Achievement of precise assembly of the JT-60SA superconducting tokamak

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ABSTRUCT

The JT-60 Super Advanced (JT-60SA) tokamak construction have been achieved respecting the requirements of very tight tolerance for the assembly and by handling very heavy components in a very close space environment. The construction of this large superconducting tokamak represents a big step forward in the world nuclear fusion history, opening the road for ITER and DEMO. Precise assembly is required, not only to avoid mechanical interference, but also to obtain good plasma performance by less magnetic error field. To complete this work, unique and well-considered procedures were introduced. In this paper, the developed technologies and their results are reported, focusing on the assembly of the final sector of vacuum vessel, central solenoid and in-vessel components.

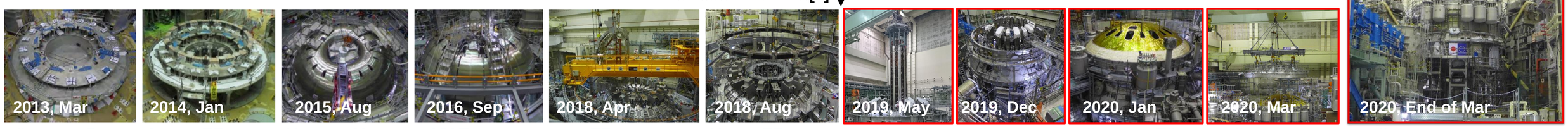
SUMMARY

- **Vacuum vessel final sector assembly**
  18 sectors of the 10m-diameter and 7m-high VV were assembled onsite by welding and the welding contraction was predicted and compensated to achieve the required high precision (typically +/-10mm and +/-20mm at the inboard and outboard walls respectively). The required tight tolerance on the positioning of the plates of the VV gravity supports with respect to the tokamak centre axis of +/-1 mm was successfully achieved.
- **Central solenoid assembly**
  Insertion of the central solenoid (CS) component was successfully done even with a minimum clearance between TFC in-bore and CS outer surfaces of 14mm by using the laser tracker measurement in real time. Finally, a precise centering of the magnetic axis within +/-1.4mm with a vertical tilt of 1.6mm was achieved.
- **In-vessel components assembly**
  For precise assembly of In-vessel components aiming to avoid unacceptable local heat load, its interface facing with the waved VV surface were precisely machined based on the VV surface measurements obtained by the laser tracker with T-probe. An accuracy of the graphite tile surface alignment within +/- 1mm has been achieved.

HISTORY OF JT-60SA CONSTRUCTION

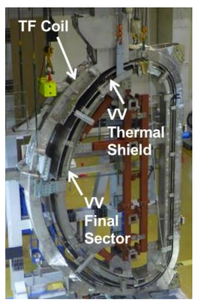
Assembly of main tokamak components started in 2013 is completed in March 2020!

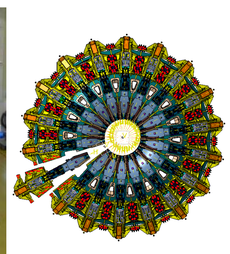
Previous IAEA FEC[1] ↓



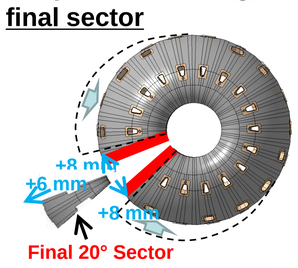
Cryostat Base | Lower EF coils | Vacuum Vessel | VV Thermal Shield | TF coils | Upper EF coils | Central Solenoid | Cryostat Body | Cryostat TS | Cryostat Top Lid | **Completion of main components**

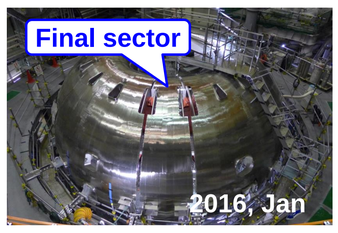
VV FINAL SECTOR ASSEMBLY [2]





Shape after welding of final sector

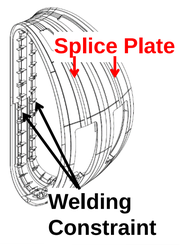


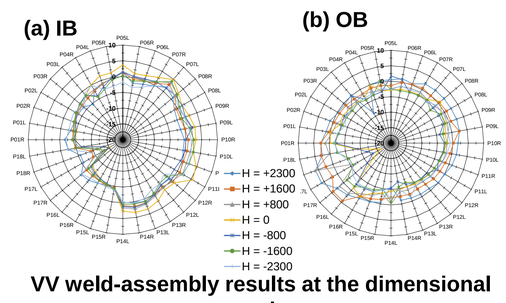


Temporary placing of final sector

- The final VV sector was pre-assembled together with the final TFC and the final VVTS in the assembly hall.
- The final VV sector was inserted into 20 degrees opening.
- The final VV sector was welded to the neighbor sectors via splice plates.

