

# Planned Operation of Tritium Recovery System Based on Investigation of LHD Exhaust System<sup>\*)</sup>

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(Received 25 November 2011 / Accepted 23 January 2012)

To understand the conditions of exhaust gas treatment at the transition point between the Large Helical Device (LHD) vacuum pumping system and the exhaust gas tritium recovery system, the gas flow rate and hydrogen concentration were measured. Simultaneous measurement of the exhaust gas flow rate and hydrogen concentration was made possible by applying two types of hydrogen monitors: a thermal conductivity sensor and a combustible gas sensor. The obtained results have led to remodeling of the LHD vacuum pumping system and an optimised plan of operation for the tritium recovery system.

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Keywords: tritium, hydrogen monitor, tritium recovery, vacuum pumping, exhaust gas, large helical device

DOI: 10.1585/pfr.7.2405009

## 1. Introduction

In order to realize the planned deuterium plasma experiments using the Large Helical Device (LHD), the National Institute for Fusion Science (NIFS) is planning to install systems for tritium recovery from exhaust gas [1].

In the LHD, two types of tritium recovery systems are planned. One will be used to recover tritium generated during the plasma experiments and contained in the vacuum pumping gas (processing capacity: 10 Nm<sup>3</sup>/h) and the other system to recover tritium remaining in the vacuum vessel and contained in the purge gas from the vessel during inspection and maintenance of the vessel (processing capacity: 300 Nm<sup>3</sup>/h).

To determine the fabrication specifications and to optimize operation of the two types of tritium recovery systems, it is necessary to understand the conditions at the transition point between the LHD vacuum pumping system and the tritium recovery system, such as the hydrogen gas concentration and exhaust gas flow rate. For this purpose, measurements were carried out on the present vacuum pumping system.

## 2. Method for Investigation

Figure 1 shows the LHD vacuum pumping system at present. Main and NBI exhaust systems consist of three kinds of vacuum pumps, i.e., mechanical pumps, turbo molecular pumps, and cryo-pumps.

To measure the hydrogen concentration and gas flow rate simultaneously, gas sampling lines were installed before and after the exhaust blower. The configuration of the measuring device is shown in Fig. 2.

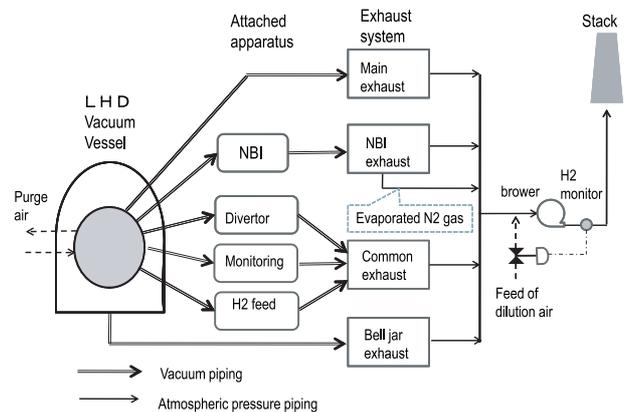


Fig. 1 LHD vacuum pumping system at present.

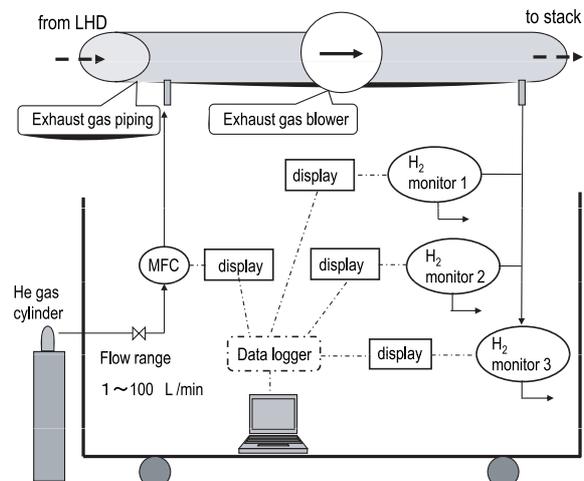


Fig. 2 Configuration of the measuring device.

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<sup>\*)</sup> This article is based on the presentation at the 21st International Toki Conference (ITC21).

Table 1 Specifications of different H<sub>2</sub> monitors used.

Hydrogen monitor	Type of sensor	Detection range	Detection limit
No.1	Gaseous heat conduction	0 -10%	0.1 %
No.2	Gaseous heat conduction	0 – 100%	0.5 %
No.3	Flammable gas combustion	0 – 4%	0.1 %

Table 1 compares the specifications of two different hydrogen monitors used in the investigation, a thermal conductivity sensor and a combustible gas sensor (Model: PE-2DC, New Cosmos Electric Co., LTD, Japan).

