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Deuterium inventory evaluation of long discharges in HT-7 superconducting tokamak

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Abstract

Long duration of HT-7 pulses provides the platform for the retention study by using particle balance method. Though it's difficult to give a quantitative result with a high accuracy, this method could be used to make the comparison by relative evaluation, omitting the system errors. It's found in this way that pumping speed has a negligible influence on retention level, while the disruption decreases retention level. The extracted particles are mainly pumped out after the plasma termination. The majority is dynamic inventory. This phenomenon is briefly discussed.

1 Introduction

Wall retention is a critical issue for ITER. It's important primarily because it could lead to safety problem when there should be accidental venting of the vacuum vessel, and secondly because it could influence the reaction efficiency and recycling. This issue has to be considered carefully when making decision, from the Plasma Facing Material selecting to the wall conditioning method exploring. Many laboratories use 'postmortem' method. Generally the Plasma Surface Interaction on the samples is not obvious enough, and the samples have to be exposed to plasma for a period before making analysis. Comparing with this method, particle balance method could provide relatively 'in time' information of the retention level. In some tokamak devices, retention is studies in this way[1, 2].

HT-7 started this study in 2004[3]. Commonly only deuterium is used on HT-7. Sometimes helium is used for a short period. Both D and He are used for wall conditioning during the experimental ran. No hydrogen is used since a few years before. There are 4 cryo-pumps and 4 TMP station for the HT-7 inner vacuum system. Recently 6 gauges are installed to monitor the inner chamber pressure. There is one QMS analyzer for the partial pressure measurement.

It's found that the system error of this evaluation method could be very big, which makes it not practical to study the related elements influencing retention. The system error is analyzed in the paper in detailed firstly. Then retention evaluation omitting the system error is proposed to compare different factors on retention level. After the discussion of the experiment results, conclusion is given at the end.

2 Error analysis of retention evaluation

Particle equation method uses the following equation set:

$$Q_{puff} = Q_{extract} + Q_{retention}$$

$$Q_{puff} = \Delta P_{tank} \cdot V_{tank}$$

$$Q_{extract} = \int P_{vv} \cdot Sdt$$

where, ΔP_{tank} and V_{tank} means the pressure change of a standard fueling tank for a discharge and volume of it, by which Q_{puff}, the input gas quantity, could be obtained; P_{vv} and S are respectively partial pressure of a specific gas in the vacuum vessel and the effective pumping speed of the pumping station for this gas, by which $Q_{extract}$, the output gas quantity, could be calculated. Then the retained value $Q_{retention}$ is simply the difference between Q_{puff} and $Q_{extract}$.

By analyzing the system error as following, it's shown that it's difficult to make the quantitative evaluation with a high accuracy. $Q_{puff}=\Delta P_{tank} \cdot V_{tank}$. For V_{tank}, error could be controlled lower than 3% by careful design and measure of the fueling tank (including the related Gas Injection System). For P_{tank}, error could be limited lower than <7% by choosing suitable gauge and Data Acquisition System. So, common error of Q_{puff} is at the level of 10%. $Q_{extract}$ has higher error primarily due to the P_{vv} error. After careful calibration with different pure gases, error of P_{vv} could be <15%. For S, pumping speed, which is obtained by measuring pumping quantity and pressure evolution, error could be suppressed within 20%. Consequently Error of $Q_{extract}$ could be limited lower than 35%. There are additionally potential error sources including pressure distribution (influence Pvv, S), gas type (influence P_{vv}) and response time (influence P_{vv}, S, P_{tank}). As a conclusion, quantitative evaluation of retention with particle balance method could only have an accuracy of 50% value after careful design of GIS and regular calibration of gauges on HT-7. And it's extremely difficult to suppress error low than 40% value, which requires a great deal of cost on equipment and time.

