Full-scale trial results to qualify optimized manufacturing plan for ITER Toroidal Field coil winding pack in Japan

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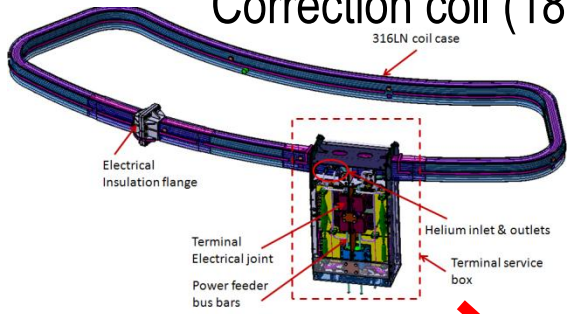
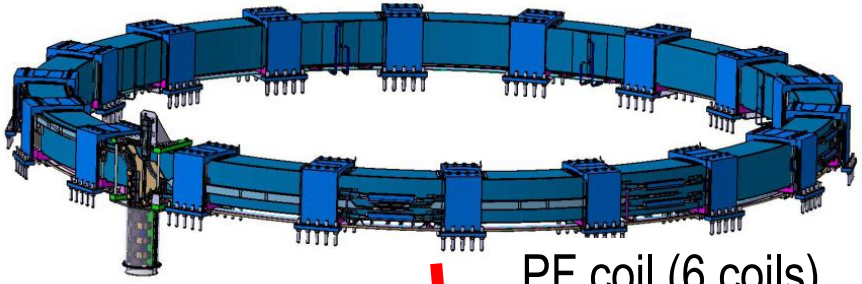
Outline

1. ITER Toroidal Field (TF) coil and its procurement in Japan
2. Technical issues and optimized manufacturing plan
3. Full scale trials for TF coil winding pack manufacture
4. Progress in TF coil series production
5. Summary

ITER magnet system

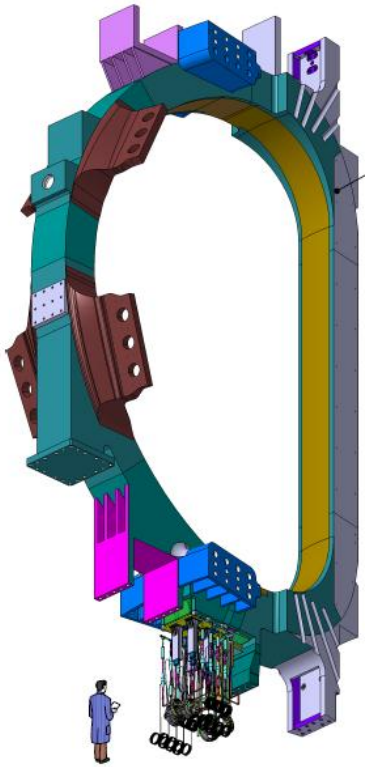
Correction coil (18 coils)

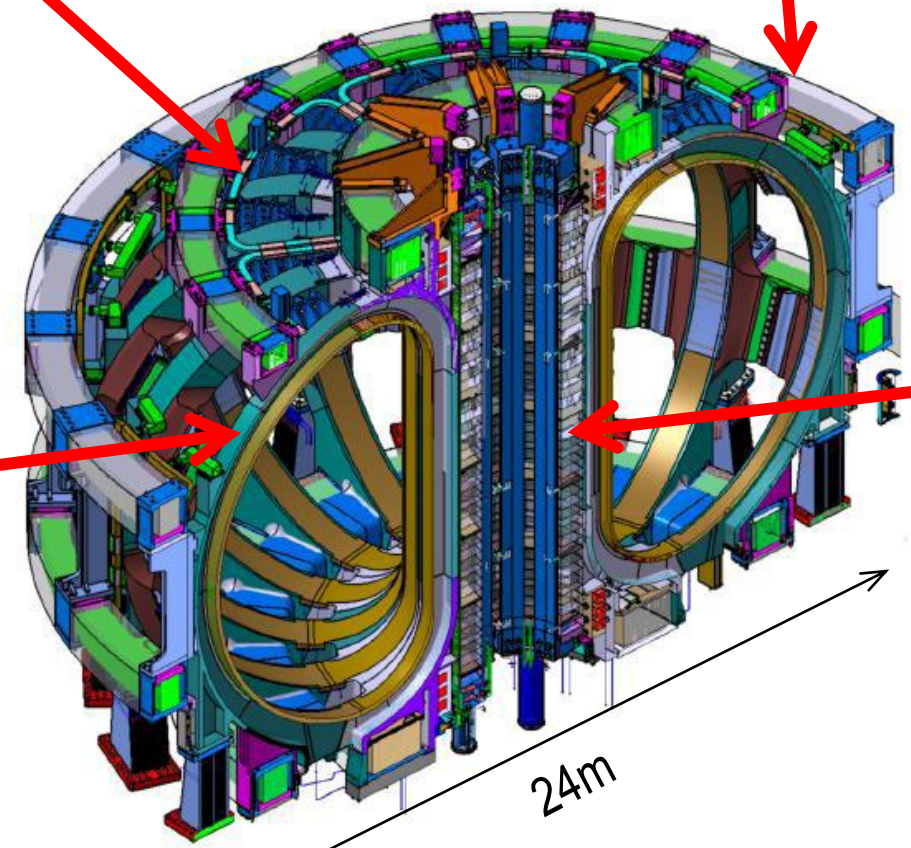


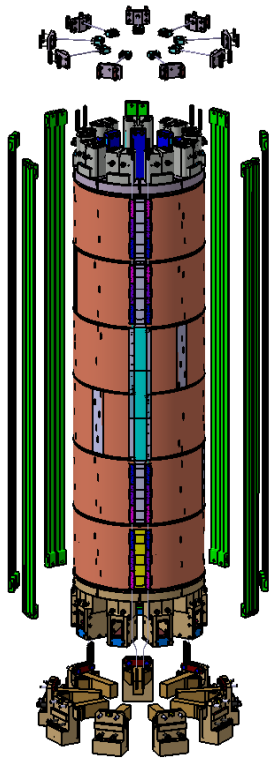


PF coil (6 coils)

