Formation of Divertor Configuration for a Quasi-Symmetry Stellarator with External Coils and its Consequences for Transport

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Divertor concept is one of the most important methods to sustain a confinement region, i.e., a core region, and to mitigate influence of components outside the plasma by covering it with open-field region, i.e., scrape-off-layer (SOL) and divertor region. The standard divertor configuration has been developed for tokamak devices, and engineering optimization are actively investigated toward reactor-class tokamak devices. However, divertor concepts of stellarator/heliotron devices are not well established. Although the helical divertor of Large Helical Device (LHD) and the island divertor of Wendelstein 7-X (W7-X) are known as the major divertor concepts for stellarator/heriotron devices, optimization is still an open question. The method of coil design to realize a divertor configuration is also not a well-defined issue.

A quasi-symmetry stellarator configuration with modular coils was employed in this study, and several types of external coils were introduced to extract the magnetic field line from the core region toward the vacuum vessel. Plasma responses to the coils are ignored for the sake of simplicity of analysis. Formation of the last closed flux surface (LCFS) and extraction of magnetic field lines outside it were confirmed for two types of external coils: poloidal field coils and saddle loop coils, by Poincaré plots. The 3-D divertor transport code EMC3-EIRENE was applied to the quasi-symmetry stellarator to evaluate the transport properties affected by the variation of the magnetic field structure.

Parameter scans with regard to the position of the plasma-facing surface were carried out with a fixed electron density and a fixed heating power in the core. In the case of the reference configuration without external coils, the core electron temperature ($T_{ec}$) decreased according to the distance between the plasma center and the surface ($D_s$), and the electron density in front of the surface ($n_{es}$) is not sensitive to the distance $D_s$. On the other hand, the results with the poloidal field coils showed that the core temperature $T_{ec}$ was not sensitive to the distance $D_s$, and the density $n_{es}$ increased according to the distance $D_s$ when the surface did not interfere with the LCFS. These opposite trends indicate that the configuration without external coils is a limiter condition, and the configuration with external coils is a divertor condition, where energy transport is sustained by the LCFS and enhanced recycling takes place in front of the surface, i.e., divertor regions. Detailed transport analysis and results with different types of external coils will be presented in the paper.