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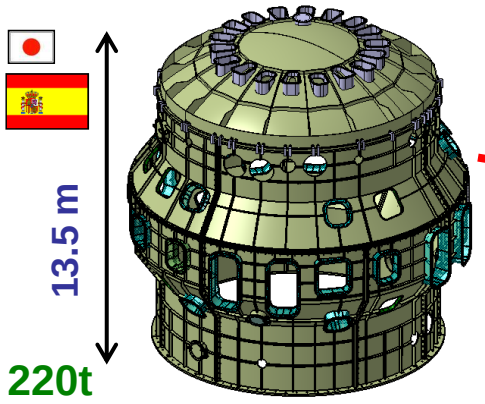
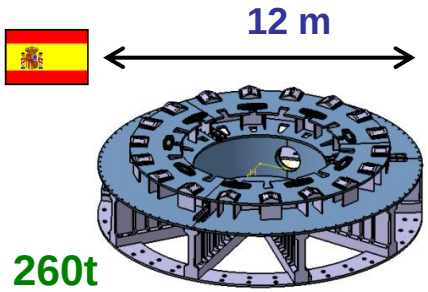
1. Introduction of JT-60SA Construction
2. Assembly Technology
3. Application to Onsite & Sector Assembly of VV
4. Manufacturing of TF Coil
5. Summary

Major Components of JT-60SA Tokamak

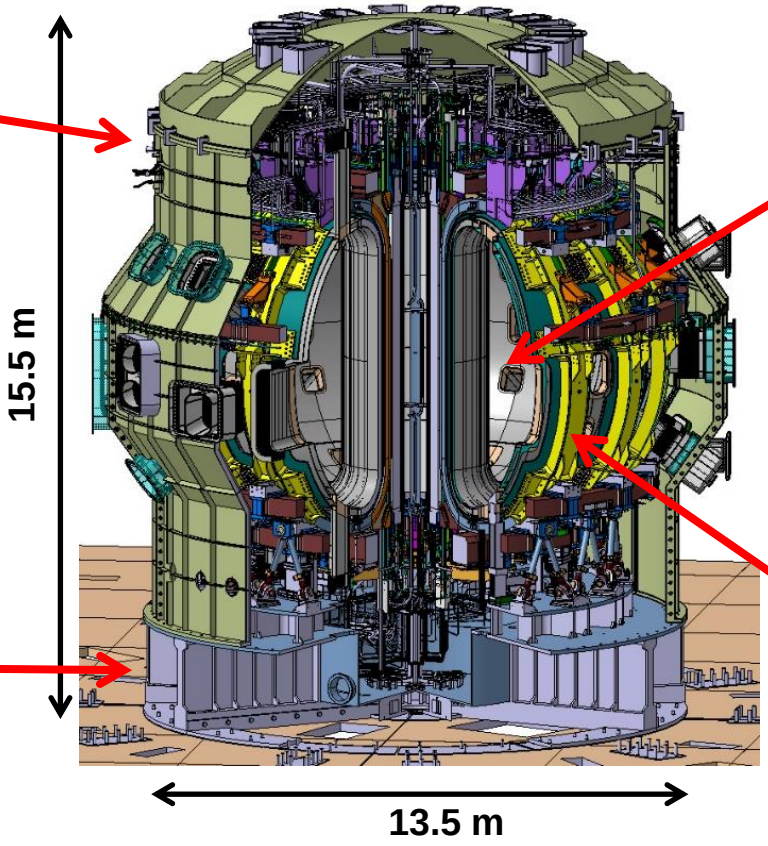
FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

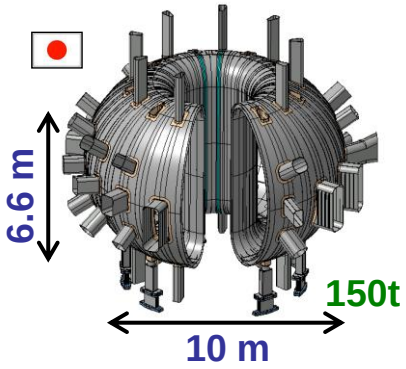


Cryostat Vessel Body

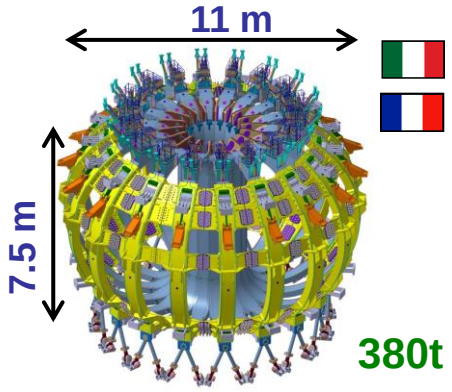


Cryostat Base





Vacuum Vessel



Toroidal Field Coils

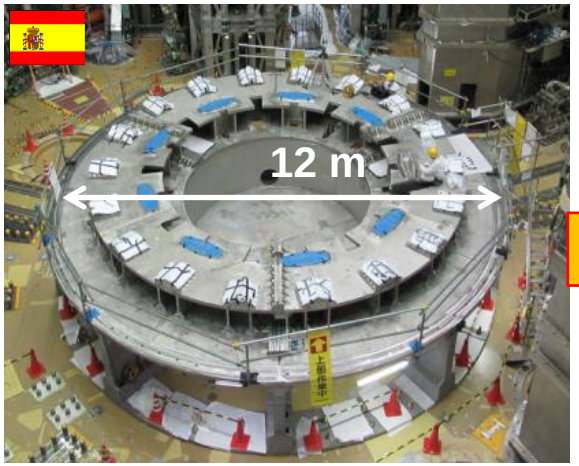
JT-60SA is fully superconducting machine.

