1-2. Device Engineering and Cooperative Development Research

(1) Physics and Engineering of LHD Torus System

Research and development related to the LHD torus system has been executed for an upgrade of LHD and consequent physics and engineering contribution to a fusion reactor. In particular, efficient fueling/pumping control and exploration of plasma wall interaction are emphasized since they have potential to improve plasma performance in the present and future experiments in LHD. Since installation of the closed divertor system has started and its effect has been investigated numerically prior to the experiment. A cluster of the related studies are motivated by the recognition that particle control is a critical issue in a fusion energy reactor. In addition, innovative studies on direct power generation, in-situ dust measurement, lithium wall conditioning, eddy currents, characteristics of solid pellet transferred in the bent guide tube and effect of helical fields have progressed. It should be noted that universities outside NIFS make major contribution to these studies.

With regard to a fueling scheme, cluster beam injection and compact torus injection have been being developed towards application and demonstration on LHD. The supersonic cluster beam (SSCB) is an improved version of cluster jet injection (CJI) with cryogenic cooling and a Laval nozzle. In SSCB, high-pressure hydrogen gas cooled by a GM refrigerator is injected to a test vacuum chamber through a fast solenoid valve with a Laval nozzle. The image of SSCB is identified by the scattering light of the intersecting laser beam. The peak scattering signals increases with the function of the valve temperature T_0^{-5} in the range between 119K and 143K, which suggests that the averaged diameter of clusters increases with cooling. The peak scattering signals also increases with the function of the backing pressure P_0^3. The divergence of cluster jet has been decreased after installation of the Laval nozzle from 22.5° to ~10°. As a consequence of a study on the compact torus (CT) injection, injection of extremely super-high speed neutral particle flow by using a CT injector has been proposed for efficient fueling. By using the improved SPICA (SPheromak Injector using Conical Accelerator) injector, a study on production of supersonic neutral particle flow has been launched. The SPICA accelerates a CT plasmoid and injects it into a long drift tube as a neutralizer cell filled with hydrogen gas, then super-high speed neutral particle flow is produced through charge-exchange (CX) reaction between CT plasma and neutral gas. The density in the plasmoid has been maximized to $1\times10^{22}\mathrm{m}^{-3}$ before neutralization. The neutralization process has been also studied by a Monte-Carlo simulation to investigate the conditions for high neutralization efficiency.

The Closed Helical Divertor (CHD) has been installed partially for the experimental campaign in 2010. The CHD consists of slanted target divertor plates and a dome structure. Enhancement of the neutral particle density behind the dome structure by more than one order of magnitude is expected for the CHD compared with that for the present open divertor configuration. Installation of a vacuum pumping system behind the dome structure is now planned for the next step. The behavior of neutral particles (H, H2) in the CHD region has been analyzed by a fully three-dimensional simulation code (EIRENE) to optimize the structure of the pumping system.

Dust generation in the fusion device and its ejection to the confined plasma are potential problems for impurity accumulations and tritium retentions. Silica (SiO_2) aerogel has been used as a dust collector in space plasma field: an aerogel has sponge-like structure in which 99 % of the volume is empty space. Thus, collided or deposited dust particles are trapped into the aerogel, and they are remained after vacuum vent. Then, information of the dust transport such as trapped angle and velocity as well as the particle properties such as size, shape and morphology will be evaluated by surface analysis. Tungsten coatings on graphite by plasma spray has been investigated under high heat flux loading. Tungsten coatings on CFC has been successfully produced by vacuum plasma spray (VPS) technique and their good thermal and adhesion properties have been confirmed by high heat flux tests. In addition, surface modifications such as blistering and hydrogen isotope/helium retention of VPS-W irradiated by a low energy and high flux hydrogen isotope/helium have been also investigated. Divertor plates receive huge heat load released from a core plasma. If the huge heat load can be converted to electricity by using a thermionic energy converter (TEC), the efficiency of the fusion reactor could be improved. Basic property of TEC has been investigated by 2D PIC simulation. Based on this analysis, The TEC module employing thoriated tungsten electrodes has been tested up to 2000K on the Active Cooling Test device (ACT).

A toroidal transport linkage code TOTAL (Toroidal Transport Analysis Linkage) has been applied to analysis of evolution of the neoclassical tearing mode with non-resonant external helical field. A small scale device with simplified helical coils has been constructed in Nagoya University to study configuration effect.

An innovative sensor to infer the plasma motion has been proposed and investigated numerically. When the plasma column shifts, eddy currents are induced in the vacuum vessel, which cause the mechanical vibration of the vacuum vessel. The number of acceleration sensors required to identify the vibration mode has been assessed.

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