Divertor Heat Flux Distribution Measurements in Radiative Divertor Operation in LHD

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Handling enormous plasma heat flux to divertor plates is essential for the achievement of steady-state fusion reactor. A radiative divertor scenario by impurity seeding was developed as an effective method to enhance the radiative power dissipation in scrape-off layer (SOL). An impact of radiative divertor should be validated by a quantitative evaluation of heat flux at divertor plates. The total heat flux is expressed by the summation of plasma heat flux along the magnetic field line, radiation power load, and neutral flux due to charge exchange in divertor region. In this study, to investigate the characteristics of total heat flux into a divertor plate during impurity seeding experiments in LHD, 2-dimensional surface temperature distribution was measured and converted to the heat flux.

Measurements of surface temperature at the divertor plate was performed by using an infrared (IR) camera system, which was installed with radiation shielding for the deuterium experiments in LHD. The flame rate of IR camera was 100 Hz with the wavelength range from 7.5 to 14.0 \( \mu \)m, and the spatial resolution was \( \sim 1 \) mm at the divertor plate.

For the conversion from surface temperature to heat flux, an analysis by finite element method (FEM) for transient thermal diffusion process in the divertor components was performed. The divertor unit as a heat disposal system in LHD is composed of isotropic fine grained graphite IG-430U plate with 15 mm thickness and water cooled copper heat sink. Because the all components are mechanically fastened by bolts, the heat transfer near the bolts is high \[1\]. The analysis considered such a distribution of heat transfer rate, thermal radiation from the surface of graphite plate, and temperature dependence of thermal conductivity of graphite.

Radiation enhancement experiments by impurity seeding were performed in LHD with magnetic axis of 3.6 m, heating power of 10 MW by neutral beam injection (NBI), and line averaged electron density of \( 1 \times 5 \times 10^{19} \) m\(^{-3}\). During the flattop of the discharge, Ne gas was injected as an impurity. In the high density case, the radiation power from the plasma after the Ne seeding was \( \sim 2 \)–3 MW, which was almost twice higher than \( \sim 1.3 \) MW observed in similar discharge without Ne puffing. As comparing the two discharges without and with Ne seeding, the result of FEM analysis showed the reduction in heat flux onto the divertor plate from \( 7 \) MWm\(^{-2}\) to \( 2 \) MWm\(^{-2}\). The enhancement of radiation power and reduction in heat flux at divertor are desired characteristics of radiative divertor experiments.

There are several peaks of connection length of magnetic field lines over a hundred meter which come from SOL region to the divertor plate. The strong reduction in heat flux was obtained at strike point, where the connection length is the longest, while the divertor heat flux showed no reduction in other region. The plasma transport process and the radiation profile will be discussed by considering the magnetic field structure.

\[1\] R. Sakamoto, \textit{et al.}, 1997 11th Int. Toki Conf. (Toki, Japan).