Development of the Thermal Insulation Devices for the JT-60SA Tokamak

Y.Shibama, G.Matsunaga, K.Kizu, F.Okano, J.Yagyu, J.Botija[1], M.Medrano[1], K.Sagawa[2], A.Hayakawa[2], S.Moriyama, E.Di Pietro[3] & M.Hanada

National Institutes for Quantum and Radiological Science and Technology (QST), JAPAN,

[1] Association EURATOM CIEMAT, SPAIN, [2] Toshiba Energy Systems & Solutions Corporation, JAPAN, [3] Fusion for Energy, GERMANY

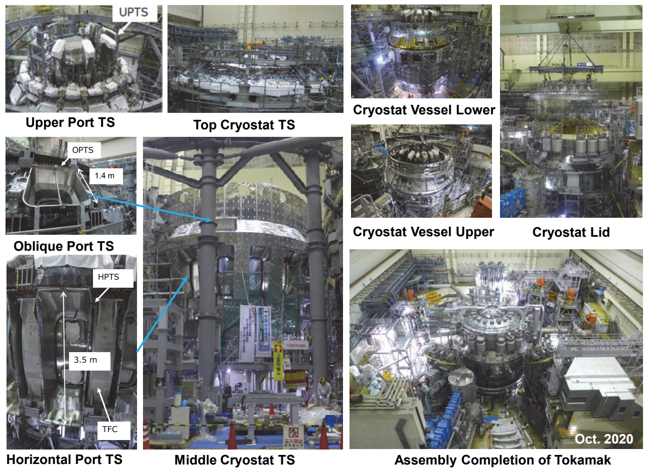
shibama.yusuke@qst.go.jp

ABSTRACT

- Thermal insulation devices such as the thermal shield (TS) and the cryostat for the JT-60SA Tokamak were developed by the design activities through the collaboration between Japan & the EU.
- Design, manufacturing & acceptance tests on these devices were successfully completed by 2019 and these devices were completely installed into the Tokamak by the end of March 2020.
- Technique & knowledge to realize high accuracy manufacturing & short time installation of these devices will contribute to the ITER construction & DEMO design.

BACKGROUND

- JT-60SA as a superconducting tokamak was constructed in the Naka Fusion Institute of QST and the tokamak assembly had started since January 2013.
- The superconducting coils were installed into the tokamak in early 2018 and then TS & Cryostat were installed to insulate these coils from the thermal radiation.
- **Thermal insulation devices procured by Japan, such as TS & Cryostat Top Lid, are reported here in detail.**
- The design requirements are to endure forces due to the operational electromagnetics & seismic events, and to absorb the thermal displacement with the clearance to the other surrounding devices.



Manufacturing of the Thermal Shield

Manufacturing of TS

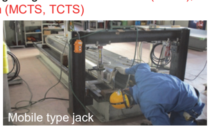
- The thermal shield was designed to insulate superconducting coils in the cryostat vacuum environment from the radiation heat intrusion of the vacuum vessel (VV) and cryostat.
- TS structure as the double wall with the 80K pipe set inside between the walls was designed with the conditions of the high-pressure gas law, and the double wall is composed of thinner stainless plates and electrically insulated in every 20-degree toroidal sector to reduce the eddy current during the operation.
- TS was designed as the VV TS (VVTS), Cryostat TS (CTS) & Port TS (PTS).
- The TS is supported at the horizontal port TS (HPTS) from the base of each TF coil.
- The TS surface facing to the cryostat vessel is entirely covered with low emissivity sheets layered as multilayer-thermal insulation (MLI), and the TS is kept at the cryogenic temperature with 80K helium gas flow during the operations.
- **The 20-degree TS sectors were manufactured in the geometrical tolerance of ±5mm to keep the over 30mm clearance between TS and each other component.**

Manufacturing Process of TS (UPTS example)

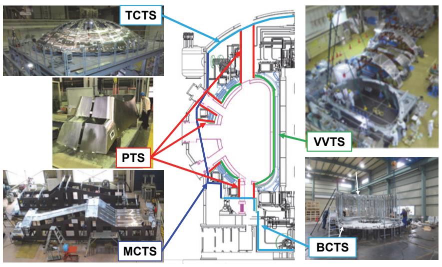
- **Achieved tolerance was less than ±5mm (required tolerance ±5mm).**
- **Pressure test (2.5 MPa) & He leak test (below 10^{-8} Pa m^3/s) were passed.**

Frame to fix the inner & outer plate onto the surface plate. Target welding distortion: ±10mm.