Take a 5 second discharge, shot 78467, as one example. Pressure change measured by a Inficon® CMR271 diaphragm gauge is 149 Pa in a 2.3 liter tank, so Q_{puff}=342 *Pal*. Three Turbo Molecular Pumps are used, and the pumping speed for deuterium, S_D, is 843 l/s. Quadrupole Mass Spectrum detected by a SRS® RGA200 shows the hydrogen deuterium ratio in the residual gas is 2/3. Considering the conversion factor for hydrogen of Inficon® PKR251 (ion gauge mode) is 2.4, $Q_{extract}$=110 *Pal*. The D retention ratio is 68%±16%. Such a big error bar almost covers the whole range of retention result calculated in HT-7.

However, by omitting the system error, the particle balance method could be used to make the comparison among the discharges relatively. Error of this relative evaluation could be from pressure distribution, gas type and response time. Pressure distribution depends on the practical pumping and puffing position. It's found that pressure in the vacuum vessel becomes uniform within 300ms when without plasma and at higher pressure (e.g. >1e-3Pa). Gas type or compounds is another error. From QMS measurement, it's illustrated that basically H isotopes occupy more than 95% of the residual gas. It's assumed that H_2, HD, D_2 have the same partial pressure sensitivity factor. Under these conditions, the error of retention evaluation is suppressed fewer than 20%. It's observed on HT-7 that measure objectives change value mainly for a few to a dozen of seconds for long plasma discharges. Therefore, the present system is capable of evaluation based on the above ideas.

Some experiments are carried out on D retention by using this relative evaluation method. From the comparison between 78466 and 78467 (successive shots, no difference except for the pumping speed), the effect on retention is not distinguishable. 79152 is a steady discharge with controlled termination, the D retention is as high as 89%. By deliberately generating disruption at the end of the discharge, the D retention level decreases gradually. The detailed analysis of D retention evolution is being conducted.

Table 1 D retention ratio of some discharges on HT-7

S.N.	S_D[l/s]	H_2/D_2	Retention	error
78466	369	2/3	68%	16%
78467	843	2/3	68%	16%
79152	843	1/2	89%	3%
79158	843	1/2	77%	5%
79164	843	1/2	62%	8%

3 Deuterium inventory in HT-7

All the gauges in the inner vacuum vessel show that pressure drops soon after the plasma is formed, keeps relatively steady in a very low value, and rises quickly to a very high value before decaying gradually. No position inside the chamber is observed to confine large amount of neutral particles during the discharge. The quantity of D confined in the plasma is so small that the majority of the puffed D must be absorbed on the wall. Because of the low particle exhaust ability of HT-7, almost more than 90% input is retained, part of which is released after the plasma termination. QMS shows that hydrogen in the released gas could be as high as 50% (even higher after boronization). It's also observed during the discharge that large amount of hydrogen enters plasma resulting in high H/(H+D) ratio. Even for helium fueled discharges, significant H outgassing is observed from QMS.

The source of the hydrogen is an open question so far. One source could be the boronization material, $C_2H_{12}B_{10}$[4]. Another source could be the water absorbed in the graphite tiles during the venting. Samples have been installed inside the vacuum chamber, and will be analyzed in the near future.

The porosity of graphite might explain the behaviour of D inventory. D is trapped after being puffed into the chamber. When without plasma, it desorbed relatively easier; while with plasma, it's trapped more firmly. The isotopic exchange leads to the release of H from the bores in graphite tiles. Effective pumping speed during the discharge is so low that no effect on retention could be observed. However, disruption could lead to enhanced temperature rise in some local areas, which helps to release the trapped particles. Further work on H inventory will be carried out for better understanding.

4 Conclusion

Error of particle balance method is analyzed. After careful design and calibration, error could be 50% for quantitative evaluation of D retention. For relative evaluation error could be suppressed fewer than 20%, providing a practical tool for retention study. Disruption favors lower retention. About 2/3 puffed D are retained relatively permanently. Among the released gas after plasma termination, H from the wall could be as high as 50%.

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