Quantitative Study of Sniffer Leak Rate and Pressure Drop Leak Rate of Liquid Nitrogen Panels of SST-1 Tokamak

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Abstract. Steady State Super-conducting (SST-1) Tokamak is in commissioning stage at Institute for Plasma Research. Vacuum chamber of SST-1 Tokamak consists of 1) Vacuum vessel, an ultra high vacuum (UHV) chamber, 2) Cryostat, a high vacuum (HV) chamber. Cryostat encloses the liquid helium cooled super-conducting magnets (TF and PF), which require the thermal radiation protection against room temperature. Liquid nitrogen (LN2) cooled panels are used to provide thermal shield around super-conducting magnets. During operation, LN2 panels will be under pressurized condition and its surrounding (cryostat) will be at high vacuum. Hence, LN2 panels must have very low leak rate. This paper describes an experiment to study the behaviour of the leaks in LN2 panels during sniffer test and pressure drop test using helium gas.

1. Introduction

SST-1 Tokamak [1] vacuum chamber comprises of the vacuum vessel and the cryostat. Vacuum vessel is an UHV chamber in which plasma will be initiated and confined. Cryostat is a HV chamber in which all super-conducting 16 Toroidal field (TF) coils, 9 Poloidal field (PF) coils, 164 LN2 panels of different shapes and sizes and Hydraulics will be enclosed. The super-conducting coils will be liquid helium cooled to 4.5 °K and will be protected against thermal radiation from hot surfaces using LN2 panels and high vacuum. The panels will be liquid nitrogen cooled and will be maintained at 80 °K during the vessel baking by passing liquid nitrogen at a rate of 1200 liters/hour through the cooling tubes brazed on the panels [2]. These panels are fabricated by brazing technique. The circular tubes (SS304L) of 14mm OD and 1 mm thickness are flattened by cold hydraulic method to elliptical shape (17mm ×10 mm) for better contact with SS sheet. These elliptical shape tubes were bent to proper shapes and then silver brazed on 2 mm thick SS 304 sheet to form the panels.

LN2 panels after fabrication are mounted outside the vacuum vessel and inside the cryostat of SST1 Tokamak as shown in Figure 1 and Figure 2. Inside of panels will be at high pressure while outside of panels will be at high vacuum, which makes it must to have very low leak rate, an acceptable local leak rate of ≤ 1 × 10⁻⁶ mbar l/s at 2.0 bar (g) internal pressure in sniffer method [3]. All these panels are individually thermal shocked and tested for leaks before installation. Since these panels are inaccessible after mounting, there is a need of some means of testing which will give rough estimation about in-situ helium leak rate. For this purpose, an experiment is set for pressure drop test and then a co-relation between sniffer leak rate and pressure drop leak rate is stabilised.
2. Experimental set-up

To carry out this experiment, four top cryostat LN$_2$ panels are considered, out of which three panels have single leak of different orders while fourth one has negligible leak. One end of these panels is welded to a 25 KF coupler for pressurization while the other end is welded to $\frac{1}{4}''$ male thread piece for transducer as shown in the figure 3. Druck transducer, an absolute pressure transducer with accuracy of ±3% of full-scale value (0 – 6 bar (a)) \cite{4} is used to measure the internal pressure of the panels. Analog output of Druck transducer is recorded through a Yokogawa X-Y recorder \cite{5} continuously. For Sniffer leak testing, a mass spectrometer based helium leak detector \cite{6} is used.
3. Experimental Procedure and Results

LN₂ panels are pressurized with helium gas up to ≅ 4 bar (a) pressure for sniffer leak testing. Sniffer leak testing is carried out for these setup thoroughly to ensure no other leaks except desired one. The detected leaks (L_m) in these three top cryostat LN₂ panels are 2.5 × 10⁻⁵, 2.6 × 10⁻⁴ and 3.0 × 10⁻⁶ mbar l/s respectively.

After completion of sniffer test, Druck pressure transducer is connected to the one end of the panel using 1/4” male thread piece. Analog output of the transducer is connected to the Yokogawa X-Y recorder and the pressure drop is recorded continuously in the form of numerical values. Then the panel is connected to a helium gas cylinder through 25 KF valve at other end. By opening 25 KF valve, the panel is pressurized slightly above 4 bar (a). After pressurization, 25KF valve is closed to remove the helium gas supply. Then the free end of 25 KF valve is closed with blank flange and the valve is opened to stabilize the pressure. After the completion of set-up, all the demountable joints are once again sniffer tested for the leak tightness ≤ 5 × 10⁻⁷ mbar l/s.

