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# Conditioning of SST-1 Tokamak Vacuum Vessel by Baking and Glow Discharge Cleaning

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## HIGHLIGHTS

- SST-1 Tokamak was successfully commissioned.
- Vacuum vessel was pumped down to $4.5 \times 10^{-8}$ mbar after baking and continuous GDC.
- GDC reduced the water vapour by additional 57% while oxygen was reduced by 50%.
- Under this condition, an initial plasma breakdown with current of 40 kA for 75 ms was achieved.

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## ABSTRACT

Steady-state Superconducting Tokamak (SST-1) vacuum vessel (VV) adopts moderate baking at $110 \pm 10\,^{\circ}$C and the limiters baking at $250 \pm 10\,^{\circ}$C for ~ 200 h followed by glow discharge cleaning in hydrogen (GDC-H) with 0.15 A/m$^2$ current density towards its conditioning prior to plasma discharge experiment. The baking in SST-1 reduces the water ($H_2O$) vapor by 95% and oxygen ($O_2$) by 60% whereas the GDC reduces the water vapor by an additional 57% and oxygen by another 50% as measured with residual gas analyzer. The minimum breakdown voltage for H-GDC in SST-1 tokamak was experimentally observed to 300 V at 8 mbar cm. As a result of these adherences, SST-1 VV achieves an ultimate of $4.5 \times 10^{-8}$ mbar with two turbo-molecular pumps with effective pumping speed of 3250 l/s. In the last campaign, SST-1 has achieved successful plasma breakdown, impurity burn through and a plasma current of ~ 40 kA for 75 ms.



## 1. Introduction

Vacuum systems of tokamak devices are fabricated from stainless steel (SS) and are designed to provide ultra-high vacuum (UHV) to meet operational requirements for the plasma discharge experiments. Unconditioned in-vessel surfaces and components release various gaseous species which can prevent stable plasma operation and a wall pumping is not favored because of release of impurities at later stage. Even after treatment of the SS surfaces with mechanical polishing, chemical cleaning, thermal cleaning and other UHV techniques they may contain few nanometers of carbon (C) and oxygen (O) and their compounds [1] which are the main sources of Low-Z impurities which are released during plasma discharge through chemical sputtering. In order to minimize the influence of impurities on the plasma performance, it is well known that the inner walls of the plasma chamber should be well conditioned using different wall conditioning techniques [2,3]. Wall conditioning techniques used in fusion devices are (1) baking of vacuum vessel inner walls and in-vessel components, (2) glow-discharge cleaning (GDC) and (3) low-Z thin film deposition on the inner-vessel surfaces. Vessel baking is a key tool in order to degas water vapor while GDC is aimed at the removal of the impurity sources containing oxide, carbide and other impurities. GDC is based on the principle of ion bombardment induced desorption and is a very effective method to decontaminate the carbon-free surfaces of the plasma device which have been exposed to air after a prolonged operation in hydrogen. It is a very simple process which does not require any magnetic field as compared to Taylor Discharge Cleaning (TDC) [4], Alternating current glow discharge Cleaning (AC) [5], Electron Cyclotron Resonance-Discharge

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Cleaning (ECR-DC) [6,7] and Ion Cyclotron Range Frequency (ICRF) clearing [8,9].

Every time machine is opened and exposed to atmosphere for prolonged period, pure $H_2$ glow discharge (H-GDC) is recommended to remove oxygen impurity, its oxides, carbon impurities and its oxides and oil hydrocarbon impurities absorbed in the wall [10]. In addition, inert gas sputter cleaning [11] and oxygen discharge cleaning [12] to remove surface carbon impurities may also be employed without enhancing subsequent impurity problems. Plasma discharges in hydrogen are well adapted to the wall conditioning when the electron density and temperature are low. Gaseous molecules containing the impurity atoms are formed and evacuated without being appreciably dissociated, ionized and redeposited onto the wall. Also during GDC, the generation of the impurities with time depends on the various parameters like vessel gas pressure, wall temperature, discharge current and voltage, pumping speed and compression ratio etc. The study of the glow discharge plasma parameters and their dependence on the residual gas composition is essential to understand the plasma surface interactions during the wall conditioning. This paper describes the evolution of impurities with temperature during vacuum vessel baking in section-II. Section-III describes the GDC system along with its design parameters. Section-IV experimentally demonstrates the breakdown voltage, volt-ampere characteristic, safe operation range and suitable cleaning patterns of Steady-state Superconducting (SST-1) tokamak.

## 2. Impurities evolution during baking

SST-1 main VV [13,14] is as a D-shaped continuous torus structure made up off non-magnetic SS 304 L materials for double-null divertor plasma operation. It has sixteen numbers of radial ports and thirty-two numbers of vertical ports. The thickness of the vacuum vessel is 10 mm while that of the ports is 6 mm. After commissioning and validation of different sub-systems of SST-1 tokamak (Fig. 1), the initial plasma breakdown up to 100 kA limiter assisted circular plasma for more than 100 ms using hydrogen gas was envisaged. Plasma position is controlled with graphite based limiters (two inboard and two outboard) mounted at diagonally opposite places. SST-1 vacuum vessel has 2.56 m height, 1.45 m width with 4.4 m poloidal length. All the plasma facing components have not yet been installed. Since SST-1 VV is not furnished with plasma facing components (PFCs) at present, the inner surface area of vacuum vessel is 75 $m^2$ while that with both main pumping lines (two nos.) and divertor pumping lines (sixteen nos.) is 215 $m^2$. The total graphite surface area of the installed limiters is 0.75 $m^2$.

