§10. Development of High Beta Plasma Formation Using ICRF High Harmonic Fast Wave

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The purpose of this collaboration is to develop an RF heating method to produce high beta plasmas, which is a common issue in spherical tokamaks (ST) and helical systems. In particular, electron heating and current drive by Landau damping and transit time damping of the high harmonic fast wave (HHFW) are explored. The development of heating scenarios is carried out on both LHD and the TST-2 spherical tokamak at the University of Tokyo with R = 0.38 m, a = 0.25 m (R/a = 1.5) and RF power of up to 400 kW at 21MHz. TST-2 has the advantages of ample experimental time and flexibility with short turn-around time for hardware modifications.

In the past, electron heating by HHFW in TST-2 has been inferred indirectly based on soft X-ray emission measurements combined with other diagnostics. In Fiscal Year 2007, a YAG laser Thomson scattering system with one spatial channel and one measurement time per plasma shot became operational. Direct measurements of the electron temperature by Thomson scattering have confirmed electron temperature increases from typically 140eV to 210eV during HHFW power injection. By varying the measurement time on a shot-to-shot basis, the electron temperature was observed to increase immediately after the beginning of the RF pulse, but then decrease gradually. The data acquisition system is presently being upgraded to allow multiple channel, high dynamic range measurements using a board-type ADC instead of a fast-sampling (100-200MHz) oscilloscope. In addition to the HHFW excited by the antenna, nonlinearly excited waves by parametric decay instability (PDI) were observed by reflectometry, visible light diagnostic, as well as electrostatic and electromagnetic RF probes.

A frequency calibration method for the Ka-band (26.5̃40GHz) reflectometer that is applicable to high time resolution measurements was developed. The density profile measurement during RF power injection revealed that the edge density increase is larger for low density, inboard shifted plasmas susceptible to PDI. Furthermore, an analytic expression for sensitivity, which is important for identifying instabilities, was obtained. A K-band (18-26.5GHz) system is being prepared to measure lower density regions.

A wave detection system using an avalanche photodiode (APD) has detected frequency broadened components believed to be due to scattering from density fluctuations, the unshifted RF component was dominated by RF noise. The adoption of a photomultiplier tube (PMT) which is less susceptible to RF noise has enabled measurement of the unshifted RF component. The level of density oscillation by the incident HHFW is of order 0.1%, consistent with previous measurement by the reflectometer. The sensitivity of PMT is degraded in the presence of magnetic field, and in the region of high photocurrent, so it has not been possible to detect weak components generated by PDI. A system using the hybrid photo detector (HPD) which has the characteristics of PMT and APD is being developed.

The RF electric field strength measured in the edge plasma by an RF electrostatic probe was of order 1kV/m, which is somewhat larger than the result obtained by the reflectometer. The electric field increases monotonically towards the plasma core. Frequency spectra obtained in hydrogen, deuterium, and helium reflect their respective ion cyclotron frequencies, increasing linearly with the magnetic field but with a relatively large offset. In addition, a previously unknown type of peak in the spectrum was discovered. Its origin is being investigated.

On LHD, heating experiments were performed using NBI and ECH in addition to ICRF heating at 38.47MHz. Two magnetic fields were used: at –1.5T, the $2\Omega_H$ resonance is located around ρ = 0.5, whereas at –1.86T, both Ω_H and $2\Omega_H$ resonances are located in the edge region at ρ > 0.9. The $2\Omega_e$ EC resonance is located at the plasma center at –1.5T, but is ineffective at –1.86T since the resonance is located far off-axis. At –1.5T, only weak electron heating was observed around ρ = 0.5 in the absence of ECH, but core electron heating by ICRF was clearly observed with ECH pre-heating. During ICRF power injection, a wave component at 7.5MHz, excited by the ICRF wave, was observed by the RF probe. Ion resonance layers exist in the plasma edge region at –1.86T, and electron temperature modulation in the edge region was observed by ICRF power modulation. In addition, the detection of fast ion components by Si-FNA suggests absorption by ions at the plasma edge.

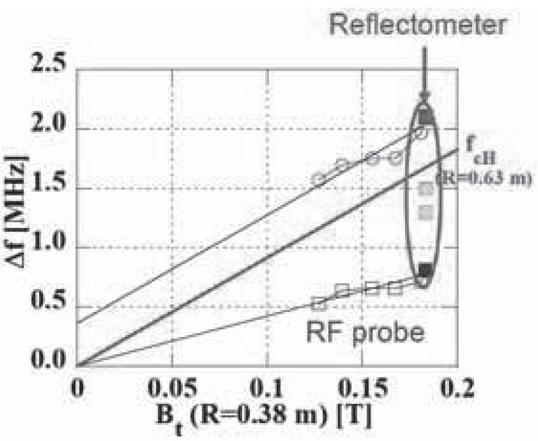

Fig. 1. Dependences on B_t of PDI peak frequencies relative to the incident HHFW frequency, measured by RF probe and reflectometer.