Overview of TST-2

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1. Introduction

TST-2 is a spherical tokamak (ST) with major radius R = 0.36 m and minor radius a = 0.23 m (aspect ratio A = 1.6), constructed as an upgrade of TST-M at the University of Tokyo [1]. Its design capabilities are toroidal magnetic field B = 0.3 T (upgradeable to 0.4 T), plasma current I = 0.2 MA, and pulse length 0.05 s. It produced the first plasma in September 1999. Plasma currents of up to 0.11 MA, toroidal fields up to 0.21 T, and discharge durations of up to 0.1 s have been achieved. Typical ion temperatures are in the range 50−100 eV. Line average densities of over 2×10^{19} m^{-3} have been obtained. Presently it can operate routinely at B = 0.2 T and I = 0.1 MA.

Large-scale reconnection events (sometimes called the internal reconnection event, IRE) are often observed in ST plasmas. Such events can cause significant loss of both energy and particles. It is important to understand the physical process leading to such events, in order to develop techniques to avoid them. Measurements of magnetic perturbations by an array of magnetic probes inserted into the plasma are described in Sec. 2. Noninductive current drive is of crucial importance for ST, since it is impractical for an ST reactor to have an Ohmic solenoid. ST plasmas generally have very high dielectric constants, $\varepsilon = \omega_{pe}^2/\omega_{ce}^2 \sim O(10^2)$, compared to conventional tokamaks which have $\varepsilon \sim O(1)$. It has been pointed out that the high harmonic fast wave (HHFW) can propagate to the core of high temperature, high-density plasmas and damp strongly on electrons, and is therefore well suited for current drive in ST plasmas [2]. Excitation of a unidirectional HHFW by a combline antenna is described in Sec. 3. Similarly, because of high dielectric constant, electron cyclotron emission cannot be used for electron temperature measurement in ST plasmas. The electron Bernstein wave (EBW) can propagate in high dielectric constant plasmas, and might offer an alternative method for diagnosing the electron temperature. First results of EBW emission measurements are presented in Sec. 4.

2. Internal Magnetic Measurements During Reconnection Events

Internal magnetic field perturbations were measured by an array of magnetic probes inserted into the plasma. The magnetic probe consists of 10 pairs of 2-axis orthogonal magnetic pickup loops spaced every 20 mm. The probe was inserted at a height of $z = -120$ mm. At around $r/a = 0.6$, a 10 kHz $n = 1$ magnetic fluctuation was observed to grow, followed by a growth of higher harmonics (up to the 4th harmonic) [3]. Outside the plasma, only the fundamental and second harmonic fluctuations could be detected. These harmonics disappeared, and modes with frequencies of 15 and 30 kHz grew just before a reconnection event. These observations suggest that nonlinear coupling of multiple helicity modes is occurring, as seen in a recent 3-D MHD simulation [4].

3. HHFW Excitation by a Combline Antenna

The combline antenna is an array of resonant loops that are excited by mutual coupling between neighboring elements [5]. It has a band-pass characteristic of the combline filter, and the phase shift between neighboring elements varies from 0 to π from the low to the high frequency end of the pass band. At the center of its pass band, the phase shift is $\pi/2$, and a highly directional traveling wave can be excited. Its advantages include simplicity of feeding (external power feed is required only for the first element, and an exit at the last element to avoid reflection) and insensitivity of the input impedance to the plasma condition (because the impedance is dominated by mutual coupling to the next element, not by plasma loading). The combline antenna used in TST-2 consists of 6 elements (current straps), and has a pass band in the frequency range 22–28 MHz. As shown in Fig. 1, it excites a traveling wave with a toroidal wave number of $k_\phi = 13\ \mathrm{m}^{-1}$ (corresponding to a toroidal mode number of $n = 7.4$) at 25 MHz (approximately $8\Omega_H$). The toroidal variation of the phase measured by an array of RF magnetic probes, located on the outboard side of the torus, was consistent with the expected toroidal mode numbers of $n = 7$–8, and the sign of n reversed when the power was fed to the antenna from the opposite direction.

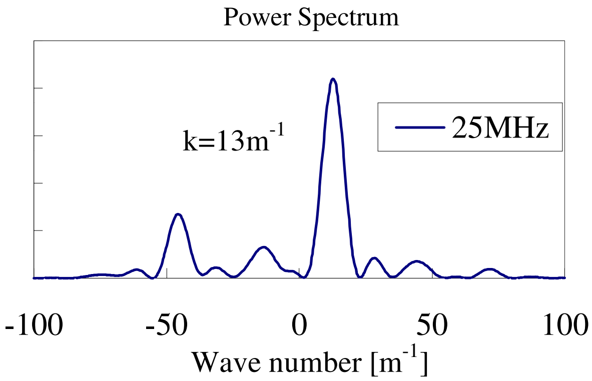

Fig. 1 The k_ϕ spectrum measured in front of the TST-2 combline antenna by a magnetic probe, in the absence of plasma.