The two monitors were installed in the sampling line at the blower exit and the hydrogen concentration was measured. Pure He gas was fed to the sampling line at the blower entrance at a constant flow rate.

The increment in concentration by the addition of He gas was determined based on the difference in values measured by the combustible gas sensor (where only hydrogen can be detected under the present conditions) and by the thermal conductivity sensor (where both hydrogen and helium can be detected under the present conditions).

The flow rate of the exhaust gas was evaluated from the dilution rate of the pure He gas as

$$F_f = F_i \times 100 / \alpha(C - C_f), \tag{1}$$

where  $F_f$  is the exhaust gas flow rate,  $F_i$  is the He gas addition rate,  $\alpha$  is the conversion coefficient from hydrogen to helium in concentration,  $C$  is the value measured by the thermal conductivity sensor, and  $C_f$  is the value measured by the combustible gas sensor.

### 3. Investigation Results

#### 3.1 Experiment during plasma discharge

The hydrogen concentration measured during regular exhaust operation, in which the inside of the LHD vacuum vessel is maintained under a high vacuum condition, was below the detection limit of the hydrogen concentration monitor (0.1%), in contrast to the expected concentration (about 60%). It has been confirmed that the hydrogen concentrations changed from 5 to 200 ppm depending on the LHD experimental conditions and methane concentration was less than the detection limit (3 ppm) by the gas chromatography (Model: XG-100H, New Cosmos Electric Co., LTD).

Subsequently, the exhaust gas flow rate was measured by adding pure helium gas at the inlet of the exhaust pump as described above. As discussed, the hydrogen concentration monitor with a thermal conductivity sensor can detect the concentration of helium gas as well as that of hydrogen. It was confirmed that the indicated value changed in proportion to the flow rate of helium gas added as shown in Fig. 3. Next, continuous addition of helium gas was carried

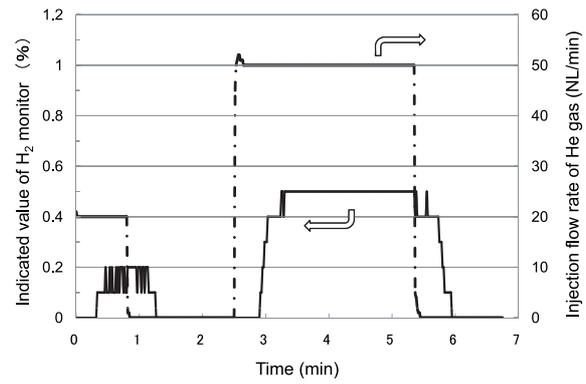


Fig. 3 Response of H<sub>2</sub> monitor (No.1) with addition of He gas.

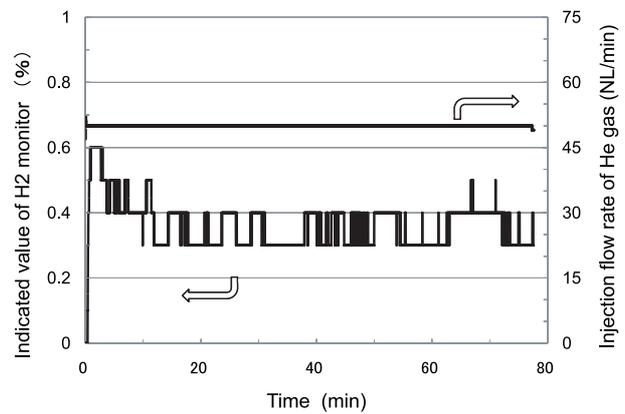


Fig. 4 Indicated values of H<sub>2</sub> monitor (No.1) under continuous addition of He gas.

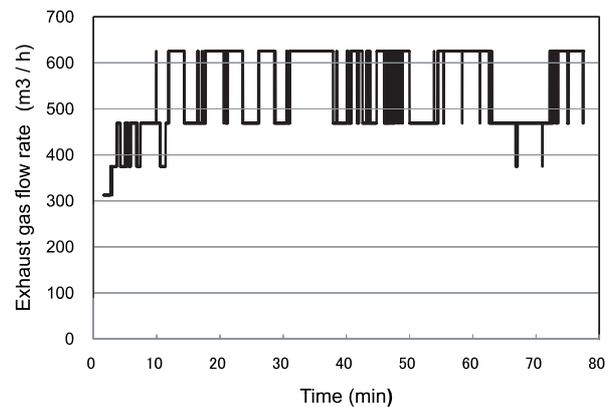


Fig. 5 Estimated exhaust gas flow rate.

out at a flow rate of 50 NL/min for about 1 hour. As shown in Fig. 4, it was observed that the indicated values varied in the range between 0.3 and 0.6%. The time dependence of the exhaust gas flow rate estimated by Eq. (1) is shown in Fig. 5.

