High Harmonic Fast Wave Experiments on the TST-2 Spherical Tokamak

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1. Introduction

TST-2 is a spherical tokamak with major radius R = 0.36 m and minor radius a = 0.23 m (aspect ratio A = 1.6) at the University of Tokyo [1]. Its design capabilities are toroidal magnetic field B = 0.3 T (upgradable to 0.4 T), plasma current I = 0.2 MA, and pulse length 0.5 s. It produced the first plasma in September 1999. Presently it can operate routinely at B = 0.2 T and I = 0.1 MA. Noninductive current drive is of crucial importance in spherical tokamaks (ST), since it is impractical for an ST reactor to have an Ohmic solenoid. Development of an efficient current drive method for ST is therefore very important. 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 dielectric constants of order 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 on electrons, and is therefore well suited for current drive in ST plasmas [2]. Excitation of a unidirectional HHFW by a combline antenna is reported in this paper.

2. Combline Antenna

The combline antenna is an array of quarter wavelength resonant loops which are excited by mutual coupling between neighboring elements [3]. It has a band-pass characteristic of the combline filter, and the phase shift between neighboring elements vary from 0 to π from the low to high frequency end of the passband. At the center of its passband, the phase shift is π /2, and it excites a traveling wave naturally. Its advantage 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 not by radiation to the plasma, but by mutual coupling to the next element). The combline antenna used in TST-2 consists of 6 elements (current straps), and it excites a traveling wave with a toroidal wavenumber of k_ϕ = 13 m^{-1} (this corresponds to a toroidal mode number of n = 7.4) at 25 MHz. The k_ϕ spectrum measured in front of the antenna by a movable magnetic probe, in the absence of plasma, is shown in Fig. 1. The antenna is fed by a transmitter operating at typically 1 kW. At this power level, 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

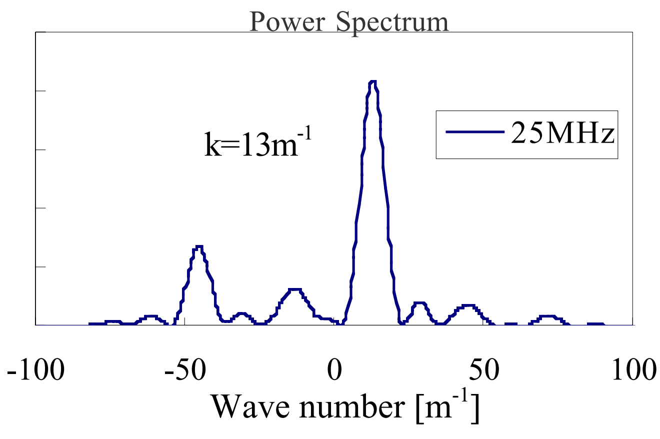

Fig. 1 The k_ϕ spectrum measured in front of the TST-2 combline antenna by a magnetic probe, in the absence of plasma. The peak toroidal wavenumber of k_ϕ = 13 m^{-1} corresponds to a toroidal mode number of n = 7.4.

power from the first current strap flows mostly to the plasma (by exciting the HHFW) rather than to the second current strap. Such high plasma loading is advantageous for delivering power to the plasma, but the antenna works as a single-strap antenna rather than a combline 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 the impedance is no longer determined by the mutual coupling alone. The plasma loading was successfully lowered by moving the plasma boundary farther away from the antenna, either by pushing the plasma toward the inner wall or by inserting a limiter beyond the antenna radius.

3. HHFW Measurements

It was reported earlier [1] that the wave fields detected on the inner wall (center stack) are more than an order of magnitude weaker than those detected on the outboard limiter. This is likely due to the thick evanescent region that exists on the high field side of the torus. Additional RF magnetic probes were installed on the outboard side. The toroidal variation of the phase was consistent with toroidal mode numbers of n = 7–8, which are the dominant mode numbers excited by the antenna, and the sign of n reversed when the power was fed to the antenna from the opposite direction.

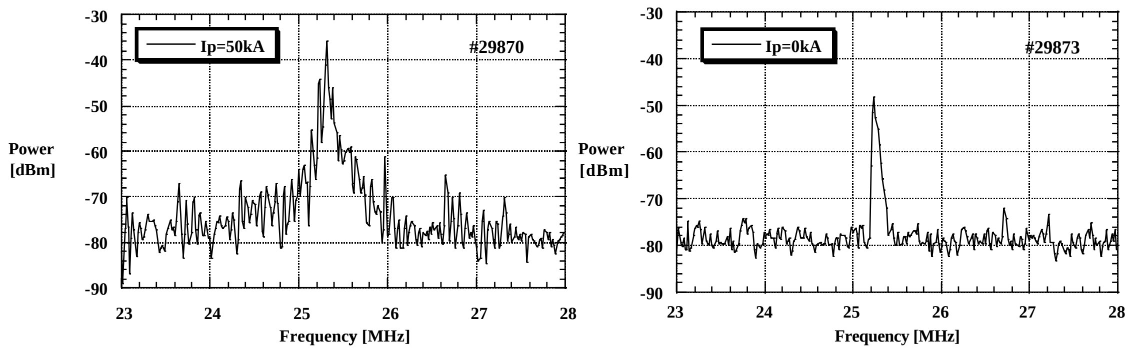

Fig. 2 Comparison of the frequency spectrum with (left) and without (right) plasma. The HHFW field was detected by a probe located on the low field side, approximately 30° away in the toroidal direction from one end of the antenna.

A broadening of the frequency spectrum of the HHFW field was observed when plasma was present. A comparison of the frequency spectrum with and without plasma is shown in Fig. 2. The signal was detected by a probe located approximately 30° away in the toroidal direction from one end of the antenna. The broadening of the frequency spectrum suggests that significant scattering of the HHFW by low frequency density fluctuations is occurring. Such a mechanism has been proposed as a factor responsible for the variability in the effectiveness of HHFW heating under different conditions in NSTX (helium vs. deuterium plasma, fast vs. slow phase velocity waves, etc.) [4].

4. Summary

A combline antenna has been used in TST-2 to excite a HHFW with finite directivity in the toroidal direction. Anomalously high plasma loading was observed. This is detrimental to excitation of a highly directional wave by a combline antenna. Plasma loading was reduced by moving the plasma farther away from the antenna. The toroidal variation of the wave field phase was consistent with the expected toroidal mode numbers of 7–8. Frequency broadening of the HHFW field was observed, suggesting that significant scattering of the HHFW by the low frequency turbulence is taking place.

References

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