At the power level of 1 kW used in these experiments, the antenna loading is dominated by HHFW excitation rather than sheath loading. Measurements of the antenna current in each strap indicate that when plasma is present in front of the antenna, induced currents in the second current strap is greatly attenuated and the currents in the third strap and beyond become negligibly small. This means that power from the first current strap flows mostly to the plasma rather than to the second current strap. Such high plasma loading is advantageous for delivering power to the plasma, but the antenna then works as a single-strap antenna. In order to excite a highly directional HHFW, plasma loading must be reduced. The high plasma loading also affects the input impedance of the antenna, because it is no longer determined by the mutual coupling alone. The reflection from the input was reduced from 20% to 5% by lowering the plasma loading by inserting a limiter beyond the antenna radius. The same effect is obtained by pushing the plasma towards the inner wall.

A broadening of the frequency spectrum of the HHFW field was observed in the presence of plasma. A comparison of the frequency spectrum with and without plasma is shown in Fig. 2. The signal was detected by a magnetic probe located approximately 30° away in the toroidal direction from one end of the antenna. The broadening of the frequency spectrum suggests that the HHFW experiences significant scattering by low frequency density fluctuations. Such a mechanism has been proposed as a factor responsible for the variability of HHFW heating under different conditions in NSTX (helium vs. deuterium plasma, fast vs. slow phase velocity waves, etc.) [6].

4. EBW Emission Measurement

EBW emission might be used as an alternative to ECE for measuring the electron temperature [7]. However, because EBW cannot propagate in free space, it must be converted

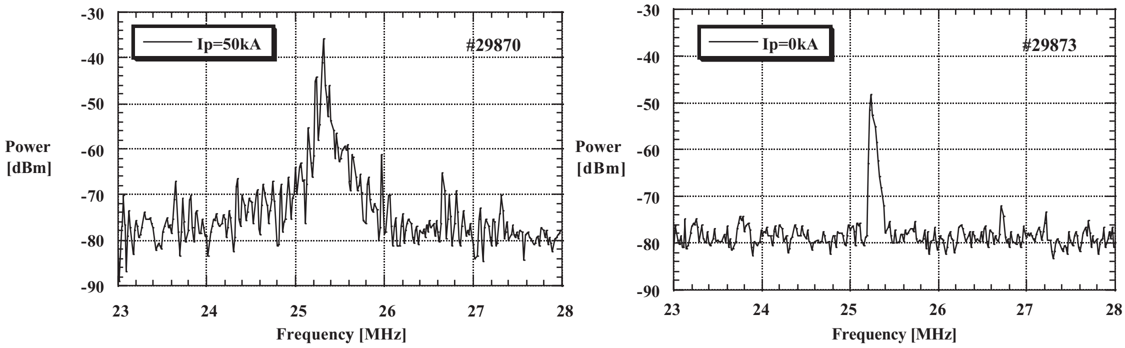

Fig. 2. Comparison of the frequency spectrum with (left) and without (right) plasma. The HHFW field was detected by a magnetic probe located on the low field side, approximately 30° away in the toroidal direction from one end of the antenna.

to an electromagnetic wave for detection outside the plasma, or it must be detected inside the plasma. The electromagnetic emission in the frequency range 5–12 GHz is detected by a heterodyne radiometer. The same system can be used as a homodyne reflectometer to measure the density gradient, which is crucial for evaluating the mode conversion efficiency [8]. Figure 3 shows a time history of the emission at 10 GHz detected by this system. At plasma current startup, a bright emission believed to be electron cyclotron emission is detected. The weaker signal detected after the density has increased beyond the cutoff is believed to be EBW emission, and has time variations correlating with IRE's.

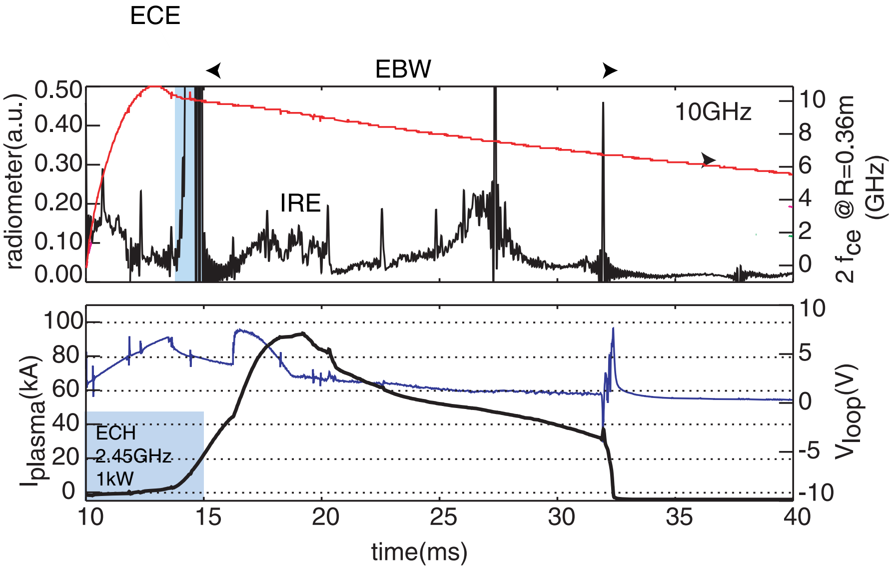

Fig. 3. Emission detected by the EBW radiometer.

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