TF coil (18 coils)

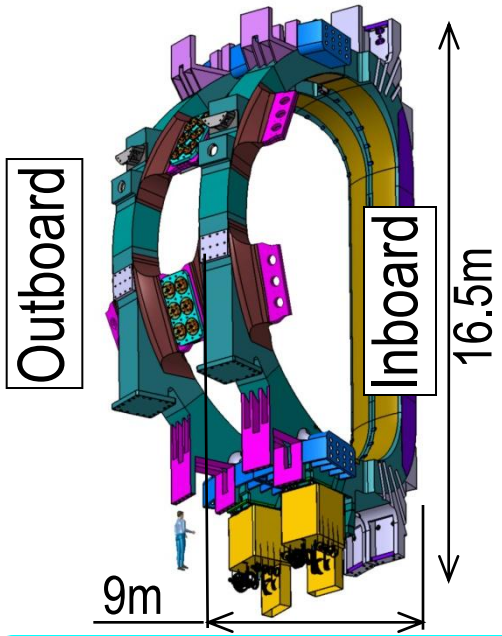




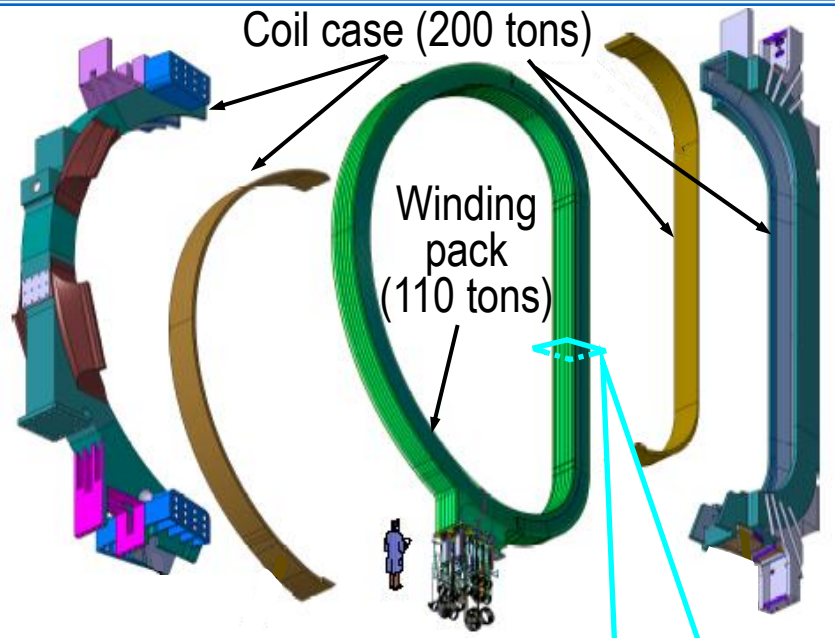


CS (6 modules)

