Status of Design and R&D Activities for ITER Thermal Shield

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Abstract. The design and R&D for ITER thermal shield (TS), has been implemented in the cooperation of ITER organization and KODA since 2007. In this paper, the status of the design and R&D activities is reported. The design of cooling line, in-pit joint, and bisecting joint, was modified recently. Structural and thermal analysis verified the modified design. R&D was implemented to validate the design and manufacturing procedure. Especially full-scaled mock-up for the inboard of vacuum vessel thermal shield (VVTS) was fabricated. Most procedures were suitable for the manufacturing VVTS as the results of the mock-up fabrication, but more rigidity of Jig & Fixture is required to meet the requirement of tolerance.

1. Introduction

The thermal shield (TS) system of ITER plays the role of reducing the heat load transferred by thermal radiation and conduction from warm components to the components and structures that operate at 4.5 K. The ITER thermal shield consists of equatorial TS (ETS), upper cryostat TS, lower cryostat TS and support TS (STS). Thermal radiation to the superconducting magnets is minimized by operating the thermal shields at low temperature and by providing surfaces with low emissivity using silver coating. Figure 1 shows the configuration of ITER thermal shields [1].

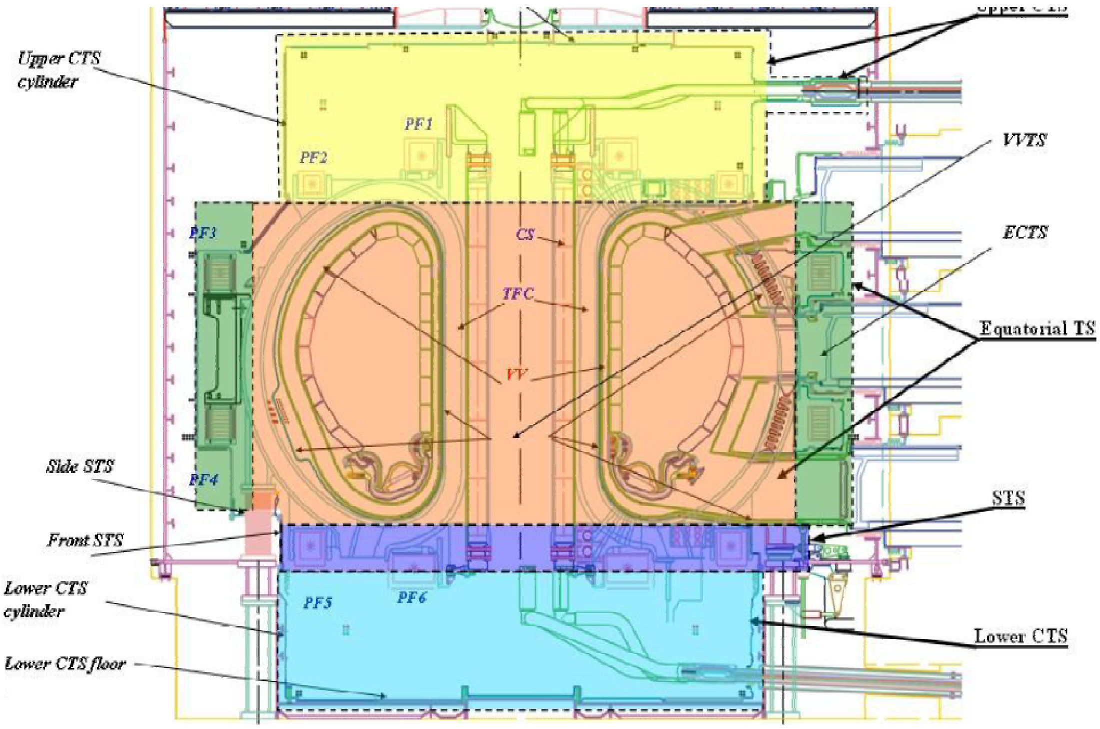


FIG. 1. Configuration of ITER thermal shield.

The ITER Thermal Shield is composed of many panels and joints which connect each panel. Cooling tubes are attached to the panel to maintain the temperature of the TS within the range of 80~100 K during plasma operation. The thermal shields are cooled by a pressurized helium gas. Pressurized helium gas from the main cryogenic plant, with an inlet temperature and pressure of 80 K and 1.8 MPa, respectively, is used to cool the thermal shield system.

