Application of Divertor Pumping to Long-Pulse Discharge for Particle Control in LHD

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Divertor pumping was applied to plasma discharges for superior fuel particle control in the Large Helical Device (LHD). The LHD is equipped with two different pumping systems. One is the main pumping system, in which the pumping speed is 260 m^3/s in hydrogen. The other pumping system is the divertor pumping system in which the pumping speed is 70 m^3/s in hydrogen. Divertor pumping was applied to 40-second long pulse Electron Cyclotron Heating (ECH) discharges to assess the improvement in particle control provided by divertor pumping. The results show that without divertor pumping, the electron density was not controlled by gas puffing using the feedback signal of line-averaged electron density. Then, the plasma confinement deteriorated, finally leading to radiation collapse. On the other hand, with divertor pumping, the density was well-controlled by gas puffing using the feedback signal. The results indicate that divertor pumping is one of the key tools for controlling the particles in fusion plasmas.

Keywords: LHD, Divertor pump, density control

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In high-temperature fusion plasmas, fuel particle control is one of the important issues for stably maintaining fusion plasmas. Divertor pumping is considered to be an important tool to control plasma density in fusion plasmas. In the divertor region, neutral particles can be compressed [1], and the divertor system is able to efficiently pump out the particles.

The importance of divertor pumping is featured not only in current operating devices, but also in future operating devices. For example, in ITER, which is now under construction, at least 200 Pa m^3/s of particle throughput is required in the divertor for steady-state operation [2]. If the divertor pressure is estimated as 1 Pa, the required divertor pumping speed is 200 m^3/s. In JT-60SA, which will start plasma operation in FY2020, 100 m^3/s of divertor pumping speed is planned for long-pulse discharges [3]. Previously, the phenomenon of wall saturation was observed in 40-second H-mode discharge in the predecessor device, JT-60U. In the saturation phase, gas puffing for fueling was not required in the latter phase of the discharge. Also, the limit of edge plasma pressure was degraded at wall saturation [4].

In the Large Helical Device (LHD), which is one of the largest helical experiment devices, the development of divertor pumping has been strongly enhanced since FY2012. For divertor pumping, we applied cryo-sorption pumps [5,6] and non-evaporable getter pumps [7] in the divertor region. We found that divertor pumping contributes to a low recycling state in short-pulse discharges of five seconds or less in the LHD. However, divertor pumping has not been applied to longer pulse discharges with hydrogen plasmas. In this paper, particle control using divertor pumping is demonstrated in a longer pulse discharge of 40 seconds.

Figure 1 shows the results of the application of divertor pumping to 40-second plasma discharges. Plasmas were heated by Electron Cyclotron Heating (ECH). Moreover, gas puffing was utilized for fueling in the discharge. We investigated such plasmas under different pumping conditions. One used the pumping system without the divertor pump and the other with the divertor pump (70 m^3/s). Here, in both cases, the main pumping system was in operation (260 m^3/s). Also, the same feed-back control of line-averaged electron density was applied. In the absence of divertor pumping, even without gas puffing, the plasma density was increasing, and the density was not controlled well by density feedback, leading to plasma radiation collapse. On the other hand, if divertor pumping was utilized, density feedback control operated well with a stable hydrogen gas puff. Figure 2 shows the relation between electron density and stored energy with and without

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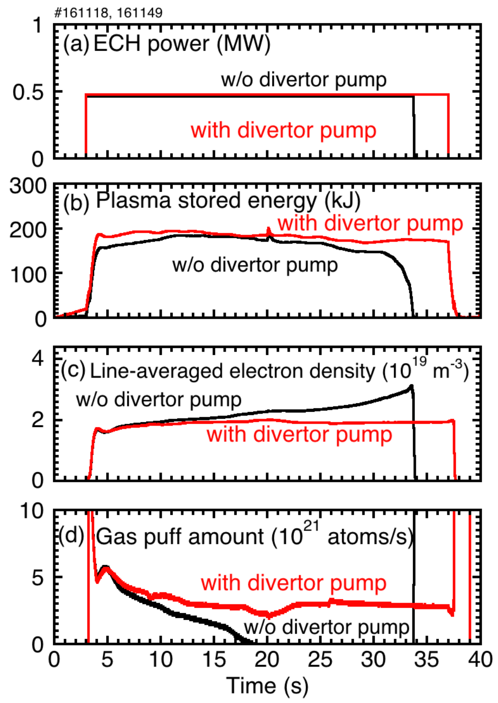