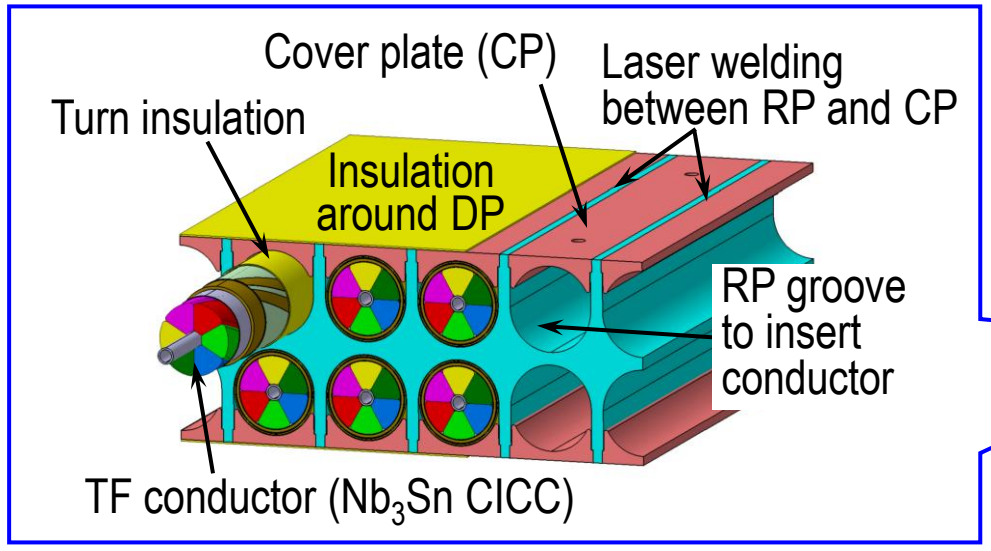
ITER TF Coil

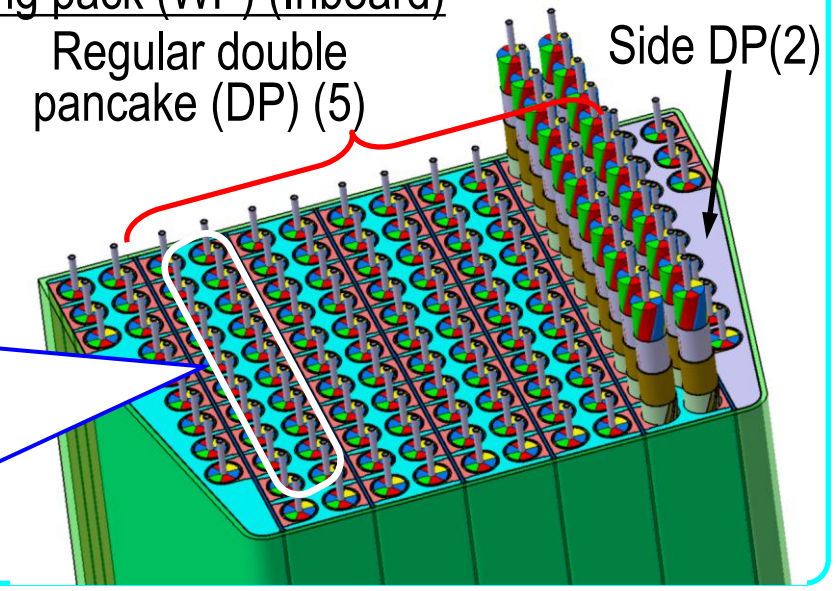


Nominal field
= 11.8T
Nominal current
= 68kA



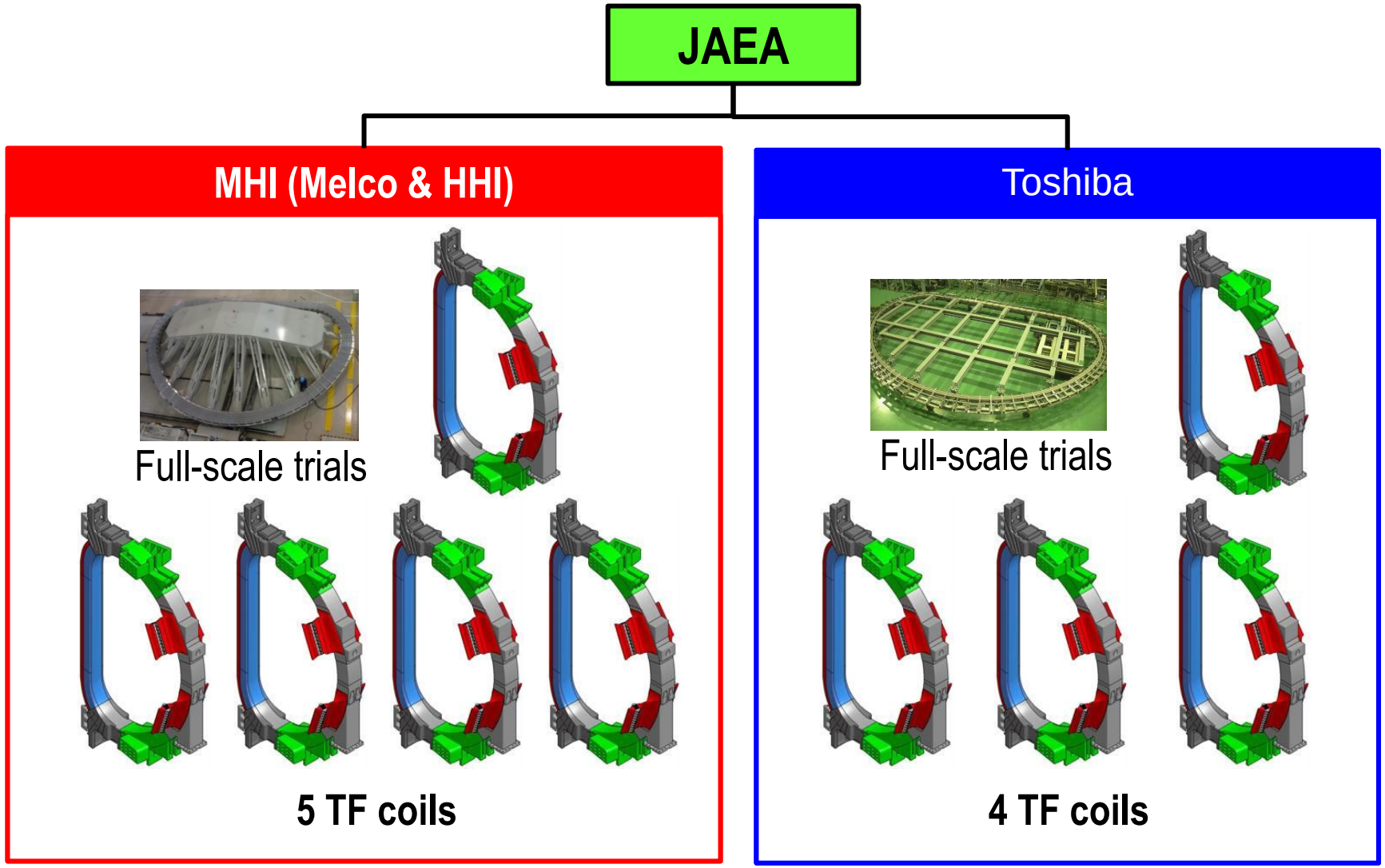
Cross-sectional view of a TF winding pack (WP) (Inboard)





Scheme of TF coil procurement in Japan

- To recover from delay by disaster in Japan in 2011 and to meet ITER schedule, JADA is building two lines for manufacturing 9 TF coils.