The preliminary design of ITER thermal shield was finalized at the early 2010. We are doing detailed design of the TS, which is to be reviewed in 2011. Especially, the design of cooling line, in-pit joint, and bisecting joint is modified recently. And some design was verified by supporting analysis.

Several R&D activities, including small mock-up and full-scale mock-up, were conducted to validate the design and manufacturing process for ITER thermal shield. R&D activities using small mock-up was conducted to check the feasibility of the manufacturing in 2009. Most processes were validated by the activities, which are silver coating, welding, in-pit joint assembly, design of bisectional joint and support [2]. A full-scale mock-up of VVTS inboard section was made of in 2010.

2. Design and Analysis

2.1. Cooing line

The design of the cooling line for the VVTS has been carried out. The main parameters for the design of cooling line are the size of the tube, the distance between cooling lines, cooling tube attachment scheme and cooling line layout. And these were decided at 2009 through the study and analysis. [3][4][5] The dimensions of the cooling tubes are 13.5 mm and 2 mm for the outer diameter and wall thickness respectively. The maximum distance between cooling lines is 350 ~ 500 mm according to the components of TS. For example, the maximum distance at the VVTS outboard panel is 350 mm. Cooling tube is to be welded directly on the panel in a staggered fashion to minimize welding distortions and to maximize thermal contact.

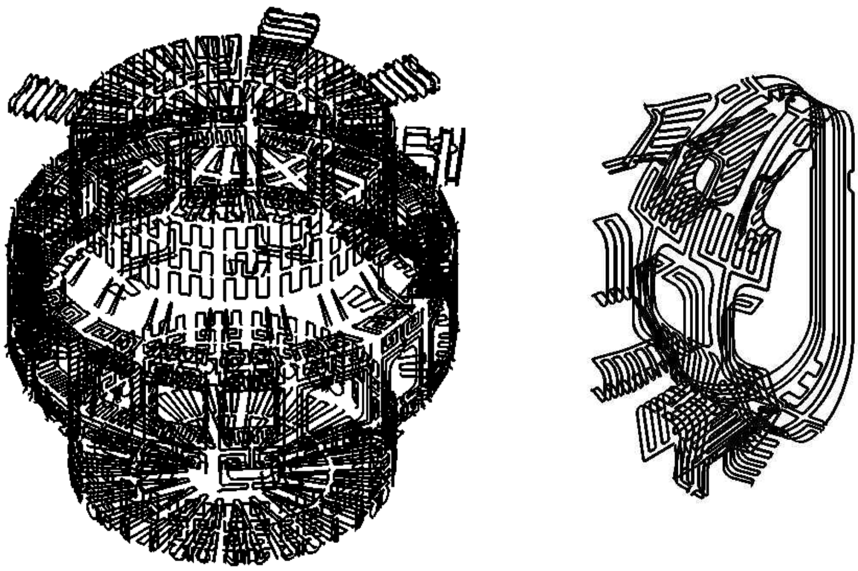


FIG. 2. Design of the cooling line for ITER thermal shield.

The final layout of cooling line is designed as shown in figure 2. This design reflects all results of previous studies and analyses. We conducted thermal analysis to validate this design with new FE model. All panels are integrated in the model to include the effect of joint between panels. As the results of the analysis, some hot spots were found in the CTS panel as shown in figure 3. Specific region of hot spot is on the upper VVTS ring, rear ECTS cylinder, and central disks of upper and lower CTS. Even if the area of hot spot is rather small, the heat load to magnet was over than the requirement.

