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Development of Mechanical Mounting Scheme for Plasma Facing Components of SST-1 Tokamak

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Abstract

Steady-state Superconducting Tokamak (SST-1) is being designed for 1000 seconds of continuous operation with total input power up to 1.0 MW. The tokamak will have a D-shaped plasma with double null divertor. Each toroidal module of inboard as well as outboard divertor will have graphite tiles mechanically mounted on a metallic backplate made of high strength copper alloy. The poloidal cross-section of divertor plates has been designed such that the average heat flux on graphite tiles is less than 0.6 MW/m^2 which is nearly the limit on incident heat flux for mechanically attached graphite tiles for plasma facing components in tokamaks. As a first step towards development of plasma facing components, preliminary experiments are conducted with a test mockup to develop the mechanical mounting scheme for attachment of graphite tiles on actively cooled copper backplate. This paper describe the results of these experiments.

Keywords:

SST-1 tokamak, plasma facing components, divertor plate, mechanical mounting scheme, heat removal scheme

1. Introduction

Steadystate Superconducting Tokamak (*SST*-1) is being designed to operate for 1000 sec with a D-shaped plasma having double null divertor configuration and total input power of 1.0 MW. Plasma having major radius (R_0) of 1.1 m and minor radius (a) of 0.2 m will be generated to carry 220 kA current in presence of toroidal magnetic field of 3.0 T (at $R = R_0$). Plasma equilibria under consideration will have elongation (κ), triangularity (δ) and internal inductance (li) in the range of 1.7 – 1.9, 0.4 – 0.7 and 0.75 – 1.40 respectively. A typical equilibrium will have $\kappa = 1.8$ and $li = 1.0$ and will be symmetric about the midplane.

Plasma Facing Components (*PFCs*) of SST-1 mainly consists of Divertor, Limiter, Passive Stabilizer and Baffle plates [1]. Typical assembly of PFCs will have graphite or C-C composite tiles of approximate size 75 × 75 × 25 mm^3 mechanically attached to about 25 mm thick backplate made of copper alloy (Cu-Cr-Zr) with *flexible graphite sheet* used at copper-graphite interface to reduce thermal contact resistance. Steel tubes will be brazed (or welded) to the backplate for cooling as well as baking purpose. In steady-state operation, divertor plates will be receiving maximum heat load. Therefore, poloidal inclination of divertor plates has been optimized so as to intercept maximum area of *scrape off layer* (*SOL*) while *maintaining average heatflux on carbon tile to be less than* 0.65 MW/m^2. The poloidal location of strike point of SOL on top/bottom divertor plate has been fixed for all equilibria. Thus, seperatrix of SOL for all equilibria

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under consideration will intercept the top/bottom divertor plate at the predetermined strike point location.

Experimental as well as computational study is being carried out to develop mechanical mounting scheme for plasma facing components of SST-1. Results of some preliminary experiments conducted in this regard are presented here.

2. Assembly of Test Mockup

Test mockup consists of nine graphite tiles of size $50 \times 50 \times 25$ mm^3 arranged in the form of 3×3 matrix. Each tile is centrally bolted to a copper backplate of size $150 \times 150 \times 18$ mm^3 by using steel fastners. The backplate is actively cooled by water flowing through 8 mm ID copper tube brazed to the backplate as shown in Fig. 1. The steel fastners consists of a cylindrical nutbar of diameter 12 mm & length 50 mm having threaded hole for M6 size bolt at its center, M6 size bolt of length 75 mm and disc springs. The nutbar inserted in the graphite tile is tightened with an M6 size bolt as shown in Fig. 2.

Compliant Layer i.e. flexible graphite sheet (GRAFOIL®) having 0.7 mm thickness is inserted between graphite tile and copper backplate to reduce thermal contact conductance. The M6 size bolt is tightened with 4 Nm of torque to apply pressure on the tile as well as graphite sheet.

3. Pressure Distribution on Compliant Layer

The experimental studies [2] conducted elsewhere for development of mechanically mounted first wall components indicate that pressure on compliant layer should be above 0.2 MPa for improved contact conductance. The pressure distribution on a compliant layer was measured by using PRESCALES® of type LLLW & LLW along with FPD-305 Densitometer and FPD-306 Pressure Reader manufactured by Fuji Film Co. Ltd., Japan.

Pressure on both side of the compliant layer was measured for 4 Nm torque as shown in Fig. 3. It can be seen that the pressure all over the compliant layer is above 0.9 MPa. Moreover, pressure distribution is almost same on either side i.e. copper side and graphite side of the compliant layer.

4. Thermal Response of the Test Mockup

The experimental studies [2,3] to improve heat removal capability of mechanically mounted graphite tiles in plasma facing components has indicated maximum operating limit on incident heat flux to be about 0.6 to 0.75 MW/m^2.

