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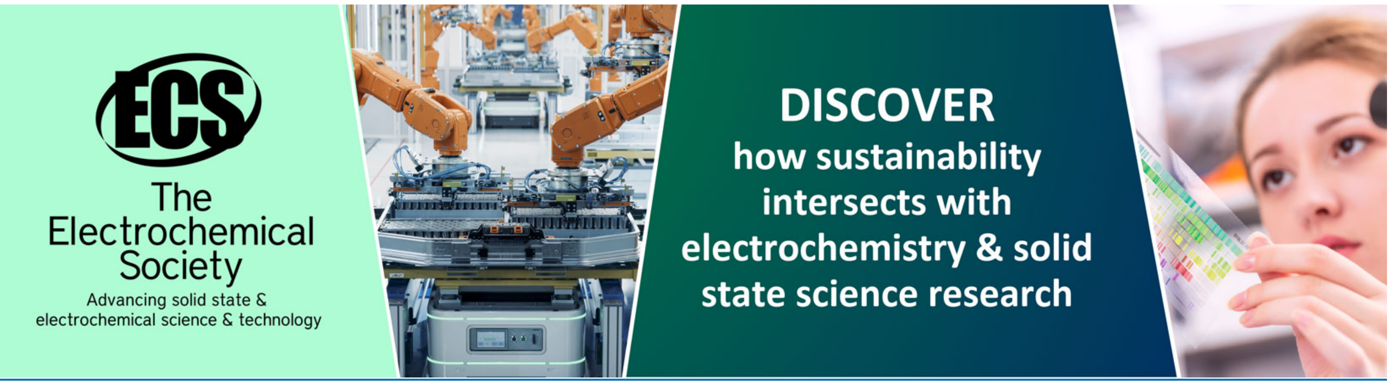

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Baking of SST-1 vacuum vessel modules and sectors

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Abstract. SST-1 Tokamak is a steady state super-conducting tokamak for plasma discharge of 1000 sec duration. The plasma discharge of such long time duration can be obtained by reducing the impurities level, which will be possible only when SST-1 vacuum chamber is pumped to ultra high vacuum. In order to achieve UHV inside the chamber, the baking of complete vacuum chamber has to be carried out during pumping. For this purpose the C-channels are welded inside the vacuum vessel. During baking of vacuum vessel, these welded channels should be helium leak tight. Further, these U-channels will be in accessible under operational condition of SST-1. So, it will not possible to repair if any leak is developed during experiment. To avoid such circumstances, a dedicated high vacuum chamber is used for baking of the individual vacuum modules and sectors before assembly so that any fault during welding of the channels will be obtained and repaired. This paper represents the baking of vacuum vessel modules and sectors and their temperature distribution along the entire surface before assembly.

1. Introduction

SST-1 vacuum vessel [1, 3] is fabricated as a continuous torus structure using non-magnetic SS 304L material. For easy fabrication and assembly point of view, SST-1 is divided into sixteen (16) parts out of which eight (08) of them are vessel sectors (VS) while other eight are vessel modules (VM). Vessel Sector (VS) is comprised of one number of radial port (RP), two numbers of vertical ports (top and bottom each) and one number of vessel sector ring whereas vessel module (VM) is made up of one number of VS and two numbers of inter connecting rings (ICR) on both sides. The thickness of vacuum vessel is 10 mm while that of the ports is 6 mm. Figure 1 shows the schematic of VS and VM.

Since an ultra-high vacuum (UHV) is the basic requirement for plasma discharge inside any tokamak, the baking facility to bake the main vacuum vessel has to be developed. Baking effectively reduces the net gas load due to out-gassing of the materials. Also it reduces the surface impurities like water vapor, heavy hydrocarbons and other gases get absorbed / adsorbed into the bulk of parent materials during fabrication and commissioning. These high-Z impurities, if present, will lead to plasma contamination during the plasma discharge. Further during the cool down of cryostat components like toroidal filed (TF) coils and 80 K thermal shields, there is a probability of the vacuum vessel attending low temperature due to conduction and radiation leading to water condensation. In order to avoid this condition, the vacuum vessel has to be kept at elevated temperature during cryostat components cool down.

