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

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The purpose of this collaborative research is to develop a radiofrequency (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 fast wave at relatively high harmonics of the ion cyclotron frequency are explored. The fast wave in this frequency range is called the high-harmonic fast wave (HHFW).

Development of heating scenarios is carried out on both LHD at NIFS and the TST-2 spherical tokamak at the University of Tokyo. On LHD, existing ICRF transmitters and ICRF loop antennas can be used. The transmitters can provide power in the frequency range of 30 to 80 MHz. TST-2 is presently the largest ST device in Japan, with R = 0.38 m and a = 0.25 m (aspect ratio / = 1.5). It has already achieved toroidal magnetic fields of up to 0.3 T and plasma currents of up to 0.14 MA. RF power of up to 400 kW in the frequency range 10–30 MHz is available for this experiment. In addition, transmitters at 200 MHz, previously used on the JFT-2M tokamak, have been transferred from JAERI during this fiscal year. TST-2 has the advantages of ample experimental time and flexibility with short turn-around time for hardware modifications. For example, different wave excitation schemes using different antennas can be studied.

During Fiscal Year 2004, experiments were not performed on TST-2 because of power supply and RF system upgrades and modifications following relocation of the device to the Kashiwa Campus of the University of Tokyo. While TST-2 was located in the Hongo Campus, only one transmitter was used for a short pulse (1 ms) because of space limitation. After relocation to the Kashiwa Campus, two transmitters were installed and the full power supply capability was restored. This upgrade enables higher power (400 kW) operation for a longer pulse (> 10 ms) duration. Power supplies for the coil systems were also upgraded, in order to enable operation at higher toroidal fields and plasma currents for longer durations (several tens of ms). A power crowbar circuit has been implemented to produce a more constant toroidal field waveform. In order to provide more flux swing (Volt seconds), the ohmic heating (OH) coil circuit was modified to enable a double-swing operation. This improvement has enabled the loop voltage to stay positive for several tens of milliseconds.

While TST-2 was at the Hongo Campus, an antenna consisting of two current straps was used to excite the HHFW. This antenna had a fixed spacing between the two current straps (18° center to center), and the Faraday shield orientation was horizontal. The antenna was modified to enable excitation of different toroidal mode numbers (and therefore, the wavenumber parallel to the magnetic field) by varying the distance between the two current straps. Since the excitation of the slow wave at the plasma periphery can lead to increased edge electric fields, and therefore generation of impurities, the Faraday shield was modified to follow the average inclination of the magnetic field for typical operation (about 30°) in order to short out the electric field parallel to the magnetic field lines. The modified antenna is shown in Fig. 1. The RF current flows on the current strap (width 10 cm, height 60 cm). The separation between the two current straps can be adjusted in the range 25–35° by changing the feeder connectors. This range corresponds to toroidal mode numbers 10.3–14.4, which should be absorbed strongly by electrons with temperature around 200 eV.

The TASK/WM full wave code was used to identify promising heating scenarios and to design a proper antenna for such scenarios. A typical example for a central density of 3×10^{19} m^{-3}, central electron density of 300 eV, toroidal magnetic field of 0.3 T, and toroidal mode number of 9 is shown in Fig. 2. It can be seen that there are two wavelengths across the plasma minor radius, and that the absorption profile is peaked off-axis under this condition.

TST-2 is currently back in operation, and RF heating experiments are scheduled to resume in FY2005.

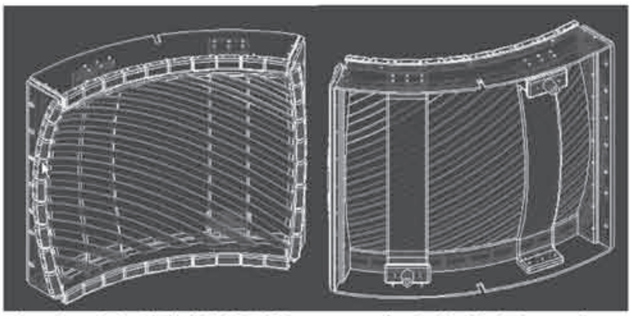

Fig. 1. Modified HHFW antenna for TST-2. Front view (left) and rear view (right).

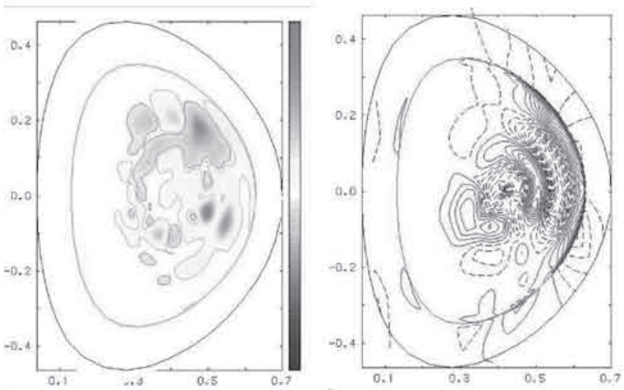

Fig. 2. HHFW absorbed power profile (left) and electric field profile (right) for TST-2, calculated by TASK/WM.