§49. 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, however, 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/ECCD experiments in the LATE [1, 2] and CPD devices to establish the physical and technical bases for ECH/ECCD method. 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 attainable plasma current has been extended from Ip=12 kA to 15kA by enlargement of the equilibrium vertical field by enforcement of the coil power supply as shown in Fig.1. The plasma current increases with increases of the injected power and the equilibrium vertical field.

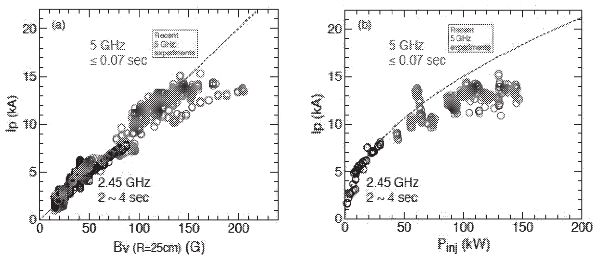

Fig.1 The plasma current increases with increases of the injected power and the equilibrium vertical field Bv.

With the increase of the plasma current Ip, X-ray emission intensity Ix is enhanced nearly proportional to Ip, suggesting that main part of the plasma currents is carried by a fast electron tail. The poloidal beta has been estimated to be over unity based on the magnetic analysis [2], while the contribution from the bulk electron component is as low as ~ 0.1, being consistent with the presence of the current currying large electron tail. Furthermore, the directional X-ray measurement, where forward emissions are found to be about two times larger than backward emission along the electron drift direction, certainly indicates the presence of the unidirectional fast electron tail. The electron density is well over the plasma cutoff density, which indicates that the mode-converted electron Bernstein waves drive both the bulk and the tail electrons. Direct loss of these fast electrons to the limiters has been estimated by measuring the temperature rise of molybdenum limiters during discharges. The total amount is about half of the injection power. Absorption rate of EBW by the tail electrons to the bulk electrons has been estimated by a numerical code to be roughly 1/4 to 1/2, depending on the numerical models for fast electron tail, also being consistent with the limiter heat load results. The code has been applied to the CPD case as shown in Fig.2, suggesting that the EBWs can be also useful to drive the fast electrons for ECCD in QUEST.

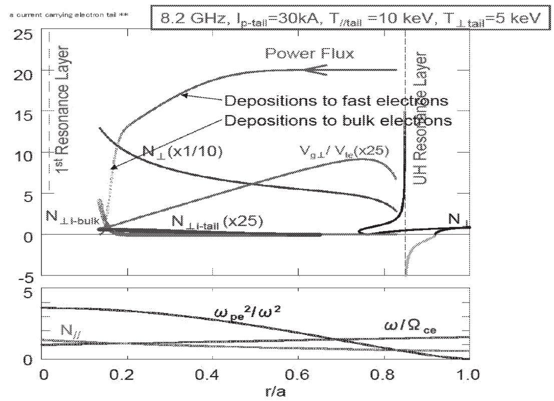

Fig.2 Propagation and absorption of EBW in a QUEST plasma

The RF injection system is composed of eight horn antennas on CPD. Four horns will be used as X-mode antennas and the others as O-mode ones. As in the case of O-mode injection, the injection angle to the magnetic field is a key to excite EBW in the plasmas, two mirrors are installed to control the injection angle.

The leaked RF power through the vacuum window was measured to estimate the absorbed RF power in plasmas. The time evolutions of the leaked RF power normalized by that without plasmas are monitored. When the injection mode of RF is mixture of O and X mode, the leaked RF power is strongly reduced with the production of plasma down to 0.5 (X mode) and 0.3 (O mode) from 1.0 in ECR plasam. And at the start-up of the plasma current, the leaked RF power of X mode was reduced more and this is no contradict to the mode conversion efficiency from X mode to EBW.

The RF driven current up to 1kA can be obtained on CDP. The direction of the current depends on the direction of vertical magnetic field. The parameter dependence will be investigated from now.

References

[1] H. Tanaka et al., Proc. 21th IAEA Fusion Energy Conf. EX/P6-6, 2006
[2] T. Yoshinaga et al., Nucl. Fusion,**47**(2007)210-216.