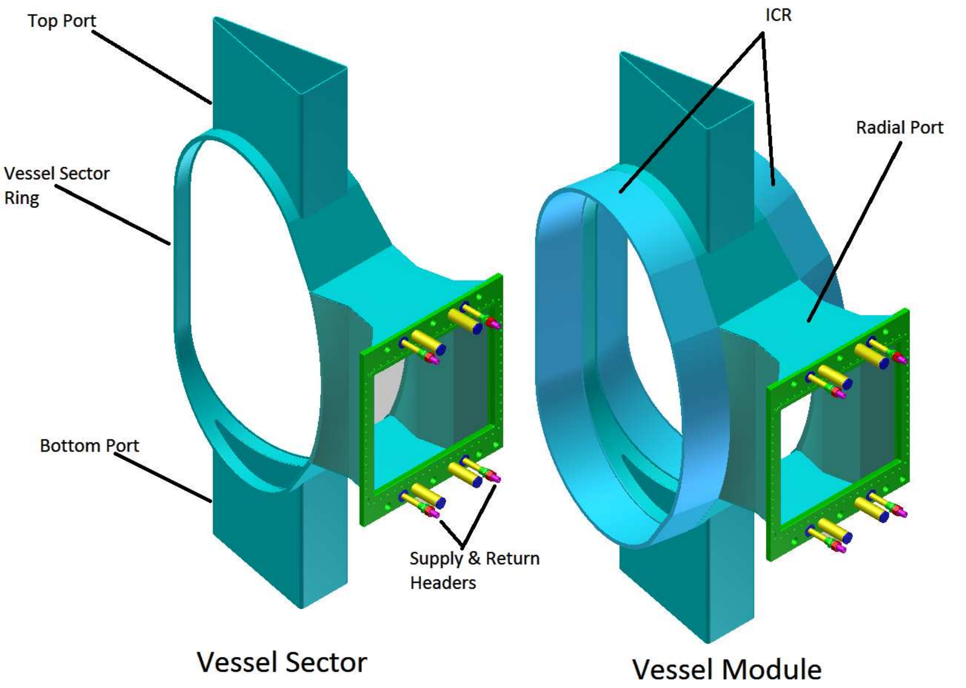

Figure 1. Schematics of SST-1 vessel sector (VS) and vessel module (VM).

2. SST-1 VS and VM baking

For steady state baking of vacuum vessel at 150 °C during bake out and to maintain the vacuum vessel at 50 °C during cool-down phase, U-shaped SS 304L channels of 2 mm thickness have been welded on the inner surfaces of the vessel wall. Figure 2 shows the baking paths of each vacuum vessel indicating the different numbers of bends, the details of which is given in the table 1. The internal baking layout as shown in the figure 2 is preferred due to constrains like space availability and the mounting of thermal shields over the outer surface of the vacuum vessel to protect superconducting TF coils from radiation. For such baking option, the gases like Oxygen, Nitrogen, Air or water can be used as a heating medium. Nitrogen gas [4] is preferred due to the following advantages over other gases like

- Non-corrosive and non-toxic nature.
- Non-combustible and non-supporting of combustion.
- Does not combine with other gases under normal conditions.

Table 1. Different bends of each vessel sector baking layout.

Paths	No of bends			
	Meter	90°	Interconnecting	Closed loop
Radial port	8	12	0	0
Top vertical port	19	7	0	0
Bottom port	19	8	0	0
ICR	2	0	2	2

