MITSUBISHI ELECTRIC
Changes for the Better

ITER/BA成果報告会2018

核融合炉用大型超伝導コイルを作って判った技術ポイント

Fabrication results provide progress
in large scale superconducting magnets for fusion reactor

三菱電機株式会社

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Contents

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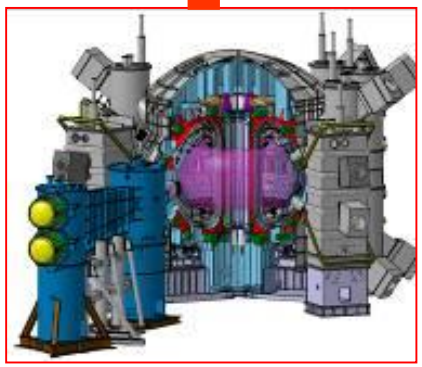
Contribution to SC magnets

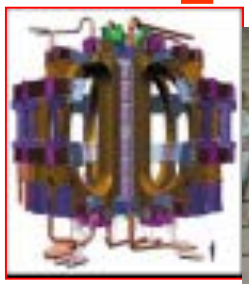
1960 | 1980 | 1990 | 2000 | 2005 | 2008 | 2010 | 2018

JFT-2M (常電導)
Normal conduction
Complete 1983

ITER R&D CS Insert Coil
Complete 1999



JT-60SA EF,CS Coil
Start 2009.2



ITER TF Coil
Start 2012.8

Fusion

Muon Channel (Univ. of Tokyo)
Complete 1979

VENUS (KEK)
Complete 1985

SC Ring Cyclotron (Riken)
Complete 2006

Neutrino Beam Line (KEK)
Complete 2007

Accelerator

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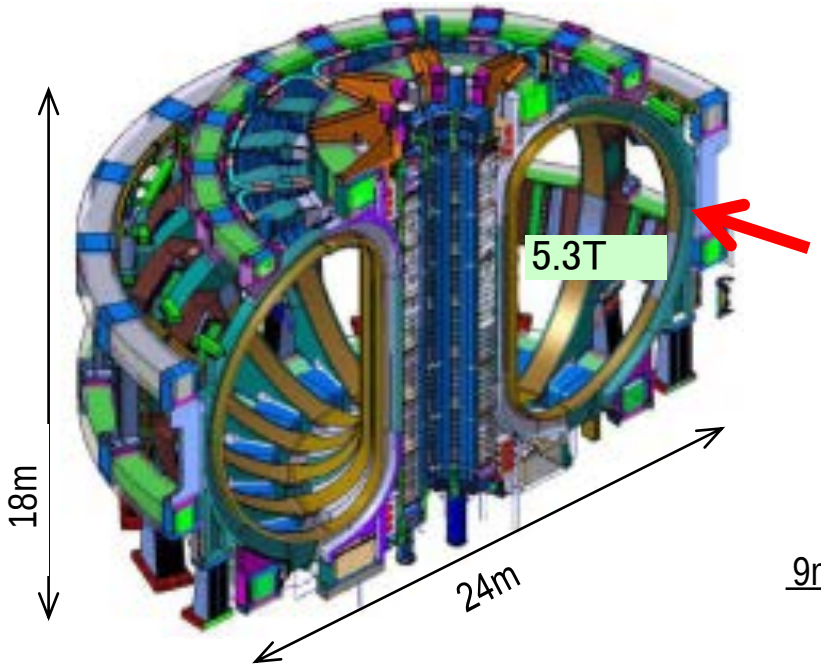
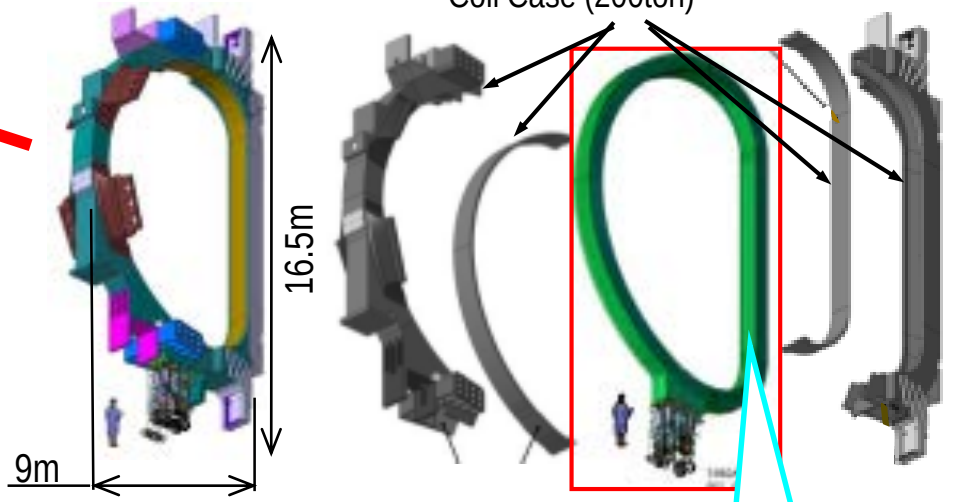
Structure of ITER TF coil

