§14. Development of a High Beta Plasma Formation Method Using the ICRF High Harmonic Fast Wave

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The purpose of this collaborative research is to develop a radiofrequency heating method that can be used at low magnetic fields for high beta plasma research on LHD. In particular, electron heating by Landau damping of the fast wave at relatively high harmonics of the ion cyclotron frequency, the high-harmonic fast wave (HHFW), can be explored using the existing ICRF transmitters which can provide power in the frequency range of 30 to 80 MHz.

Development of heating scenarios is carried out on both LHD at NIFS and the TST-2 spherical tokamak at the University of Tokyo, which share the same objective of studying high beta plasmas. At LHD, existing ICRF loop antennas are used. The combline antenna developed under the previous LHD Project Research Collaboration by our group[1] will be used, if this antenna is installed on LHD. At TST-2, development using two transmitters at a frequency of around 20 MHz will be used, taking advantage of ample experimental time and flexibility with short turn-around time for hardware modifications.

During Fiscal Year 2003, TST-2 was temporarily moved to Kyushu University (Fig. 1) to perform ECW/EBW heating and current drive experiments utilizing the TRIAM-1M LHCD system (200 kW @ 8.2 GHz). No ICRF/HHFW experiments were performed on either LHD or TST-2. In principle, electron Bernstein wave (EBW) can also be used in LHD at low field if it can be excited successfully, since EBW can be absorbed completely even at high electron cyclotron harmonics.

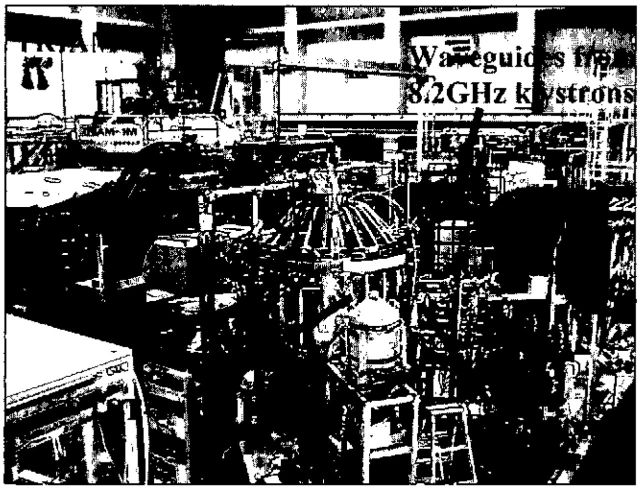

Fig. 1. TST-2 at Kyushu University

EBW heating experiments based on the X-B mode-conversion scenario were performed on TST-2. The X-mode launched perpendicularly from the low-field side encounters a triplet consisting of the R-cutoff, the UH resonance and the L-cutoff. An efficient MC is predicted when a suitably steep density gradient (small density scale length, L_n) in the triplet region is realized. In this experiment, the launcher consisting of 8 waveguide horn antennas, and a local limiter surrounding the antennas, movable in the range R = 625 mm to 665 mm and used to change the density gradient in front of the antennas, were installed on the low filed side of the torus, below the midplane. An RF leakage monitor was used as an indicator of RF power that was neither absorbed by the plasma nor reflected back to the launcher.

Evidence of electron heating was observed as increases of the stored energy and soft X-ray ($h\nu > 1$ keV) emission. The density was higher than the cut-off density ($n_e l > 4\times10^{18}$ m^{-2}, $l \sim 0.7$m) and the RF leakage was negligibly small. The plasma kinetic energy W_k increased from 150 to 170 J, and the total (kinetic plus poloidal magnetic) energy W_{tot} increased from 340 to 390 J, suggesting a possibility of current drive in addition to heating. A step-function like response observed in H_α emission (rise time ~ 0.6 ms) indicates that some power is deposited directly in the plasma edge.

The net injected RF power was 90 kW, whereas the ohmic input power was approximately 120 kW. The stored energy increase is rather small compared to the heating power increase. If 50% of the injected RF power were assumed to be absorbed, an L-mode type energy confinement time scaling would predict a stored energy increase of 17%, which is not inconsistent with the observation. However, the absorbed power estimated from the break-in-slope analysis of the stored energy was only about 6 kW from $\Delta dW_k/dt$ (and 15 kW from $\Delta dW_{tot}/dt$). A significant portion of the injected power may have been absorbed before reaching the plasma core. Collisional damping, a possible candidate for such an absorption, is calculated to be significant only when the electron temperature is low (< 10eV), but Langmuir probe measurements showed $T_e \sim 10$ eV at R = 620 mm.

Plasma formation, as well as plasma current ramp-up and maintenance by RF power alone was also achieved on TST-2. A quasi-steady-state plasma current of 4 kA was sustained for 0.28 s with 100 kW of RF power at a toroidal field of 0.16 T and a steady-state vertical field of 0.002T. The electron temperature measured by soft X-ray pulse height analysis was 180 eV. The electron density was less than 10^{18}m^{-3}, suggesting that the current was probably driven by ECW, not by EBW. Extension of this method to higher plasma currents and higher densities remains a challenge.

TST-2 was moved to the Kashiwa Campus after completion of these experiments. Electron heating experiments using the HHFW will begin in FY2004.

References

1) Takase, Y., et al.: Nucl. Fusion **44** (2004) 296.