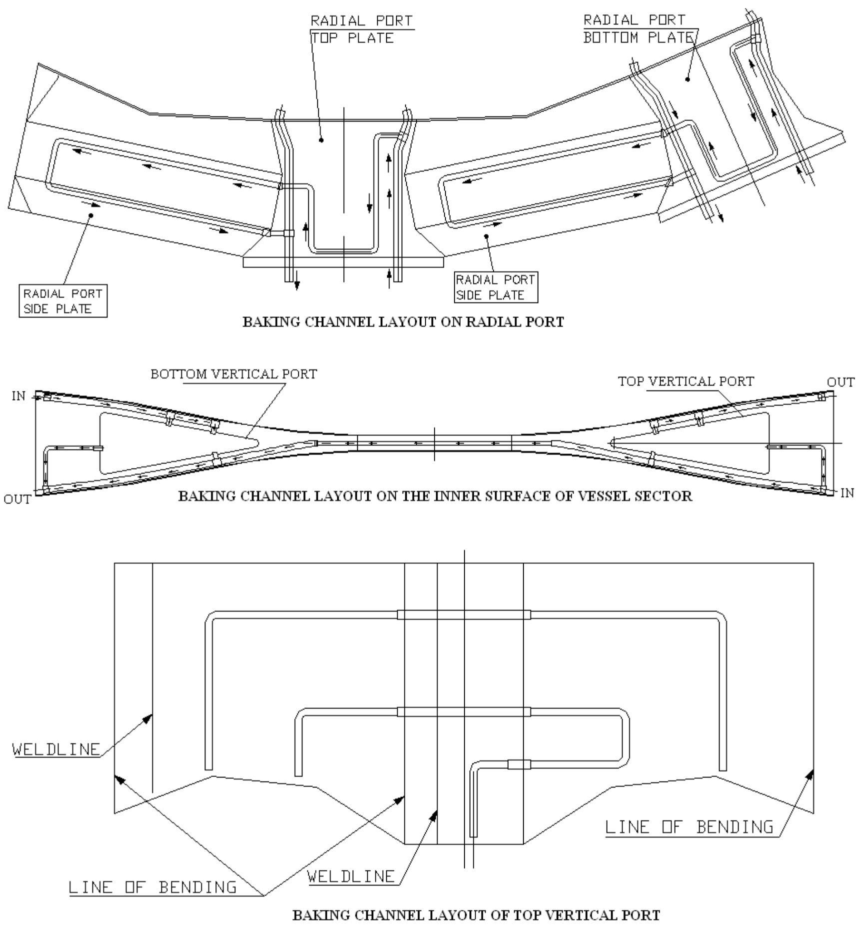

Figure 2. Baking lay-out of SST-1 vacuum vessel.

For the baking purposes, all sixteen-vessel sectors will be connected in parallel with the main header of hot nitrogen gas heating and supply system. Supply and return main headers are of four inch size while sub-headers are one inch size. All these supply and return lines are thermally insulated using perlite material to reduce the radiation heat loss. Each vessel sector / module has two numbers of diagonally opposite supply and return lines provided on radial port as shown in figure 1. Metal braided flexible stainless steel hoses along with indigenously developed demountable type bull nose coupler are used to connect this header to SST-1 tokamak.

This hot nitrogen gas heating and supply system comprises of series connected positive displacement blowers to boost the inlet gas pressure to required value. It has 150 kW capacity shell and tube type heater to heat this pressurized nitrogen gas. Schematic layout of the same is shown in figure 3. Nitrogen cylinders are connected in parallel to the cylinder manifold which contains pressure regulator, control valve and non-return valves. Dry nitrogen gas are fed to the suction chamber of higher capacity up to a pressure of 3.5 bar (a) through this manifold. During operation if the suction chamber pressure reduces below a set point, a low-pressure switch mounted on suction chamber will open the manifold inlet valve to compensate the pressure drop. A safety valve is also provided with the suction chamber to avoid any pressure rise above the set point. All the above functions are controlled via the control panel and PLC based system. Control panel consists of volt meter, ammeter, flow indicator and controller, temperature indicator and controller, pressure indicator, AC drive and ON / TRIP indicator lamps. All the necessary safeties for temperature, pressure and high current etc are provided in the system to ensure the safe functioning. These safety arrangements will take care of high and low pressures, high current and over loading, proper water cooling and flow rate etc.