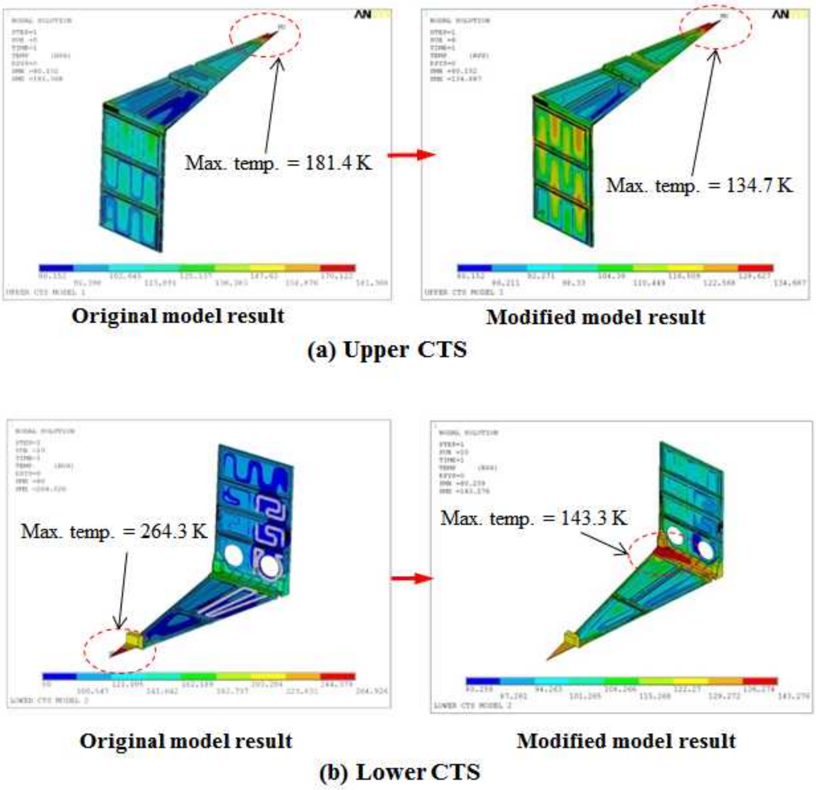


FIG. 3. Results of thermal analysis for upper and lower CTS.

TABLE I: RESULTS OF THE 3D FULL MODEL THERMAL ANALYSIS

(a) Original Design

No.	Panel	Heat load to Magnet [W] POS	Heat load to Magnet [W] BOS
1	Upper CTS Lid	94.62	100.01
2	Upper CTS Cylinder	125.54	214.52
3	Upper CTS Shroud	53.7	72.93
4	Upper VVTS Ring	119.7	472.2
5	Upper ECTS Ring	93.46	302.66
6	ECTS Cylinder	127.04	185.6
7	ECTS Port Shroud	119.14	249.62
8	Lower ECTS Ring	71.27	210.2
9	Rear ECTS Cylinder	149.83	346.54
10	Side STS Ring	13.05	20.16
11	Front STS Cylinder	15.48	15.75
12	Lower CTS Cylinder	166.24	170.7
13	Lower CTS Floor	300.5	306.68
Total (analysis result)		**1449.6**	**2667.6**
Total (requirement)		**1049**	**1916**

(b) Modified design

No.	Panel	Heat load to Magnet [W] POS	Heat load to Magnet [W] BOS
1	Upper CTS Lid	73.86	78.11
2	Upper CTS Cylinder	120.44	210.7
3	Upper CTS Shroud	53.52	72.7
4	Upper VVTS Ring	39.57	94.82
5	Upper ECTS Ring	67.39	182.12
6	ECTS Cylinder	123.26	184.97
7	ECTS Port Shroud	119.14	249.69
8	Lower ECTS Ring	68.30	201.34
9	Rear ECTS Cylinder	71.06	149.49
16	Side STS Ring	13.05	20.16
17	Front STS Cylinder	15.48	15.75
18	Lower CTS Cylinder	126.64	129.56
19	Lower CTS Floor	125.06	127.14
Total (analysis result)		**1016.8**	**1716.6**
Total (requirement)		**1049**	**1916**

Two solutions are proposed to remove the hot spot, which are attaching multi-layer insulation (MLI) and adding additional cooling line. MLI is attached on the rear ECTS cylinder and disks of upper and lower CTS. Additional cooling line is added on the upper VVTS ring. The result is shown in Table I. The modified design satisfies the heat load requirement. The usage of MLI in the local area of ITER CTS will be decided in the future.

