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Operation of cryostat vacuum vessel of HT-7 superconducting tokamak

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Abstract

The superconducting tokamak HT-7 has been in operation for over 10 years. The safe and reliable operation of its cryostat vacuum vessel, which contains the superconducting coils is essential for each experimental run since the superconducting toroidal field coils are contained inside the vessel. In this paper, the operation is reviewed with the emphasis on the analysis on anomalous pressure rises and the corresponding solutions. It is shown that under close monitoring and timely handling, the cryostat vacuum vessel could still satisfy the requirements of the experimental operation despite of the material aging. This provides guideline for vacuum operating of HT-7. The experiences should be valuable for other superconducting projects as well, including a whole superconducting tokamak under construction, EAST.

Keywords: Superconducting tokamak; Cryostat; Vacuum

1. Introduction

Generally the vacuum system for HT-7 tokamak is divided into two groups, the 'inner vacuum' group which concerns the vessel containing the plasma and the related pump stations, and the 'outer vacuum' group which refers to the cryostat vacuum vessel (CVV) and its pump stations. Their specifications are given in Tables 1 and 2, respectively. A safe and stable operation of this CVV is essential for the experimental runs because the superconducting toroidal field coil cryostat is contained in this vessel. The vacuum operation before plasma experiments is divided into three stages. In the first stage, the "inner vacuum" vessel is connected with the CVV, and a rough pumping station pumps two vessels from the atmosphere to about 10 Pa in 2–4 h. In the second stage, two vessels are pumped separately by two pumping groups. The CVV is kept at 10^{-2} Pa, and leak detecting and wall conditioning is carried out in the "inner vacuum" vessel. This stage lasts 5–7 days typically. In the third stage, the cryostat is cooled in 4–5 days, and further wall conditioning is carried out at the same time. At the end of this stage, the device is ready for plasma experiments.

During its over 10-year operation since 1994, focuses of vacuum operation have been put primarily

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Table 1
Specifications of the “inner vacuum” vessel

Volume (m^3)	4.5
Surface area (m^2)	82 (including tiles)
Temperature	$T_{wall} < 250\,°C$
Pumping speed (m^3/s)	1 (excluding cryopumps)
Ultimate pressure (Pa)	$<5 \times 10^{-5}$

Table 2
Specifications of the cryostat vacuum vessel

Volume (m^3)	5
Surface area and temperature	$18\,m^2$ (<250 °C), $36\,m^2$ (room temperature), $100\,m^2$ (about 80 K), $100\,m^2$ (about 5 K)
Pumping speed (m^3/s)	1.2
Ultimate pressure (Pa)	$<5 \times 10^{-2}$ (at room temperature), $<5 \times 10^{-4}$ (during cryogenic operation)

on those topics concerning the ‘inner vacuum vessel’ containing the plasma, such as achieving higher vacuum, conditioning the plasma facing surface, while the importance of the CVV operation has been overlooked. Due to the lengthened plasma duration and higher plasma parameters, there are higher requirements. However, after 10 years operation, aging effect of the materials starts to emerge. There are more and more chances that the CVV is not running in a steady state, and sometimes the experimental run has to be suspended. Therefore, this is time that the HT-7 CVV operation should be reviewed, both from the point of view of dealing with anomalous pressure rise of the CVV, and that of accumulating experiences for the superconducting devices in the future. In Section 3, the vacuum requirements on the CVV are analyzed. In Section 4, different situations of anomalous pressure rise in CVV are listed. The effect is evaluated and the mechanisms are analyzed. In Section 5, solutions are proposed and the summary is made.

2. Inner structure of the CVV

Fig. 1 gives the cross-section of HT-7. HT-7 CVV has an inner structure like an automobile tire. The inner tube (inner VV shell) is the vessel holding plasma, while the outer tube (CVV shell) is the vessel facing the atmosphere. In between there is cryostat. In the cryostat, continuous liquid helium is pressurized to

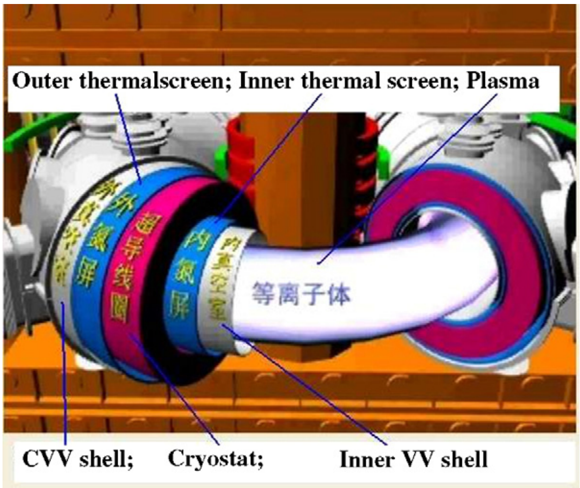

Fig. 1. Cross-section of HT-7.

flow through the copper tubes holding the superconducting coils. The utilized superconducting material, NbTi requires the coil temperature be lower than 9 K for superconductive operation. There are also ‘inner’ and ‘outer’ thermal screens for screening the radiation. The former is installed between the ‘inner VV shell’ and the cryostat, while the latter between the cryostat and the ‘CVV shell’. Flowing liquid nitrogen in the embedded tubes in both shields keeps the shields at a temperature around 80 K. Small epoxy resin blocks keep these five layers of different temperature from contacting each other for better heat isolation. High vacuum is kept in the CVV.

3. Vacuum requirements on the CVV

The primary task of the CVV operation is to keep the residual gases in the molecular state, in which the heat loading through the residual gases is minimized. The heat load power, Φ, in the molecular state is proportional to the partial pressure, as illustrated in the following equation:

$$\Phi = cPA\,\Delta T \quad (1)$$

where c is the coefficient, P the pressure, A the total area and ΔT is the temperature difference between the liquid nitrogen shield and the cryostat. When the pressure is at 10^{-4} Pa, the heat load is at the level of 1 W.