Quality control of FWC during assembly and commissioning in SST-1 Tokamak

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Abstract. First Wall Components (FWC) of SST-1 tokamak, which are in the immediate vicinity of plasma, comprises of limiters, divertors, baffles, passive stabilizers designed to operate long duration (~1000 s) discharges of elongated plasma. All FWC consist of copper alloy heat sink modules with SS cooling tubes brazed onto it, graphite tiles acting as armour material facing the plasma, and are mounted to the vacuum vessels with suitable Inconel support structures at inter-connected ring & port locations. The FWC are very recently assembled and commissioned successfully inside the vacuum vessel of SST-1 undergoing a rigorous quality control and checks at every stage of the assembly process. This paper will present the quality control aspects and checks of FWC from commencement of assembly procedure, namely material test reports, leak testing of high temperature baked components, assembled dimensional tolerances, leak testing of all welded joints, graphite tile tightening torques, electrical continuity and electrical isolation of passive stabilizers from vacuum vessel, baking and cooling hydraulic connections inside vacuum vessel.

1. Introduction

After eleven successful experimental campaigns since the commissioning of Steady-state Super conducting tokamak (SST-1) [1, 2], First wall components (FWC) were installed in SST-1 vacuum vessel as one of the up-gradation objective during October, 2014 to May 2015. FWC of the SST-1 Tokamak consists of Inboard divertor plates (IDP), Outboard divertor plates (ODP), Inboard passive stabilizers (IPS), Outboard passive stabilizers (OPS), main baffle (MBAF) [3]. Assembly requirements of FWCs are proper alignment with the machine centre, leak tightness of hydraulic connections, Electrical isolation of IPS and OPS from other in-vessel components of vacuum vessel and baking of all graphite tiles up to 1000 °C [4,5] before assembly inside SST-1 machine.

2. Baking of graphite tiles

FWCs of the SST-1 machine consist of copper alloy back plates with brazed stainless steel tube. Plasma facing side of these back plates were covered with graphite tiles which are mounted mechanically. These graphite tiles have been manufactured by CNC machining. During the machining graphite tiles absorb many impurities i.e. atmospheric dust, gases and metallic tool particle. In order to remove all these impurities from porous graphite tiles, baking of these tiles was carried out at 1000 °C for 10 hours in vacuum condition. A dedicated vacuum furnace with graphite as electrode having a

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capacity to reach temperature up to 1200 °C was used for the baking of ~ 3800 PFCs graphite tiles. As per loading capacity of furnace, each batch consists of ~ 200 tiles were baked to 1000 °C in a vacuum condition of 1.0×10^{-5} mbar as shown in figure 2. Residual gas analyser (RGA) has been used for analysing the release of the different gas species. A snap shot of RGA scan shown in figure 1 depicts the low level of the hydrogen and oxygen residuals in range of 1.0×10^{-6} mbar at room temperature (RT) and at the flat top condition. After baking, all the graphite tiles were packed in vacuum tight sealed bags.

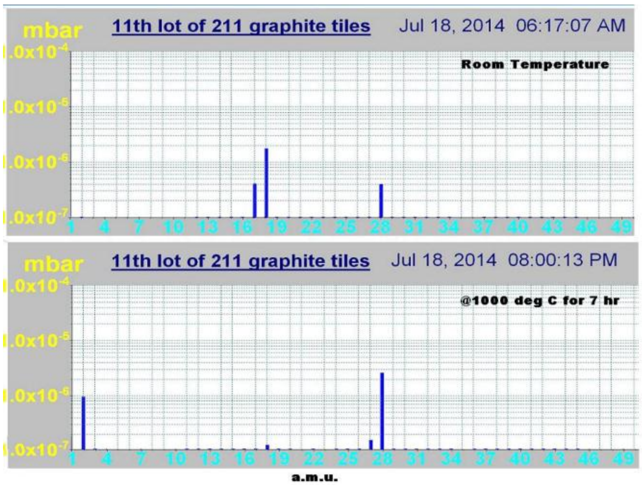

Figure 1. RGA Spectra of graphite tiles at RT and 1000 °C.

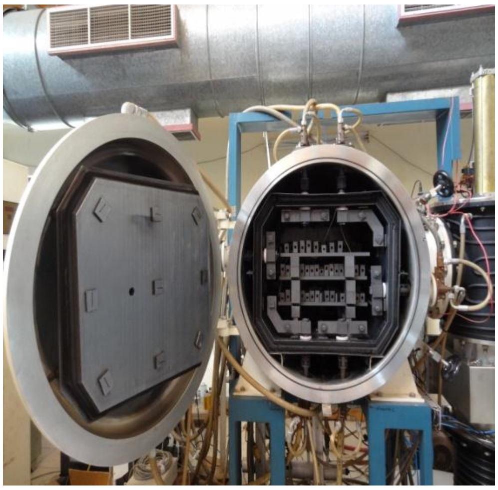

Figure 2. Vacuum Furnace loaded with graphite tiles.