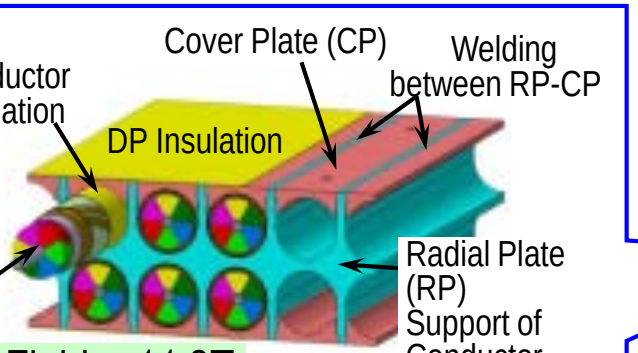
ITER magnet system

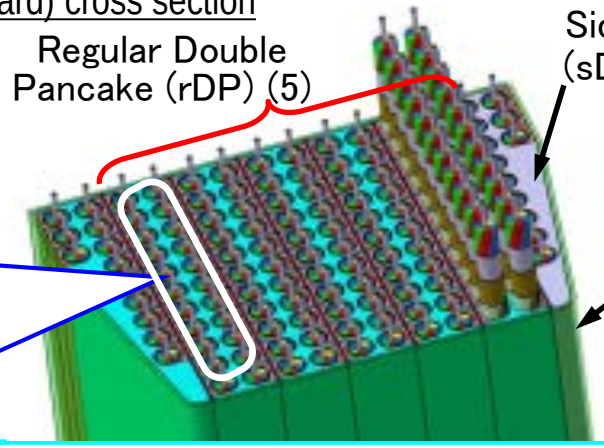


Toroidal field (TF) coil
(A large scale superconducting magnets for fusion reactor)



Winding Pack (inboard) cross section





Rated Magnetic Field = 11.8T
Rated Current = 68kA

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Requirement for ITER TF coil

ITER : Energy extraction from Fusion reaction

ITER TF coil

Large current

Super Conductor
(High current density,
Small power loss)

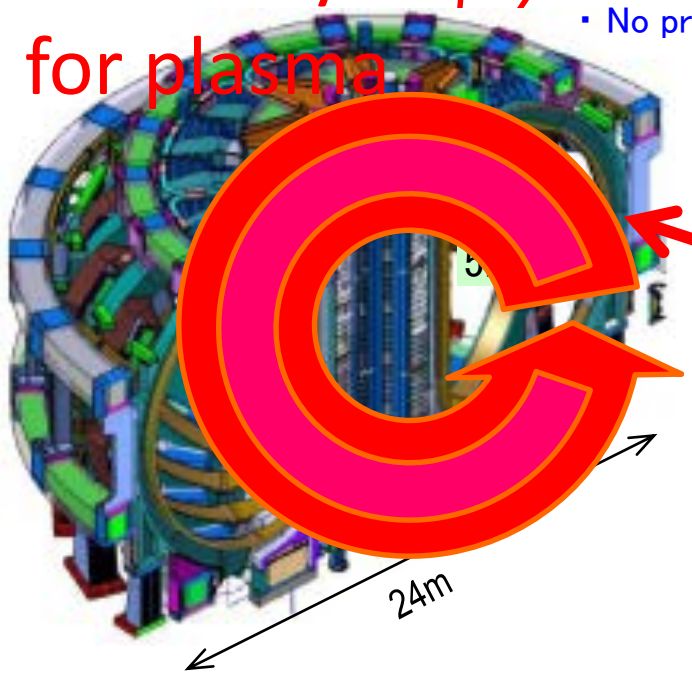
High magnetic field

Accuracy
assembly
for plasma

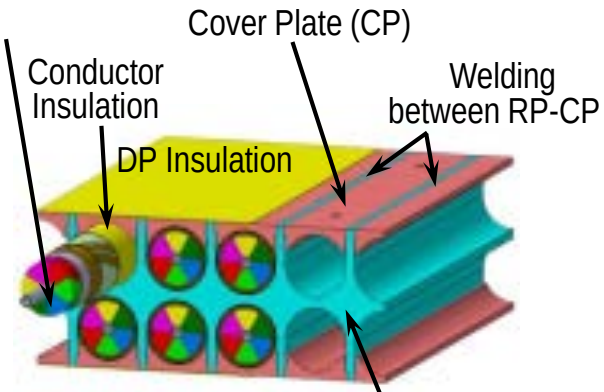
TF conductor(Nb_3Sn)

Rated Magnetic Field = 11.8T
Rated Current = 68kA

- Need heat treatment
- No processing after heat treatment



Accuracy ～mm



Radial plate
Reinforcement for
conductor

Strong electro
magnetic force

Mechanical
strength

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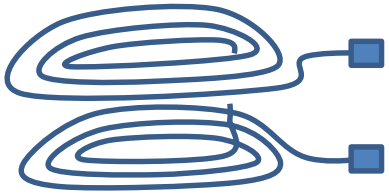
Manufacturing Process

Overview

Winding

Winding for Double pancake（DP）



Heat treatment

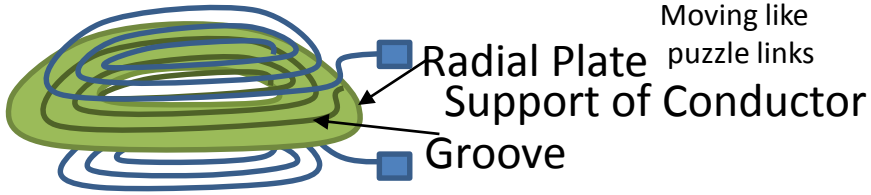
Phase formation of Superconductor

Subsequent process:

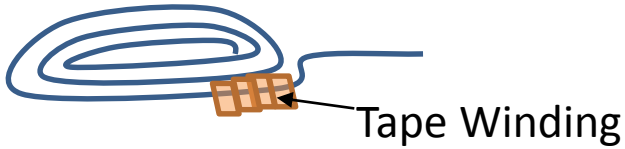
Acceptable distortion ≤ 0.1%

Transfer

Conductor into Groove of Radial Plate



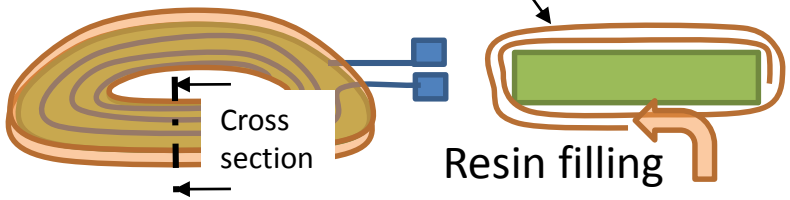
Conductor Insulation



DP Impregnation（155℃）

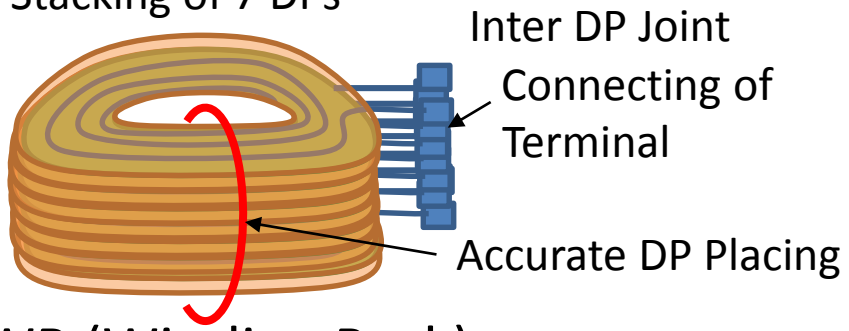
Insulation, Resin impregnation, Cure of Radial Plate holding Conductor

Stackable geometry　Insulation taping



DP Stacking

Stacking of 7 DPs



WP (Winding Pack) Impregnation（155℃）

Insulation, Resin impregnation, Cure of Stacked DPs

WP Cold Test（-196℃）

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Manufacturing Process（Winding）