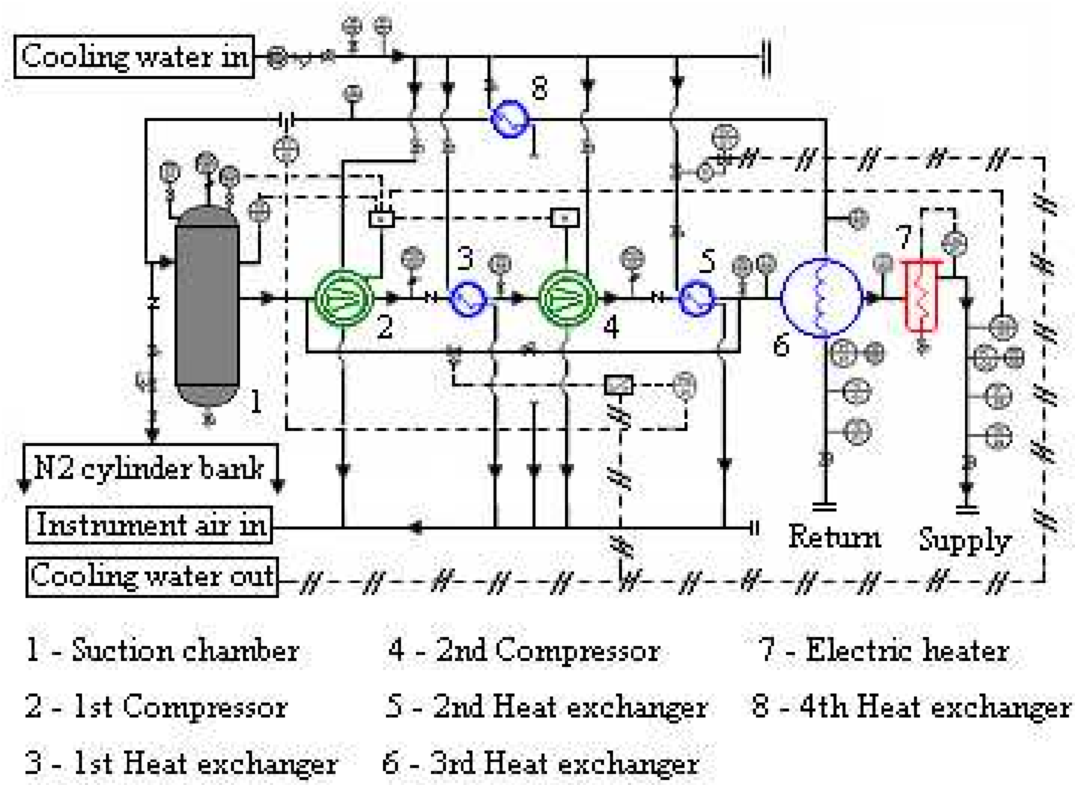

Figure 3. Schematic layout of Nitrogen Gas Heating and Supply System.

3. Experimental set-up and Results

A dedicated high-vacuum (HV) chamber of 2.4 meter diameter and 3.5 meter height is fabricated for baking these sixteen numbers of VS and VM. Since this chamber has very larger dimension, double O-ring configuration was utilized along with inter-space pumping in order to ensure the better leak tightness. Two numbers of 500 ISO-F flanges are provided on this chamber, out of which one is used for pumping purpose while other is used for human entry. Four numbers of 63 CF flanges are provided for connecting supply and return lines of VS and VM with hot nitrogen gas supply and return lines as shown in the figure 4.

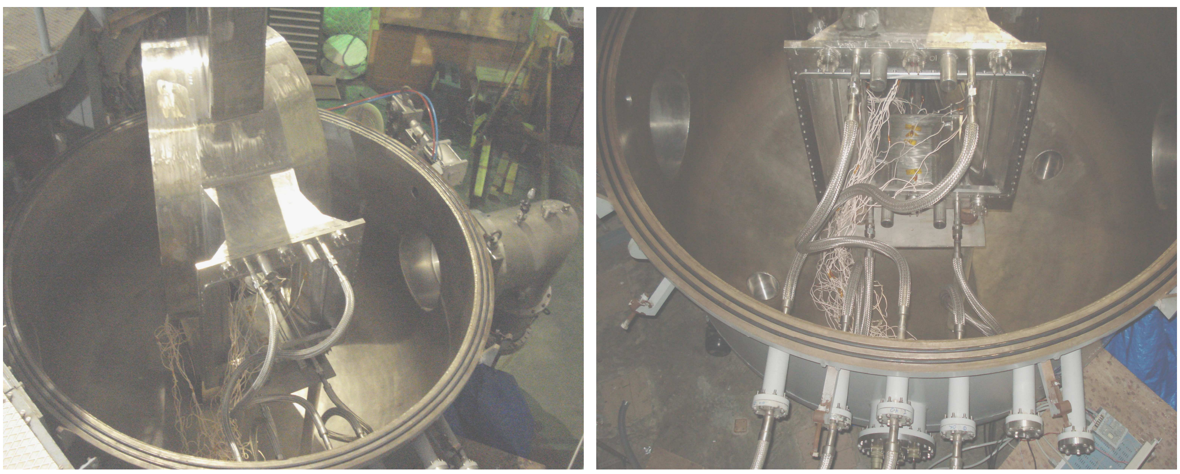

Figure 4. Experimental set-up for VS and VM baking.

