§3. Development and Application of a Ray-tracing Calculation System with 3D Equilibrium Mapping in the LHD ECH Experiments

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In fiscal year 2014, we have installed a new gyrotron (154 GHz, 1 MW). In addition, the injection parameters were optimized by using a code described in later. As a result, we have succeeded in achieving a high central electron temperature of 7.5 keV for a relatively high ion temperature and high density plasma (5 keV and 1.3×10^{19} m^{-3} at the center). Figure 1 shows the electron temperature and density profiles. After the optimization, the central temperature increased from 6 keV to 7.5 keV.

The optimization has been carried out by using the ray-tracing code "*LHDGauss*",[1] which has been upgraded to include the real-time three-dimensional (3D) mapping obtained during experiments.[2] For ray-tracing calculations, the *LHDGauss* can automatically read necessary data registered in the LHD database after a discharge, such as ECH injection parameters (e.g., Gaussian beam parameters, target positions, polarization, and ECH power) and Thomson scattering diagnostic data along with the 3D equilibrium mapping data. The equilibrium map with the electron density and temperature profiles is then extrapolated into the outside of the last closed flux surface. Mode purity, which is the ratio between the ordinary mode and the extraordinary mode, is obtained by calculating the 1D full-wave equation along the rays. The modeled density profiles and the magnetic shear under a given polarization are taken into account in the calculation. Power deposition profiles are calculated for each Thomson scattering measurement timing as soon as the LHD database is completed.

Figure 2 shows that the refracted EC beam under the experimental n_e and T_e profiles and the 3D equilibrium mapping results in on-axis heating. Using the calculation results of the *LHDGauss*, the injection directions of each ECH antenna were optimized, and the high temperature operational regime in the LHD was successfully expanded as a result (Fig. 1). Feedback of the injection condition for the required deposition profile on a shot-by-shot basis has resulted in an efficient experimental procedure. In the near future, higher T_e can be expected by optimizing not only the direction of each injection antenna but also the polarization of the waves with the help of the *LHDGauss*.

1) Kubo, S. *et al.*: Proc. 11th Int. Congress on Plasma Physics, AIP Conf. Proc. **669** (2003) 187.

2) Suzuki, C. *et al.*: Plasma Phys. Control. Fusion **55** (2013) 014016.

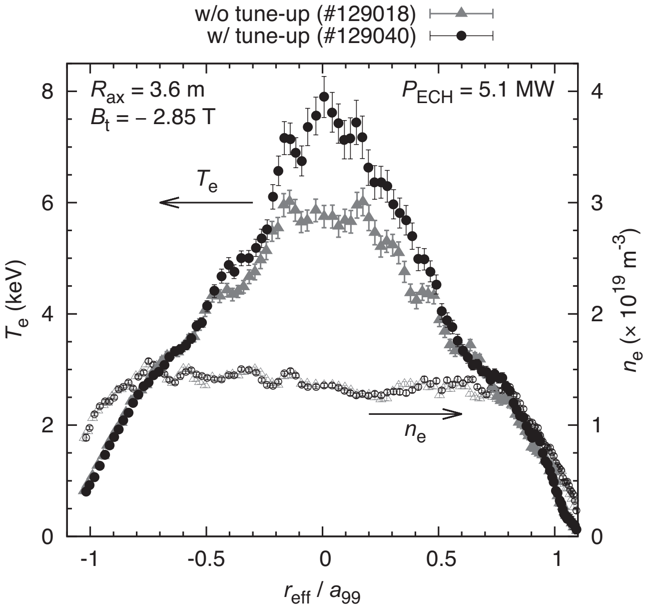

Fig. 1: T_e and n_e profiles as a function of r_{eff}/a_{99} before and after tuning the injection antennas for all the ECH lines.

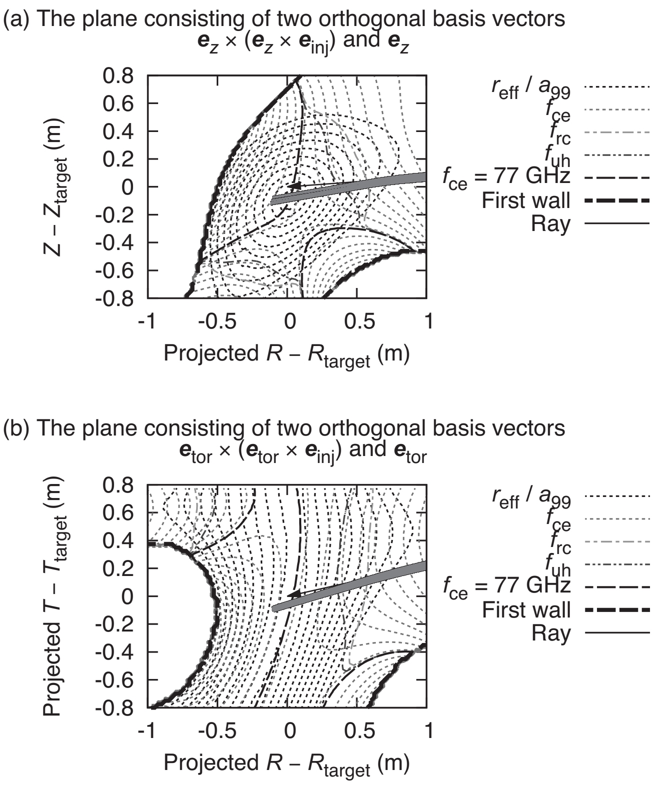

Fig. 2: Projected ray trajectories in the two planes for the EC waves injected from an outer-port launcher. Magnetic flux surfaces and EC resonance lines are also shown.