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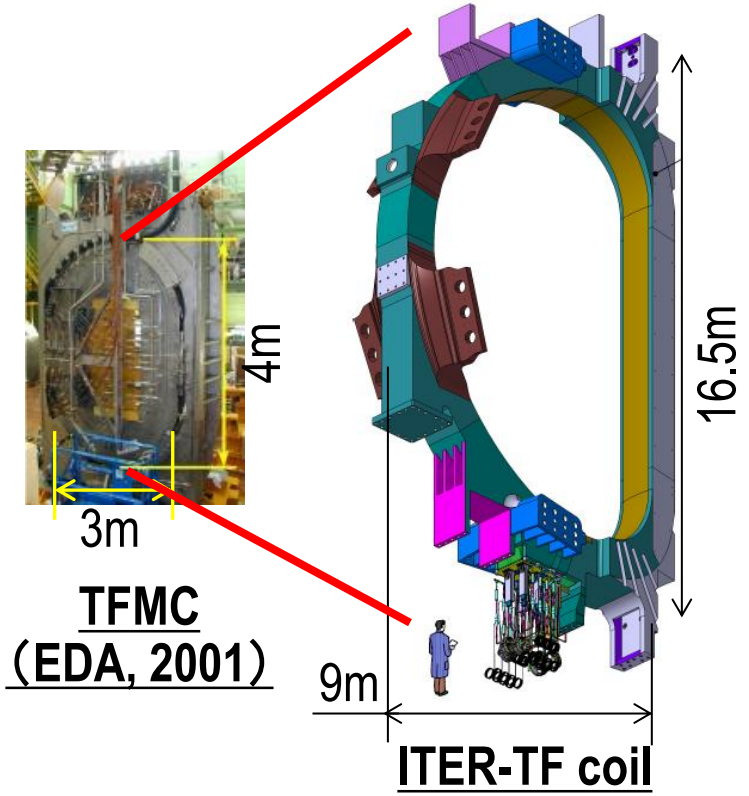
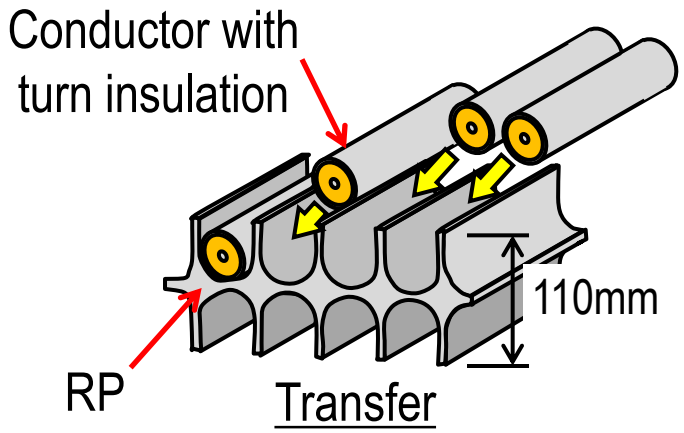
Challenge in TF coil WP manufacture

- Basic technique of TF coil manufacture was demonstrated by TF model coil (TFMC) development during ITER-EDA.
- Although TF coil ≈ 3.5 X TFMC,
  tolerances of TF coil ≈ those of TFMC.
- Allowable strain of TF superconductor <0.1%
  ➔ Tight tolerance is challenging.



Most critical challenge (Transfer)

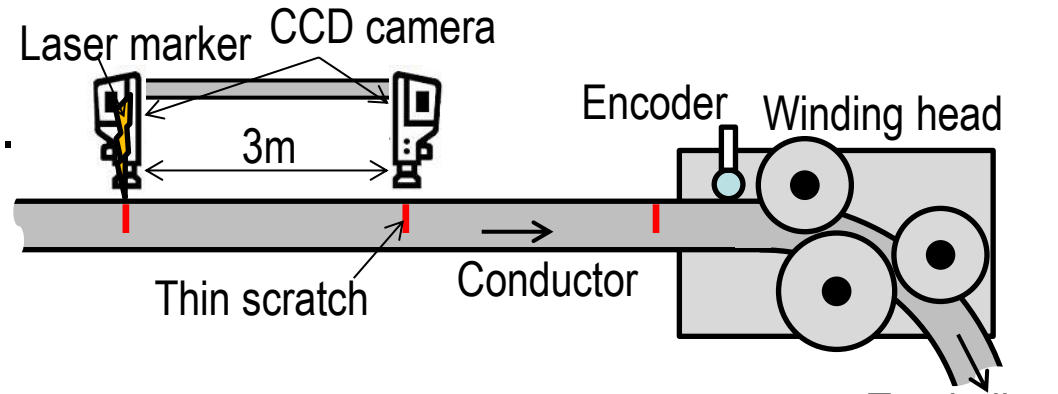
- TF conductor elongation after heat treatment ≈0.05%
- Other sources originating error;
  Winding, RP and dimension measurement
- Gap between conductor turn insulation and RP groove surfaces = 1mm or 1.5mm
- Original tolerance ≈ ±**0.02%** in length