- **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

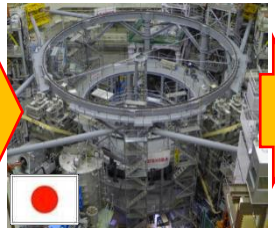
FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

Started in Jan. 2013

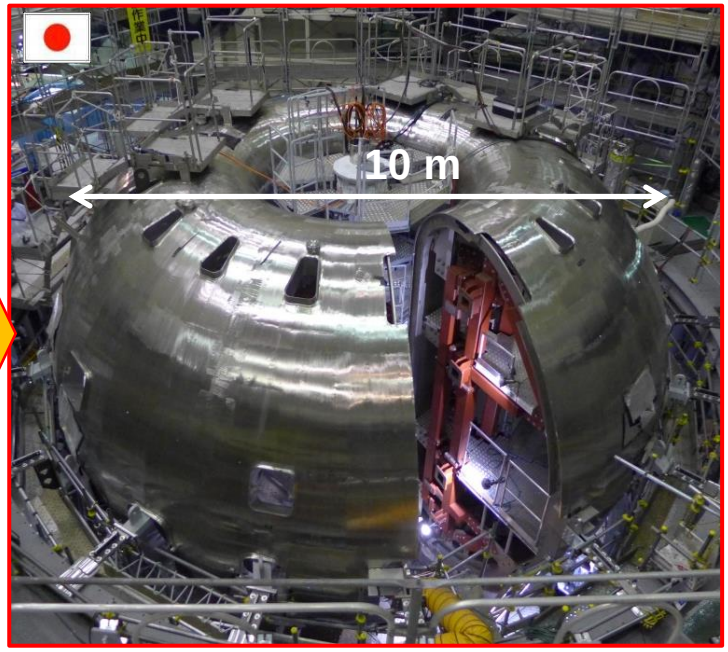


Cryostat Base
(280 tons)

Lower EF Coils
(100 tons)



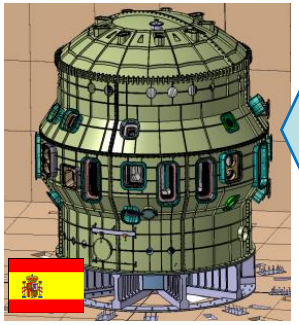
Assembly Frame



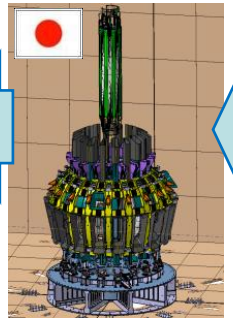
Vacuum Vessel 340° Sector
(Oct. 2015)

We are here!

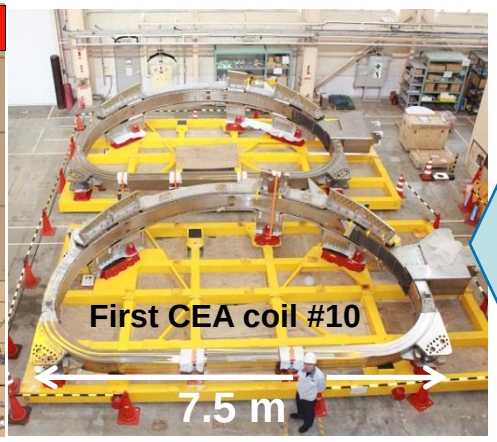
First Plasma in 2019



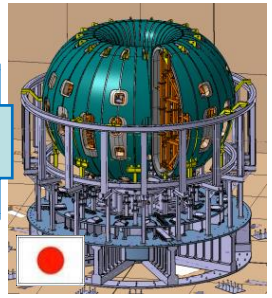
Cryostat Vessel Body
(220 tons)



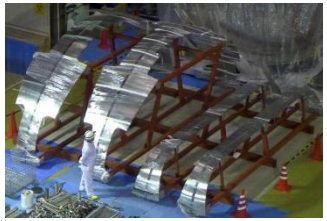
PF Coils
(185 tons)



TF Coil (370 tons)



VV Thermal Shield
(28 tons)



Key Issues in Manufacturing & Assembly

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

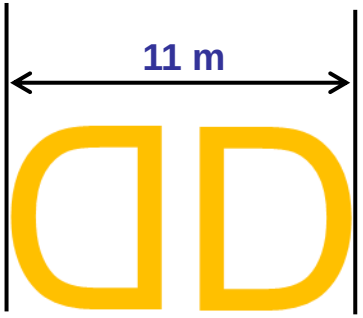
There are two major issues in manufacturing and assembling the components of JT-60SA, whose size and weight are over 10 m and 2600 tons.

1. Tight tolerances of manufacturing & assembly

- Reduce the magnetic field error (below 10^{-4} B_{tor})
- Keep proper gaps between components

> Tolerance is about 0.01% of the scales of 10 m size components, namely, less than 10 millimeter.

Schematic of TF Coil



Tolerance: 2mm

2. Smooth assembly without backward process

Development of assembly technology with an efficient assembly process.

Development of Assembly Procedure

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

To realize the tolerance & smooth assembly, assembly process 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

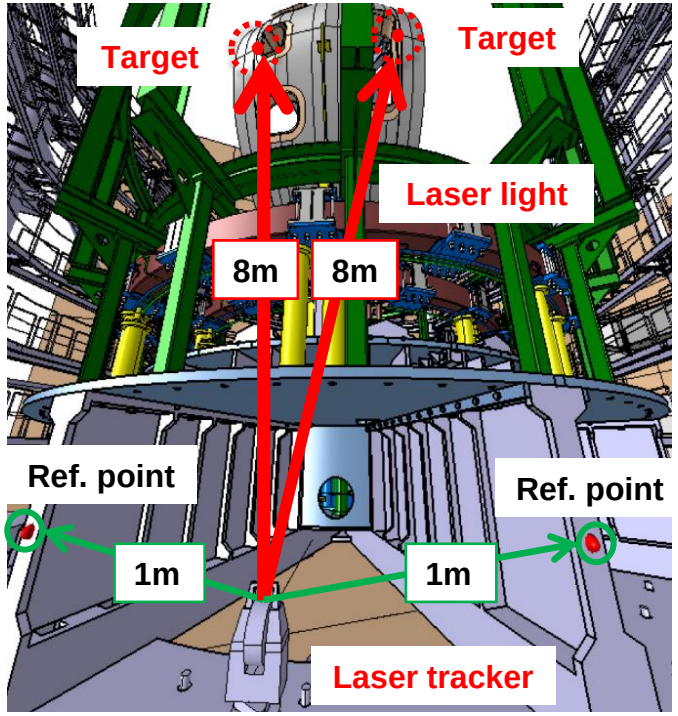
- Lines of sight of the laser light are acquired to measure the position in torus hall.
- Many reference points (~ 80) are sets to recognize the position of laser tracker.

> Spatial resolution of measurement is less than 0.5 mm.

Target Reflector

Laser Tracker

Setting of the sector of vacuum vessel



Application to Assembly of Cryostat Base

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

Cryostat Base (CB) is 260 tons and 12 m of diameter.

Seven parts are manufactured in factory and assembled onsite.

