§1. Installation of the Closed Helical Divertor in LHD

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To investigate the controllability of neutral particles and its effects on plasma performance, the closed helical divertor with in-vessel cryo-sorption pump was installed on torus-inboard side in 6 out of 10 toroidal sections of LHD prior to the 16th experiment campaign in 2012. Design of the in-vessel pump was carried out based on the results of calculation using a neutral particle transport code, EIRENE, and a finite element method code, ANSYS.

Figure 1 shows the horizontal cross-section of the closed helical divertor at the equator. It consists of divertor plates, dome and cryo-sorption pumps. The divertor plates and the dome are made of isotropic graphite (IG-430U, TOYO TANSO). They consist of two parts which are tightly fixed with bolts sandwiching a SUS316L cooling pipe (27.2 mmϕ), and are cooled by water. The divertor plates and the dome form the baffle structure[1]. The design of the baffle structure was carried out with a full 3D neutral transport code, EIRENE[2]. In 2010, the baffle structure without the in-vessel cryo pump was installed in 2 out of 10 toroidal sections, and the simulation results obtained in the design were confirmed by comparison between the compression ratio of neutral particles in the divertor with the baffle structure and that in the "open" helical divertor[3]. Neutral pressure under the dome rises during a discharge up to 1 Pa.

The in-vessel cryo-sorption pumping system was designed based on the calculated results with use of EIRENE code and a finite element method code, ANSYS[4, 5]. Figure 1 also shows schematic view of the cryo-sorption pump. The cryo-sorption pump consists of a helium-gas-cooled cryo-sorption panel, liquid-nitrogen-cooled chevron-type shields, and water-cooled louver-type shields. To install the pump under the dome on the helical shaped LHD vacuum vessel, the pump consists of 4 to 6 pump units in each toroidal section. Typical sizes of the unit are 160 mm in width, 100 mm in height and 440 mm in long. Figure 2 shows a schematic view and photo of the pump-units on the vacuum vessel. The units are connected by the coolant pipes made of SUS316 in series. The units are electrically insulated from the vacuum vessel to avoid damage induced by glow discharge for the wall conditioning. The operating temperature of the pump is 10-20 K.

In Fig. 2, a photo of the cryo-sorption panel is shown. The substrate of the panel is made of copper (62 mm × 390 mm × 3 mm thickness). Small pieces (~ 5 mm) of activated charcoal are bonded on the panel with an indium layer. We did not use organic adhesives which are used in usual cryo-sorption pump to avoid out-gas and degradation of the adhesives during baking (~95 ºC) for the wall conditioning.

A photo of the liquid-nitrogen chevron-type shield made of copper is in Fig. 2. Typical sizes of the chevron blades are 30 mm in width, 58 mm in height and 100˚ in angle. The distance between the blades is 7.6 mm. In Fig. 2, a photo of water-cooled louver-type shield made of SUS316L is shown. It consists of three blades with the distance of 8 mm. These shields are blackened with nickel plating to reduce the invasion of the radiation power to the cryo-sorption panel from the divertor plasma and plates which reflects on the shields. Metallic mesh panels made of SUS316 (40 mesh/inch, 0.19 mmϕ) are inserted between the chevron and the louver shields to reduce the invasion of microwave power of the electron cyclotron heating. Refrigerator to cool the cryo-sorption panel consists of three Gifford-McMahon cycle 4K cryo-coolers (RDK-415D, Sumitomo Heavy Industries, Ltd). Its total cooling capacity is 30 kW at 8 K. The flow rate of the liquid-nitrogen to cool the chevron-type shield is 40.4 L/h.

1) Masuzaki, S. et al.: Fusion Eng. Des. **85** (2010) 940.
2) Shoji, M. et al.: J. Nucl. Mater. **363-365** (2007) 827.
3) Masuzaki, S. et al.: J. Nucl. Mater. **438** (2013) S133.
4) Shoji, M. et al.: Plasma Fus. Res. **6** (2011) 2401035.
5) Murase, T. et al.: in this annual reports

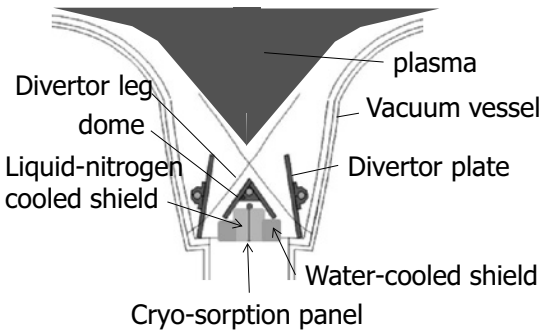

Fig. 1. Horizontal cross-section of the closed helical divertor at the equator.helical divertor at the equator.

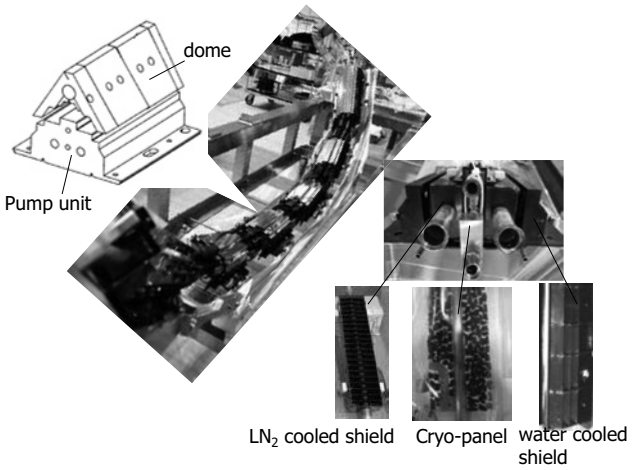

Fig. 2 Schematic view of the pump-unit and photos of connected pump-units, front view of the pump-unit, cryo-panel and shields.