In order to check thermal response, the test mockup was irradiated with 2.1 kW CO_2 LASER beam having rectangular cross-section. The incident heatflux on test mockup was controlled by operating LASER at different power levels and the area of cross-section of beam on test mockup is adjusted by using Zinc-Selenide lens. The power of 2.1 kW was sufficient to irradiate one of the nine graphite tiles having surface area of 50 mm × 50 mm with heat flux of 0.75 MW/m^2. The laser was operated in continuous mode for minimum 600 seconds during each test.

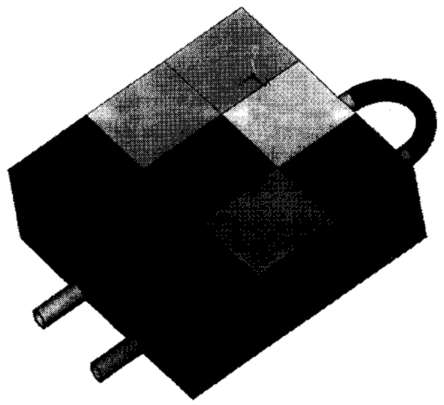

Fig. 1 Assembly of Test Mockup showing nine graphite tiles (50 × mm 50 × mm × 25 mm) mechanically mounted on a copper backplate (150 × mm150 × mm × 18 mm) having U-shaped copper tube (8 mm ID) brazed to it for active cooling.

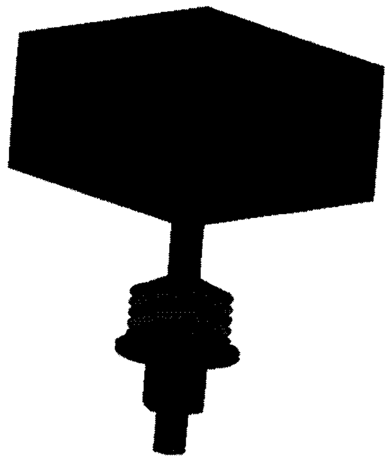

Fig. 2 Mechanical mounting scheme showing M6 size stud at center of the graphite tile mechanically attached (tightened) to a cylindrical nutbar (12 mm dia) inserted through the thickness of tile.

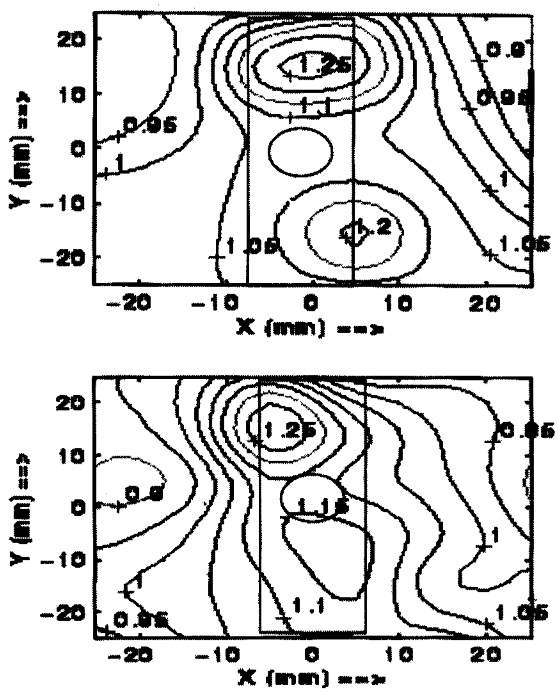

Fig. 3 Pressure distribution on both (copper & graphite) sides of compliant layer for 4 Nm torque on M6 size bolt at center (X = 0, Y = 0) with nutbar placed along Y-direction.

The test mockup is supplied with water at 22.5°C (room temperature) flowing through a 8 mm ID copper tube at flow rate of 12 liter per minute to generate heat transfer coefficient of approximately 17,000 W/m^2K.

Temperature at the surface of the graphite tiles is measured using an Infra-Red Thermometer. Following table shows the measured surface temperature as a function of incident heat flux.

Incident Heat Flux on graphite tile (MW/m^2)	Surface Temp. of graphite tile (degree C)
0.052	356
0.066	382
0.077	413
0.084	430
0.297	543
0.378	596
0.468	630
0.756	930

The experiment with highest available heat flux of 0.75 MW/m^2 was repeated several times. However, no physical damage could be observed with any component of the test mockup.

5. Conclusions

The experiments conducted to study thermal response of a test mockup with mechanically mounted graphite tiles are presented in this paper. For $50 \times 50 \times 25$ mm^3 graphite tile and 0.7 mm thick flexible graphite, 4 Nm of torque on M6 size bolt was found to be sufficient to produce minimum pressure of 0.9 MPa on compliant layer. Each tile of the test mockup is found to withstand several exposures to heatflux of 0.75 MW/m^2 with surface temperature of graphite below 1000°C.

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