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

Takase, Y., Kasahara, H., Adachi, Y., Sasaki, M., Oosako, T., Tojo, H., Sumitomo, N., Shimada, Y., Nuga, H., Tsujimura, J. (Frontier Sci. and Sci., U. Tokyo),
Fukuyama, A. (Eng., Kyoto U.),
Watari, T., Mutoh, T., Kumazawa, R., Seki, T., Saito, K.

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).

The 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 RF power in the frequency range 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 R/a = 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 JAEA. 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 2005, HHFW heating experiments on TST-2 have resumed after completing power supply and RF system upgrades, following the relocation of TST-2 to the Kashiwa Campus of the University of Tokyo. The two RF transmitters were brought up at a frequency of 21 MHz, and it was confirmed that each transmitter can produce output powers of up to 200 kW for about 10 ms, which is longer than the energy confinement time in TST-2. The antenna for exciting the HHFW in the plasma was upgraded to allow variation of the $k_{\parallel}$ spectrum, where $k_{\parallel}$ is the component of wavenumber parallel to the magnetic field. This antenna consists of two vertically oriented induction loops (called current straps) which can be positioned at three different locations toroidally. Up to 200 kW of power can be delivered to each strap. When the RF currents flowing in the straps are out of phase, the spacing between the two current straps defines half a wavelength in the toroidal direction. The range of toroidal wavenumbers that can be excited by this antenna corresponds to toroidal mode numbers of 4 to 10. In addition, to avoid impurity generation by the RF sheath, the Faraday shield is tilted by 30° to align with typical magnetic field lines in front of the antenna.

Electron heating experiments using the HHFW have restarted on TST-2. The antenna input impedance changes in the presence of the plasma. Therefore, it is necessary to realize appropriate impedance matching in order to transfer the RF power delivered from the transmitters to wave power in the plasma. This is accomplished by use of matching circuits consisting of parallel and series variable capacitors. The development of a matching algorithm has enabled easy achievement of impedance matching.

Time evolutions of the soft X-ray emission intensity are shown in Fig. 1 for different RF powers: 0 kW, 180 kW and 360 kW. A doubling of the injected RF power causes a doubling of the soft X-ray emission increase. Since no appreciable changes are observed in the electron density or the radiated power, the sudden changes of the time derivative of soft X-ray emission at RF turn-on and turn-off are interpreted to be due to the electron temperature increase. Furthermore, the larger increase and the faster response observed on channels viewing the plasma core indicate that the wave absorption and electron heating are occurring in the plasma core.

The wavenumber spectrum differs greatly when only one strap is used to excite the wave instead of two straps. When only one strap is used, the fraction of power at low toroidal mode numbers (5 or less) is larger, and wave absorption is expected to be less effective. Both the wide-band (visible to soft X-ray) radiation increase and the stored energy increase were greater for two strap excitation, indicating that better absorption is achieved when the wavenumber spectrum is peaked at finite $k_{\parallel}$, as expected.

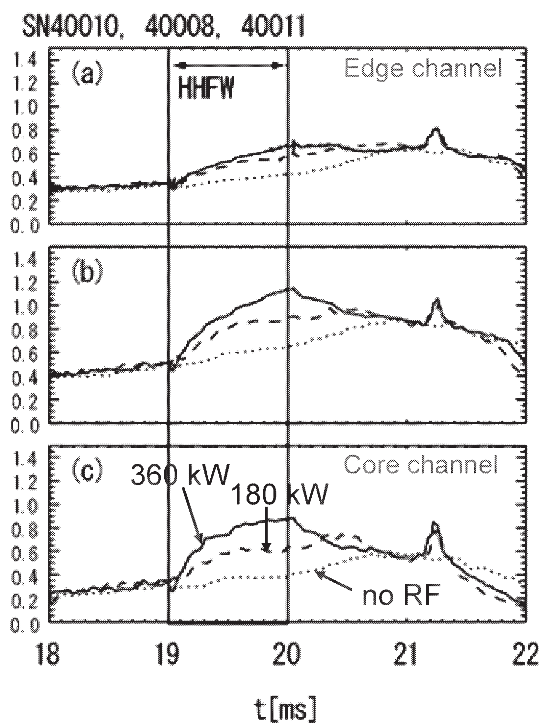

Fig. 1. Time evolutions of soft X-ray emission intensity for different HHFW powers, 0 kW, 180 kW, and 360 kW.