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Helium wall retention in long pulse discharge in LHD
LHDにおける長時間放電時のヘリウム壁排気

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Global helium particle balance in long-pulse discharges is analyzed in the Large Helical Device (LHD). The global particle balance analysis is applied to long pulse discharges over 40 min. by ICRH and ECH, indicating that the helium wall retention is dynamically changed in time. In this study, the wall retention changed during a discharge is discussed.

1. Introduction

The retention of not only a fuel such as hydrogenic isotopes but also of helium generated by the fusion reaction in the plasma facing components (PFCs) is one of the crucial points to be investigated for fusion devices, particularly for steady-state long-pulse discharges. In the fusion devices using full-carbon as PFCs, the retention of helium has been demonstrated to be modest [1]. Compared with full-carbon devices, the Large Helical Device (LHD) has a peculiar plasma facing components, which are composed of the first wall with stainless steel and the divertor with carbon. The co-deposition layer with a mixture of carbon and stainless steel, which is different from a base material, is found to be formed [2]. In this study, we report the experimental results which exhibit a different behavior of helium retention in long pulse discharges of LHD plasmas.

2. Global particle balance analysis

The gas balance analysis relies on the measurement of the injected and pumped particle fluxes during the plasma discharges and also after the discharges. Therefore, identification of supplied and exhausted particles should be undertaken carefully. The particle conservation can be simply described as follows:

$$\begin{aligned}\int \Gamma_{\rm puff} dt &= N_{\rm p} + N_{\rm n} + N_{\rm wall} + \int \Gamma_{\rm Ex} dt \\ &= \int n_{\rm e} dV_{\rm p} + P_0 V_{\rm vessel} + N_{\rm wall} + \int S_{\rm p} P_0 dt.\end{aligned}$$

Here, $\Gamma_{\rm puff}$ (Pa m^3/s) is the gas influx required for maintaining the plasma density. $\Gamma_{\rm Ex}$ (Pa m^3/s) is the exhausted flux by pumps. N_p (Pa m^3), N_{wall} (Pa m^3) and N_n (Pa m^3) denote the particle inventory in the plasma, and the neutrals in the wall and in the vessel, respectively. n_e is the averaged plasma electron density and V_p is the plasma volume. $\Gamma_{\rm Ex}$ is evaluated from the pumping speed (S_p) and the pressure in the vacuum vessel (P_0). From the particle conservation, N_{wall} can be evaluated.

3. Experimental setup

It is worth noting that PFCs play an important role for the wall retention study. As described above, in the PFCs, the first wall and divertor tiles in LHD are made of stainless steel (SUS-316L) and carbon, respectively. In this paper, we regard the "wall" as both the first wall and the divertor tiles, because they cannot easily be distinguished from each other in the global particle balance analysis. The postmortem analysis in LHD reveals that the mixed-material deposition layer composed of dominant carbon (~98%) and a slight amount of iron (~2%) is formed [2]. We have recently found that this mixed-material deposition layer is a possible contributed factor of helium retention. Formation of the microscopic modification of the wall surface, such as helium radiation damage and mixed-material deposition layers due to the plasma wall interaction, were confirmed on the first-wall surface after the long pulse helium discharge [3].

Tokitani et al. have reported that the amorphous-like porous structure of the mixed-material deposition layer seems to act as an effective trapping site for helium, and this trapping mechanism could be the main role of the wall pumping of the helium during long pulse discharges. The detailed discussion based upon the postmortem analysis is described in Ref. [3]. The vacuum vessel wall temperature is maintained below 75 ℃ while the superconducting helical coils are energized, and it is limited to no higher than 95 ℃ in order to avoid heat conduction to the superconducting helical coils even at baking for wall conditioning.

In this study, global helium particle balance analysis is conducted in long-pulse helium plasma discharges with ICRH and ECH. The longest pulse discharge has been achieved with a duration time of 48 min. The helium-rich state maintained during the discharge (He/H > 9) is confirmed by a quadrupole mass spectrometer.

4. Global particle balance analysis in long-pulse discharges.

A line-averaged electron density is 1.2×10^{19} m^{-3}, and electron and ion temperatures of 2 keV by the averaged heating power of 1.2 MW are obtained during the long pulse discharges. Figure 1 shows the temporal evolution of the wall retention in the long pulse. The dynamic change of the helium wall retention is observed. The inventory can be mainly separated into three phases. In the first phase, defined from 0 to ~300 sec., quite high wall inventory occurs. In this phase, more than 80 % of the puffed helium is retained in the wall. After the first phase, the wall inventory shows modest declination. Namely, in the time range between ~300 and ~1,500 sec., the wall retained the particles in the first phase rather releases some particles. However, the high wall inventory appears again in the third phase from ~1,500 sec. to the end of the discharge. In the discharge, the wall inventory including the dynamic retention is 85±30 Pa m^3 (60±20 % of injected amount).

In order to understand the behavior of the dynamic and temporal change of the wall inventory, we make a simple assumption that there are two kinds of helium reservoir. Thus, one reservoir is "divertor plate with carbon", and the other one is "first wall with stainless". In the first wall, the thermal desorption spectra results show that the retained helium amount in the deposition layer linearly increases with the exposure (discharge) time [3], suggesting that the first wall contributes to the helium retention with constant retention rate during the discharge. On the other hand, in the carbon utilized in the divertor plates, ion beam experiments show that the helium retention rate depends on the specimen temperature [4]. Thus, the divertor plates, whose temperature is changed between room temperature and 300 ℃ by the plasma flux during the discharge, have a possibility to contribute the helium retention with "not" constant retention rate.

In order to clarify the hypothesis, we have investigated the relationship between the retained helium amounts and the temperature of the divertor plates at the end of the "phase 1" in various discharges, as shown Fig. 2. So far, the clear dependence is not seen. In order to verify the assumption, further analysis has been undertaken.

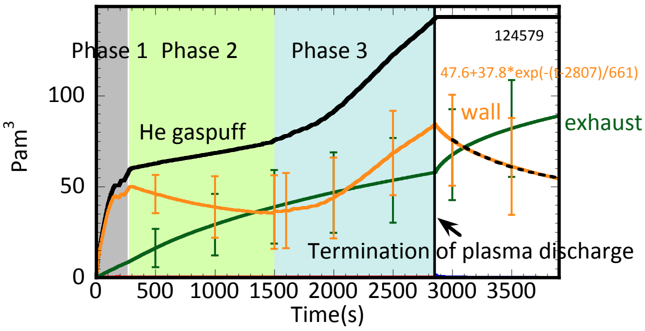

Fig. 1. Waveforms of global helium particle balance analysis conducted in the two similar long discharges over 40 min.

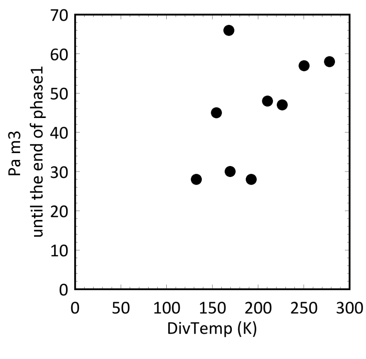

Fig. 2. Retained helium amounts and a temperature of divertor plates at the end of the phase 1 in various discharges.

References

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