In contrast to the expected flow rate (about 0.005 Nm<sup>3</sup>/h), large flow rates of 500 to 600 Nm<sup>3</sup>/h were observed. Upon investigation of the source of the unexpectedly high exhaust gas rates, it became clear that evap-

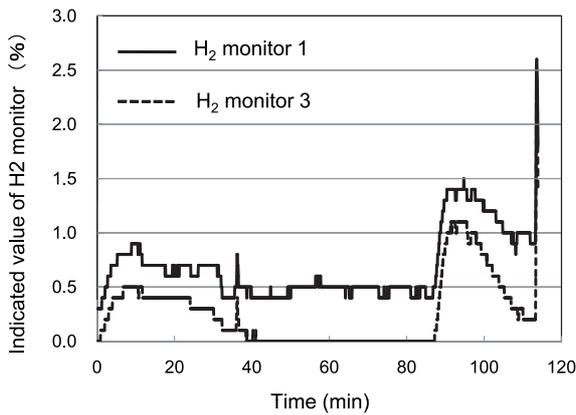


Fig. 6 Indicated values of H<sub>2</sub> monitors (Nos.1 & 3) under addition of He gas during NBI cryo-pump regenerative operation.

orated liquid nitrogen from cooling of the cryo-pumps of the Neutral Beam Injector (NBI) was being discharged into the vacuum pumping system. It was also confirmed that the measured values of the exhaust gas flow rate corresponded well with the amount of liquid nitrogen consumed.

### 3.2 During NBI cryo-pump regenerative operation

A detectable concentration of hydrogen was observed during NBI cryo-pump regenerative operation. Figure 6 shows the simultaneous measurement of the exhaust gas flow rate and hydrogen concentration under continuous helium gas addition at a fixed flow rate of 20 NL/min.

Here, the value measured by the hydrogen monitor with a combustible gas sensor corresponds only to the hydrogen concentration. During regenerative operation, several cryo-pumps are operated in order. Thus, the resulting changes in hydrogen concentration are related to the regenerative operation.

The value measured by the thermal conductivity sensor corresponds to the sum of the hydrogen and helium concentrations. Again, based on the difference between the values measured by the two types of hydrogen monitor, it is possible to determine the increase in helium gas concentration under continuous helium gas addition at a fixed flow rate.

By inputting the measured increase in helium gas concentration into Eq. (1), the time dependence of the exhaust gas flow rate can be estimated as shown in Fig. 7. By decreasing the amount of liquid nitrogen used for cooling the cryo-pumps during the regenerative operation, the exhaust gas flow rate could be gradually decreased from 250 Nm<sup>3</sup>/h to 100 Nm<sup>3</sup>/h.

An intermittent increase in exhaust gas flow rate is also observed corresponding with a sharp increase in hydrogen concentration.

The intermittent increase in exhaust gas flow rate at the time of about 95 minutes suggests that the hydrogen

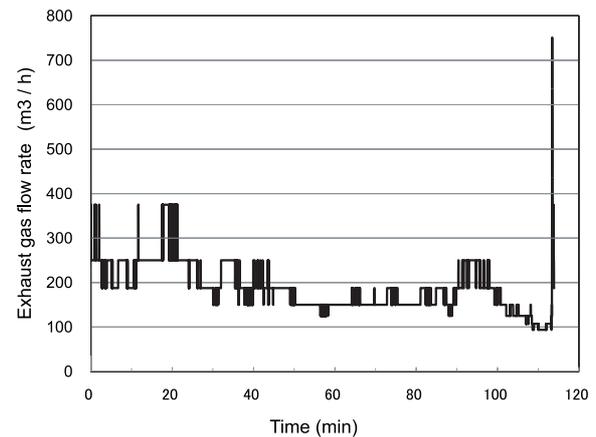


Fig. 7 Estimated exhaust gas flow rate during NBI cryo-pump regenerative operation.

discharge time is about 5 minutes and the discharge hydrogen gas flow rate is about 50 Nm<sup>3</sup>/h, giving a discharge volume of hydrogen gas of about 4 m<sup>3</sup>. The evaluated volume of hydrogen gas agrees fairly well with the average amount of hydrogen gas consumed during the NBI operation (regenerated NBI: 4units, gas consumption: 1.7 m<sup>3</sup> per unit NBI).

