Neutral Gas Compression in the Helical Divertor with a Baffle Structure in the LHD Heliotron

Suguru MASUZAKI, Masahiro KOBAYASHI, Mamoru SHOJI, Masayuki TOKITANI,
Tomohiro MORISAKI, Ryuichi SAKAMOTO, Masaki OSAKABE, Takanori MURASE,
Takashi KOBUCHI, Hiroaki YONEZU, Yasuhiko TAKEIRI, Hiroshi YAMADA,
Akio KOMORI and the LHD Experiment Group

National Institute for Fusion Science, Oroshi 322-6, Toki 509-5292, Japan

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The helical divertor in the Large Helical Device (LHD) was partially modified before the experimental campaign in 2010 to demonstrate the ability of particle control by installing a baffle structure. The baffle structure consists of water cooled divertor plates combined with baffle plates and a dome in the private region. The neutral pressures in the modified and an existing unmodified helical divertors have been measured by using fast ion gauges during the campaign. The recycled neutral gas was successfully compressed in the modified divertor during discharges, and more than ten times higher pressure was observed there than in the unmodified divertor as expected from the neutral transport calculations.

Keywords: LHD, helical divertor, baffle structure, particle control, neutral compression, fast ion gauge

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The control of the neutral particles using a divertor is a crucial issue especially for next generation fusion devices, such as ITER, DEMO and the helical reactor FFHR [1]. Hydrogen isotopes, helium ash and impurities have to be pumped to sustain the fusion burning plasma steadily. In tokamaks, particle control experiments using closed divertors and divertor pumping have been conducted [2–4]. In helical devices, closed divertor experiments were also conducted in the Compact Helical System (CHS) [5], Wendelstein-7AS [6] and LHD [7] using a magnetic island. In LHD, the local island divertor (LID) experiment was conducted, and the effective particle control was demonstrated [8]. Furthermore, the super dense core (SDC) plasma operational regime caused by the formation of the internal diffusion barrier (IDB) was obtained in the high pumping operation using LID [9]. However, the wetted area on the divertor head in LID was so small that it cannot be utilized during long pulse operation with high performance plasma. The wetted area in the helical divertor which is naturally equipped in the heliotron magnetic configuration is larger than that in the LID. However, the neutral pressure in the helical divertor is up to 0.01 Pa order even during a high density discharge in which the line averaged density is higher than 10^{20} m^{-3}, and it is considered that a ten times higher neutral pressure is necessary for effective particle control using divertor pumping [10]. The relatively low neutral pressure in the helical divertor was considered to be caused by the three dimensional plasma distribution in the divertor and the large volume of the vacuum vessel. Therefore it is necessary to install a baffle structure to compress neutral particles in the divertor.

The designing of a baffle structure for the helical divertor was conducted by using a neutral transport code, EIRENE [11]. The code was applied to the neutral behavior in the existing divertor configuration before the start of the design, and the results of the calculation were validated by comparing them and experimental results obtained by spectroscopic measurements [12]. The development of the plasma facing components for the divertor was conducted using the electron beam irradiation device, ACT (Active Cooling Test stand) in NIFS, on the basis of the mechanically jointed water-cooled divertor plate used in the existing divertor [10, 13]. The divertor plates temperature is considered to be highest during steady state discharge with 3 MW heating power which is an experimental goal of LHD. In such discharges, the largest heat flux to divertor plates is estimated to be 1.5 MW/m^2, and the divertor plates were developed to tolerant the heat load. The design of the divertor and the development of the plasma facing components were completed in 2008, and two of ten torus inboard side divertors were modified by installing the baffle structure before the experimental campaign in 2010 to demonstrate the ability of the neutral particle compression in the helical divertor [10].