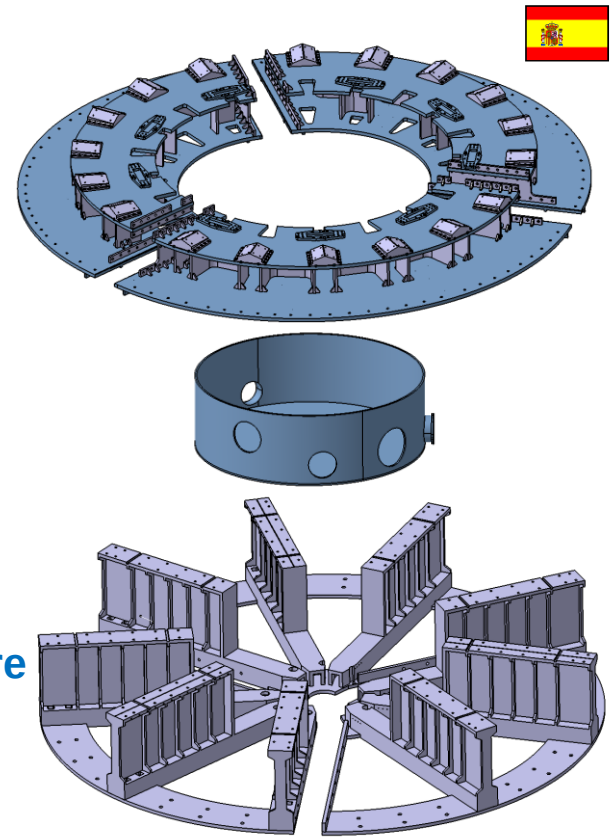
Parts of CB

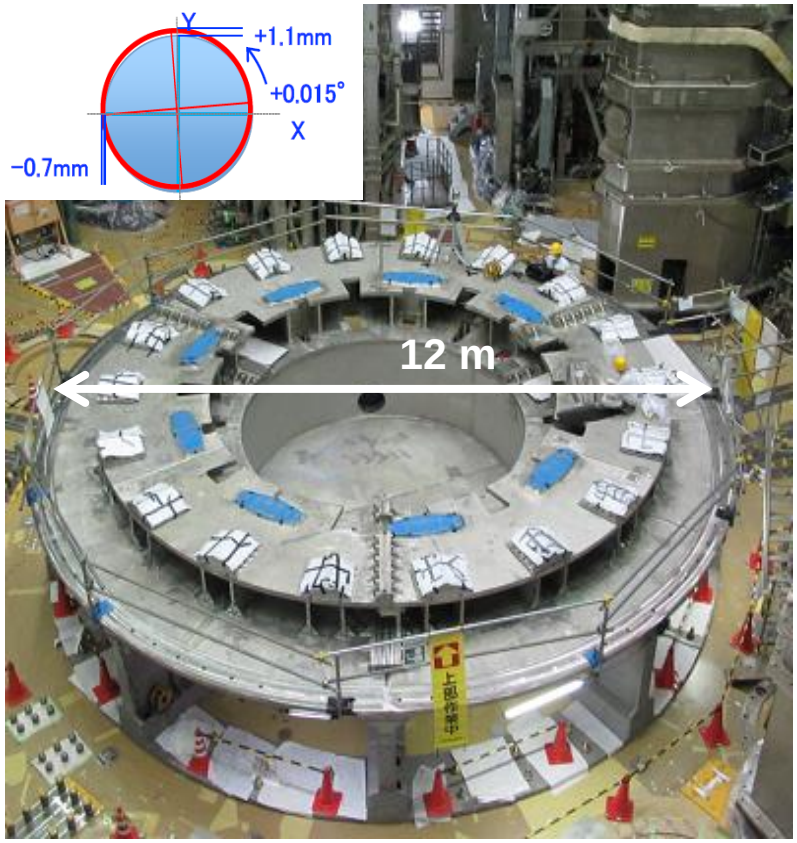
Assembly by laser metrology

Double Ring (three pieces)

Inner Cylinder (one piece)

Lower Structure (three pieces)





Manufacturing accuracy:
1 mm within tolerance.

Assembly accuracy:
~2 mm of allowable level.

Manufacturing of VV Sector

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

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

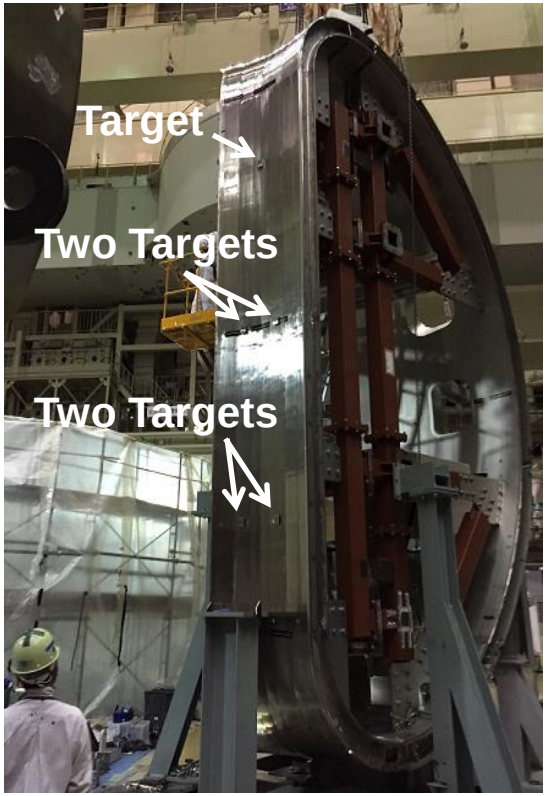
Manufacturing accuracy :±2 mm at inboard (IB) and ±5 mm at outboard (OB)
within tolerances of ±10 mm at IB and ±20 mm at OB