- Final sector will be set back by 6 mm in the radial position.
- Outward off-alignment of 8mm will be compensated by welding shrinkage of the final sector.

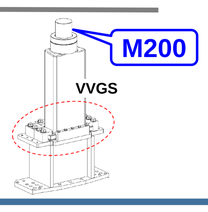




VV weld-assembly results at the dimensional error at sector generatrix
(a) the inner wall of the in-board (specified in ±10 mm).
(b) the inner wall of the out-board (specified in ±20 mm).

VV gravity supports (VVGSs)

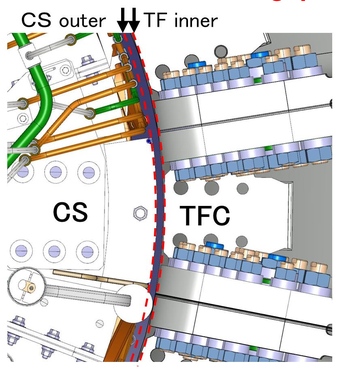
- After the welding of VV final sector, measurement of VV by the laser tracker was done to fix VVGs position.
- Based on this measurement, opened female screw for M200.
- Finally, the required tight tolerance on the positioning of the plates of the VV gravity supports with respect to the tokamak centre axis of +/-1 mm was successfully achieved.

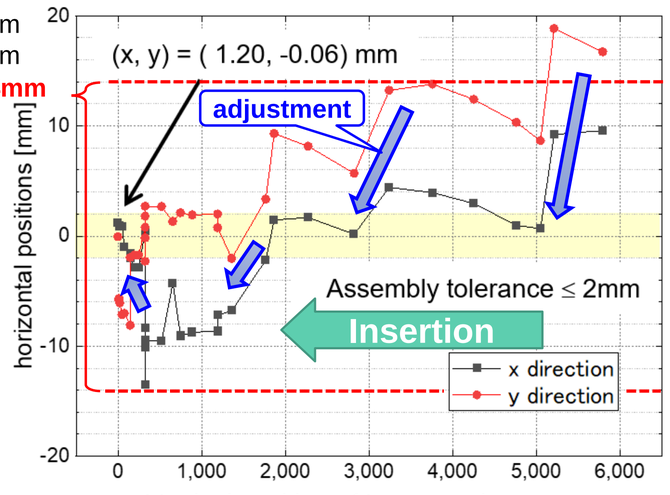


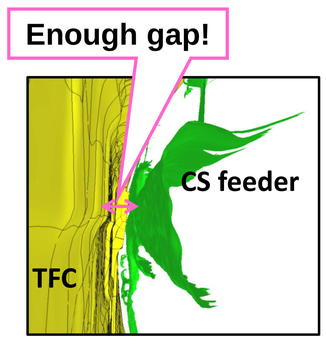
CS ASSEMBLY [3]

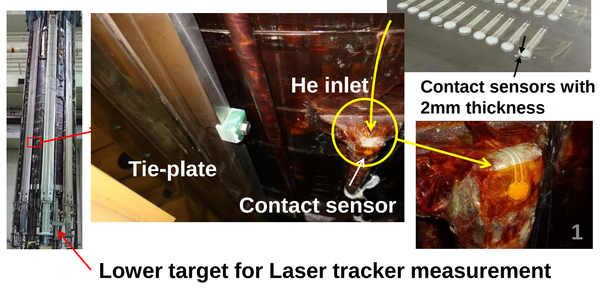
11m height/ 2.1m diameter/ ~100 tons weight

CS outer radius : 1,052 mm
TF inner radius : 1,066 mm
Minimum gap 14mm









- The vertical alignment between the top and bottom of magnetic axis was achieved within 4mm before assembly.
- CS was carefully inserted into TFC inside monitoring CS position by Laser tracker.
  ➔ horizontal position adjusted
- To detect crash between CS and TFC, 80 contact sensors were preset on He pipes/ feeders/ tie plates.
  ➔ No contact detected

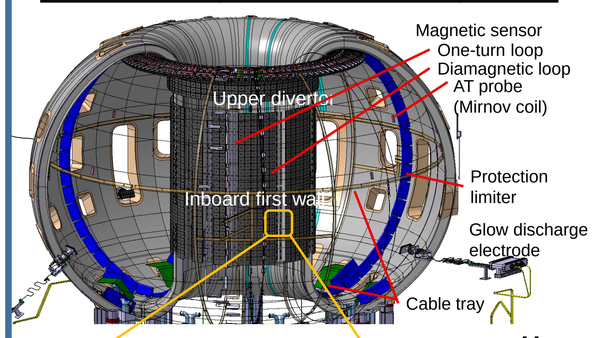
3D scanning by F4E before CS insertion provided us useful information. Enough gaps were confirmed and CS insertion was carried out with confidence.

