ECH experiments aiming at further advanced operations in LHD

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Since the latest experimental campaign, sub-cooling of the superconducting helical coils has expanded the possible operational regime of magnetic configuration in the large helical device (LHD). Relationship between the achievable central electron temperature with the formation of electron internal transport barrier and magnetic configurations has been studied. Since the relativistic down-shift of the electron cyclotron resonance (ECR) layer is not negligible in the high electron temperature regime, it is preferable to set the magnetic axis on the high field side of the non-relativistic ECR layer. Over 10keV central temperature has been obtained in such a preferable magnetic field configuration. Higher harmonic resonance heating has been also studied to extend heating regime of electron cyclotron heating (ECH).

Super dense core (SDC) plasma operational regime has been found in LHD [1]. In the SDC regime, the central plasma electron density is $4.5 \times 10^{20} m^{-3}$ that is five times as high as the cutoff density for fundamental electron cyclotron (EC) waves. High-density operation scenario for ignition has been proposed in the heliotron configuration [2]. High power and long pulse external heating operation in extremely dense and relatively low temperature regime is required to achieve the ignition. Therefore it is significant to study electron cyclotron heating /current drive (ECH/ECCD) with use of electron Bernstein waves (EBWs) for further advanced operation scenario in such over-dense plasmas. ECH by EBWs generated via O-X-B mode conversion process has been already demonstrated in an over-dense plasma [3], where the line averaged electron density at the central code is $1.0 \times 10^{20} m^{-3}$. 84GHz EC waves of 270 kW were injected with 47Hz 100% power modulation from one transmission line. FFT analysis of the ECE signals shows the increase in electron temperature on the central region. However, higher EC power injection comparable to NBI power is required to affect macroscopic plasma parameter. Simultaneous EC power injection from multiple transmission lines and enhancement of the power source itself are necessary.

ECH system in LHD has been upgraded aiming at power and long pulse operation. Two 82.7GHz, three 84GHz and three 168GHz systems are used for ECH. In one of the 84GHz systems, a high power (84GHz/0.8MW) gyrotron was newly installed. Maximum 2MW has been injected simultaneously into LHD vessel. Two of the existing transmission lines that consist of 88.9mm corrugated waveguides have been evacuated so that higher power can be transmitted without arcing. A longer pulse and higher power gyrotron (77GHz/1MW/5sec.) is now being developed.

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