Positioning & Alignment of VV Sector

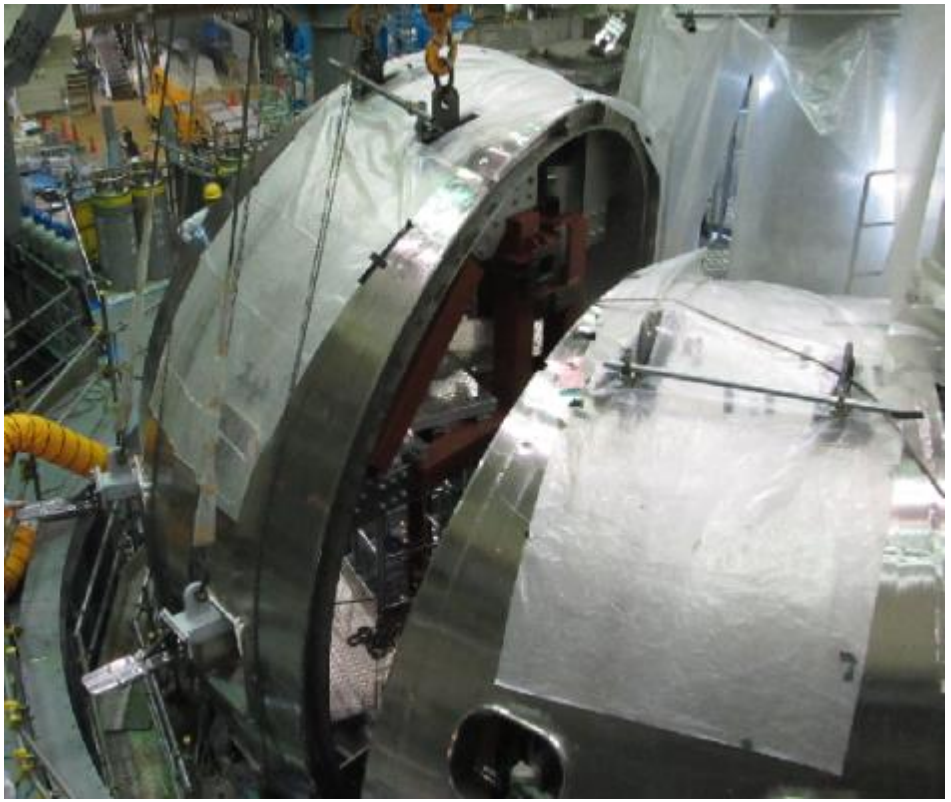
FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

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.

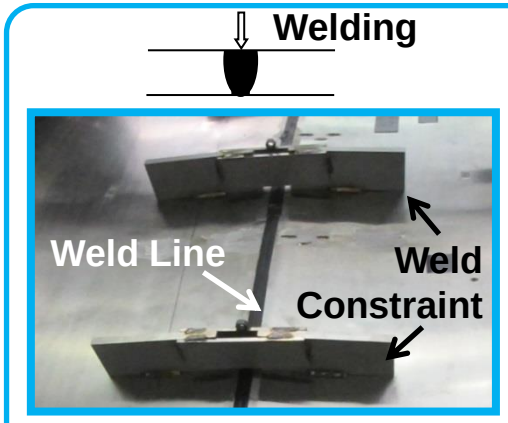


Suppress Weld Deformation by Prediction

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

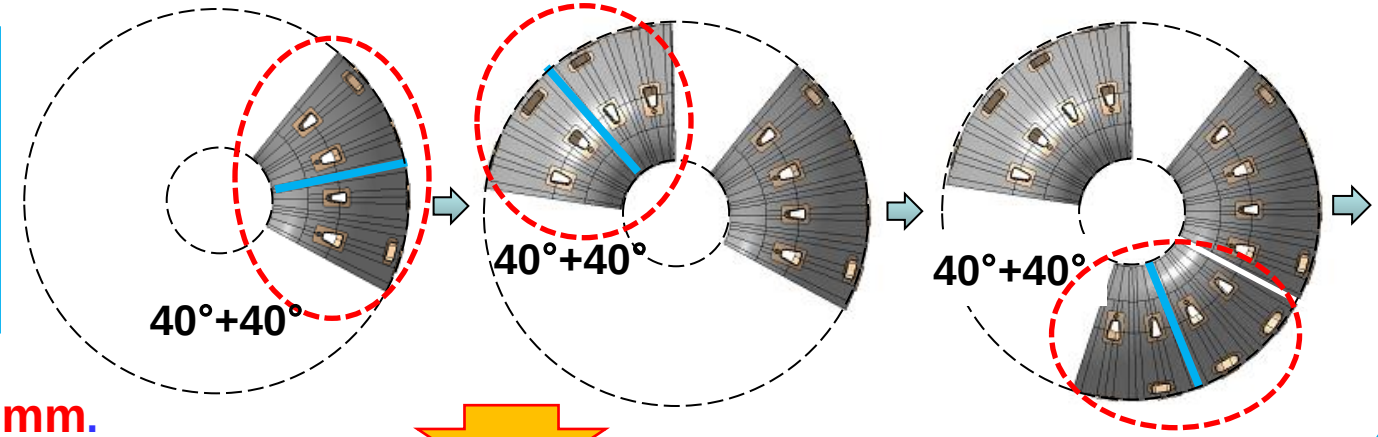
To avoid the accumulation of welding deformation through sequential joint of sectors, two types of welding joint are applied.

Direct welding

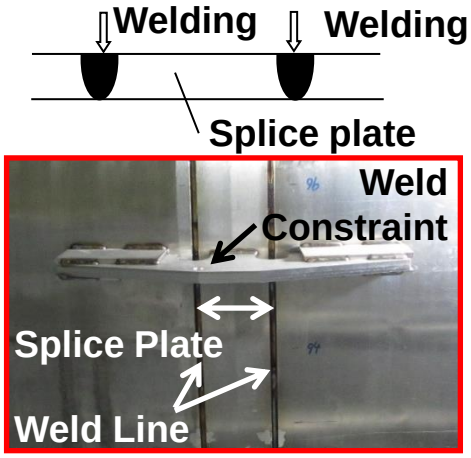


One welding line

Toroidal shrinkage of 4 mm.