Fig. 1 Time evolution of (a) heating power of ECH, (b) plasma stored energy, (c) line-averaged electron density and (d) gas puff amount. Red solid line shows the case with divertor pump and black solid line shows the case without divertor pump.

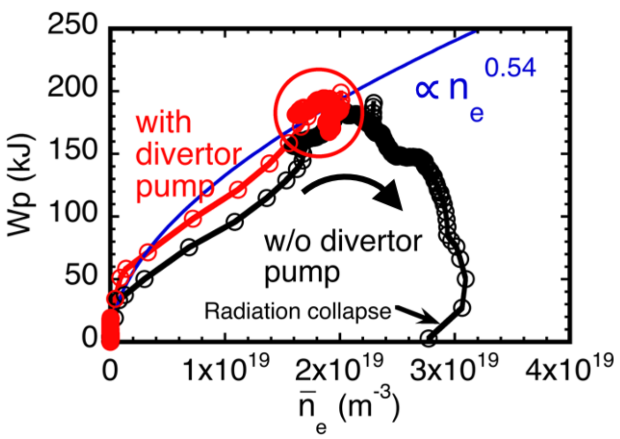

Fig. 2 Stored energy as a function of averaged electron density. Blue solid line represents ISS04 scaling. Red symbols show the case with divertor pumping and black symbols show the case without divertor pumping. In the case with divertor pumping, stable stored energy and electron density is obtained as shown in the red circle.

divertor pumping. In the case without divertor pumping, the stored energy rolled over due to the increase in density, resulting in a deterioration of plasma confinement. However, in the case with divertor pumping, constant density and stored energy was maintained during the ECH injection following ISS04 scaling [8]. These results show that

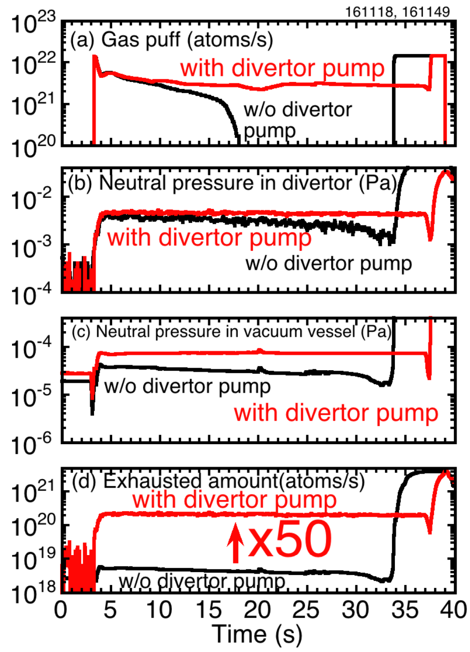

Fig. 3 Time evolution of (a) gas puff amount, (b) neutral pressure in divertor region, (c) neutral pressure in vacuum vessel and (d) exhausted amount. Red solid line shows the result with divertor pump and black solid line shows the result without divertor pump.

divertor pumping makes it easier to control the density and could contribute to particle control in further long-pulse discharges. In addition, feed-back control of higher density would be possible using divertor pumping. The particle exhaust amount was also evaluated as shown in Fig. 3. In the case with divertor pumping, the exhausted amount became up to 50 times larger than the case without divertor pumping. Here, the exhausted amount was evaluated from the compressed neutral pressure in the divertor region (Fig. 3 (b)) and the pumping speed of the divertor pumping in the case with divertor pumping. In the case without divertor pumping, the exhausted amount was evaluated from the neutral pressure in the vacuum vessel (Fig. 3 (c)) and the pumping speed of the main pumping system. The results show that efficient exhaust was attained by use of the divertor pump.

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