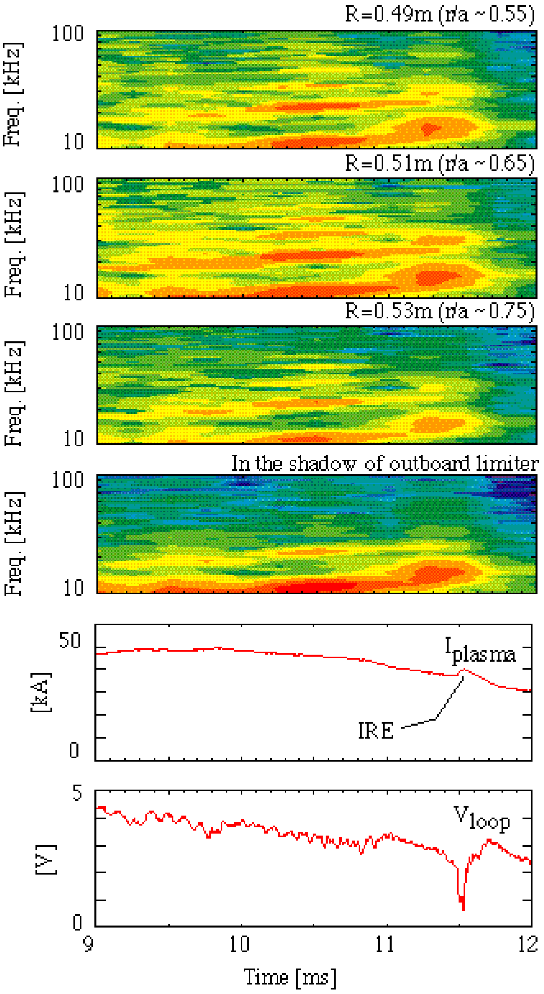

Fig. 4: Frequency spectra of dB_r/dt at R=0.53, 0.55, 0.57 m and dB_z/dt in the shadow of the outboard limiter.

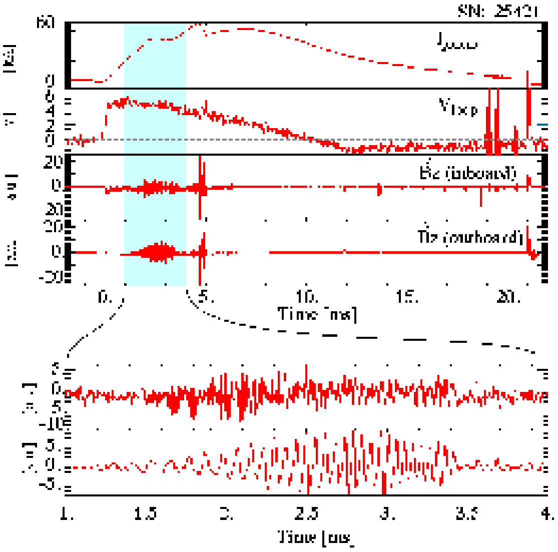

Fig. 3: Discharge with stabilization of the n=1 MHD activities.

This type of discharges has a slightly slower plasma current ramp up rate than that shown in Fig. 2. In addition, the plasma current tends to saturate at a lower level in lower toroidal field discharges. These observations imply that this MHD activity is induced by a broadening of the current profile and/or by a decrease of the edge safety factor. This mode may be identical to that observed previously on CDX-U [3].

4. Higher order fluctuations before IRE

A 10 kHz, n=1 MHD mode grows before an IRE. Frequency spectra of the magnetic fluctuation measured outside the plasma show coherent modes only at the fundamental and the second order harmonic frequency. For the purpose of detecting higher order harmonics, a magnetic pickup coil array was inserted to a depth of $r/a \approx 0.55$ from the low field side. The magnetic fluctuation was measured up to 100 kHz.

Figure 4 shows the frequency spectra of the internal magnetic fluctuations and the plasma current and the loop voltage. At R=0.49~0.51m, the spectra show a growth of 10 kHz fluctuations followed by a growth of up to 4th harmonic. In contrast, the 10 kHz mode appears behind the limiter similarly to the discharge shown in Fig. 2. The spectra also show stabilization of harmonics and a growth of mode with half integer harmonic frequency such as ~15 kHz and ~30 kHz just before the drop of loop voltage. These observations suggest that some non-linear process may be acting on MHD activities that lead to the IRE.

5. Summary

In this paper, the present status of TST-2 and initial results of IRE investigation was presented. On TST-2, MHD activities with a frequency of around 10 kHz and a toroidal mode number of one are usually observed to grow up before an IRE. At an IRE, an abrupt increase of the plasma current and a decrease of the loop voltage and up to 40% drop of the line-averaged density are observed. No drastic response was observed on the OV line intensity and on the ion temperature obtained from OV Doppler broadening.

Internal magnetic measurements show that the frequency of the MHD activity can spread up to the 4th harmonic of the 10 kHz mode observed outside the plasma. Before an IRE, the amplitude of these harmonics grows simultaneously. After stabilization of harmonics, half integer harmonics grow before an IRE and vanish after an IRE.

The MHD modes observed may be the cause of the plasma current saturation. In some discharges in which these modes are stabilized, the plasma current ramps up again. However, detailed study of the relationship between plasma current saturation and MHD mode activities require more precise plasma position control and is planned after the installation of a new pair of poloidal field coils and a pre-programmable power supply.

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