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

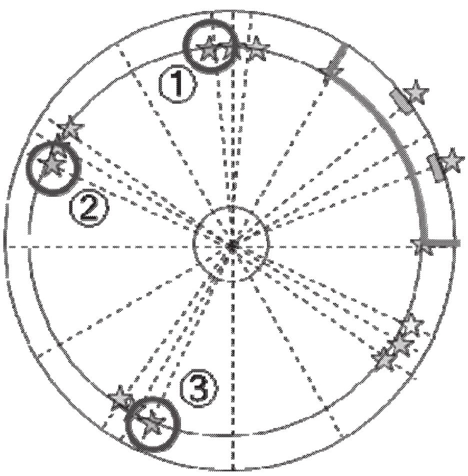
Takase, Y., Masuda, T., Oosako, T., Sugiyama, J., Tojo, H., Tsujimura, J. (Frontier Sci., Univ. Tokyo),
Torii, Y. (High Temp. Plasma Ctr., Univ. Tokyo),
Kainaga, S., Sumitomo, N. (Sci., Univ. Tokyo),
Fukuyama, A. (Eng., Kyoto Univ.),
Watari, T., Kasahara, H., Kumazawa, R., Mutoh, T., Saito, K., Seki, T., Shimpo, F.

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 2006, HHFW heating experiments were performed on TST-2. RF system upgrades have enabled reliable operation at power levels exceeding 200 kW at a frequency of 21 MHz. TST-2 has a comprehensive wave diagnostic capability, including an imaging reflectometer to measure the wave induced density fluctuations in the plasma interior, and rf magnetic probes distributed throughout the vacuum vessel wall to measure RF magnetic fields at the plasma edge. Frequency spectra indicating the occurrence of parametric decay were observed by both reflectometer and rf probes. The decay process is most likely decay of the fast wave to ion Bernstein wave and ion cyclotron quasimode. The strength of parametric decay is not uniform, but has a spatial structure. The most pronounced dependence of parametric decay was found to be the position of the plasma outer boundary, and becomes most intense when the PF3 (vertical field) coil current is reduced and the plasma boundary approaches the HHFW antenna located on the outboard side of the torus. The upper limit of the RF electric field evaluated from the reflectometer data was 1 kV/m for 250 kW RF input power. This is an order of magnitude smaller than the value expected based on TORIC full-wave calculation. The reasons for this discrepancy may be due to RF power losses associated with processes not considered in the calculation, such as parametric decay and scattering by density fluctuations.

Fast wave electron heating experiments were performed on LHD using NB, EC, and IC (38.47 MHz) at a magnetic field of 1.86 T. EC heating was not effective because the EC resonance was not centrally located. In hydrogen plasmas, absorption by ions is negligible. In this case, larger increases in the plasma stored energy was observed at lower densities. When helium gas is introduced, the third harmonic ion cyclotron resonance for helium appears in the plasma core. In this case, the stored energy increase became much smaller. This may be attributed to absorption of the fast wave by helium ions, with subsequent rapid loss of accelerated helium ions, or to RF power losses at the edge due to nonlinear phenomena such as parametric decay.



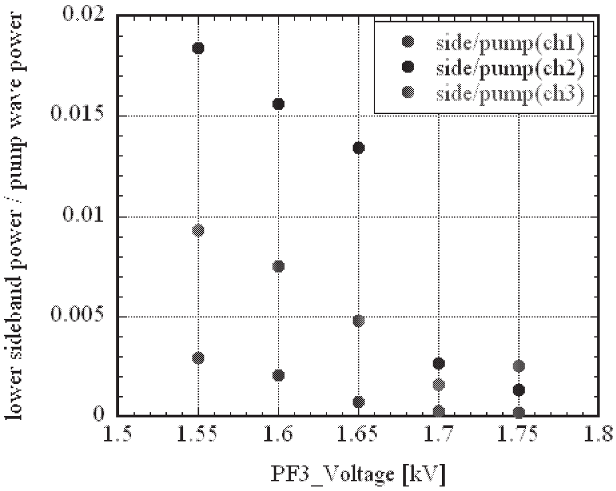


Fig. 1. Dependence of parametric decay on plasma position. The lower sideband wave (19.5 MHz) power normalized by the pump wave (21 MHz) power, measured at three locations indicated in the left figure (top view of TST-2). Parametric decay becomes stronger when the plasma becomes closer to the antenna as the PF3 coil current is reduced.