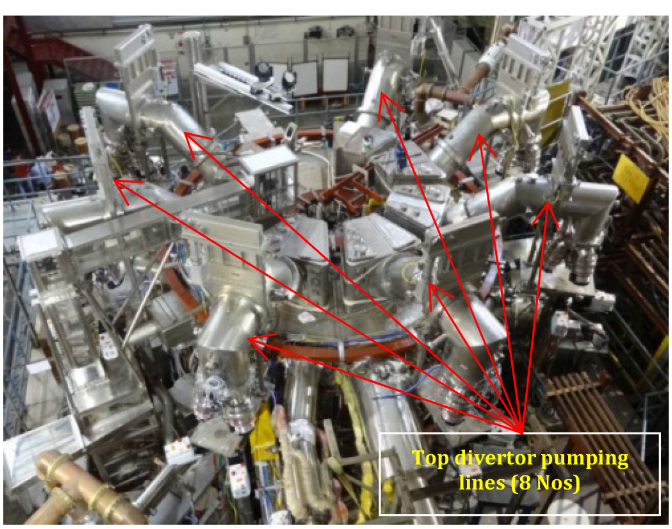


**Fig. 1.** Snap-shot of SST-1 tokamak with divertor pumping lines.

Since SST-1 tokamak is a superconducting device, all toroidal & poloidal field coils and associated 5 K & 80 K cold masses were cooled during the start of the operation of SST-1 superconducting tokamak. In order to avoid excessive cooling of the vacuum vessel by radiation losses from the cold masses, hot nitrogen gas was flown through U-channels welded on the inner surfaces of VV using nitrogen gas heating and supply system [15], allowing VV to be maintained either at room temperature (RT) or baked to higher temperatures. The limiters were baked to higher temperature using conventional method. Roughing and purging of SST-1 VV was carried out for several times using pure and dry nitrogen gas to reduce the moisture effects. After repeating this procedure, VV was finally pumped using turbo-molecular pumps [16] mounted at the radial ports R-3 and R-11. After a week of pumping under leak rate below $1.0 \times 10^{-8}$ mbar l/s at RT, a base pressure of $5.37 \times 10^{-6}$ mbar was achieved. Under this condition, VV was baked to $110 \pm 10\,^{\circ}$C followed with baking of limiters to $250 \pm 10\,^{\circ}$C for several days. All the pumping ducts and their lines were baked using heating tapes and pad up to the same temperature simultaneously. Due to baking, the base pressure got deteriorated initially and then improved with time and reached to the ultimate of $3.85 \times 10^{-7}$ mbar. During this entire operation, different impurities were released from VV inner surfaces and limiters which were monitored using residual gas analyzer installed in one of the main pumping line (R-3) near the TMP. The total pressure and the partial pressures of impurities released with baking temperature are represented in Table 1.

With baking, the partial pressure of water vapour was reduced by 95% of its initial value while that of oxygen was reduced by 60% of its initial value. During the campaign, such baking activities were carried out for few several times.

## 3. Design of glow discharge

The schematic of the DC glow discharge (GDC) system of SST-1 tokamak is shown in Fig. 2. It is used for additional cleaning of VV inner walls and in-vessel diagnostic components of SST-1 tokamak in addition to baking. The two GDC anodes are fabricated from electro-polished 304 L stainless steel of 175 mm × 125 mm × 20 mm size. They are mounted at the diagonally opposite radial ports R-7 & R-16. Both the anodes are mounted on the curved surfaces of the inter-connecting ring of D-shaped VV. Each anode is insulated from the vacuum vessel with two numbers of $Al_2O_3$ ceramic rods (Fig. 3) and these insulated electrodes are 100 mm away from the vessel wall.

The inner wall of the tokamak acted as the glow discharge cathode in the circuit. Each of the GDC electrodes was powered by an independent power supply with varying voltage from 0 to 1000 VDC and adjustable current from 0 to 15 A. The insulated anode was connected to the power supply through coaxial feed-through and insulated cable. Thus GDC anode, operating gas and VV wall will form the complete circuit. The experimental database of the various tokamak devices suggests that glow current densities at the walls

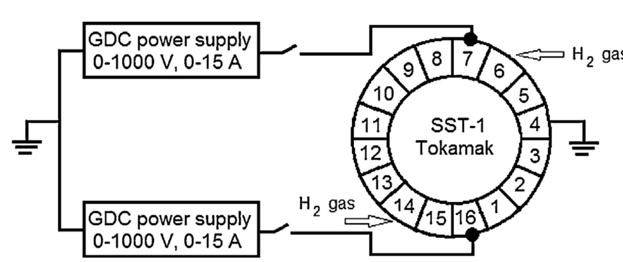


**Fig. 2.** GDC system installed at radial ports (R-7 & R-16) of SST-1.