§38. Start-Up and Sustainment of Spherical Tokamak by ECH/ECCD

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Spherical Tokamak (ST) concept is attractive since it maintains high beta plasmas in a compact shape of low aspect ratio. Without central Ohmic solenoid, structure of ST reactor is greatly simplified. We need a non-inductive method for plasma initiation and current start up. The electron cyclotron heating and current drive (ECH/ECCD) is potentially an attractive candidate for this purpose since plasma initiation and current start-up might be realized simultaneously by microwaves launched far from the plasma with a simple launcher. We have attempted ECH experiments in the Low Aspect ratio Toru Experiment (LATE) device [1, 2] and found that low aspect ratio equilibria with the toroidal currents up to12 kA are obtained as shown in Figure 1. In near future ECH/ECCD start-up will also be investigated in the QUEST device.

LATE is a tiny device with a vacuum chamber made of stainless steel in the shape of a cylinder with the diameter of 1.0 m and the height of 1.0 m [1]. The center post is a stainless steel cylinder with the outer diameter of 11.4 cm, enclosing 60 turns of conductors for the toroidal field. The return conductors are grouped into 6 limbs and go around far from the vacuum vessel, which allows good accessibility to the vacuum chamber and suppresses toroidal field ripple at a low level (1.5 % at R=50 cm and 0.07% at R=30 cm). There are four sets of poloidal field coils. One is for feedback control of vertical position of the plasma loop, and the rest are for the vertical field for equilibrium and their currents are preprogrammed. There is no central solenoid for inductive current drive. Three 2.45 GHz magnetrons, including two 5kW CW tubes and a 20 kW 2 seconds tube, and a 5 GHz klystrons (130kW, 60msec) are used for ECH. In all cases, microwaves are injected from radial ports with injection angles slightly deviate (about 15 degrees) from normal to the toroidal field.

In the case of a 2.45 GHz microwave pulse for 2 seconds, a plasma current of 2 kA has been spontaneously initiated by Prf=15 kW under a weak steady vertical field of Bv=17 Gauss, and then ramped up with slow ramp-up of Prf and slow ramp-up of Bv for the equilibrium of the plasma loop and finally reaches 8 kA at Bv=90 Gauss and Prf=35kW. T In the case of a 5 GHz microwave pulse (130 kW, 60 ms), a plasma current of 6 kA has been spontaneously initiated under a steady field of Bv=56 Gauss, and then ramped-up with a ramp of Bv and reached 12 kA at Bv=100 Gauss. 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.

Spontaneous current generation (current jump) has been observed for a wide range of Bv. This bridges the gap between the open field equilibrium maintained by the pressure driven current in the external field and the closed field equilibrium at a larger current. Experimental results and the theoretical analyses suggest a current jump model that is based on the asymmetric electron confinement along the field line appearing upon simultaneous transitions of field topology and equilibrium [2].

Once a closed field is formed, EC current drive may become effective, since EC-driven current carrying passing electrons are confined as far as the plasma loop is in equilibrium by an appropriate ramp of Bv field. In the experiments, significant hard X-ray emissions have been observed. Their intensity increases as the plasma current increases, suggesting that current carrying fast electron tail is formed.

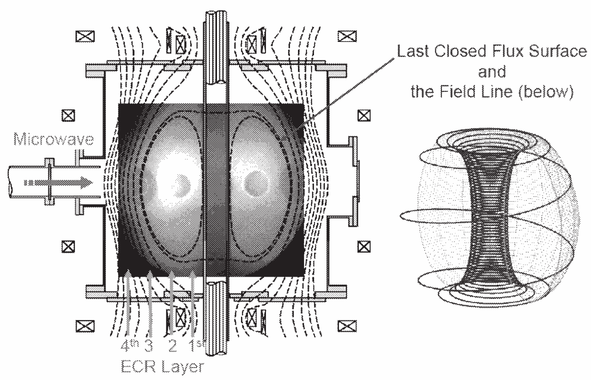

Fig. 1 Microwave Spherical Torus produced in the LATE device (Ip=12kA, Bv=100Gauss, Bt=720 Gauss)

In CPD, an 8.2 GHZ microwave was injected by eight horn type antennas as shown in Fig. 2. Four horn antennas were adjusted to O-mode injection and the others to X-mode. Two flat mirrors to control the injection angle in the case of O-mode injection were installed.

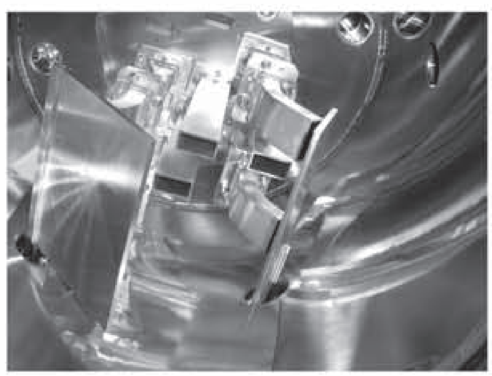

Fig. 2 A photograph of the antenna system for an 8.2 GHz microwave installed on CPD.

References
[1] T. Maekawa *et al*. Nuclear Fusion, **45** (2005)1439.
[2] T. Yoshinaga et al., Phys. Rev. Lett.,**96**(2006)125005