§33. Attainment of High-T_e Core Plasma by Sub-Cooled Helical Coil Field and Localized ECH

Shimozuma, T., Kubo, S., Inagaki, S., Yoshimura, Y., Igami, H., Notake, T., Mutoh, T.

Achievement of high electron temperature and control of electron temperature gradient by ECH is particularly important in view of not only obtaining high performance plasmas, but also studying fusion relevant low collisionality plasmas. In Large Helical Device (LHD), a magnetic configuration with inward-shifted magnetic axis and with rather low magnetic field had to be used for central heating by ECH due to the maximum magnetic field limitation. In the latest experimental campaign, sub-cooling of the helical coils expanded a possible operational regime of magnetic configuration.

In the 10th experimental campaign, the ECH system of LHD consisted of nine gyrotrons (two 82.7GHz/0.45MW/2s, three 84GHz/0.8MW/3s, one 84GHz/0.2MW/1000s and three 168GHz/0.5MW/1s), transmission lines and quasi-optical antennas. Total injection power reached over 2MW.

When the electron temperature surpasses 10keV, the absorption location of ECH power moves to the higher magnetic field region because of the relativistic down-shift of ECR. The magnetic field strength for ECR increases with an increase of relativistic factor γ. A core plasma could be efficiently heated by setting the magnetic axis on the high field side of non-relativistic ECR.

In the recent experiments in LHD, sub-cooling of the helical coils allowed higher magnetic field on the axis, leading to expansion of the freedom of the magnetic configuration. Plasma production and heating via fundamental and second harmonic ECR was performed by centrally focused ECH (Power is about 1.6MW) in the new configuration of R_{ax}=3.5m, B_0=2.931T, which was expected to be preferable to achieve high core temperature. In Fig. 1, profiles of the electron temperature and density are shown. The temperature profile was obtained by Thomson scattering and the density profile was measured by the FIR laser interferometer. The electron temperature profile is a centrally peaked profile with central value of about 10 keV, while the density profile shows rather flat or hollow one around the center.

Figure 2 shows the dependence of the central electron temperature T_{e0} on square root of ECH power normalized by line-averaged density, $\alpha \equiv (P_{ECH}/\bar{n}_{19})^{\frac{1}{2}}$, for plasmas produced and sustained by only ECH power in past experimental shots, where P_{ECH} is ECH power in MW and $\bar{n}_{19}$ is line-averaged electron density in 10^{19} m^{-3}. The difference of the symbols corresponds to the magnetic configurations: 1) (R_{ax}, B_0)=(3.5m, 2.829T), small closed circles, 2) (3.5m, 2.931T), triangles, 3) (3.53m, 2.907T), large closed circles, 4) (3.53m, 2.951T), inverted triangles. The data points are divided into two groups; one shows linear dependence on α and another shows transition to high temperature state. For R_{ax}=3.53m, the higher is the magnetic field, the smaller α is so that high-T_e transition may occur. In R_{ax}=3.5m cases, the transition occurs in higher α value than that in 3.53m cases, and such transition was not observed in lower magnetic filed of B_0=2.829T. The configurations 2) and 4) are the case in which the magnetic axis located on the high filed side of ECR, and 1) is the case in which the axis locates on its low field side. The configuration 3) corresponds to on-axis ECR. The threshold of α in transition from low to high temperature looks to depend on the magnetic configurations.

Aiming at producing a higher performance plasmas, a high power and long pulse gyrotron (77GHz/1MW/5sec) is being developed. In parallel, evacuation of corrugated waveguides in the transmission lines is promoted to enable higher power transmission and to avoid dangerous arcings in the transmission lines.

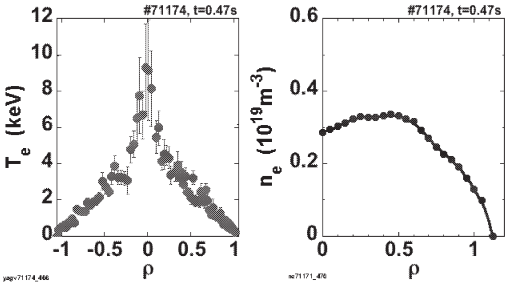

Fig. 1: Electron temperature and density profiles of high Te shot.

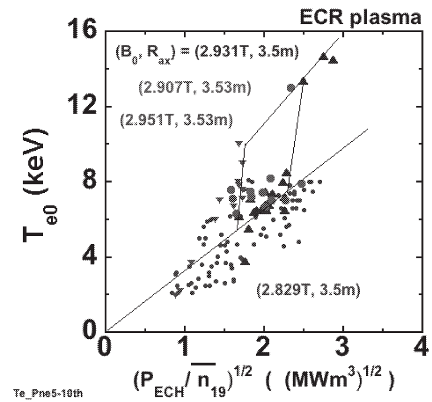

Fig. 2: Attained T_{e0} is plotted as a function of square root of ECH power normalized average density for different magnetic configurations. Small closed circles correspond to B_0=2.829T, large closed circles to 2.907T, triangles to 2.931T, inverted triangles to 2.951T.