§5. Electron Bernstein Wave Heating by Long Wavelength Microwave in a Spherical Tokamak and a Helical Device

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On the LATE device at Kyoto University, formation of Spherical Tokamak by ECRH without center solenoid have been conducted [1], while on the CHS device at NIFS, experiments for transport study based on the “non-dimensionally similar approach” have been conducted to simulate various transport processes in high temperature plasmas[2]. In both cases, the plasmas are generated and maintained by ECRH in over-dense regime via mode- converted electron Bernstein waves (EBW) from long wavelength microwaves and efficient coupling from external microwaves to EBW is crucial for experiments. The main purpose of the present study is to study coupling processes and to develop the effective launching method for efficient coupling.

Main objective of the LATE (Low Aspect ratio Torus Experiment) device is to demonstrate formation of ST plasmas by electron cyclotron heating (ECH) alone without center solenoid and establish its physical bases. By injecting a 2.45 GHz microwave pulse for 4 seconds, a plasma current of 1.2 kA is spontaneously initiated by P=5 kW under a weak steady vertical field of Bv=12 Gauss, and then ramped up with slow ramp-up of Bv for the equilibrium of the plasma loop and finally reaches 6.3 kA at Bv=70 Gauss. This currents amount 10 percents of the total coil currents of 60 kA for the toroidal field. Magnetic measurements show that an ST equilibrium, having the last closed flux surface with an aspect ratio of R0/a=20.4 cm/ 14.5 cm=1.4, an elongation of K=1.5 and q_{edge}=37, has been produced and maintained for 0.5 s at the final stage of discharge. Spontaneous formation of ST equilibria under steady Bv fields, where plasma current increases rapidly in the time scale of a few milliseconds, is also effective and a plasma current of 6.8 kA is spontaneously generated and maintained at Bv=85 Gauss by a 5 GHz microwave pulse (130 kW, 60 ms). In both cases the plasma center locates near the second or third harmonic EC resonance layer and the line averaged electron density significantly exceeds the plasma cutoff density, suggesting that harmonic EC heating by the mode-converted EBW supports the plasma.

The mode conversion rate is estimated based on the plasma slab model [3]. In the case of 2.45 GHz experiments, free space wavelength (12.2 cm) is comparable to the plasma radius (20 cm), where maximum mode-conversion rate after optimization of injection angles and polarizations is only 60 %. On the other hand, in the case of 5GHz, oblique injection with left-handed circular polarization can give 90 % mode-conversion rate.

In CHS, 2.45 GHz microwaves up to 45 kW are injected perpendicularly to the toroidal field, into hydrogen, helium or neon gas. Most experiments were carried out in the so-called outward shifted configuration of Rax=0.974m, where Rax is the magnetic axis position in the vacuum field. This magnetic configuration was chosen from a point of view of convenience for Langmuir probe measurements. The toroidal field strength at the plasma center Bt was scanned from ~1000G to ~600G. The line averaged electron density reached to the maximum at Bt=613G, which was about three times, five times and 10 times higher than the O-mode cutoff density for hydrogen, helium and neon fuel gas, respectively. The dependence of the achieved electron density on fuel gas seems to be determined by plasma transport rather than RF physics. Note that the fundamental cyclotron layer at Bt=613 G is placed near the plasma boundary (ρ~0.9) and the upper hybrid resonance layer is in the edge region with steep density gradient. The power deposition was measured using a power step technique, and concentrated in high density region inside the left hand cutoff [4]. These results suggest that launched electron cyclotron waves are mode-converted at the upper hybrid resonance layer to EBW, and damped trough collisional damping. However, cyclotron damping cannot be ruled out in these experiments because polarization and directivity of the launched long wave-length waves cannot be specified definitely.

References

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