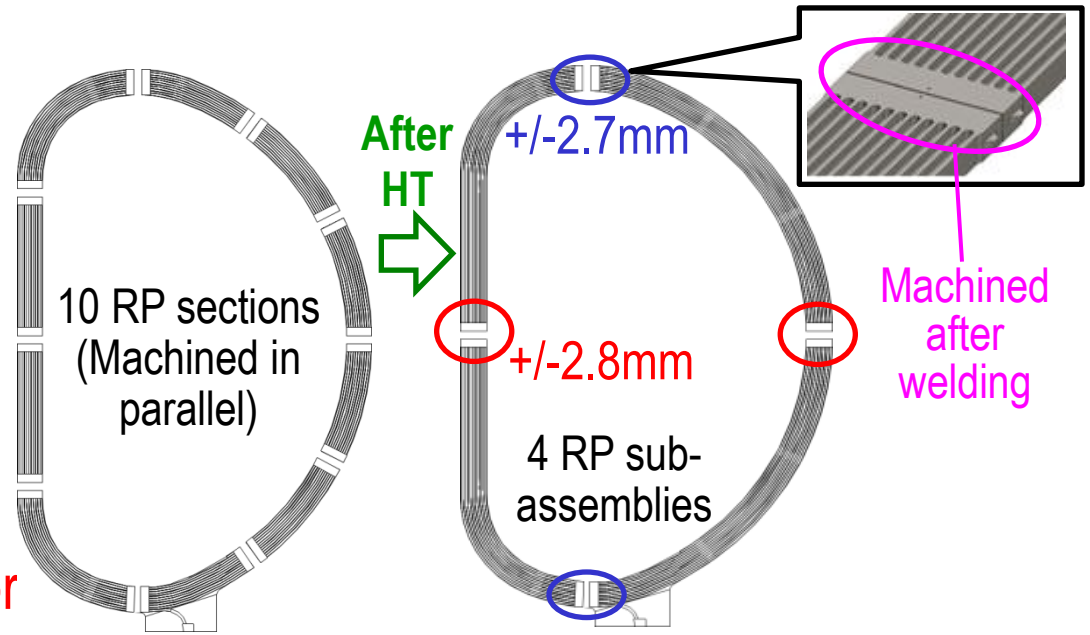
Solution of challenge in transfer

- To enable transfer, manufacturing plan is optimized.

1. High accuracy winding technique using optical measurement system.
   (Target accuracy = ±**0.01%**)
2. Highly accurate prediction of conductor elongation by heat treatment (HT).
   (Target accuracy = ±**0.02%**)
3. 4 RP sub-assemblies are assembled to fit RP groove length to heat-treated winding length.
   (Relaxed tolerance in conductor length ≈±**0.04%**)

