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Divertor plasma and neutral particles behavior under the local island divertor configuration in the Large Helical Device

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Abstract

In the Large Helical Device (LHD), the local island divertor (LID) experiment has been conducted to investigate how to improve the core confinement with edge plasma control. An advantage of the LID configuration over the intrinsic helical divertor is the high pumping efficiency with the closed divertor module (neutralizer and pumping duct) and high speed pump-system. The particle evacuation efficiency, evacuated particle number/fueled particle number, has been estimated in experiment. This efficiency depends on the relative position of the closed divertor module (divertor head) to $m/n = 1/1$ magnetic island's outer separatrix corresponding to the divertor leg, and the efficiency is revealed to be 0.6–1. A new operational regime with high core density ($>4 \times 10^{20}$ m^{-3}) and a strongly peaked density profile has been discovered in the LID discharges. It is considered that a large effective pumping efficiency is necessary to enter this operational regime.

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Keywords: Density control; Divertor; Divertor geometry; Divertor plasma; LHD

1. Introduction

Particle control using a divertor is a crucial issue to realize a nuclear fusion reactor. In the Large Helical Device (LHD), the world's largest superconducting heliotron-type device [1], plasma experiments under two types of divertor configurations, the helical divertor (HD) and the local island divertor (LID), have been conducted.

The HD is intrinsic in the heliotron-type magnetic configuration, and has no baffle structure and no divertor pumping system at this stage in LHD [2].

The LID was installed in LHD in 2003 [3]. In Fig. 1(a), the basic concept of the LID is depicted. The perturbation field generated by 10 pairs of coils is resonant with the $q = 1$ surface, and generates an $m/n = 1/1$ magnetic island in the periphery of the LHD confinement region. A divertor head consisting of neutralizer plates and a pumping duct is inserted into the island in a horizontally elongated

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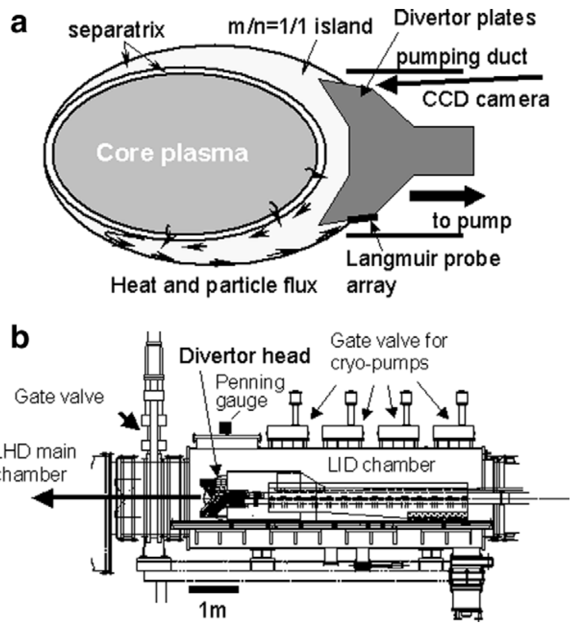

Fig. 1. (a) Schematic view of the LID system and (b) basic concept of the LID.

cross-section where the width of the island is maximum (about 20 cm). The pumping duct surrounds the neutralizer, and it works as a baffle. The outer separatrix of the island connects the neutralizer plates in the divertor head, and the last closed flux surface is determined by the inner separatrix of the island. Plasma–surface interaction occurs ideally only at the divertor head, and it is toroidally and poloidally localized. Therefore, high pumping efficiency and impurity control can be expected with the proper divertor head configuration and pumping system. In LHD, a field line tracing code which is coupled to a random walk process to simulate the diffusive particle behavior [5] predicted that over 80% of the particle out-flux from the confinement region is collected by the LID target plates [6]. From the results of neutral transport simulation using the DEGAS code, it was found that a pumping efficiency up to 50% could be achieved [6]. In discharges with the LID configuration in LHD, strong reductions of the particle flux and the heat load to helical divertor plates measured by Langmuir probes and thermocouples are observed. This indicates that most of the particle flux and the heat flux are collected by the LID divertor head as predicted, and recycling is localized in the LID region as expected [2]. In recent experiments, improved confinement with $\tau_E/\tau_{E,ISS95} \sim 1.2$, where $\tau_{E,ISS95}$ is the energy confinement time estimated using the International Stellarator Scaling 95, have been achieved in multiple-pellet fueled discharges [4], and a very high core density ($>4 \times 10^{20}$ m^{-3}) with a strongly peaked profile is achieved during those discharges [7].

In this study, divertor plasma and neutral particle behaviors are investigated, especially the pumping function of the LID configuration, and its impact to core plasma properties.

2. Experimental set-up

Fig. 1(a) shows a schematic view of the LID configuration. A divertor head is installed into the magnetic island. The LID pumping system with eight cryo-pumps (42 m^3/s × 8) and a turbo-molecular pump (4.4 m^3/s) is located outside of the LHD main chamber. These pumps are attached to a manifold (LID chamber in Fig. 1(b)). The effective exhaust velocity for hydrogen is about 200 m^3/s. That is almost the same as the effective exhaust velocity of the main pump-system in LHD. When a discharge under the HD configuration is conducted, the divertor head is drawn out, and the LID pump-system works as an additional main pump-system. To investigate neutral particle behavior, a Penning gauge is installed on the LID chamber. A Langmuir probe array (10 ch/array) is embedded in the divertor plates (see Fig. 1(a)). The shapes of probe electrodes are dome-type ($r = 1.5$ mm), and are made of isotropic graphite. The distance between electrodes is about 10 mm. Thermocouples are embedded in 16 divertor plates to monitor the divertor plate's temperature. They are 10 mm from the surface of the divertor plates.

An ASDEX-type fast ion gauge is installed in the LHD main chamber, and it monitored the neutral pressure at the torus inboard side helical divertor region in the same toroidal section as the LID head. A Langmuir probe array is embedded in a divertor tile near the ASDEX gauge.

A Thomson scattering measurement was utilized to obtain the electron density and temperature profiles on the center chord in the horizontally elongated cross-section that is 72° in toroidal angle away from the LID head.

$H\alpha$ monitors are distributed toroidally. In the experimental conditions described in this paper, no significant difference in $H\alpha$ behavior is observed in the toroidal direction, and the signal of the monitor about 108° in toroidal angle away from the LID head is used in this paper.