- Automated forming with winding head
- High accuracy winding：

  conductor circumference control 34m ±2mm

  （Temperature difference order of 10 K）

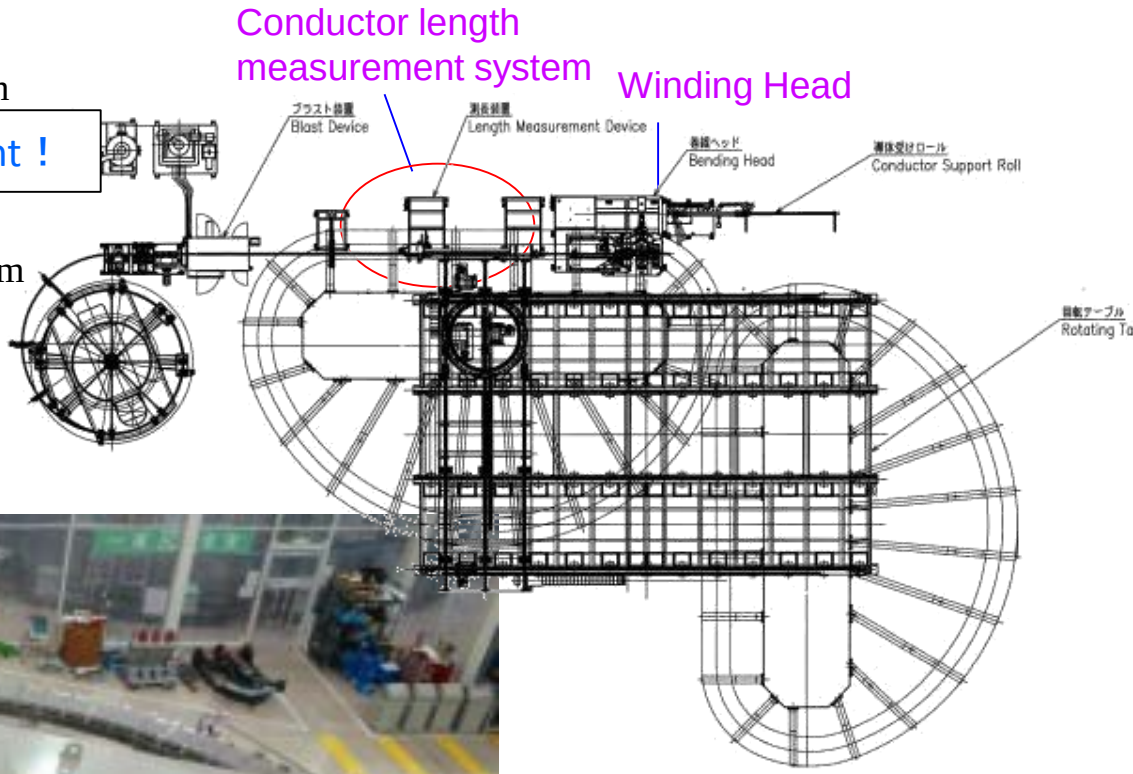
  Because of inserting to groove

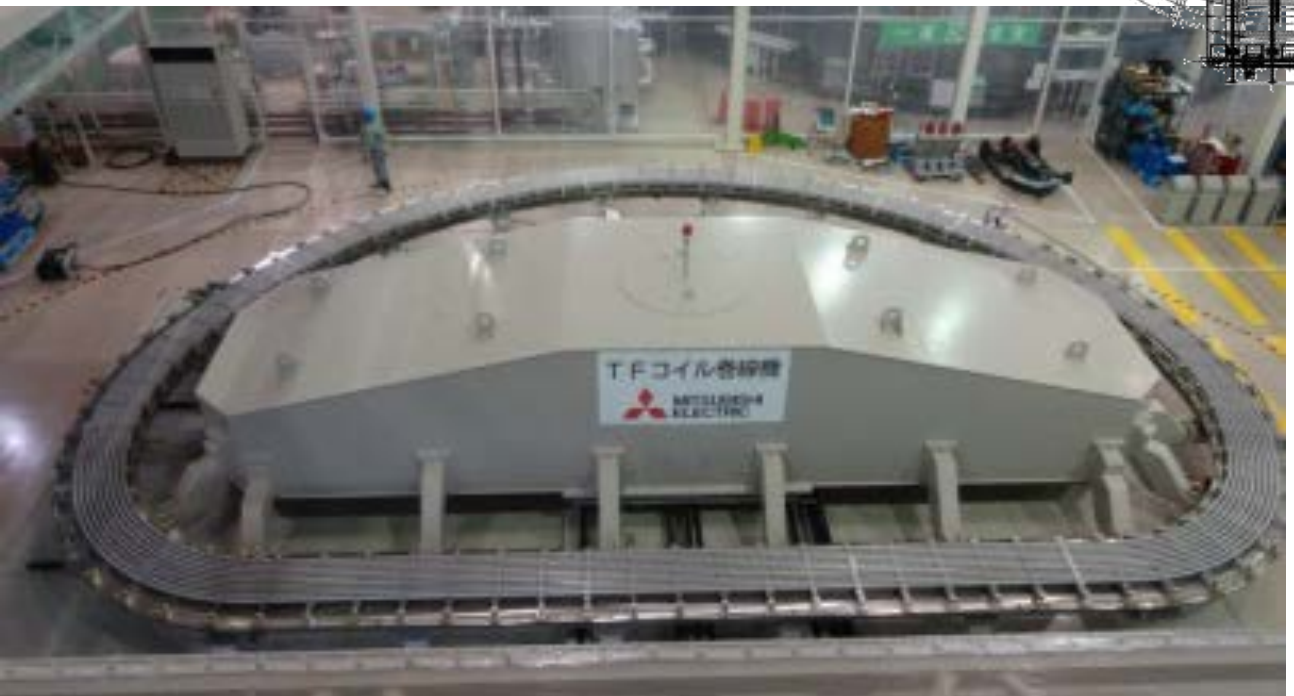
Point！

- Accuracy of conductor length measurement 0.1mm

  Laser Tracker.

  Length Measurement Device





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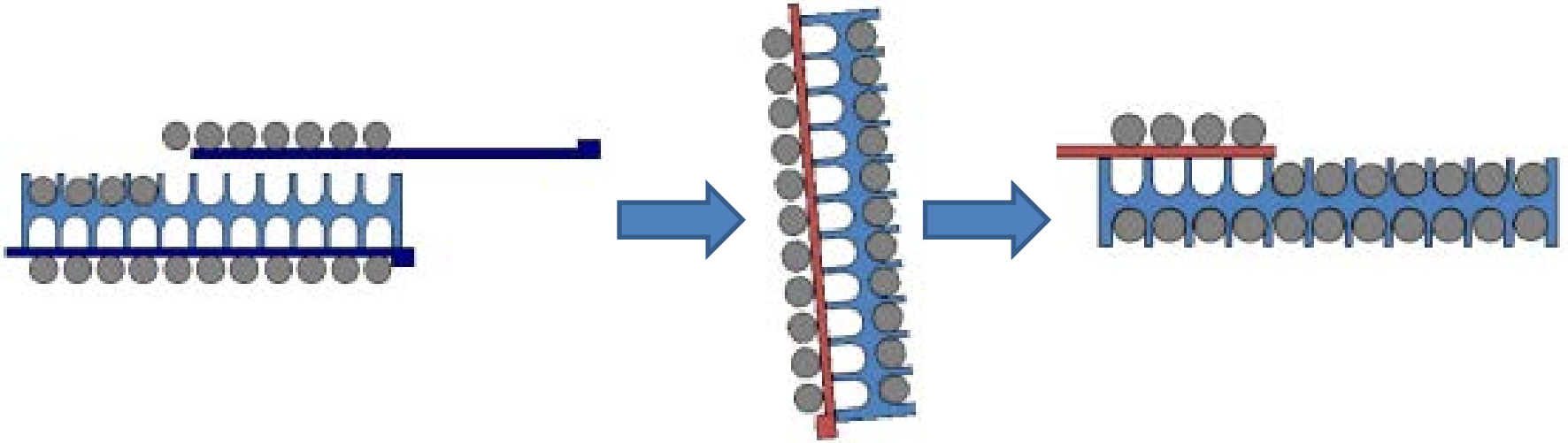
Manufacturing Process（Transfer）



Point ！

Acceptable coil distortion < 0.1%

Layer transition part of conductor

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Manufacturing Process（Conductor insulation）

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Manufacturing Process（DP impregnation）

Result of flatness measurement of the impregnated dummy DP.