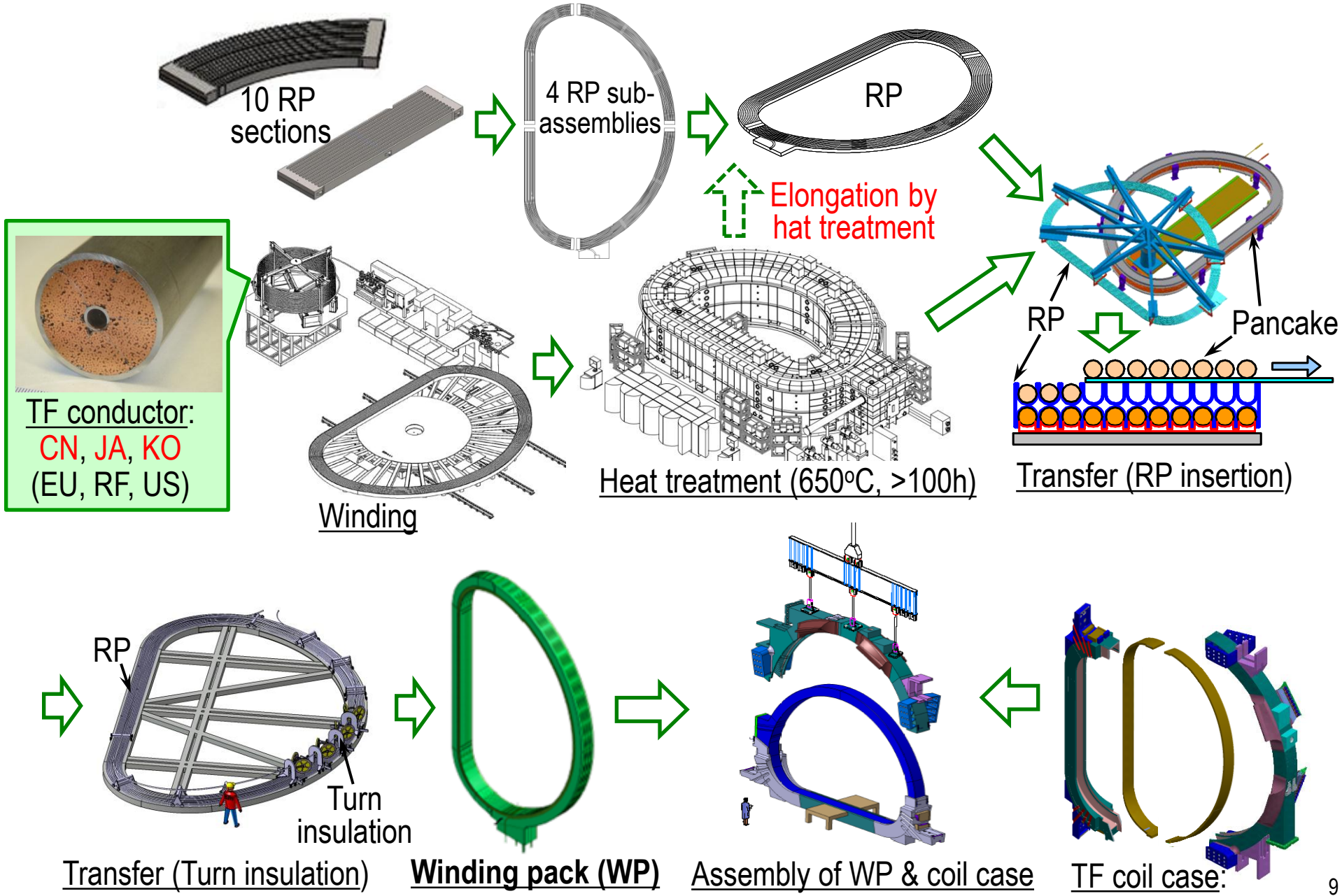


Optical measurement system during winding



New RP manufacturing procedure

Optimized TF coil manufacture procedure