2.2. In-pit Joint

VVTS in-pit Joint is used for the final assembly between VVTS 40 degrees Sectors at the site TOKAMAK pit. Reference design of in-pit joint is splice plate type as shown in figure 4, Type 3. The misalignments that the in-pit joint must compensate during the site assembly are 10 mm in toroidal, 14 mm in poloidal and 12 mm in radial directions, respectively.

The splice plate type is good for compensating rather big misalignment required by assembly stage but it is week under the shear load. So, three types are proposed for the in-pit joint as shown in figure 4. Bi-directional shear pin is applied at the type 1 and mono-direction shear pin is applied at the type 2. Type 1 is applied to the only weak point such as joint to joint cross-section area and where maximum force is applied. Specific location is shown in figure 4. In the other region, type 2 and type 3 will be applied. Type 1 has merit on the structural rigidity but has demerit on the assembly and manufacturing, so, the application should be limited.

To validate the design of in-pit joint, structural analysis was done under the electromagnetic load, which mainly induces shear stress on the joint. Main force acting on the joint is in-plane shear and tensile force. Maximum stress is 26 MPa and 15 MPa respectively. As the results of the analysis, maximum stress is within the allowable limit. Other region has more margins; due to maximum load condition is applied in this analysis. The results are shown in figure 5. Fabrication feasibility and on-site fabrication of splice plate will be checked in near future.

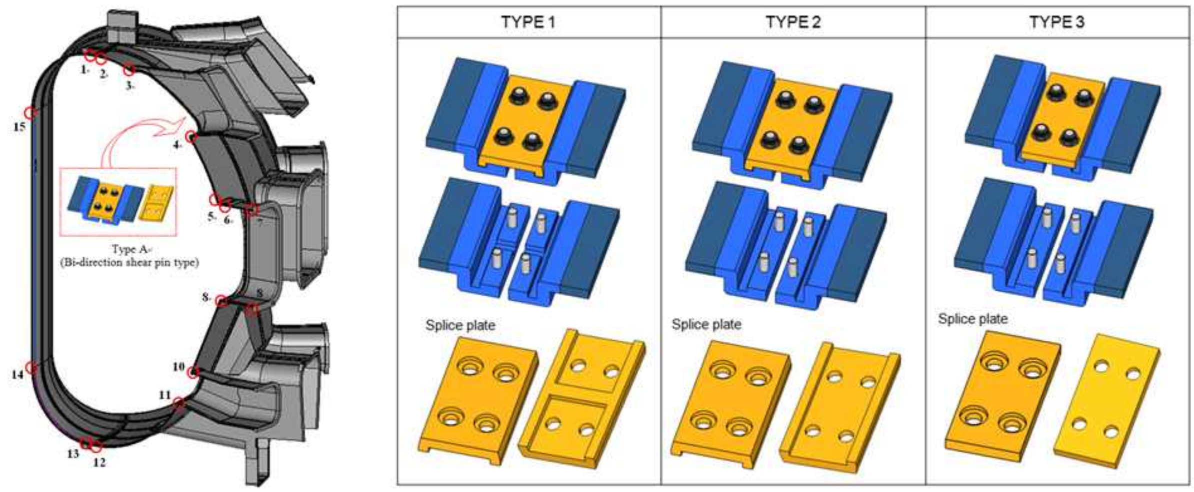
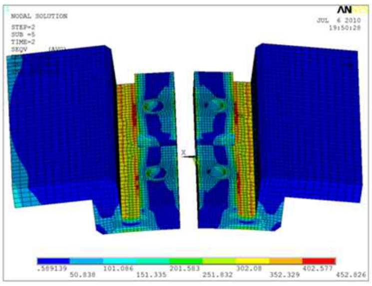


FIG.4 Design of the in-pit joint for ITER thermal shield.



Stress Component	Equivalent Stress	Allowable Stress
P_m	40 MPa	175 MPa(1.2Sm)
P_L+P_B	246 MPa	263 MPa (1.8Sm)

FIG.5 Structural analysis result of in-pit joint for ITER thermal shield.