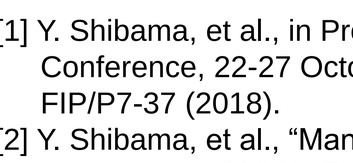
CS final position

lower center	(x,y)=(-0.21, 0.00) mm	< 2mm (requirement)
upper center	(x,y)=(1.37,-0.01) mm	< 2mm (requirement)
verticality 1.58mm (w.r.t. dz= 8,022mm)		< 2mm (requirement)
vertical error -1.2mm, toroidal error 1.0mm		< 2mm (requirement)

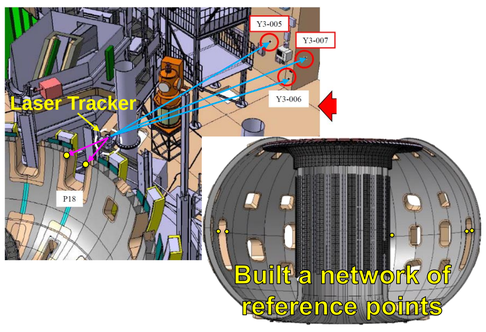
IN-VESSEL COMPONANT ASSEMBLY [4]

In-vessel Components for initial operation

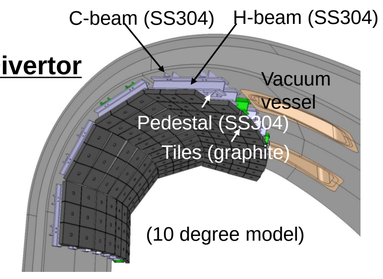




- Tiles of first wall were installed within tolerance of +/-1mm.
  ➔Hight of VV surface was adjusted by varying thickness of shims.



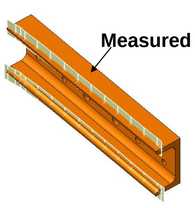
Upper Divertor

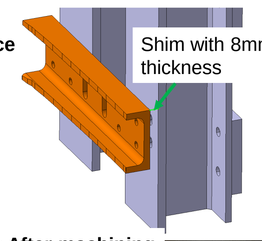


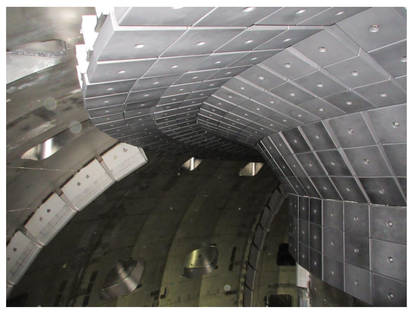
Machining of all C-beams

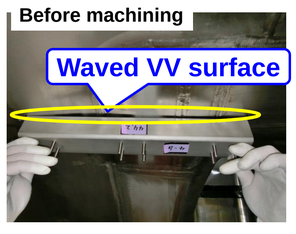
Processed all (144!!) C-beams along the measured VV surface.

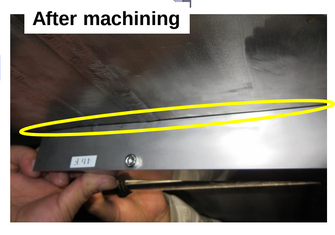
1. Measure the VV surface at the C-beams welding position with T-probe and laser tracker.
2. Put the measured surface with C-beams and H-beams in CATIA.
3. Fix the H-beam and shift the C-beams as C-beams include the measured surface and have the shim with the most thin integer thickness of 1mm to 9mm.











Successfully machined C-beams

- Gap between machined C-beams and VV surface is within 0.5mm

Accuracy of +/-1mm at the tile surface has been achieved < Requirement

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[2] Y. Shibama, et al., “Manufacturing and welding assembly of the vacuum vessel on JT-60SA”, Fusion Eng. Design 160, 111918 (2020).
[3] H. Murakami et al., "Completion of Central Solenoid for JT-60SA", IEEE Transactions on Applied Superconductivity, Vol.31, 4201005 (2021).
[4] M. Takechi et al., "In-vessel components for initial operation of JT-60SA", submitted to Fusion Eng. Design (2020).