§71. Slow X-B Heating in Super Dense Core Plasma

Yoshimura, Y., Kubo, S., Shimozuma, T., Igami, H., Takahashi, H., Nishiura, M., Ogasawara, S., Makino, R., Kobayashi, S., Ito, S., Mizuno, Y., Okada, K., Takita, Y., Mutoh, T.

In LHD, evident electron Bernstein wave (EBW) heating was successfully performed. These experiments were carried out by use of the ECH system that was upgraded by installation of high-power, long-pulse 77 GHz gyrotrons and a water-cooled, widely movable plane mirror which provided a wide range of EC-wave beam injection direction. The EBW heating was achieved by the mode conversion to EBWs from injected EC-waves, by so-called slow-XB technique. With the technique, increases in plasma stored energy W_p and electron temperature T_e were observed in overdense plasmas. Especially, by the slow-XB technique in a super dense core (SDC[1]) plasma, an electron heating was successfully demonstrated in the plasma core region where the central electron density n_{e0} was about three times higher than the plasma (or, O-mode) cut-off density of applied 77 GHz EC-waves.

High-density operation scenario for future fusion reactors has been proposed, based on the experimental findings in LHD and W7-AS.[2] There, the density limit is determined by the heating power while that of the tokamaks is determined by the so-called Greenwald limit. The high-density operation has advantages on the enhancements of the fusion reaction rate and energy confinement, and reduction of the engineering demands. Among the heating tools in fusion plasmas with high density, EBW heating is an attractive technique. The EBWs can be excited by use of compact antenna system installed apart from the plasmas, contrary to the ICRF antenna, and can reach the high-density plasma core region, contrary to the neutral particles from NBIs. To realize excitation of EBWs by the slow-XB technique, EC-waves in X-mode polarization should be injected to plasmas from high magnetic field side (HFS). In LHD, newly installed inner-vessel mirror close to a helical coil is used for the HFS injection.[3] As seen in Figs. 1 and 2, evident increases in T_e in the plasma core region and W_p were caused by the HFS injection with 0.18 s pulse width to the plasma with n_{e0} of 2.4×10^{20} m^{-3}, that is, 3.3 times higher than the plasma cut-off density (7.35×10^{19} m^{-3}) for O-mode waves, and 1.6 times higher than the left-hand cut-off density (1.47×10^{20} m^{-3}) for slow-X-mode waves. Thus, the heating effects especially the increase in the electron temperature in the plasma core region should be attributed to the mode-converted EBWs, not to the X- or O-mode waves. Here it is noted that the increase in T_e is not caused by the decrease in ne in the plasma core region. W_p and T_{e0} start increasing (decreasing) at the ECH-on (off) timing, while n_{e0} continuously decreases (see Fig. 1). The absorbed power P_{abs} evaluated from the changes in dW_p/dt at the on/off timings of EC-wave injection is ~300 kW (see Fig. 1). Injected EC-wave power P_{ECH} is 875 kW so that the heating efficiency P_{abs}/P_{ECH} is evaluated as ~34% in this discharge. For a plasma with the line average electron density $n_{e,\,ave}$ of 7.5×10^{19} m^{-3}, P_{abs}/P_{ECH} of ~70% was achieved.[3] In the higher density case, though larger beam refraction would prevent a part of the beam from entering into the plasma core region resulting in a degradation in the efficiency, higher efficiency would be expected by optimization of magnetic configuration and wave polarization.

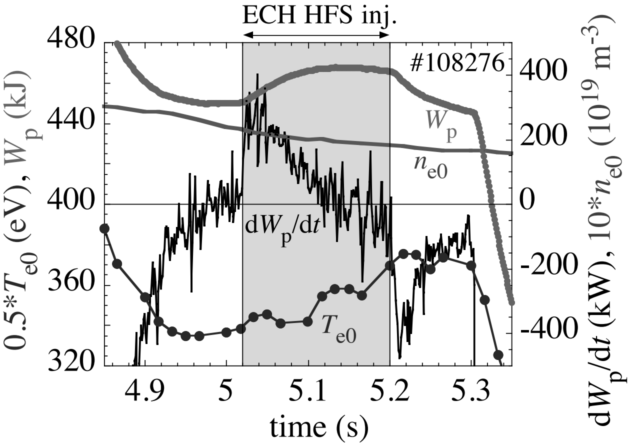

Fig. 1. Time evolutions of plasma stored energy W_p and its time derivative, $0.5\times T_{e0}$ and $10\times n_{e0}$ in the SDC discharge with HFS-ECH.

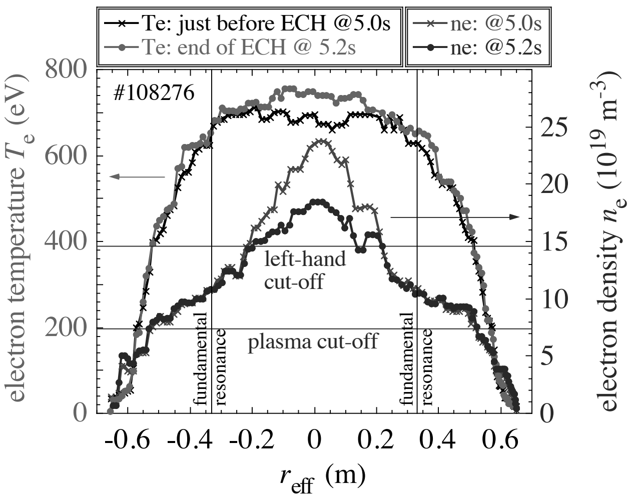

Fig. 2 Profiles of T_e and n_e at just before and at the end of ECH pulse in the SDC discharge with HFS-ECH.

1) R. Sakamoto *et al.*, Fusion Sci. Technol. **58** (2010) 53.
2) H. Yamada *et al.*, Plasma Phys. Control. Fusion **49** (2007) B487.
3) Y. Yoshimura *et al.*, to be published in Plasma Sci. Technol.