2.3. Bisecting Joint

The bisecting of VVTS is required to reduce the size of the electro plating bath. It has merit on the reducing cost and risk in the manufacturing. The bisecting joint for the inboard 10 degree of VVTS was designed as shown in figure 6. The flange joint is applied and it is located at the center. This joint should have enough strength under the dead weight, seismic and electromagnetic load. And the tolerance due to the assembly should be minimized. The number of bolt and pin is decided by simple calculation considering applied load. The bisecting flange has 9 bolt holes and 4 pins for the in board 10 degree of VVTS. Due to the design change, the design of cooling line and manifold will be revised in the future.

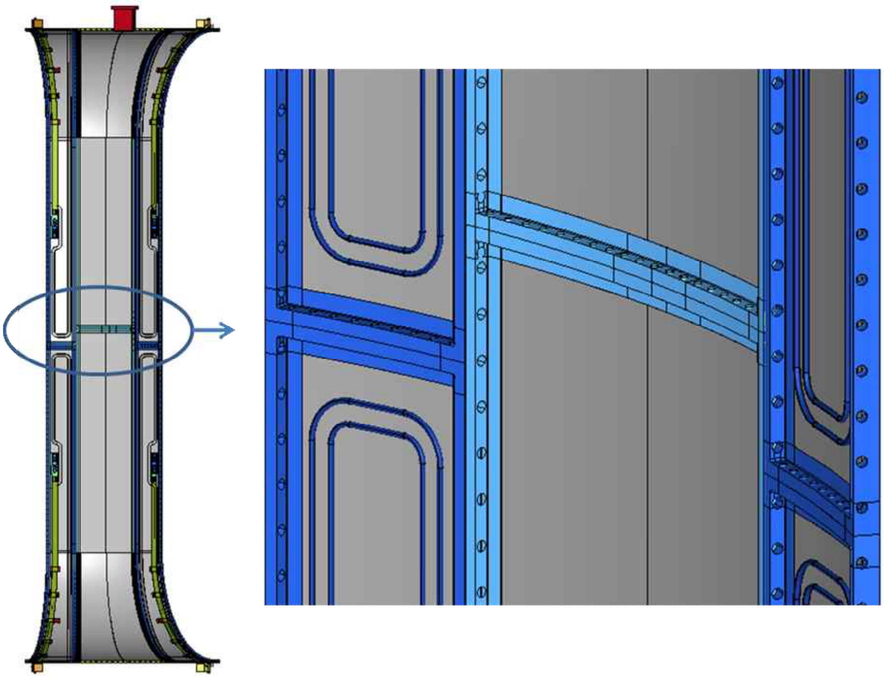


FIG. 6. Design of the bisecting joint for VVTS inboard 10 degree.

3. R&D Activities

A full-scale mock-up of VVTS inboard section was made of. VVTS inboard 10 degree section consists of 20 mm panels on which cooling tubes are welded and flange joints that connect adjacent thermal shield sectors. The whole VVTS inboard is divided into two by bisectional flange joint located at the center. [6]

Most critical tolerance is required in the region of VVTS inboard because it is located in the narrow space between TF magnet and vacuum vessel. So, validation of the design and manufacturing process for the VVTS inboard is very important to finalize its design and requirement before the starting its fabrication.

The main procedures of fabrication are as follow: (i) cutting; (ii) Forming; (iii) buffing; (iv); welding; (v) machining; (vi) silver coating; (vii) assembly; (vii) inspection. Silver coating process was excluded in this research because we don't have enough big facilities to coat full-scale VVTS until now.

Laser cutting was applied on the 20 mm plate and plasma cutting was applied on the 70 mm plate. 3 mm margin is considered for the plasma cutting to eliminate thermally affected zone. We checked deviation of dimension by using standard template after forming and 3 roll bending process. The maximum deviation was 1 mm. It was hard to estimation the amount of spring back after forming process. Several re-works for the forming were done to meet the requirement. This data will be considered in the design of jig and detailed step of the process.

Gas Tungsten Arc Welding (GTAW) was used for the all welding process. Welding quality and distortion are most important factor. Welding condition, which is current, welding shape, speed, filler, was decided by pre-qualification. We checked weld fully by non-destructive examination, which is RT, and there was no defect on the welding region. But welding contraction is varied from 3.5 mm and 5 mm depending on the welding type and welding jig. Direct welding of cooling tube and panel was applied and there was no leak or damage on the cooling tube.