3. Leak testing and baking of FW modules

All FW modules copper alloy back plates were required to be baked to achieve ultra-high vacuum inside vacuum vessel and also they have to be cooled during the plasma experiments for the extraction of incident heat flux. A common hydraulic circuit was used for heating and cooling of these modules (figure 3). During the heating, hot nitrogen gas was passed through these piping and while for cooling demineralised water at RT was used. In order to ensure the leak tightness of ~ 10^{-9} mbar l/s, all FW modules brazed piping along with their hydraulic circuit including flexible bellows & isolators were tested for leaks at RT as well as at baking temperature using a dedicated vacuum chamber. The vacuum baking chamber along with loaded copper back plates, flexible bellows & isolators is shown in figure 4 and the schematic P&I diagram is shown in figure 5. At RT, the entire circuit was leak tested and then the chamber was pumped down to high vacuum of ~ 1.0×10^{-5} mbar. At this vacuum, it was heated up to 250 °C and at this condition leak tightness was carried out by pressurizing it with helium gas. The holding time and temperature of baking were 8 hours and 250 °C respectively. A snapshot of the all copper plate baking temperature with respect to time is shown in figure 6 which depicts the uniform temperature rise of all FW modules up to 250 °C.

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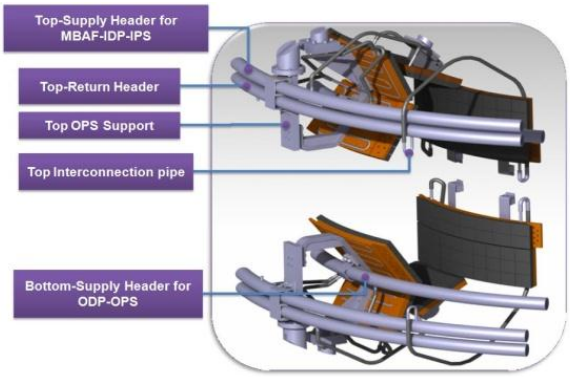

Figure 3. 3D model of PFC with Hydraulics

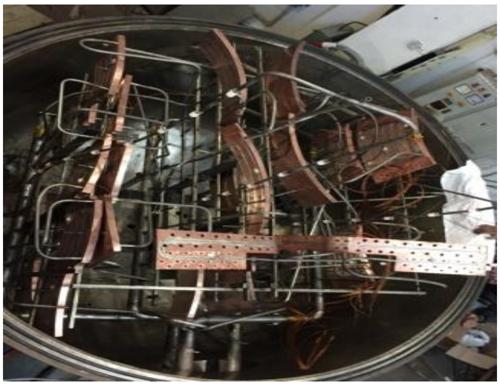

Figure 4. Baking facility for copper back plate

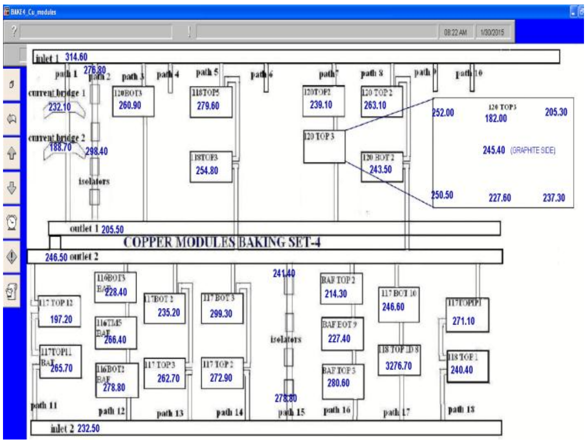

Figure 5. Schematic diagram of backing flow path

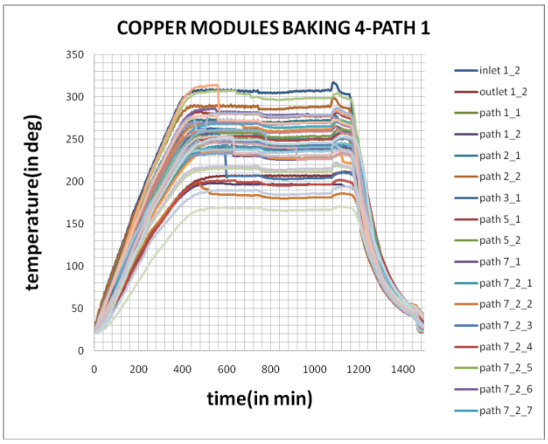

Figure 6. Copper module baking of set 4

The hydraulic circuit of FWCs consists of 2 supplies headers and 1 common return header each at top and bottom sides. MBAF, IDP and IPS (top/bottom) are connected in series and fed through two supply headers each having 11 parallel sub-connections while ODP and OPS (top/bottom) are connected in series and fed through another two supply headers each having 16 parallel sub-connections. Due to space constraints in vacuum vessel, all the possible joints were welded outside. Minimum joints were kept for the in-situ welding. The joints made outside of the vessel were leak tested in vacuum condition before their welding inside the vacuum vessel. Final in-situ welding connections of each path were made in parallel to the final assembly of respective back plates. All the connections of each hydraulic path except the connection with supply and return header were leak tested in vacuum mode. During the leak testing of these 54 parallel paths, leaks of ~ 10^{-2} mbar l/s to 10^{-6} mbar l/s were found in 8 welding joints. These joints were repaired and re-tested for leaks. At the end of the assembly of all the back plates, two joints of each hydraulic path were remained to be leak tested. Leak testing of these connections was done in the final testing of entire hydraulic circuit in vacuum and sniffer mode at 8 bar pressure.