TS dimensions were controlled by dummy welding: Target distortion: <10mm (UPTS), <2mm (MCTS, TCTS)

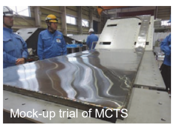


Hydraulic jack attached on the surface plate: Target distortion: ±2mm



Manufacturing Process of MCTS

- **To keep the tolerance as +/-2.5mm, MCTS was designed as five split pieces with the mock-up results and assembled as 9m MCTS structure.**
- **Same methods of the UPTS was adopted and carefully welded due to the port bores.**



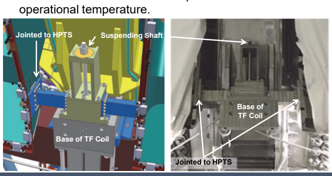
Manufacturing Process of TCTS

- **Same methods of the UPTS & MCTS was adopted.**
- **Inner shell & cooling pipe were welded on the cupper heat sink plate to reduce welding distortion.**
- **Target values to the dimensional control are,**
  Welding distortion: <2mm
  Length: ±1mm (±2.5mm)
  Width; ±1mm (±5mm)
  Port opening; <±5mm (±5mm)

TCTS set on cupper heat sink plate

TS gravity support is designed as suspend type to reduce heat intrusion to the superconducting coils,

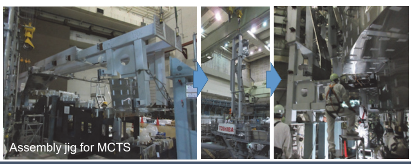
- Longer distance of heat conduction was designed to reduce heat intrusion to the superconducting coils.
- Suspending shaft is supported by spherical bearing in order to absorb the thermal displacement due to the operational temperature.



Assembly Onsite

Jigs for onsite assembly are prepared for each TS,

- TS is flexible structure as a single piece so that each TS was assembled with specifically prepared jigs to set them within ±10mm tolerance.



CONCLUSION

- The 20-degree TS sectors were successfully manufactured within the tolerance and the clearance between TS and other devices were kept in onsite assembly.
- CTL half pieces were manufactured within tolerance and successfully jointed as one lid onsite.
- The thermal insulation devices on the JT-60SA & its manufacturing were developed and top region of the TS & Cryostat were assembled on-schedule.

Manufacturing of the Cryostat Top Lid

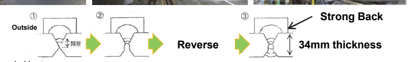
Manufacturing of Cryostat

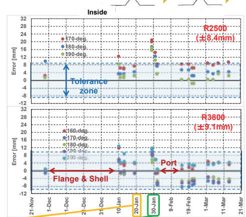
- Cryostat is designed to provide vacuum environment of 10^{-3} Pa to insulate superconducting coils thermally from the ambient.
- Cryostat was divided mainly in three parts, such as base (CB), cylindrical section (CVBCS) & lid (CTL), and the manufacturing size is limited by the Japanese domestic transportation.
- The CB & CVBCS were manufactured in the EU and the CB was installed into the tokamak in early 2013 & the CVBCS in 2019.

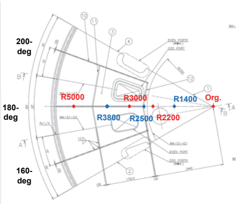
Manufacturing of Cryostat Top Lid

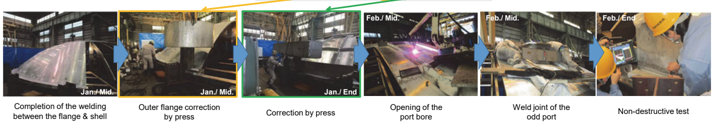
- Cryostat Top Lid (CTL) was manufactured in Japan.
- The CTL was manufactured as the two half-pieces, and these pieces were weld-jointed as one onsite in February 2020.
- **Dimensional tolerances were; spherical radius 8m±8mm, & outer diameter 11.5m±5mm to joint these two pieces as one lid onsite.**

- **Manufacturing process was established through the mockup.**
- **To reduce the welding distortion in shell of the 34mm thickness, the reversible jig was introduced to allow the flat position welding with x-groove.**
- **Over 20 mm of welding distortion was observed at the top side and suppressed in the correction step.**
- **Port bores were opened after the suppression of the welding distortion due to the rib reinforcements joints.**
- **Tolerance in the mock-up was fulfil the specification requirements.**
- **In product lid manufacturing, more steps of distortion corrections are introduced in manufacturing process corresponding to the mockup results.**

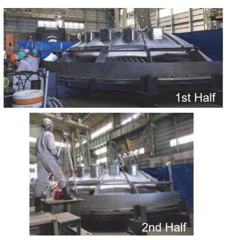


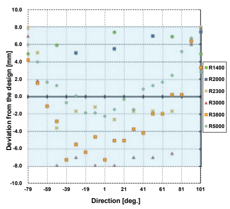




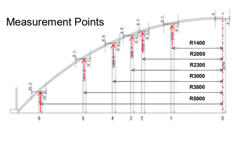


- **Two product half-pieces were manufactured and passed the spherical radius tolerance of +/- 8mm.**
- **Outer diameter of the half sector was within the lid tolerance +2.5/-5mm.**





Dimensional deviation of the 1st half.



Measured points of the spherical radius.

- **Two half-sectors were jointed as one lid in the assembly hall.**
- **Joint error in outer diameter was max. 3mm and min. -4mm, within the tolerance (±5mm).**
- **Error of each port center were from -10mm to -1mm out of tolerance (±5mm), but there is no problem in practical use.**
- **None of weld defect was confirmed by PT.**
- **No leakage was confirmed on each weld region by helium leak test.**