Figure 1 shows both the schematic view of the existing and modified divertor. In the existing divertor, the plasma facing surfaces of the divertor plates face the main plasma. On the other hand, they face the private region in the modified divertor. In the private region, there is the “dome”

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author’s e-mail: masuzaki@LHD.nifs.ac.jp

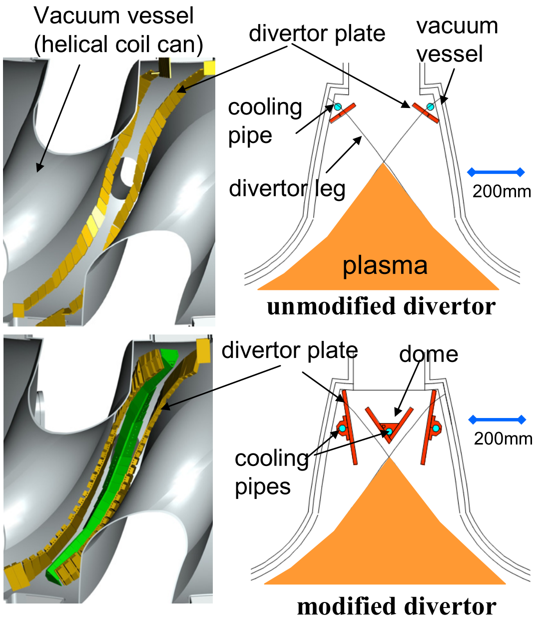

Fig. 1 Schematic views of an unmodified (top) and a modified divertor (bottom) in the torus inboard side. The right hand side figures are the cross-sectional views of them in the equatorial plane.

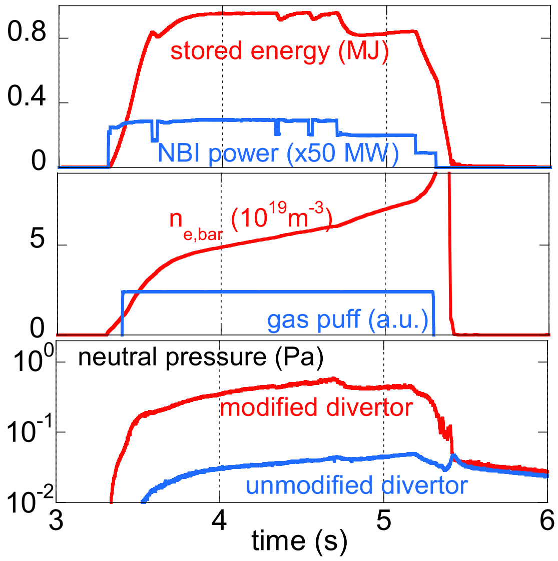

Fig. 2 Time evolutions of the stored energy and NBI power (top), line averaged density and fueling amount (middle) and neutral pressure in the modified and unmodified divertors (bottom) during a density ramp-up discharge.

structure. Due to the changes of the divertor plates' angles and the installation of the dome, it was expected from the neutral transport calculation that the neutral pressure under the dome is ten times or more higher than that in the private region in the existing divertor [10]. The divertor plates and dome are made from isotropic graphite, and they are water cooled by mechanical jointing to water cooling pipes made of SUS316 [10, 13].

To measure the neutral pressure in the modified divertor, three ASDEX-type fast ion gauges were installed under the dome. To compare the pressure between the modified and unmodified divertors, another fast ion gauge was installed in the torus inboard-side private region of an unmodified divertor. These fast ion gauges were calibrated by using a cold cathode gauge and a capacitance gauge from 5×10^{-3} to 2 Pa.

Density ramp-up discharges were conducted in a standard magnetic configuration in which the magnetic axis radius is 3.6 m to compare the neutral pressures in the modified and the unmodified divertors. Figure 2 shows the time evolutions of plasma stored energy, line averaged electron density ($n_{\mathrm{e,bar}}$) in the center-chord and the neutral pressure near the equatorial plane in these divertors during a density ramp-up discharge. Hydrogen gas puffing was conducted during the discharge, and $n_{\mathrm{e,bar}}$ increased up to 7×10^{19} m^{-3}. The neutral pressures in both divertors increase with the increase of $n_{\mathrm{e,bar}}$, and the pressure in the modified divertor is more than 10 times higher than that in the unmodified divertor through the discharge. After the termination of the neutral beam injection, the neutral pressure in the modified divertor decreases and becomes the same as that in the unmodified divertor. This result proves that the neutral particle compression in the modified divertor works well.

Any negative effects on the plasma operation caused by the installed baffle structure have not been observed up to now. After this experiment campaign, checking for damages to the baffle structure will be conducted, and we are going to investigate surface changes, such as erosion and deposition layer formation on the plasma facing surfaces to understand material migration in the modified divertor region. The initial result promises that an upgraded divertor system with pumps under the dome enable efficient active particle control in LHD.

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