System was run via PLC program in auto mode with predefined set parameters. Various interlocks are incorporated into the PLC program to ensure maximum safety to plant operation. Before starting the system it checks for all interlock conditions like water temperature, water flow, reservoir tank pressure, etc. It starts the system cycle after pre-filling system reservoir tank with nitrogen gas up to 1.0 bar (g) and steady state flow condition was established. After confirming the normal system operation by running system for few minutes, the heater was switched ON in Warm UP mode. In this mode system passes 10-15 % (adjustable) of full current into the heater for 15-20 (adjustable) minutes. After completion of Warm Up mode, heater enters run mode. In this mode, current supply of heater is increased gradually depending on ramp rate. Normally ramp rate of 50 °C /Hr is used. Heater current is controlled based on feedback from supply gas temperature. K-type Thermocouples are installed at different locations in the system. PLC gets supply gas temperature from thermocouple and pass on it to PID controller which in turn controls 4-20mA output for AC drive. AC drive passes current based on 4-20 mA current input from PLC. Pressure transmitter is installed on reservoir tank to give pressure information to PLC. Based on this feedback, system controls the switching of solenoid valve to maintain the pressure within specified range. Orifice based mass flow meter is installed in return line for measuring the mass flow rate.

K-type Kepton insulated thermocouples are mounted at the different locations of VS / VM using high temperature Ceramabond glue from M/s. Aremco. Both these thermocouples and glue can withstand the temperature up to 500 °C. Also these thermocouples are calibrated using high temperature hot bath at 100 °C, 150 °C and 250 °C within the accuracy of ± 1 °C. Temperature signals from vacuum chamber are acquired through de-mountable type 36-pins feed-through using MASIBUS make DATA logger. Temperature data from this DATA logger is stored in PC using CITECT SCADA based software via RS-485 transfer protocol. All sixteen VM and VS are baked up to 150 ^{0}C for a flattop of eight hours. Cool down of VS / VM is completed by flowing room temperature nitrogen gas through them. Figure 5 shows the temperature profile at different locations of one of the vessel module.

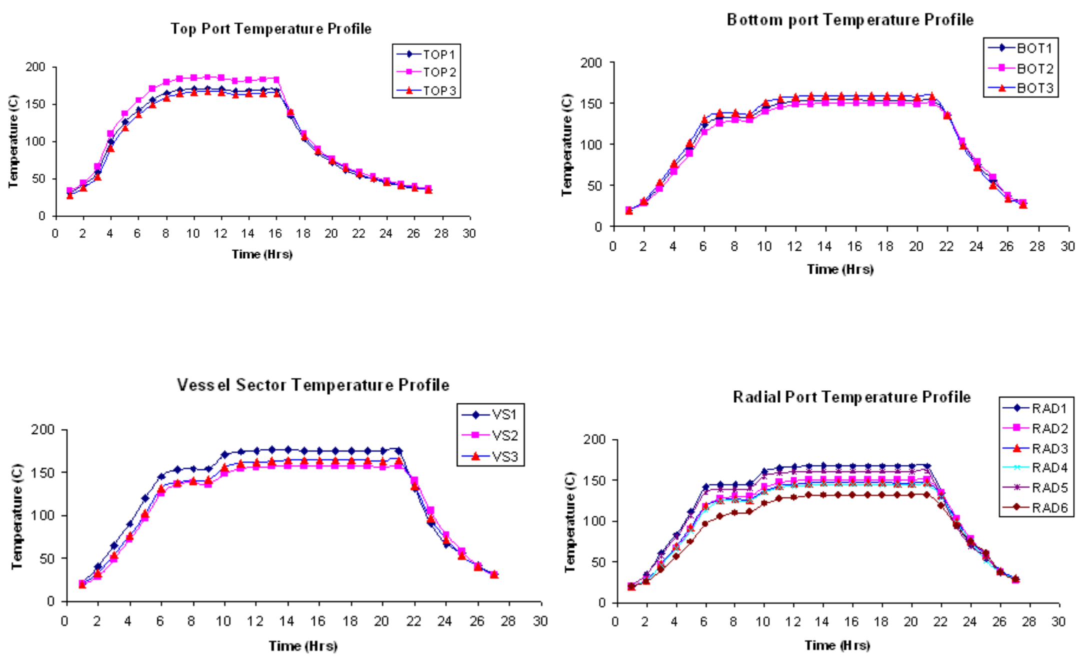

Figure 5. Temperature profile at different locations of one of the vessel module.

4. Conclusion

Nitrogen gas heating and supply system for SST-1 Tokamak is demonstrated successfully in its present status for baking of vessel modules and sectors. We are further planning to upgrade the system equipped with more reliable blower system so that desired mass flow rate of 1.1 kg/s at 4.5 bag (a) can be achieved in order to baking the entire SST-1 vacuum vessel. Further the baking channels layout inside the vacuum chamber is demonstrated for their performance as per design requirement.

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