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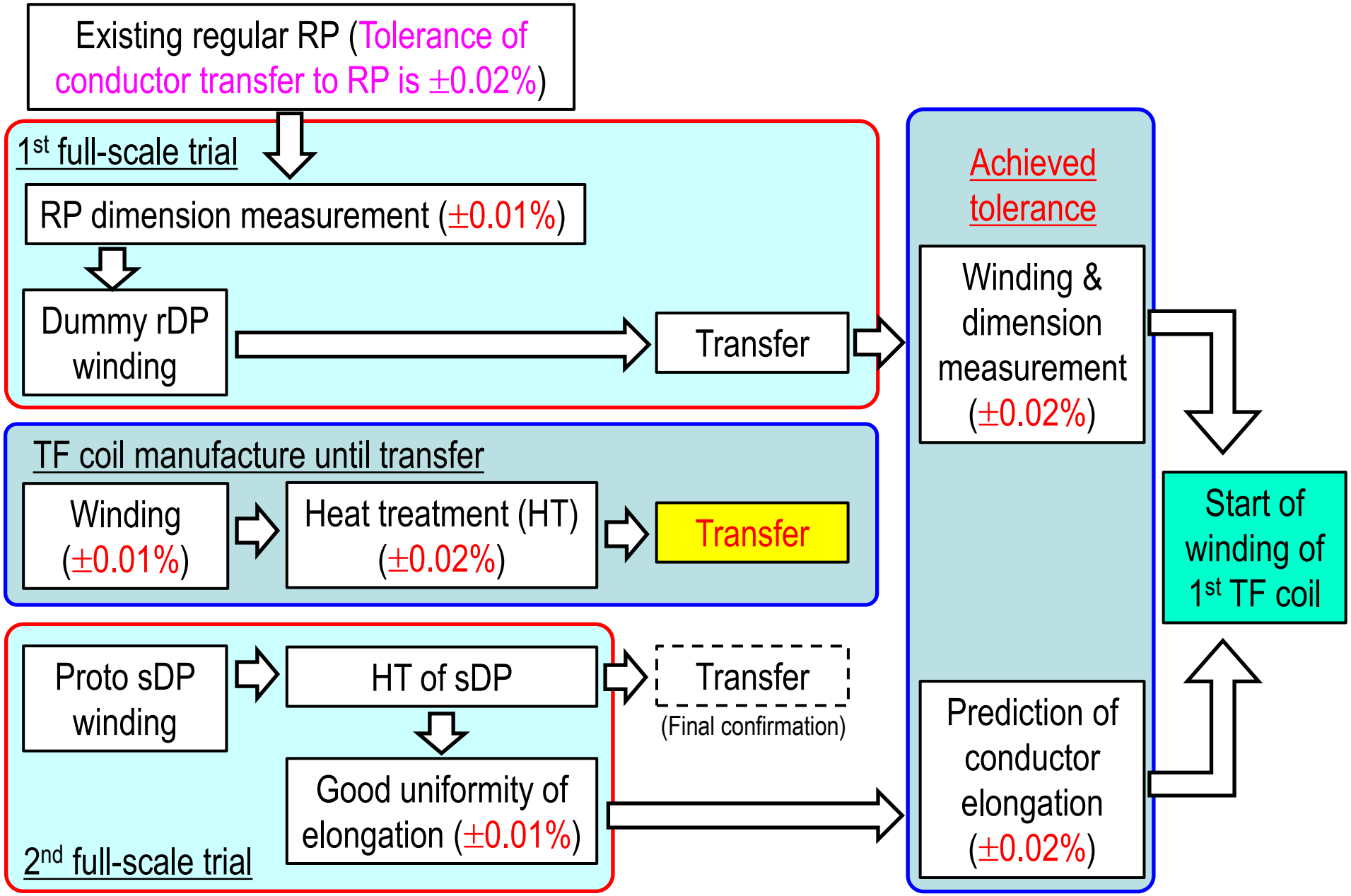
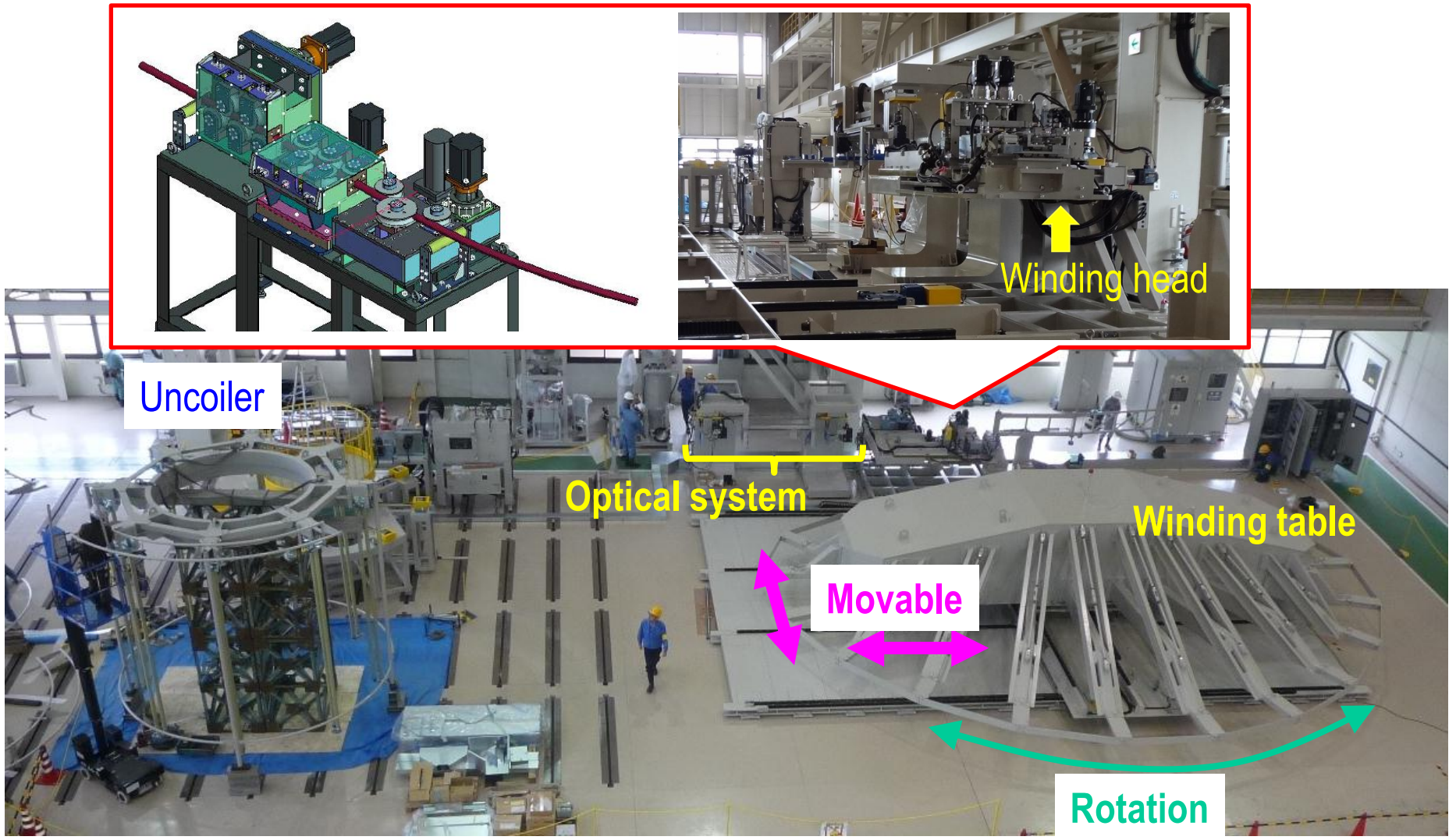
Strategy to accelerate full-scale trials to start series production