The sharp increase in exhaust gas flow rate at the time of about 110 minutes corresponds to the feed of dilution air for reducing the hydrogen concentration in the exhaust gas.

## 4. Remodeling Plan for Vacuum Pumping System

The following two issues were identified for improving the present exhaust system:

- (1) An exhaust gas line for evaporated liquid nitrogen not containing tritium should be installed independently in order to reduce the capacity of the tritium recovery system.
- (2) The exhaust gas line during the regular exhaust operation (small gas flow rate and high hydrogen concentration) and the exhaust gas line during maintenance (large gas flow rate and air as the main component) should be installed separately to allow individual tritium recovery systems having different treatment capacities.

As such, two exhaust lines have recently been scheduled to be installed in addition to the present exhaust line as shown in Fig. 8.

## 5. Operation Plan of Tritium Recovery System

For tritium recovery from the vacuum exhaust gas during plasma discharge, a system is planned to perform catalytic oxidation of the hydrogen gas containing a small amount of tritium, and removal of tritiated vapor by the MS

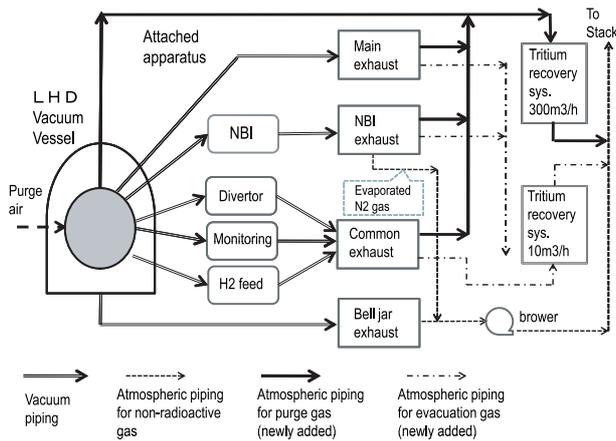


Fig. 8 Optimized plan of operation for vacuum pumping system of LHD.

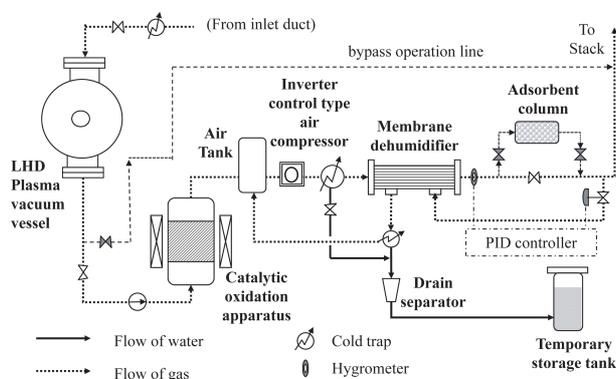


Fig. 9 Planned purge gas detritiation system for LHD.

adsorption column, with a treatment capacity of 10 Nm<sup>3</sup>/h.

On the other hand, for tritium recovery from the purge gas of the LHD vacuum vessel during maintenance, a system is planned that will perform catalytic oxidation and removal of tritiated vapor by a polymer membrane dehumidifier, with a treatment capacity of 300 Nm<sup>3</sup>/h [2–4] as shown in Fig. 9.

Application of a polymer membrane dehumidifier instead of a conventional MS adsorption column is expected to make the recovery system more compact and cost-effective.

For tritium recovery from the vacuum exhaust gas during the plasma discharge experiment, a system is planned to treat the exhaust gas during the cryo-pump regenerative operation in addition to the regular evacuation operation during the plasma discharge experiment.

For tritium recovery from the purging air of the LHD vacuum vessel, it is planned to treat the evacuated air in the vessel during start-up operation of LHD in addition to the purging air during maintenance of the vessel interior.

## 6. Conclusions

- 1) Simultaneous measurement of the flow rate and hydrogen concentration of exhaust gas from a LHD vacuum pumping system was conducted by combining hydrogen monitors based on a thermal conductivity sensor and a combustible gas sensor.
- 2) This method was shown to be effective in clarifying the desorption behavior of hydrogen during the reproduction operation of the cryo-pump of the NBI as well as in estimating the exhaust gas flow rate during normal evacuation operation.
- 3) The results of the present investigation have led to planned remodeling of the vacuum pumping system and an optimised plan of operation for tritium removal.

## Acknowledgement

This study has been supported in part by a Grant-in-Aid for Scientific Research on Priority Areas, 19055002, from MEXT.

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