§1. Study of Wave Physics in High Beta Plasmas

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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) and the lower hybrid wave (LHW) 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 either 21 MHz and 200 MHz. TST-2 has the advantages of ample experimental time and flexibility with short turn-around time for hardware modifications.

Wave studies are performed on TST-2 using various diagnostics including magnetic probes, electrostatic probes, and microwave reflectometry. These diagnostics provide a unique capability to study different aspects of wave phenomena systematically with broad spatial coverage. Physical processes of interest include multiple reflections, mode conversion, wavenumber diffusion due to scattering by density fluctuations, and nonlinear processes such as parametric decay instability. Understanding of these processes are necessary for improving the efficiency and controllability of heating and current drive. A new wave diagnostic using microwave interferometry is also being developed. This research is an important element that leads the All-Japan ST Research Program. Techniques developed through this research can be utilized on other ST devices, and can be applied to LHD with appropriate modifications. In particular, since the frequency range of the existing ICRF heating equipment for LHD (30 to 80 MHz) corresponds to the regime of HHFW for high beta experiments which use low magnetic fields, HHFW electron heating experiments on TST-2 are directly relevant and can provide useful contributions.

In ST, the most critical issues are non-inductive plasma current generation, ramp-up, and sustainment without the use of the central solenoid. ST plasma formation by ECH is already demonstrated in many STs including TST-2, but there are several candidates for the physical mechanism of current formation. TST-2 has demonstrated for the first time that the high- $_p$ ST plasma produced by ECH can be sustained by RF power alone, either at 21 MHz or 200 MHz. This result indicates strongly that the plasma current is not produced by non-inductive current drive but is driven spontaneously by the pressure gradient. The physical mechanisms of spontaneous formation of the ST configuration and plasma current generation are being clarified through increasingly more detailed measurements and analyses. In 2010, further plasma current ramp-up to over 10 kA was achieved by exciting a uni-directional travelling wave at 200 MHz. This was accomplished by combining slow increases of the RF power and the equilibrium vertical magnetic field.

In LHD, ICRF heating experiments using the new “wavenumber-controlled” two-strap antenna, similar to the HHFW antenna used in TST-2, started in 2010. For successful ICRF heating, it is critically important to eliminate edge power losses. In previous long-pulse experiments using the old single-strap antennas, an impurity influx from the “hot spot” on the antenna lead to a radiative collapse of the plasma. The hot spot is believed to be caused by high energy ions created by edge RF absorption or RF sheath acceleration. In contrast to the single-strap antenna which excites a broad $k_{||}$ (parallel wavenumber) spectrum centered around zero, the two-strap antenna excites a narrow spectrum centered at finite $k_{||}$, preventing the generation of weakly damped low $k_{||}$ waves which are responsible for creating enhanced RF electric fields at the edge and large RF sheaths. A typical example of RF sustained discharge using the new antenna is shown in Fig. 1. It can be seen that the plasma stored energy (W_p) and the ion temperature (T_i) increase significantly when 1 MW of ICH power is injected simultaneously with 2.5 MW of ECH power, and that W_p is comparable during ICH only and ECH only periods in spite of the lower ICH power by more than a factor of two. These results indicate highly efficient ICRF heating.

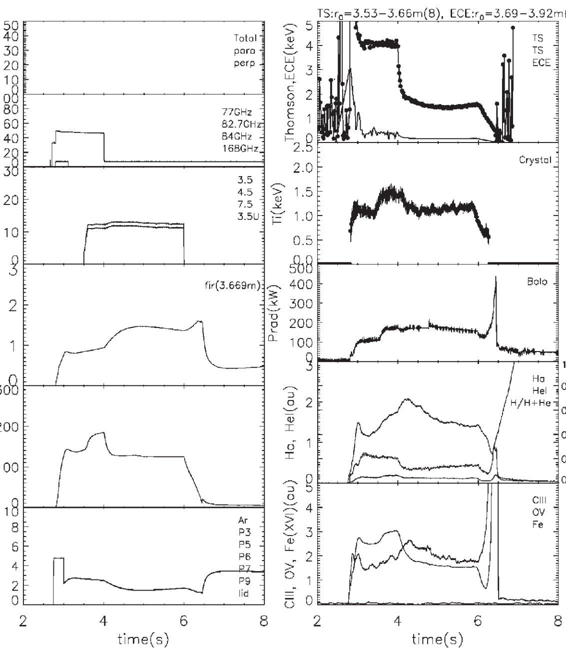

Fig. 1. LHD plasma sustained by ICRF minority ion heating (#104813): B = 2.75 T, R_{ax} = 3.6 m, B_q = 100 %, = 1.254.