The flatness of 2 mm was achieved. Point !

Weight 14t

⇒Following process: Stacking seven DPs

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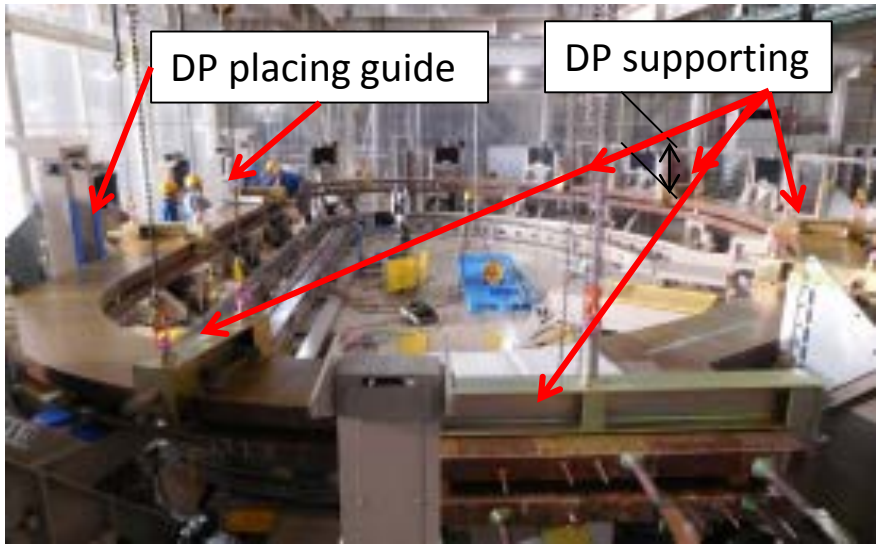
Manufacturing Process（DP stacking）

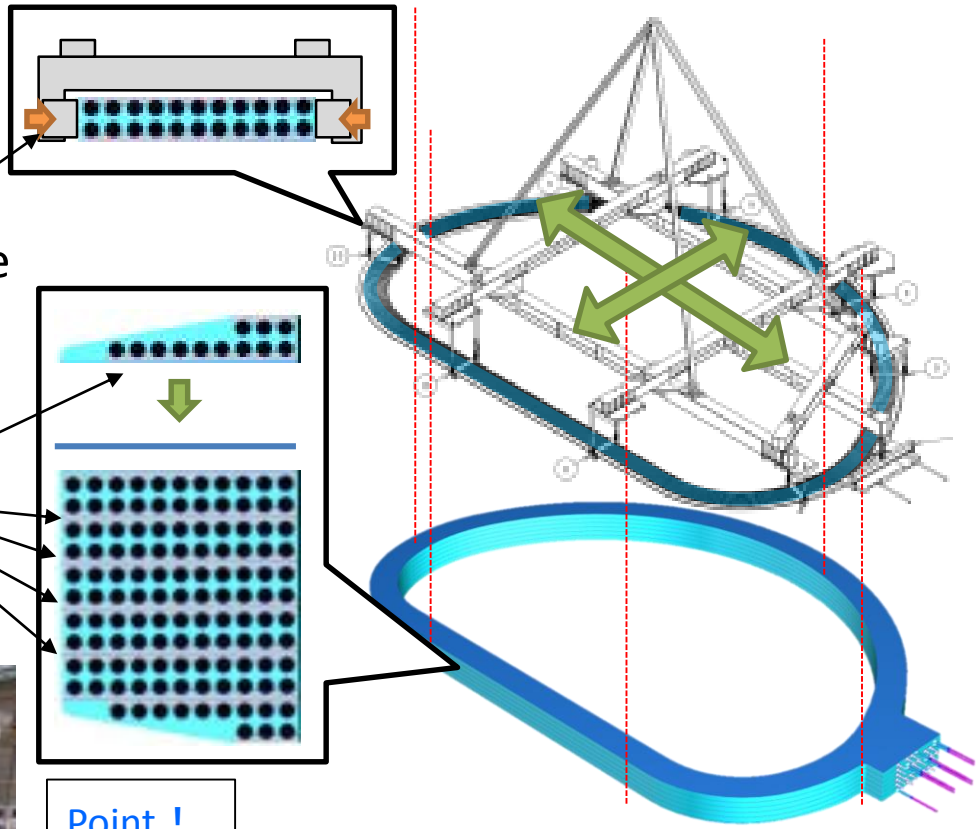
Stacking of
seven completed DPs

DP supporting by friction force

No gap between DPs

No support under DPs





Point ！

Height of suspension points
controlled within 10mm
Thickness of 120 mm
but deformation occur
0.1mm: DP placing control accuracy