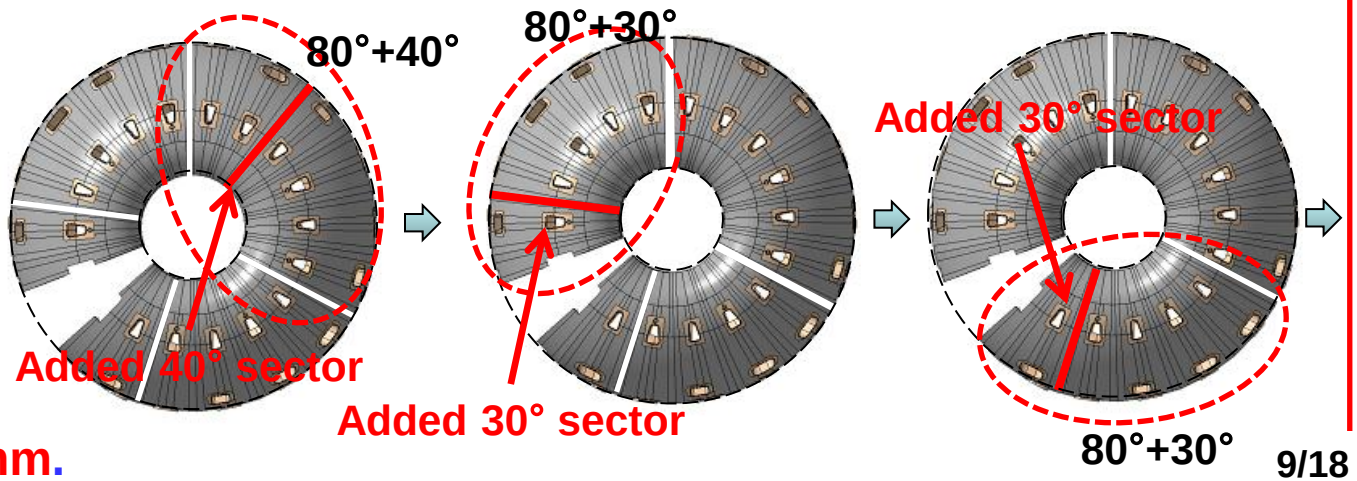


Welding via splice plate



Two welding lines

Toroidal shrinkage of 8 mm.



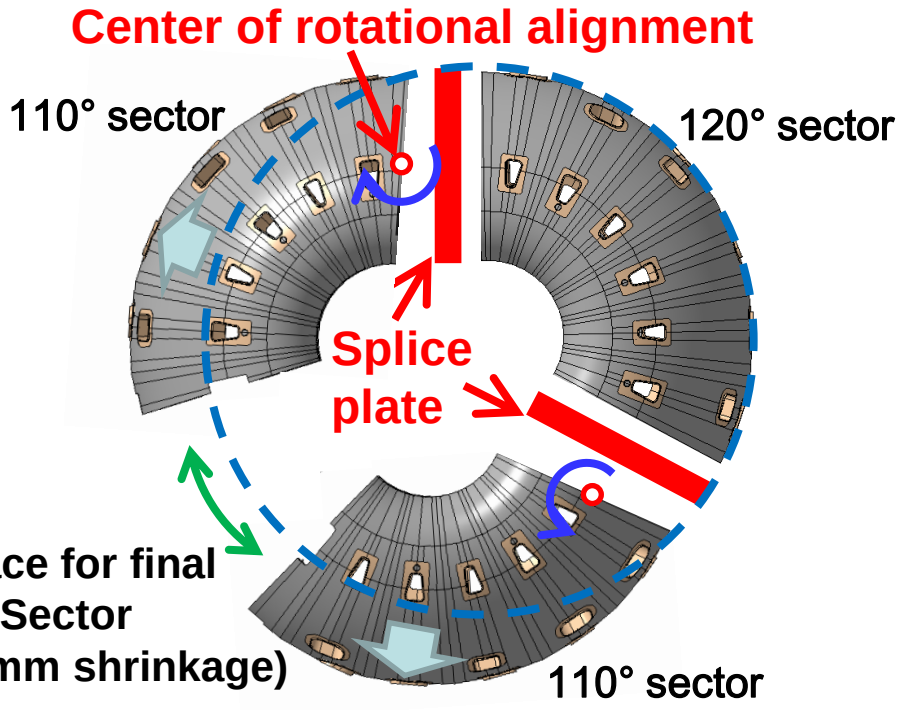
Welding Design for Final Sector Assembly

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

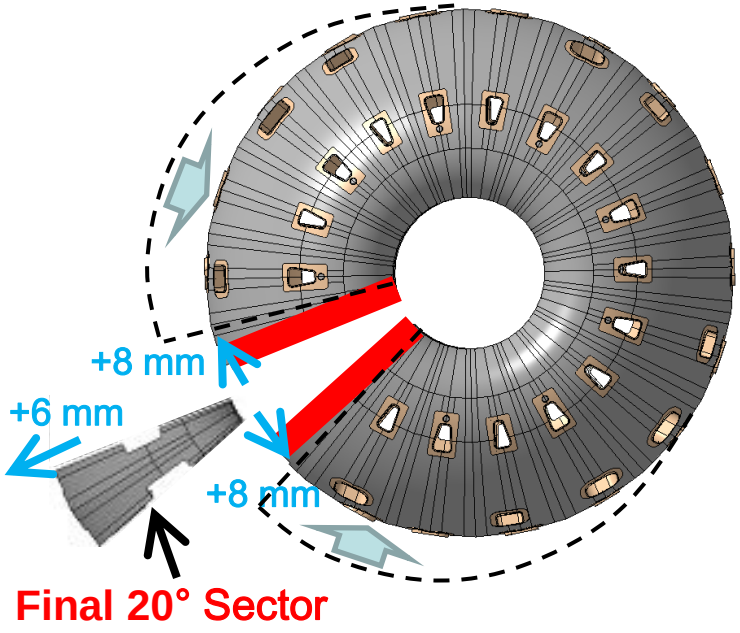
Three large sectors were mutually jointed by welding via splice plates.
The sequence is as follows:

- 120° sector as center is fixed and then 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 8mm will be compensated by welding shrinkage of the final sector.

