1-2. Device Engineering and Cooperative Development Research

(1) Physics and Engineering of LHD Torus System

Research and development of the LHD torus system have been conducted for a future upgrade of LHD and a reactor design. In particular, establishment of efficient fueling and pumping schemes is emphasized since it is directly related to confinement improvement in the present experiment and also particle control is a major critical issue in a reactor.

Helical systems have already demonstrated their advantage in high density operation. In addition, recent discovery of Internal Diffusion Barrier (IDB) in the LHD experiment motivates a novel scenario of super high density reactor operation with the density of more than $5\times10^{20}m^{-3}$. This high density scenario is attractive because it enhances fusion output, it improves confinement due to favorable density dependence of energy confinement time and reduction of neoclassical helical ripple transport, and it mitigates critical engineering demands, in particular, plasma wall interaction. Experiment evidence indicates that edge plasma control by efficient pumping and direct core fueling by pellet injection are prerequisite to this improved confinement mode.

The present divertor configuration in LHD is an open divertor. No baffles and an active pumping facility have not installed in the vacuum vessel yet. The closed divertor is planned to enhance capability of particle control and the conceptual design is stimulated. Heliotron configuration which LHD employs has a built-in helical divertor due to its intrinsic nature of magnetic configuration. Four divertor legs are extracted from the confinement region. The cross section is similar to a double null configuration in tokamaks, however, this structure rotates poloidally in a toroidal excursion.

To improve the particle capability in the helical divertor (HD), the neutral pressure should be increased by one to two orders of magnitude to make the divertor pumping effective. Therefore the installation of the appropriate baffle structure is necessary. The particle flux evacuated by the divertor pump should be balanced to the fueling particle flux for the steady state operation, and is expected to be comparable to the fueling by pellet injection, that is about 5×10^{22} H/s (~100 $Pa\cdot m^3/s$) in LHD. The target parameters of the design are the pumping speed > 100 m^3/s (for 1 toroidal section) and the neutral pressure in the divertor region > 0.1 Pa. Two types of the new HD structure equipping baffle structures are proposed for the HD. One type uses the intrinsic helical divertor structure and another type employs the closed divertor modules which are installed on the inboard side of the ergodic layer in each toroidal section. By utilizing the three-dimensional plasma and neutral transport code, EMC3-EIRENE, the profiles of the heat deposition and the neutral pressure in these two types of HD structures have been investigated.

Development of a compact pumping system is a key technological issue for the future upgrade for HD. Capability of a superpermeable membrane (Group Va metal) pumping is investigated as an alternative candidate of a cryo-pumping. Hydrogen absorption performance so far has been investigated for a Nb panel and the drop of absorption rate has been found in low temperature range. Therefore, hydrogen absorption properties in low temperature range, in particular, in the vicinity of room temperature (< 100 C°) are investigated for a Group Va metal panel (Nb and V).

The pellet injection system in LHD is composed of two injectors; a pipe-gun with 10 barrels and a repetitive pellet injector with a screw extruder. Both injectors employ He refrigerators and serve the LHD experiment routinely as a primary experimental tool. Pellet injection is effective to control plasmas for diverse objectives. A variety of injection velocity and size are required to fulfill the experimental conditions. Controllability of the pellet velocity is investigated from the ideal gun theory including the effect of reflected shock wave. This model will be extended to assess the effect of species of propellant gas.

Assessment a novel scenario of a high density operation in a reactor, FFHR, has been done from the aspect of penetration depth of fueling pellets. With regard to the injection velocity, the velocity of 1500m/s which lies within the established technology is sufficient to fuel at an IDB without perturbing the core temperature. Optimization of fueling scenario will proceed with the progress in clarification of transport process of an IDB in the LHD experiment.

Development of advanced fueling using a compact torus (CT) is also continued in the experimental facility, SPICA (SPeromak Injector using Conical Accelerator). The effect of length of an accelerator on the parameter of a CT has been investigated. The CT with the density above $8\times10^{20}m^{-3}$ is successfully accelerated to 200km/s. Through the series of experiments, the CT accelerator can be optimized in terms of the length.

New experimental findings in LHD and these technological achievements in development programs stimulate each other and a rector assessment is conducted on the bases of both database

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