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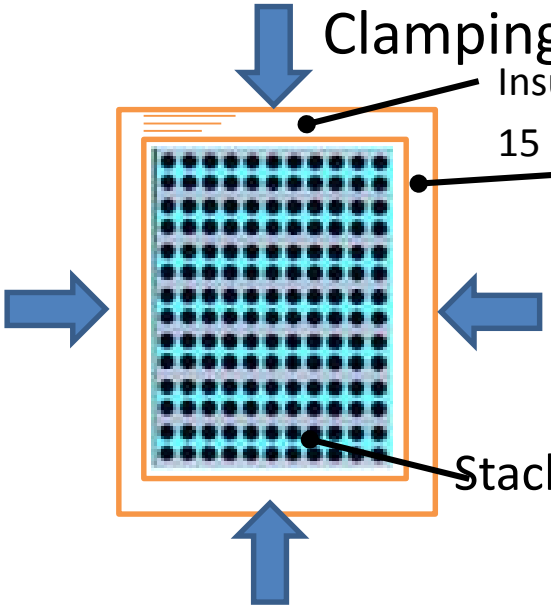
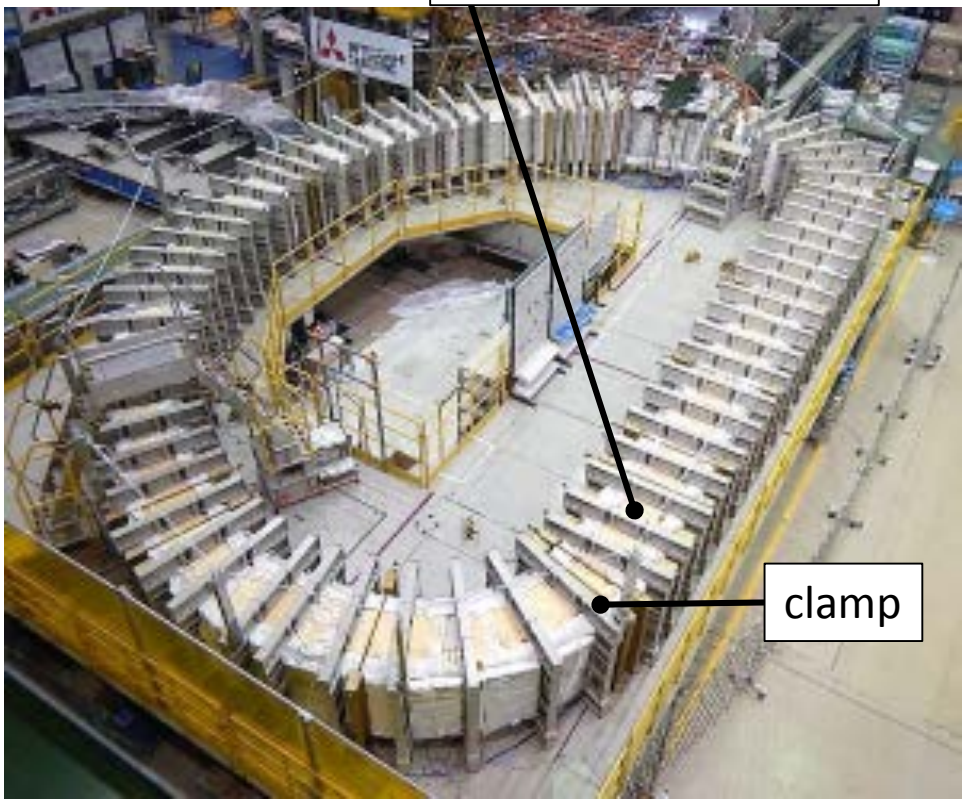
Manufacturing Process（WP impregnation）

Mechanical press⇒High accuracy outer dimension of WP



Point ！

Impregnation vessel
Engineering for
thermal expansion
Sliding on support

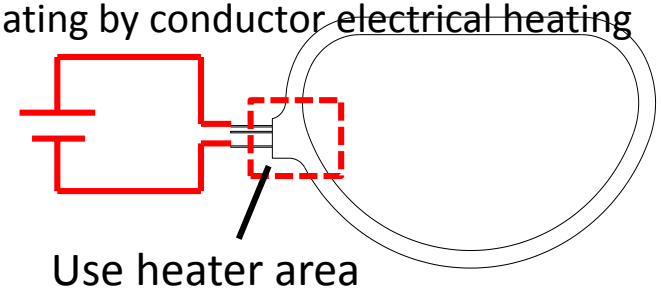


Temperature control in curing process

（Small temperature difference

(155^{+5}_{-10}℃)）

Heating by conductor ~~electrical heating~~



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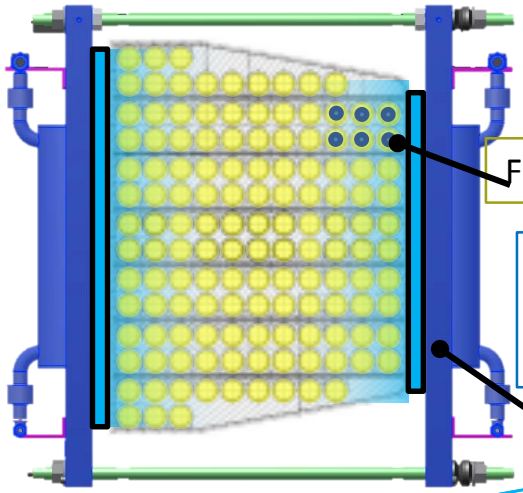
Manufacturing Process（Cold test）

WP（100t）was cooled to around -196℃ (LN temperature) in small temperature difference (50K)
Duration：24 Days



Cooling method⇒Media：-Liquid nitrogen(LN)
–Temperature controlled gas nitrogen,
Huge cryostat