Set of two 110° sectors



Shape after welding of final sector



Completion of VV 340°

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

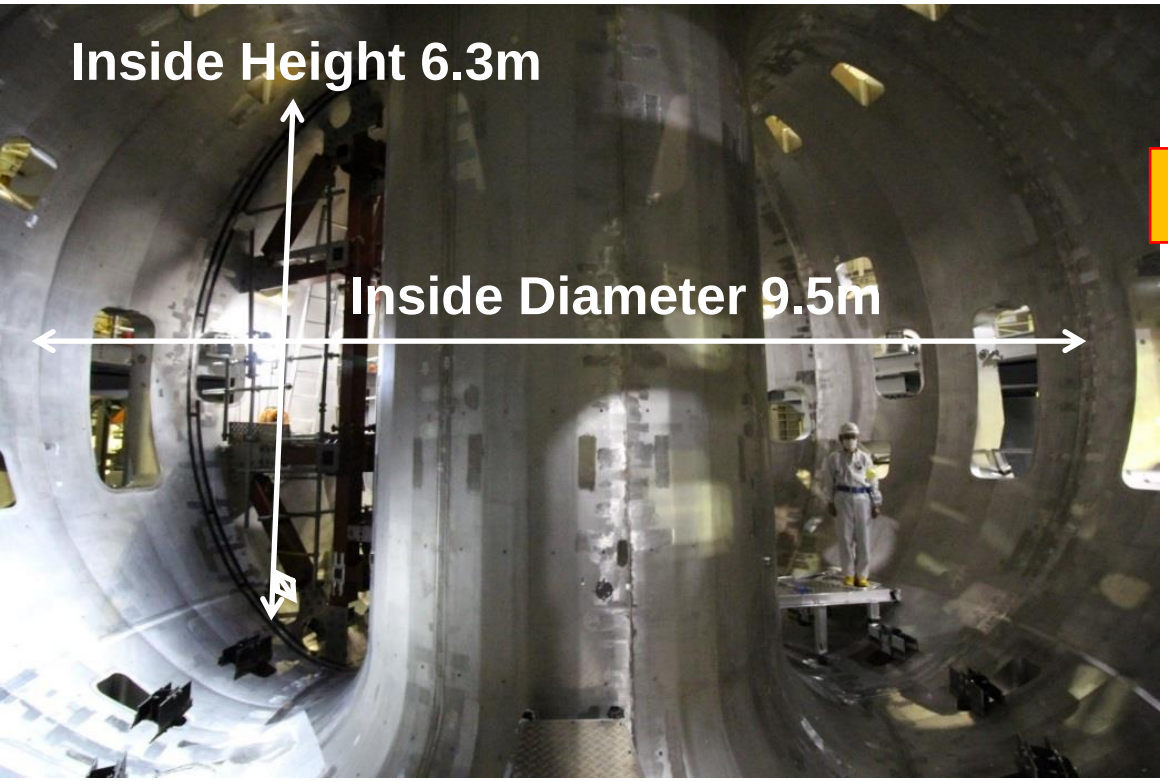
Accuracy of 340 degree sector:
±4 mm (IB) & +8/-2 mm (OB) within tolerance.

Assembly of VV Thermal Shield

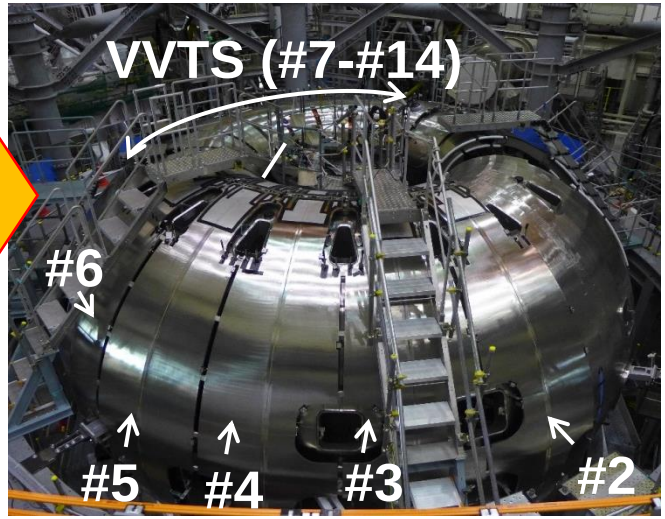
Start: in Feb., 2016

Completion: Nov., 2016

Inside Vacuum Vessel



VV Thermal Shield Assembly

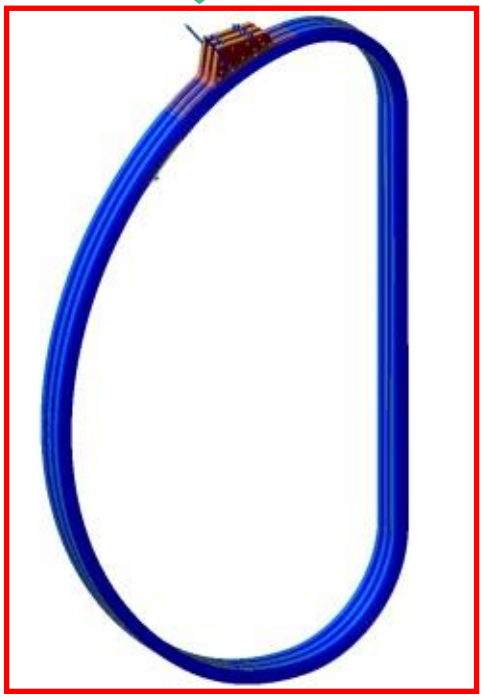


The assembly technology for JT-60SA is expected to be applied to the ITER assembly.

Manufacturing of TF Coil procured by F4E and CEA

NbTi strand Conductor

ENEA (ICAS)



Winding Pack

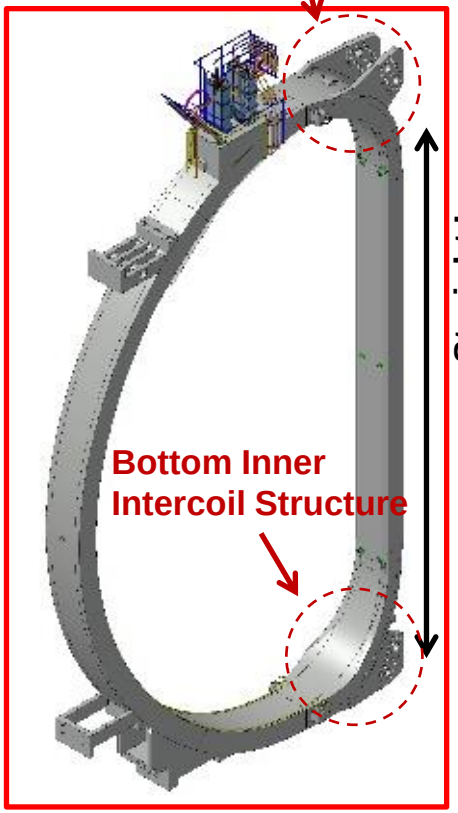
CEA (GE) ENEA (ASG)

Coil Case

ENEA (Walter Tosto)

Casing

CEA (GE) ENEA (ASG)