The panel is kept in a closed air-conditioned room to avoid any effect on the volume of the pressurized panel and drift in the electronic circuits due to change in temperature. The pressure drops are recorded with time for each panel and are shown in the figure 4 and figure 5. The leak rate L_c for this method is given by

\[ L_c = \frac{P_2 - P_1}{t_2 - t_1} V \text{ mbar l/s} \]

Where, P₁, P₂ are the initial and final pressures (mbar), t₁, t₂ are the initial and final times (second), and V is the enclosed volume under test (liter).
The net volume of each panel configuration includes the volumes of panel tubes, extended pipes and 25 KF valve. The volumes are

1\(^{st}\) panel with leak of \(2.50 \times 10^{-5}\) mbar l/s: 1.45 liter.
2\(^{nd}\) panel with leak of \(2.60 \times 10^{-4}\) mbar l/s: 1.37 liter.

Above equation implies that if the slop for figure 4 and figure 5 are known then the leaks can be evaluated by multiplying with the volume of each panel. A liner curve fitting for these graphs are having 99 % of accuracy. The slop for figure 4 is 0.525 while that for figure 5 is 4.878. The leak rates calculated for these panels are

\[ \dot{L}_{e1} = 2.11 \times 10^{-4} \text{ mbar l/s} \]
\[ \dot{L}_{e2} = 1.86 \times 10^{-3} \text{ mbar l/s} \]

The ratios for these calculated leak rates with the measured values are 8.46 and 7.14 respectively.

Figure 4. Linear fit for the pressure drop curve of \(2.5 \times 10^{-5}\) leak.
The pressure drops with time for the panels with the measured leak rate of \(3.0 \times 10^{-6}\) mbar l/s and negligible leak are given in the table 1. The pressure drops for these two panels have shown fluctuation within the accuracy limits of the pressure transducer.

3.1. Table-1

Table 1. Pressure drop for the panels having – 6 order leak and negligible leak.

| Date    | Time     | 3.0 \times 10^{-6} Leak | 3.0 \times 10^{-6} Negligible | 3.0 \times 10^{-6} Leak | 3.0 \times 10^{-6} Negligible |
|---------|----------|--------------------------|--------------------------------|--------------------------|--------------------------------|
| panel   | panel    | Date | Time     | Date | Time     | Date | Time     | Date | Time     |
| mbar    | mbar     | mbar | mbar     | mbar | mbar     | mbar | mbar     | mbar | mbar     |
| 14/5/07 | 15:10    | 4079 | 4046     | 25/5/07| 14:21    | 4052 | 4032     | 14/5/07| 15:10    |
| 15/5/07 | 14:20    | 4061 | 4028     | 26/5/07| 14:20    | 4042 | 4020     | 15/5/07| 14:20    |
| 16/5/07 | 14:20    | 4051 | 4018     | 27/5/07| 14:20    | 4040 | 4020     | 16/5/07| 14:20    |
| 17/5/07 | 14:15    | 4044 | 4012     | 28/5/07| 14:20    | 4039 | 4020     | 17/5/07| 14:15    |
| 18/5/07 | 14:08    | 4053 | 4028     | 29/5/07| 14:20    | 4037 | 4017     | 18/5/07| 14:08    |
| 19/5/07 | 14:20    | 4059 | 4036     | 31/5/07| 15:15    | 4035 | 4015     | 19/5/07| 14:20    |
| 20/5/07 | 14:20    | 4059 | 4032     | 1/6/07 | 14:20    | 4033 | 4015     | 20/5/07| 14:20    |
| 21/5/07 | 14:20    | 4062 | 4041     | 2/6/07 | 14:20    | 4035 | 4018     | 21/5/07| 14:20    |
| 22/5/07 | 14:18    | 4058 | 4035     | 3/6/07 | 14:20    | 4037 | 4022     | 22/5/07| 14:18    |
| 23/5/07 | 14:22    | 4054 | 4031     | 4/6/07 | 14:20    | 4030 | 4012     | 23/5/07| 14:22    |
| 24/5/07 | 14:21    | 4053 | 4030     | 5/6/07 | 14:15    | 4030 | 4015     | 24/5/07| 14:21    |

Figure 5. Linear fit for the pressure drop curve of 2.6 × 10^{-4} leak.
4. Conclusion

From the above results, it is observed that the leak rate estimated from the pressure drop test is always more than the measured value from sniffer method. Average ratio of these test values is approximately 7 to 8 times for the panels of – 4 to – 5 order leaks. For the leaks in the – 6 order range and below, it is very difficult to get the ratio as the pressure drop measurements are within the error limits.

This higher factor is likely due to the following reasons (1) most of the leaks are developed in the panels in the brazed portion of the pipe which are not fully accessible for sniffer test (2) Because of the configuration of brazing, the detected location of the leak may be away from the actual one leading to the lower measured value.

5. References

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