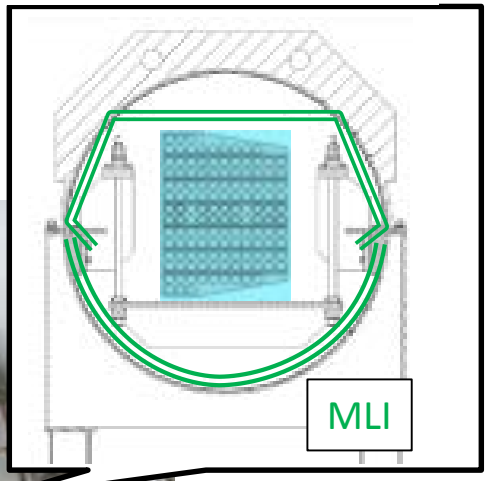
Flow media into conductor

Thermal conduction cooling jig on surface of WP
（Control storage LN）

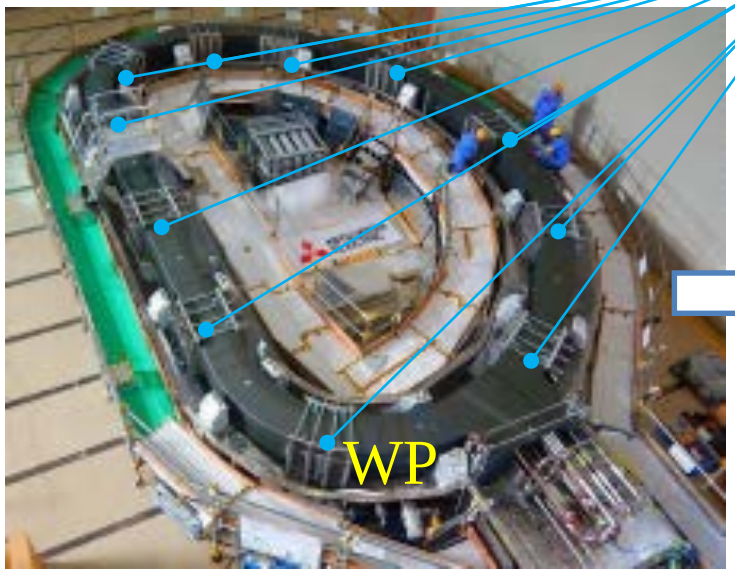
Thermal conduction cooling jig

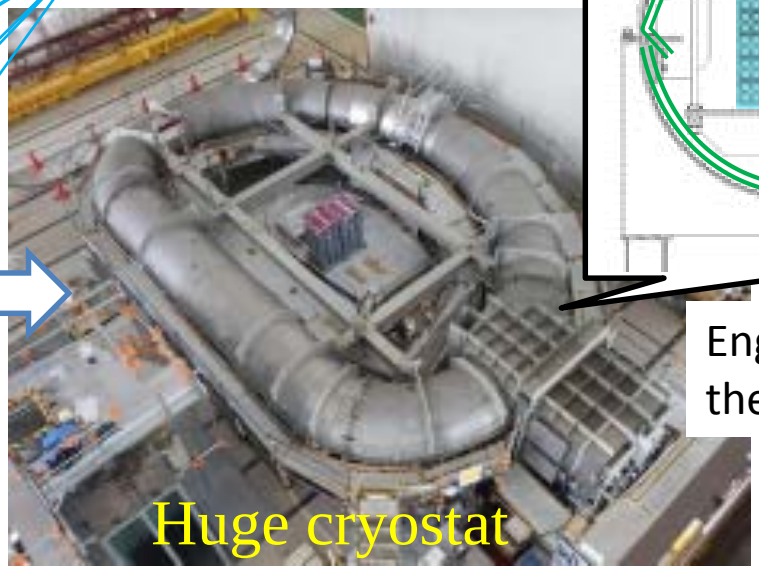
Point ！

Hanging WP
Engineering for thermal shrinkage



Engineering for thermal shrinkage





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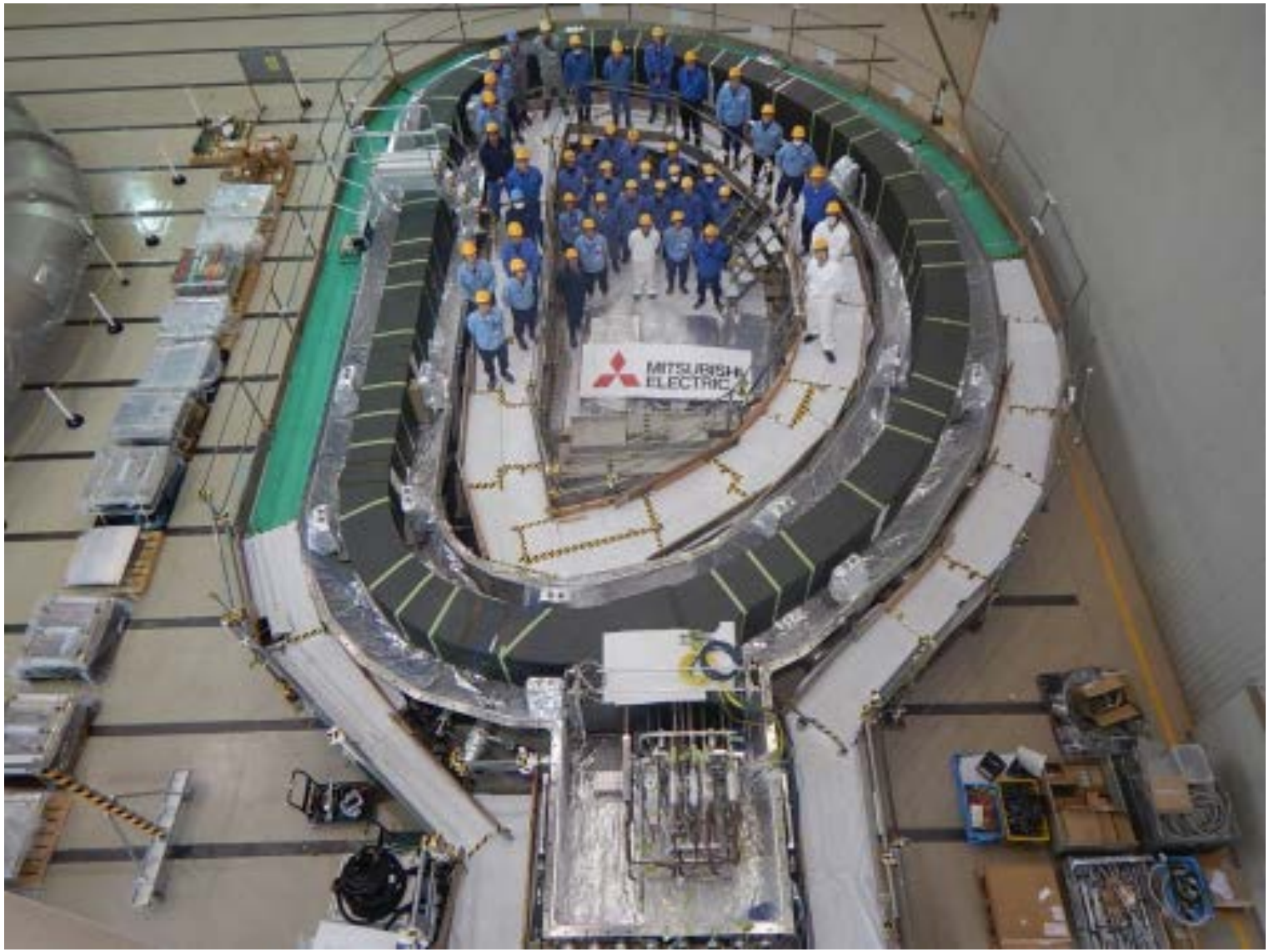
Manufacturing Process (Assembly completed 1st WP)



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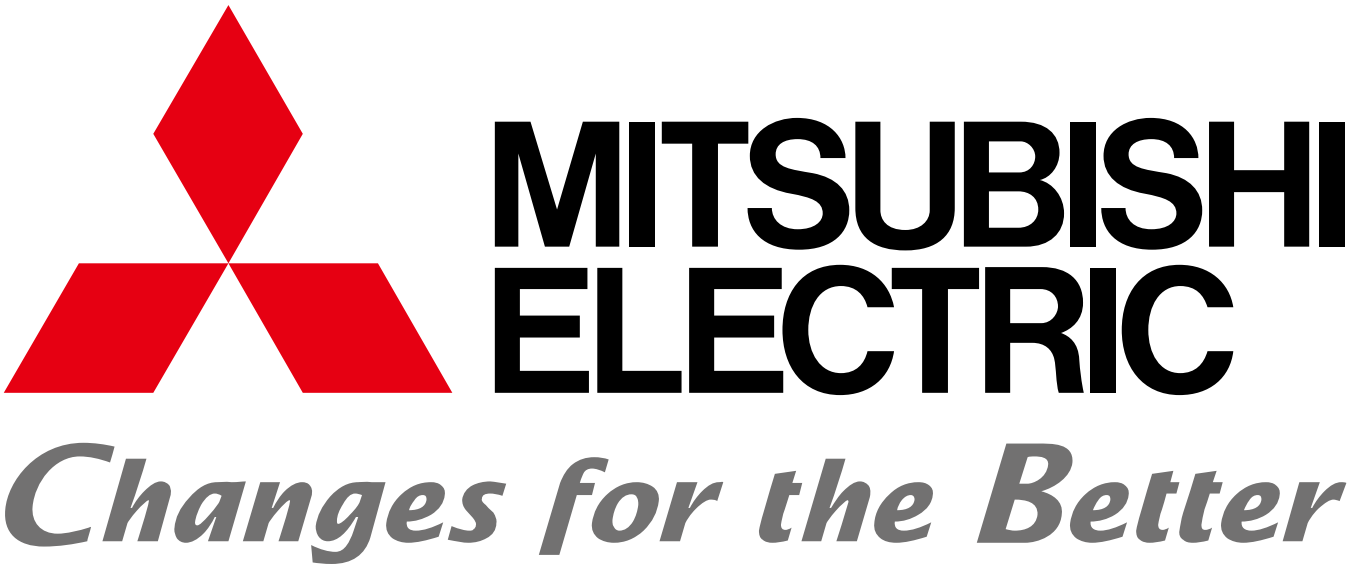
Progress provided from fabrication results

Because of large scale superconducting magnet

- Control of influence by temperature is provided.
  Example: High accuracy measurement
  ⇒ Temperature control
  Relaxation of thermal expansion and shrinkage
  ⇒ Control of position between WP and jigs
  Relaxation structure of position difference
- Strain control fabrication process is provided
  Example: Deformation by gravity
  ⇒ Design of handling jigs, control of deformation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