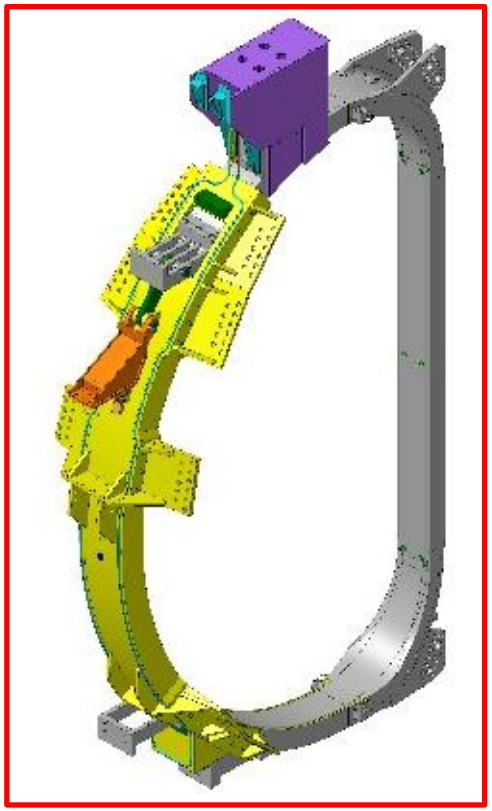
Outer Intercoil Structure

CEA (SDMS)

Acceptance Test

Integration

CEA (GE) ENEA (ASG)



TFC Manufacturing Workshop by CEA

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

Workstation 12
Packing &
Expedition

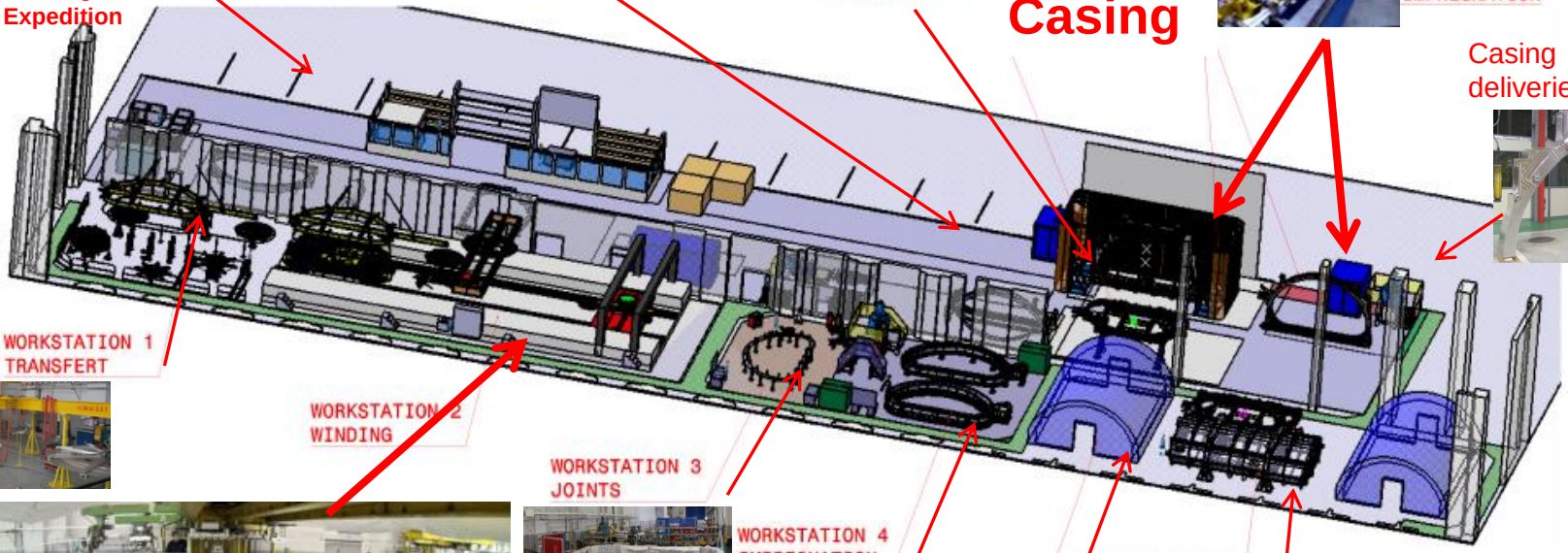
Workstation 10 & 11
Control & Piping

WORKSTATION 7
TRANSFERT

Casing

IMPREGNATION

Casing
deliveries



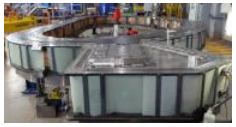
WORKSTATION 1
TRANSFERT

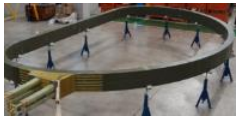
WORKSTATION 2
WINDING

WORKSTATION 3
JOINTS

WORKSTATION 4
IMPREGNATION

WORKSTATION 5
INSULATION COIL





WORKSTATION
PASCHEN TEST

Winding Pack

Testing

TF coils are manufactured and tested in the inline factory to keep the high quality assurance.

Winding Pack (WP) Manufacturing

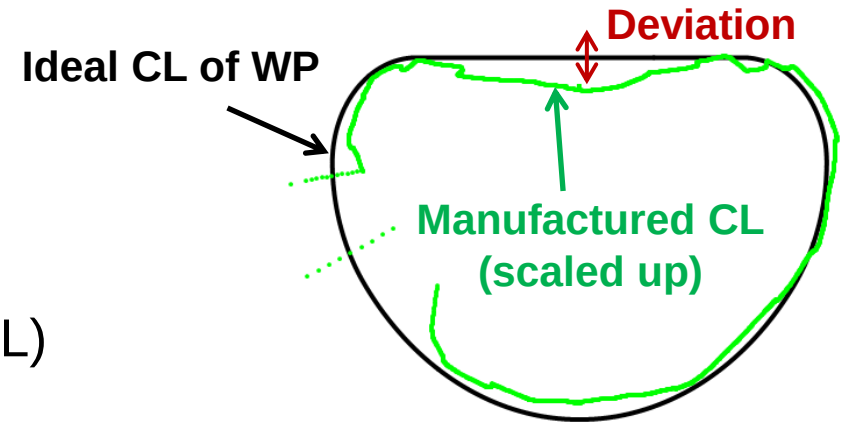
FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

Three important process are shown.

- **Winding Pack (WP)**
- **Casing**
- **Test**

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

Winding controlled in D-shape & planarity



WP was manufactured in acceptable accuracy.