Machining was performed by 5-axis milling machine. Special jig was used for the machining to prevent the movement during the process. The inboard of VVTS consists of thin plate, so the rigidity of the jig and fixation mock-up to the jig is very important. Even if the final result of the machining is within the requirement, the jig should be reinforced in the future, because it did not fully prevent the vibration at the end of straight region.

FIG. 7. Manufacturing process of the mock-up.

The mock-up consists of two identical parts, upper and lower segment. Two segments were assembled using bisectional joint. Bisectional flange joint was successfully assembled by inserting pins and tightening with bolt/nut. Bolt hole margin of 2 mm for sector flange was revealed to be sufficient by successful sector assembly of upper and lower parts of mock-up. By comparing the 3D scanned data with the corresponding CAD data, it was found that the final dimensions of mock-up meet the tolerance requirement.

We found the inboard section of VVTS is flexible considering its tolerance. Maximum 20 mm can be adjusted by the power of man. It is merit in the assembly but the jig and Fixture for welding, machining, assembly, and handling should have enough structural rigidity to prevent undesirable deformation.

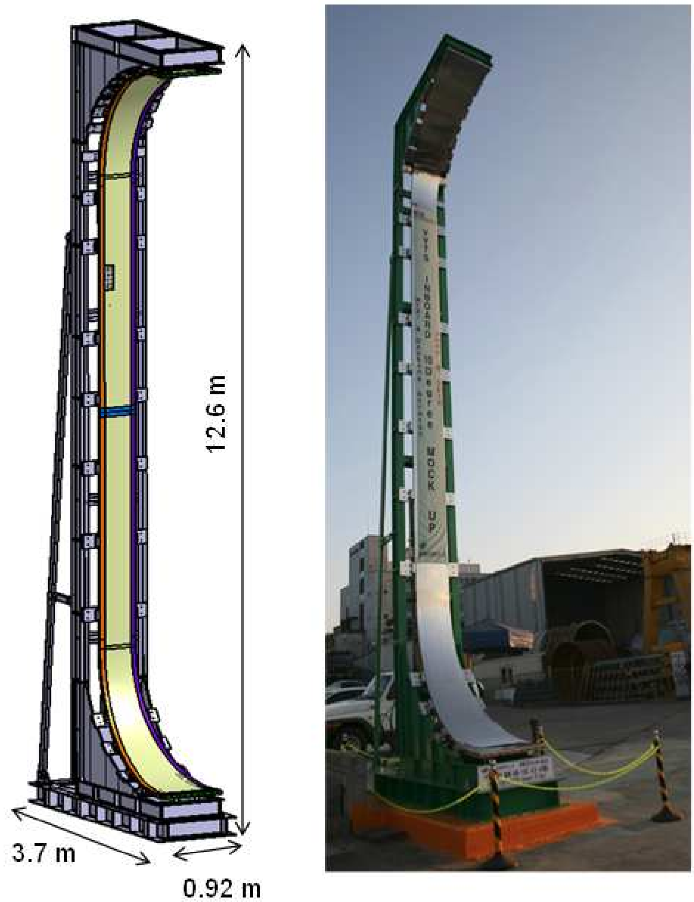


FIG. 8. Assembly of Full-scale mock-up of Inboard 10 degree section of VVTS.

4. Summary

The design of cooling line, in-pit joint, and bisecting joint is modified recently. The design was verified by supporting analysis. Thermal analysis was done to verify the design of cooling line, but some hot spots were found in the CTS panel. MLI and additional cooling line is applied on the hot spots and the modified design satisfies the heat load requirement. Three types are proposed for the in-pit joint according to the location and structural analysis validated the design. Conceptual bisecting joint was proposed to reduce the size of the electro plating bath.

A full size mock-up of VVTS 10° inboard section was made and all processes for VVTS manufacture except silver electroplating were demonstrated. Although the dimension of mock-up is marginal compared with the CAD model due to the flexibility of mock-up, main manufacturing processes are verified. The jig and Fixture for welding, machining, assembly, and handling should have enough structural rigidity to prevent undesirable deformation.

Acknowledgment

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