§2. 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) 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 21MHz. TST-2 has the advantages of ample experimental time and flexibility with short turn-around time for hardware modifications.

Wave studies are being performed on TST-2 using various diagnostics including magnetic probes, electrostatic probes, and microwave reflectometry. The HHFW excited by the antenna (pump wave) decays into the lower sideband (LSB) resonant mode and the non-propagating ion-cyclotron quasimode (ICQM) by parametrically. Previous experiments have shown that the low frequency oscillation (LFO) corresponding to ICQM is electrostatic, and that the pump wave has a long correlation length. However, the frequency of the LFO is the same even on the high field side of the torus where the local cyclotron frequency is higher by a factor of three compared to the low field side. The bispectral power analysis was used to discriminate between the resonant propagating mode and the nonlinearly driven beat oscillation for the first time. In particular, the LFO observed in the scrape off layer was identified to originate from the forced beat generation by the pump wave and the LSB wave. The dependences of the pump wave, LSB wave and LFO powers on the bispectral power are shown in Fig. 1. The linear relationship indicates the nonlinearly excited component, whereas the finite y-intercept indicates the resonant mode component. The fact that the y-intercept of the LFO power is close to 0 indicates the dominance of the nonlinearly excited component over the resonant mode component.

UTST is a plasma merging device similar in size to TST-2, and aims at developing a way to sustain the high beta ST plasma formed by plasma merging by HHFW and NBI. A new HHFW antenna was installed and up to 80 kW of RF power at 21 MHz (previously used on TST-2) was successfully injected. UTST is equipped with a 9 × 9 array of magnetic probes to measure the toroidal and vertical components of the magnetic field inside the plasma. These probes were used to measure the spatial profile of the RF magnetic field associated with the HHFW. The RF magnetic field is polarized predominantly in the toroidal direction, and its amplitude is modulated strongly by the plasma. This may be an indication that the observed HHFW field is affected by changes in the propagation path or absorption by the plasma.

In ST, a major issue is 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-β_p ST plasma produced by ECH can be sustained by RF power (21 MHz) alone. 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 the initially formed plasma, the density, pressure, and toroidal current are all concentrated in a crescent-shaped region on the outboard side of the torus where the magnetic field configuration is open. According to equilibrium analysis, the plasma pressure is highly anisotropic. A transition to a toroidal configuration with closed flux surfaces (ST equilibrium) occurs spontaneously when the toroidal current exceeds a threshold level.

Preparations for further plasma current ramp-up experiments using waves in the lower hybrid frequency range on TST-2 are progressing. These experiments require higher fields (~ 0.3 T) to ensure adequate accessibility. Since ECH (2.45 GHz) pre-ionization is not effective at these fields, a hot-cathode biased electron source was developed and was shown to be effective in assisting plasma formation. Testing of four 200 MHz transmitters and power combiners was completed successfully, and initial experiments using the two-strap loop antenna used for the 21 MHz experiment has begun..

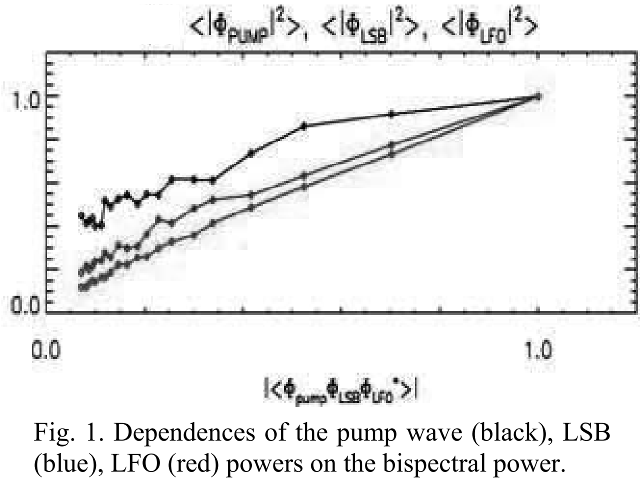

Fig. 1. Dependences of the pump wave (black), LSB (blue), LFO (red) powers on the bispectral power.