- Deviation from the ideal Center Line (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

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

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

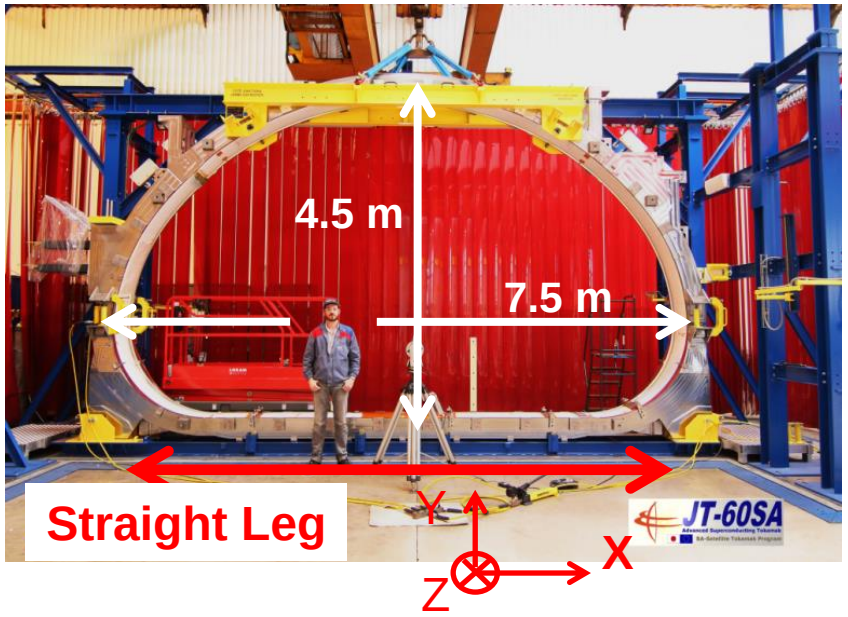
WP was positioined in high accuracy in the case by using laser tracker.
(Placed: -0.14 mm in X, +0.15 to +0.36 mm in Y)

Progressive counter bending was 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.

TIG twin heads robot was applied to enhance the efficiency of work.

Coil Case from F4E



Longitudinal welding by TIG twin heads

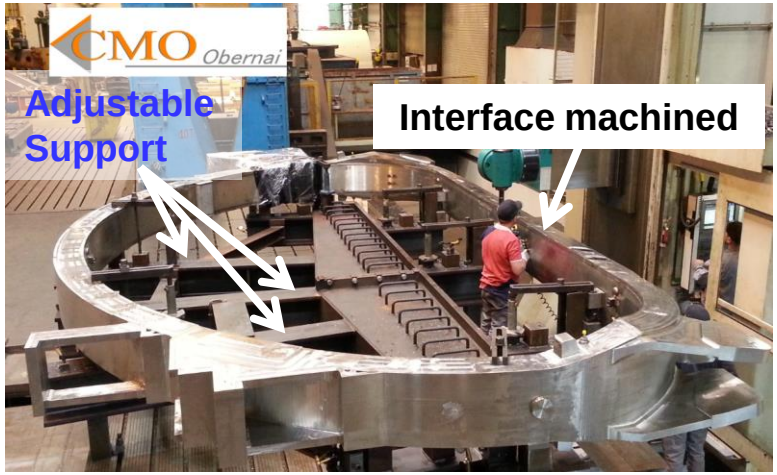
Coil Machining & Acceptance Tests

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

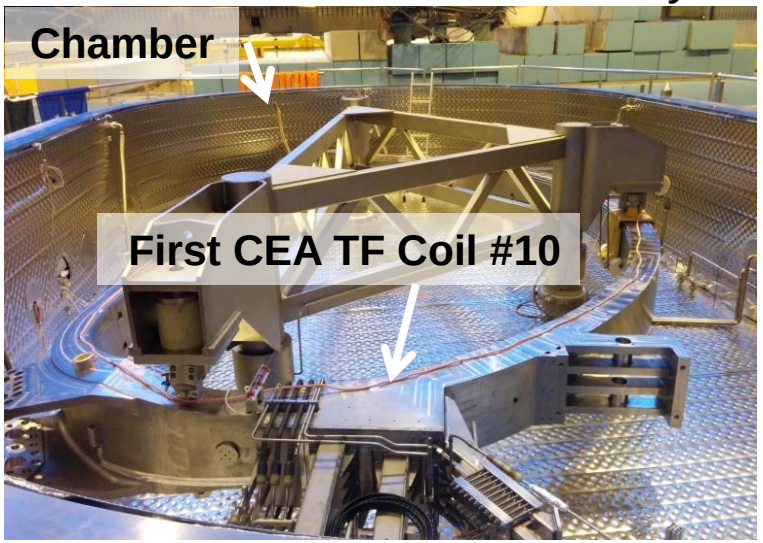
To realize the designed tolerance of the distance from the center line to the interface surface,
Interface surfaces were machined.

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

Planarity & horizontality are adjusted to ± 0.05 mm



First Coil in Cold Test Facility



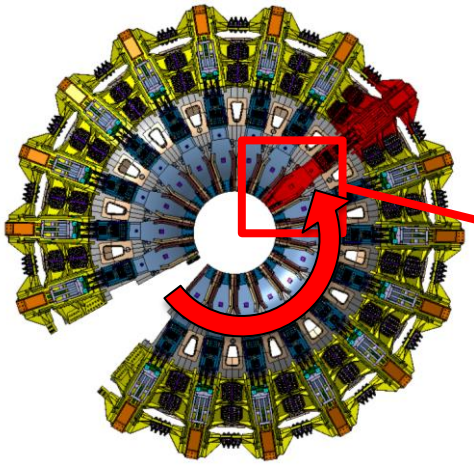
First TF Coil was tested beginning 2016, and five TF Coils fulfilled performance requirements.

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

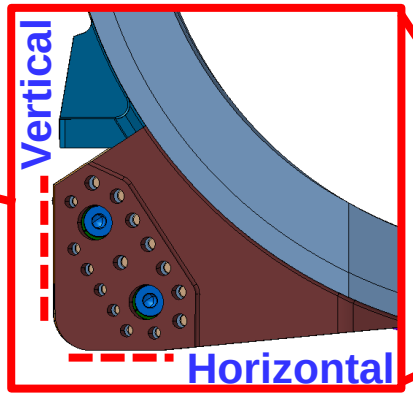
Onsite Assembly of TF Coils

FIP/4-1Ra
Y.Shibama
FIP/4-1Rb
P.Decool

- **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 neibour coil by bolts.**



Position of first coil



Lower IIS ref. planes

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.**