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Vacuum system of SST-1 Tokamak

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HIGHLIGHTS

- Air leaks developed during ongoing SST-1 cooldown campaign were detected online using RGA.
- The presence of N_2 and O_2 gases with the ratio of their partial pressures with ∼3.81:1 confirmed the air leaks.
- Baking of SST-1 was done efficiently by flowing hot N_2 gas in C-channels welded on inner surfaces without any problem.
- In-house fabricated demountable bull nose couplers were demonstrated for high temperature and pressure applications.
- Cryopumping effect was observed when liquid helium cooled superconducting magnets reached below 63 K.

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ABSTRACT

Vacuum chambers of Steady State Superconducting (SST-1) Tokamak comprises of the vacuum vessel and the cryostat. The plasma will be confined inside the vacuum vessel while the cryostat houses the superconducting magnet systems (TF and PF coils), LN_2 cooled thermal shields and hydraulics for these circuits. The vacuum vessel is an ultra-high (UHV) vacuum chamber while the cryostat is a high-vacuum (HV) chamber. In order to achieve UHV inside the vacuum vessel, it would be baked at 150 °C for longer duration. For this purpose, U-shaped baking channels are welded inside the vacuum vessel. The baking will be carried out by flowing hot nitrogen gas through these channels at 250 °C at 4.5 bar gauge pressure. During plasma operation, the pressure inside the vacuum vessel will be raised between 1.0×10^{-4} mbar and 1.0×10^{-5} mbar using piezoelectric valves and control system. An ultimate pressure of 4.78×10^{-6} mbar is achieved inside the vacuum vessel after 100 h of pumping. The limitation is due to the development of few leaks of the order of 10^{-5} mbar l/s at the critical locations of the vacuum vessel during baking which was confirmed with the presence of nitrogen gas and oxygen gas with the ratio of ∼3.81:1 indicating air leak. Similarly an ultimate vacuum of 2.24×10^{-5} mbar is achieved inside the cryostat. Baking of the vacuum vessel up to 110 °C with ±10 °C deviation was achieved with a net mass flow rate of 0.8 kg/s at 1.5 bar gauge inlet pressure and supply temperature of 230 °C at the heater end. Also during gas feed system installation, the pressure inside the VV was raised from 3.01×10^{-5} mbar to 1.72×10^{-4} mbar by triggering a pulse of lower amplitude of 25 voltage direct current (VDC) for 100 s to piezoelectric valve. This paper describes in detail the design and implementation of the various vacuum subsystems including relevant experimental results.

1. Introduction

Refurbishment of steady state superconducting (SST-1) tokamak [1] has been completed as shown in Fig. 1 and at present the machine is under commissioning phase since June 2012 [2]. During the 1st phase of campaign, ∼100 kA limiter assisted circular plasma with superconducting toroidal field (TF) magnets and poloidal field (PF) magnets would be realized. SST-1 Tokamak is designed with a major radius of 1.1 m and a minor radius of 0.2 m along with toroidal field of 3.0 T at the plasma center and a plasma current of 220 kA. Hydrogen gas will be used for plasma discharge for the longer duration up to 1000 s.

Vacuum chamber of SST-1 is divided into two parts such as vacuum vessel (VV) and cryostat (CST). The vacuum vessel is used for plasma confinement while the cryostat is used to provide the operational environment for superconducting TF & PF coils. SST-1 vacuum vessel is all welded continuous torus structure fabricated using SS 304L material having sixteen (16) numbers of rectangular radial ports (RP) and thirty-two (32) numbers triangular verticals ports (VP). Two (02) numbers of limiter systems are installed at diagonally opposite radial ports of SST-1 machine. In order to

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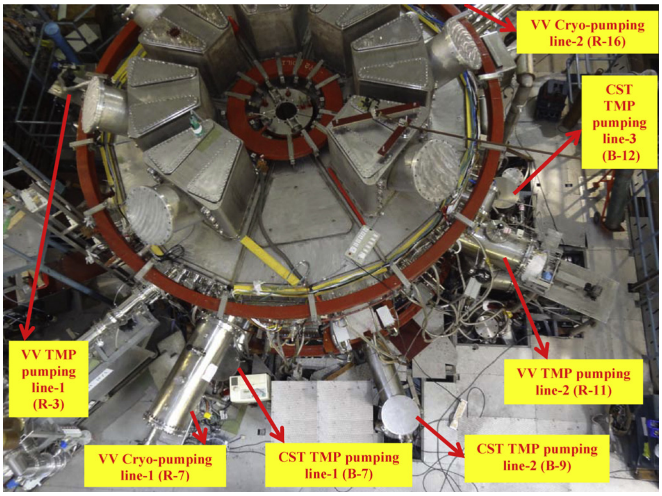

Fig. 1. Snap-shot of SST-1 Tokamak after complete assembly along with pumping lines.

achieve desired ultra-high vacuum inside the chamber, the vacuum vessel is baked at 150 °C for longer duration. Further during cool down phase and plasma operations, the vacuum chamber is maintained at 50 °C under evacuated condition to avoid the cool down of vacuum vessel toward low temperature due to radiation losses to cold masses. For baking purpose, rectangular channels (16 mm × 8 mm) of 2 mm thickness are welded on the inner surfaces of the vacuum vessel as per finite element analysis [3].

