Assembly Technologies of the 
Superconducting Tokamak on JT-60SA

FIP/4-1Ra

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JT-60SA TF Coil Manufacture, Test and Preassembly by CEA

FIP/4-1Rb

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1. Introduction of JT-60SA Construction
2. Assembly Technology
3. Application to Onsite & Sector Assembly of VV
4. Manufacturing of TF Coil
5. Summary
JT-60SA is fully superconducting machine.

- Size of JT-60SA is about half of ITER.
- The total weight is over 2600 tons.
- Structure is so complicated that a tight tolerance is required.
Process of JT-60SA Construction

Started in Jan. 2013

Cryostat Base (280 tons)

Vacuum Vessel 340° Sector (Oct. 2015)

First Plasma in 2019

Cryostat Vessel Body (220 tons)  PF Coils (185 tons)  TF Coil (370 tons)  VV Thermal Shield (28 tons)

First CEA coil #10  7.5 m
There are two major issues in manufacturing and assembling the components of JT-60SA, whose size and weight are over 10 m and 2600 tons.

1. Tight tolerances of manufacturing & assembly
   - Reduce the magnetic field error (below $10^{-4}$ B$_{\text{tor}}$)
   - Keep proper gaps between components
     - Tolerance is about 0.01% of the scales of 10 m size components, namely, less than 10 millimeter.

2. Smooth assembly without backward process

   Development of assembly technology with an efficient work process.
Development of Assembly Procedure

To realize the efficient work process, assembly technology was developed,

**Careful assessment by three-dimensional CAD**

- Development of assembly flow
- Control of gap between components.
- Design of special jigs for shape control and onsite transportation.

**Metrology for positioning with high accuracy**

- Lines of sight of the laser light are acquired to measure the position in torus hall.
- Many reference points (~80) are sets to recognize the position of laser tracker.

> Spatial resolution of measurement is less than 0.5 mm.
Cryostat Base (CB) is 260 tons and 12 m of diameter. Seven parts are manufactured in factory and assembled onsite.

Parts of CB

- Double Ring (three pieces)
- Inner Cylinder (one piece)
- Lower Structure (three pieces)

Assembly accuracy: 
~2 mm of allowable level.

Manufacturing accuracy: 
1 mm within tolerance.
Manufacturing of VV Sector

Ten sectors of vacuum Vessel (VV) were manufactured in factory and assembled onsite.

Manufacturing accuracy: ±2 mm at inboard (IB) and ±5 mm at outboard (OB) within tolerances of ±10 mm at IB and ±20 mm at OB
Prior to assembly of sector, target points for laser measurement were equipped on each sector, and then carefully set on CB with adjusting the alignment.

5 target points on IB for the position and orientation

Pre-set on cryostat base for alignment while shrinkage of 4mm / weld line is taken into account.
To avoid the accumulation of welding deformation through sequential joint of sectors, two types of welding joint are applied.

**Direct welding**

- One welding line
- Toroidal shrinkage of 4 mm.

**Welding via splice plate**

- Two welding lines
- Toroidal shrinkage of 8 mm.

- Added 30° sector
- Added 40° sector
- Added 30° sector
Mutual joint of these three sectors were done by welding via splice plates. The sequence is as follows:

- Central 120° sector is fixed and welded with two 110° sectors.
- 110° sectors were outwardly set by taking into account of 8 mm toroidal shrinkage due to the final sector welding.

- Final sector will be set back by 6 mm in the radial position.
- Outward off-alignment of 8 mm will be compensated by welding shrinkage of the final sector.
Completion of VV 340°

Accuracy of 340 degree sector: ±4 mm (IB) & +8/-2 mm (OB) within tolerance.

Assembly of VV Thermal Shield
Start: in Feb., 2016
Completion: Nov., 2016

Inside Height 6.3m
Inside Diameter 9.5m

The assembly technology for JT-60SA is expected to be applied to the ITER assembly.
Manufacturing of TF Coil procured by F4E and CEA

Outer Intercooil Structure

Top Inner Intercooil Structure

Bottom Inner Intercooil Structure

Integration

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Casing

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Coil Case

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Winding Pack

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TF coils are manufactured and tested in the inline factory to keep the high quality assurance.
Winding Pack (WP) Manufacturing

Three important processes are shown.
- Winding Pack (WP)
- Casing
- Testing

In the WP process, double pancakes were manufactured with reference frame to control the D-shape and planarity.

WP indicates an acceptable manufacturing accuracy.
- Deviation from the ideal CL in the D-shape is smaller than design tolerance. (~2 mm)
- Cross section of WP is within tolerances. 144 ±1.5 mm (T) x 342 ±1 mm (W) (design tolerance ±3 mm & ±5 mm)
Integration in Casing

Linearlity on straight leg is required to be well controlled to suppress the magnetic field error. The followings measures are taken.

WP was positioned in high accuracy in the case by using laser tracker. (Placed: -0.14 mm in X, +0.15 to +0.36 mm in Y)

Progressive counter bending applied to straight leg in order to compensate longitudinal weld shrinkages. (deformation ≈ 2 mm)

By manual transverse MAG simultaneous welding, shrinkage was < 3 mm as expected.

Twin TIG Welding was applied to enhance the efficiency of work.
Coil Machining & Acceptance Tests

To realize the designed tolerance of the distance from the center line to the interface surface, **Interface surfaces were machined.**

- Support stage by adjustable 10 points with stress free condition
- No turning over the coil

**First TF Coil was tested beginning 2016, and five TF Coils fulfilled performance requirements.**

- Room temperature test
- Cold test (Current test, etc.)

Planarity & horizontality are adjusted to ± 0.05 mm
Onsite Assembly of TF Coils

- TF Coils are aligned each other on the reference planes of lower Inner Intercoil Structure (IIS).
- This tolerance is ±1 mm in order to achieve face-to-face contact between IISs.
- IIS & Outer intercoil Structure (OIS) are jointed with neighbour coil by bolts.
Summary

• Assembly technology for JT-60SA has been developed.
  - Assembly procedure by using three-dimensional CAD
  - Metrology of the assembly by using a laser tracker
  - Welding technology by predicting welding shrinkage

• Cryostat base is assembled with allowable accuracy as low as 2 mm.

• 340° vacuum vessel is successfully assembled with allowable accuracy of ±4 mm (IB) & +8/-2 mm (OB).

• TF coils are manufactured with allowable accuracy of ±1.5 mm, and delivered to Japan.

• Assembly of TF coils starts in this December.