# §53. 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 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 small 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. 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=15 kA to 20kA by enlargement of the equilibrium vertical field and also injection RF power at 5GHz as shown in Fig.1. The plasma current increases with the increases of injected power and equilibrium vertical field.

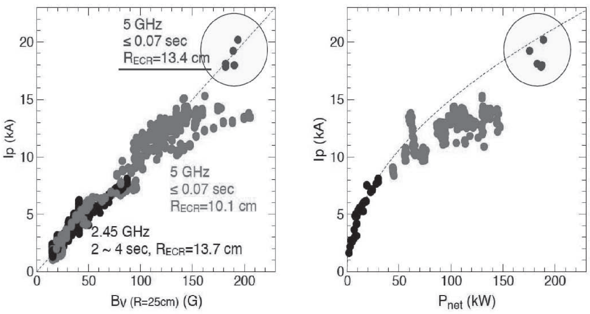


Fig.1 The plasma current increases with increases of the injected power and the equilibrium vertical field Bv.

The poloidal beta $\beta p=8\pi S<p>/\mu_0 Ip^2$ ~1.5 estimated by magnetics is essentially due to the current carrying tail electrons. Contribution of bulk electrons is only ~0.05 as estimated from the bulk density and temperature Te~60 eV. The tail pressure can be written as $p \sim nm\gamma v^2/2$ for the typical velocity v and the current density as J=Ip/S~nev. Then, the factor $C_f = Ip\beta p/I_A = (2e/mc)(<p>/J) \sim \gamma v/c$ is a measure of the tail momentum range, where $I_A = 4\pi mc/\mu_0 e$ =17 kA. While $C_f$ increases initially as Ip increases, it becomes steady when Ip>15 kA. This means that while the tail momentum range is limited by the orbit loss due to the outer shift of electron orbit from the flux surfaces, the shift becomes small at Ip>15 kA and the tail velocity distribution is rather determined by the wave N// spectrum. This is a new regime and not obtained previously. It is remarkable that Ip increases against the reverse voltage due to the self-induction. The tail energy range estimated from $C_f$ at Ip=20 kA is as large as ~500 keV, which exceeds the runaway critical energy ~2 keV for the reverse voltage of $V_L$=-0.06 V. The production of such high energy tail at the energy range far beyond the critical energy where the reverse electric force is much larger than the collisional friction force is essential for efficient current ramp-up. This was already realized for LHCD but not for ECCD. In the present case this may be realized by the forward driving force on tail electrons via EC absorption of high N// EB waves.

The velocity distribution of current- carrying fast electron tail has been investigated for a 2 seconds 2.45 GHz discharge that reaches Ip = 5.9 kA, where X-ray pulse height analysis has been carried out by taking advantage of relatively long pulse length. An X-ray energy spectra detected at both the forward and backward line- of sights. These are bremsstrahlung emissions and the radiation lobes strongly shift forwardly along the tail electron drift direction by the relativistic effect as the electron energy increases. Comprehensive analysis by including βp = 1.5 from magnetics shows that a uni- directional electron tail up to 250 keV with the pitch angles spreading out from 0° to 75° is developed and carries the current.

Plasma start-up experiments without the assistance of ohmic heating (OH) were also carried out on CPD in Kyushu University, to resolve the complicated issues concerning steady-state operation of magnetic fusion devices under the framework in by-directional collaboration program organized by NIFS and the collaborated program in the experiments are started in 2005. The RF system of 8.2 GHz in frequency and 200KW in power was used as a heating source in the experiments. The current jump was also observed on CPD beyond a certain RF power (~ 25kW), where the value of plasma current jumps up from ~1kA to ~2kA for 3ms under the constant vertical magnetic field, Bv. The signals of Hα and OII measured with spectroscopy do not change so much during the current jump. According to the magnetic measurement, the closed flux surface was formed during current jump. This suggests that the current jump is not a typical phenomenon.

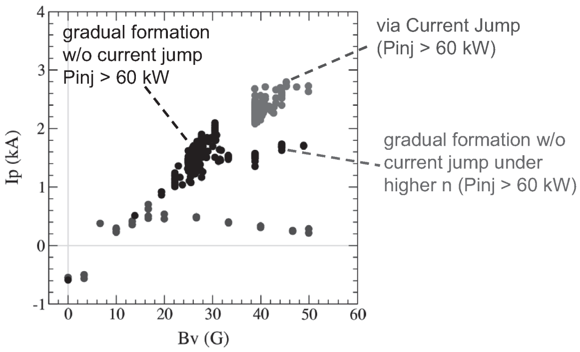


Fig. 2 The current start-up experiments on CPD.