4. QC aspect of metrology of PFC assembly

FWC are required to be assembled with high positional accuracy as plasma is to interact with FWC at certain angle. To insure the same, strict metrology protocols were generated and followed during the assembly of FWC. Typical module of FWC comprises 4 components which includes, welded part of support, bolted part of support, back plates and graphite tiles. The profiles of all the back plates were checked with accurate templates and through the laser scanning by coordinate measurement machine on ground (figure 7) before their final assembly inside vacuum vessel. IPS and OPS back plates were assembled on the ground for the identification of flaws in lap joints. For the accurate measurement of coordinates inside vacuum vessel, the combination of theodolite based laica ECDS (electronic co-ordinate determination system) measurement along with photogrammetry measurement (figure 8) was implemented. An inboard side limiter was mastered with respect to machine centre using both the techniques and aligned within an accuracy of 1 mm. The surface of the limiter was then considered as a reference and other back plates were assembled with respect to it. Precise templates of respective profiles were also used for reconfirmation. Suitable fixtures were developed for handling and alignment of back plates. The acceptance criterion was kept as ± 2 mm in deviation of elevation, poloidal and toroidal gaps between various FWC and surface profiles. Electrical isolation between IPS and OPS circuits were also ensured. Since the headers and in-vessel coils were supported on the OPS supports, thermal isolation between them was also insured. For insuring the isolation amongst the components, isolation checks were done continuously at various voltages (0-1 kV) at each stage of component assembly. The minimum value of resistance achieved amongst the components was 1 MΩ.

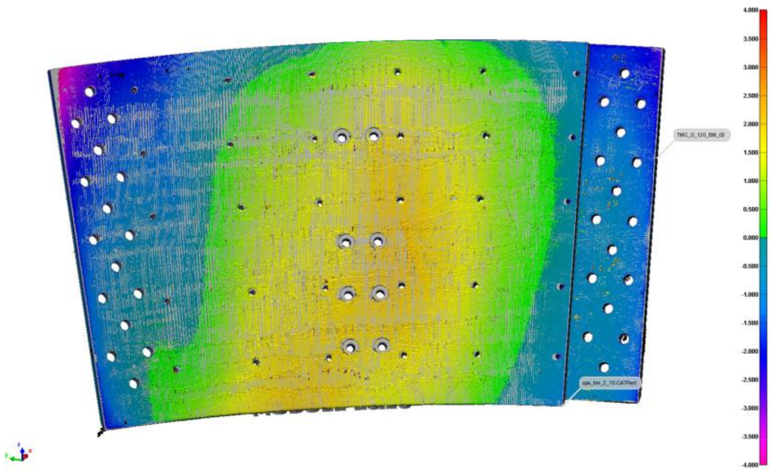

Figure 7. Scan analysis of Main baffle.

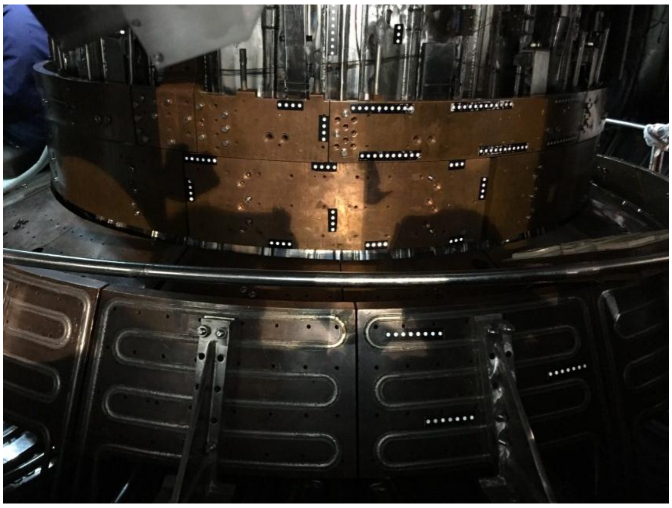

Figure 8. Photogrammetry of PFC components during assembly.

5. Conclusion

After successful assembly of PFC components in May 2015 and its rigorous testing in terms of pressure testing, vacuum mode and sniffer mode testing and thermal cycling testing, the successful result of plasma breakdown in excess of 110 kA plasma current with duration of 450 ms was achieved.

Even after four successive campaigns of plasma operation, none of the components of the PFC assembly along with its hydraulics has been failed.

Acknowledgement

I acknowledge the sincere effort of Mr. Kirit Vasava for his valuable contribution towards the assembly and integration of PFCs which leads to successful operation of tokamak for achieving desired plasma parameters.

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