Cryostat of SST-1 is a polygon structure fabricated using SS 304L material. It encloses D-shaped TF magnets (16 numbers), PF magnets (09 numbers) [4], 80 K bubble type liquid nitrogen (LN_2) radiation shields (167 numbers), their respective supply and return headers and glass-reinforced epoxy (G-10) insulating sheets used all around the magnets. All these superconducting coils are cooled up to 4.5 K using super-critical helium at 4.0 bar absolute and are protected from heat radiation coming from room temperature cryostat surfaces and vacuum vessel surfaces maintained at 50 °C during normal operation scenario and at 150 °C during baking by using 80 K bubble type radiation shields around them. TF magnets are mechanically attached with each other through outer-inter-coil-structures (OICS) and large numbers of M-20 bolts in order to protect them from out-of-plane electromagnetic forces experienced during the charging. The operation of vacuum system is divided into three modes such as (1) pump down of the vacuum vessel and cryostat and their leak detection, (2) baking of the vacuum vessel and limiters at 150 °C and marinating at room temperature (RT) and (3) gas puffing for circular plasma operation, Boronization and Glow discharge. These aspects are discussed in subsequent sections.

2. Pumping system and leak detection

The roughing of vacuum vessel from atmosphere down to 1.0×10^{-3} mbar is carried out using a single root pumping station of 1800 m^3/h while the cryostat is pumped down to this desired value using two numbers of such pumping stations connected in parallel. Electro-pneumatic valves with proper isolation are used between these pumping stations and the vacuum chambers in order to provide protection against eddy current during plasma disturbance and also for transition from low vacuum to high vacuum operation. The pumping systems of VV and CST are designed such that turbomolecular pumps (TMPs) are situated at a place where the transverse magnetic field is less than 30 gauss.

Vacuum vessel has two TMP pumping systems with net pumping speed of 4675 l/s (N_2 gas) mounted at the diagonally opposite radial ports (R-3 & R-11), each having an electro-pneumatic gate valve. A residual gas analyzer (RGA) and some vacuum gauges are mounted at end of one of the pumping lines. RGA is used to measure the partial pressures of different gases as well as the leak tightness of the vacuum vessel. An ultimate pressure of 4.78×10^{-6} mbar is achieved inside VV after 100 h of pumping. The limitation is due to the development of few leaks of the order of 10^{-5} mbar l/s at the critical locations of VV during baking which could not be rectified during the on-going cool down campaign. The partial pressures of the gases present inside VV are shown in Fig. 2. The presence of N_2 gas and O_2 gas with the ratio of ~3.81:1 indicates the presence of air leak. Also, the presence and dominance of water vapour inside VV is observed which is because of first time commissioning of the vacuum vessel.

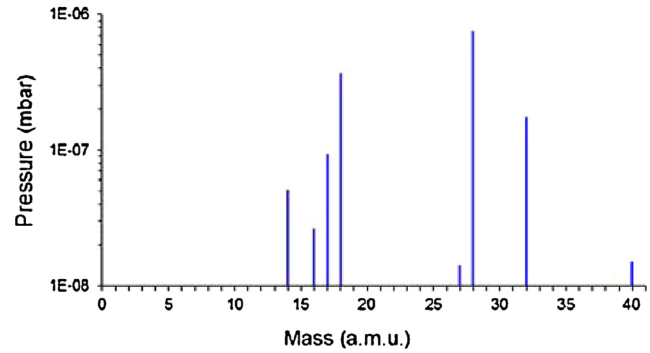

Fig. 2. Partial pressure in the vacuum vessel before baking.

In cryostat, three (03) numbers of TMP pumping systems are mounted at the bottom cryostat manhole openings (B-7, B-9 and B-12) with net pumping speed of 3250 l/s (N_2 gas) in similar configuration to VV pumping system. One of the TMP pumping lines of CST is equipped with RGA and helium leak detector in order to monitor online leak tightness of helium and nitrogen systems during the cool down campaign. Helium leak testing of CST was carried out by pressuring it to 1.1 bar absolute using a mixture gas (90% N_2 gas + 10% He gas) and the leak tightness of all weld joints as well as the de-mountable joints were ensured below 1.0×10^{-6} mbar l/s in sniffer method. As soon as the base pressure inside the cryostat was reached to 2.54×10^{-4} mbar, the cool down campaign for the magnet and thermal shields was started. During cool down, the cryo-pumping effect due to LN_2 thermal shields attaining the temperature of ~80 K was observed where the water vapour gets condensed. The ultimate vacuum achieved inside the cryostat is 2.24×10^{-5} mbar as shown in Fig. 3.

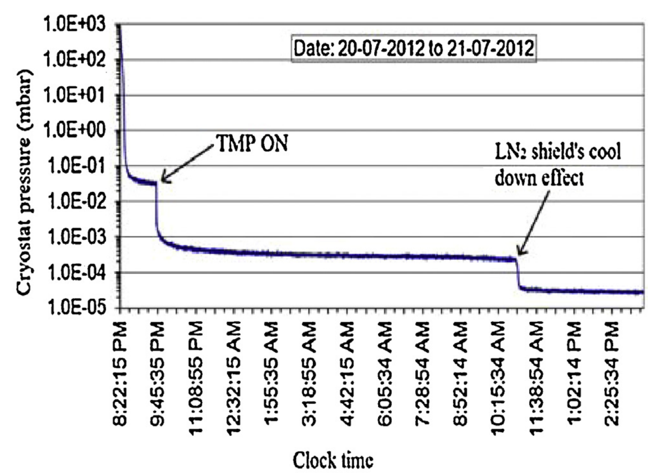

Fig. 3. SST-1 cryostat vacuum during cool down.