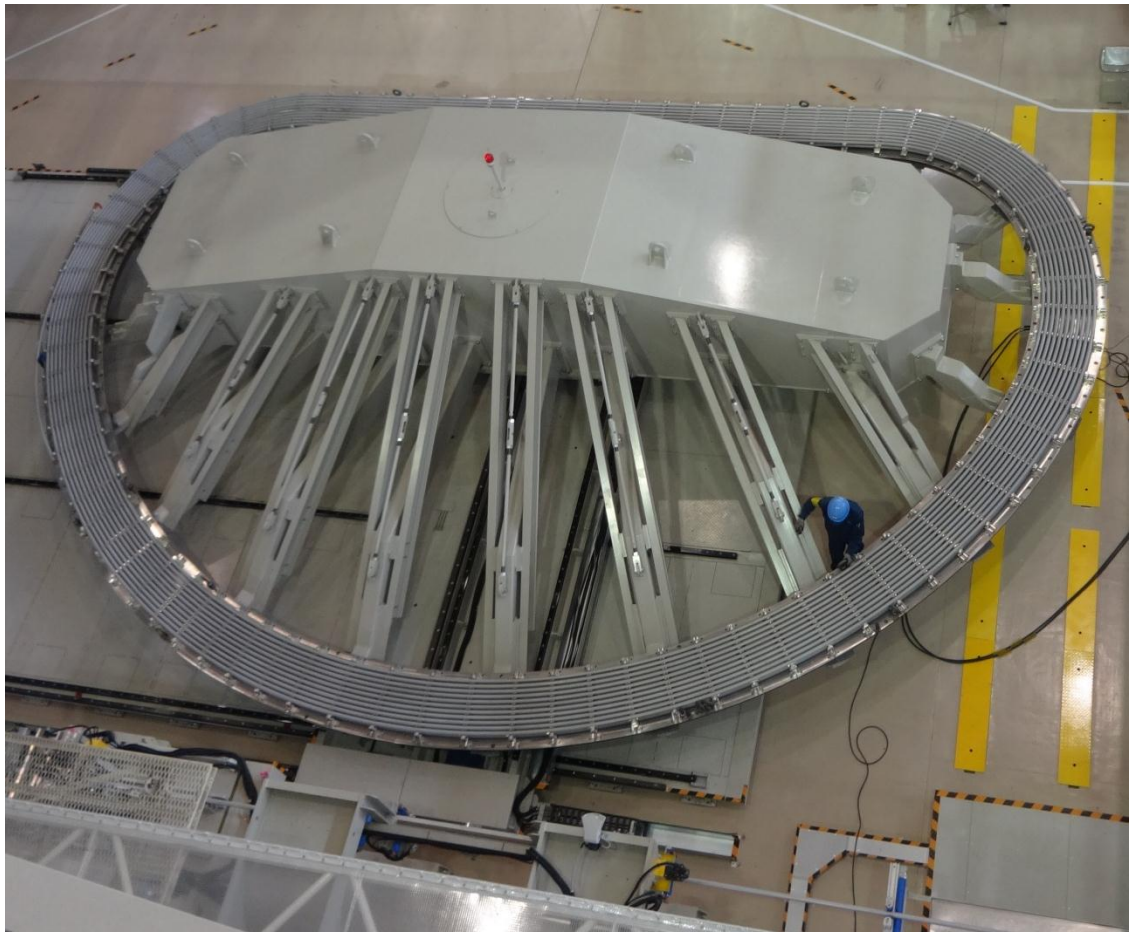
Winding machine qualification

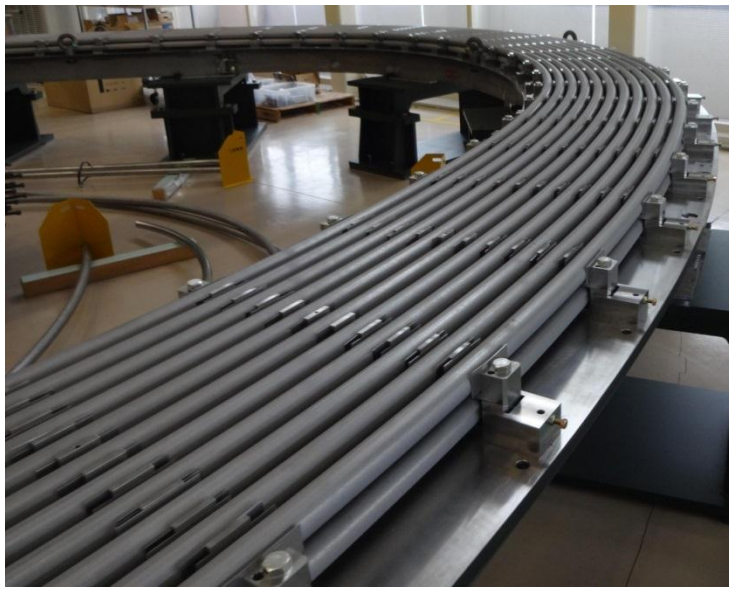


- Commissioning was completed in September 2013.

Winding by new winding machine

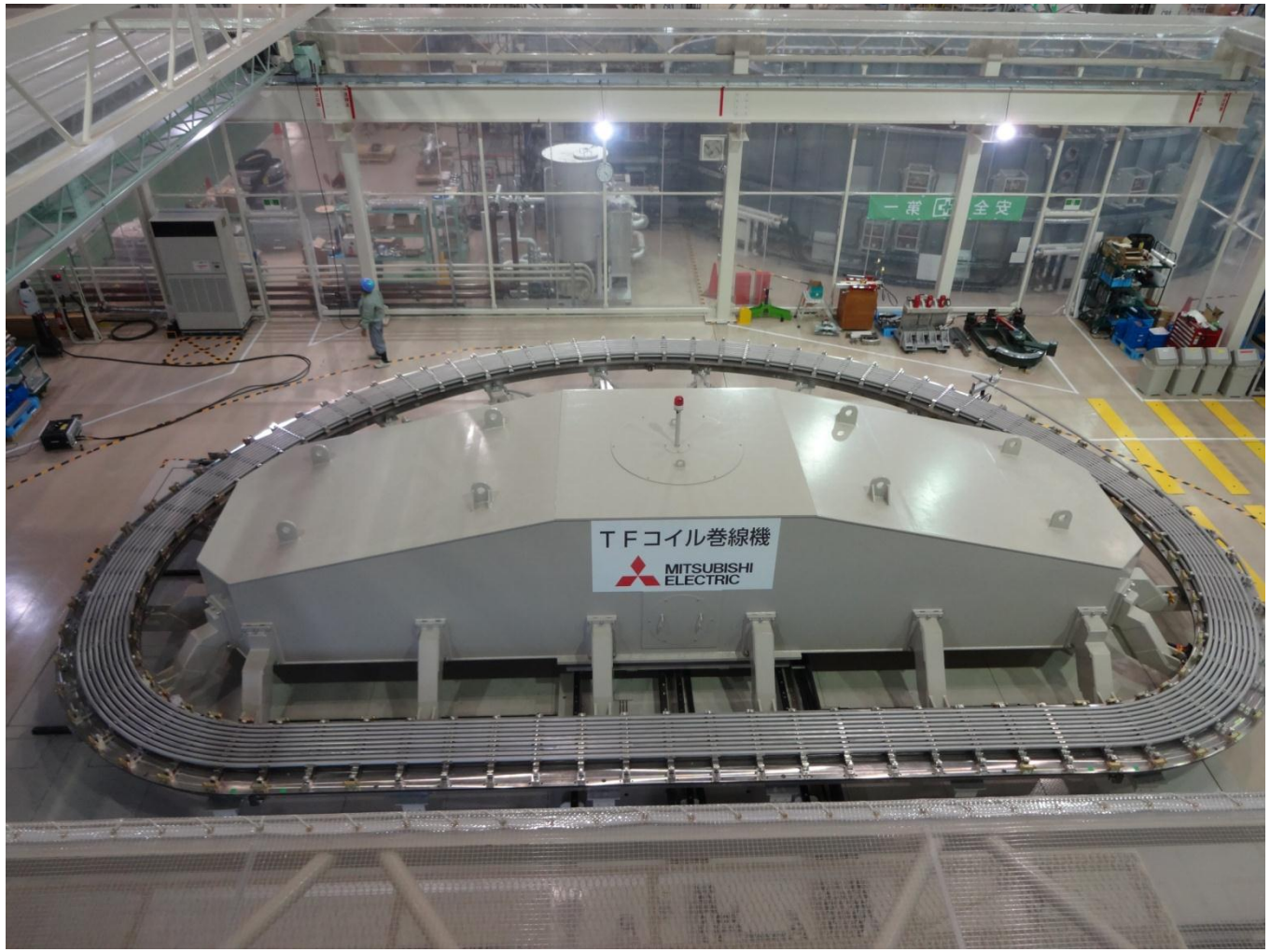
Dummy regular DP (rDP) winding





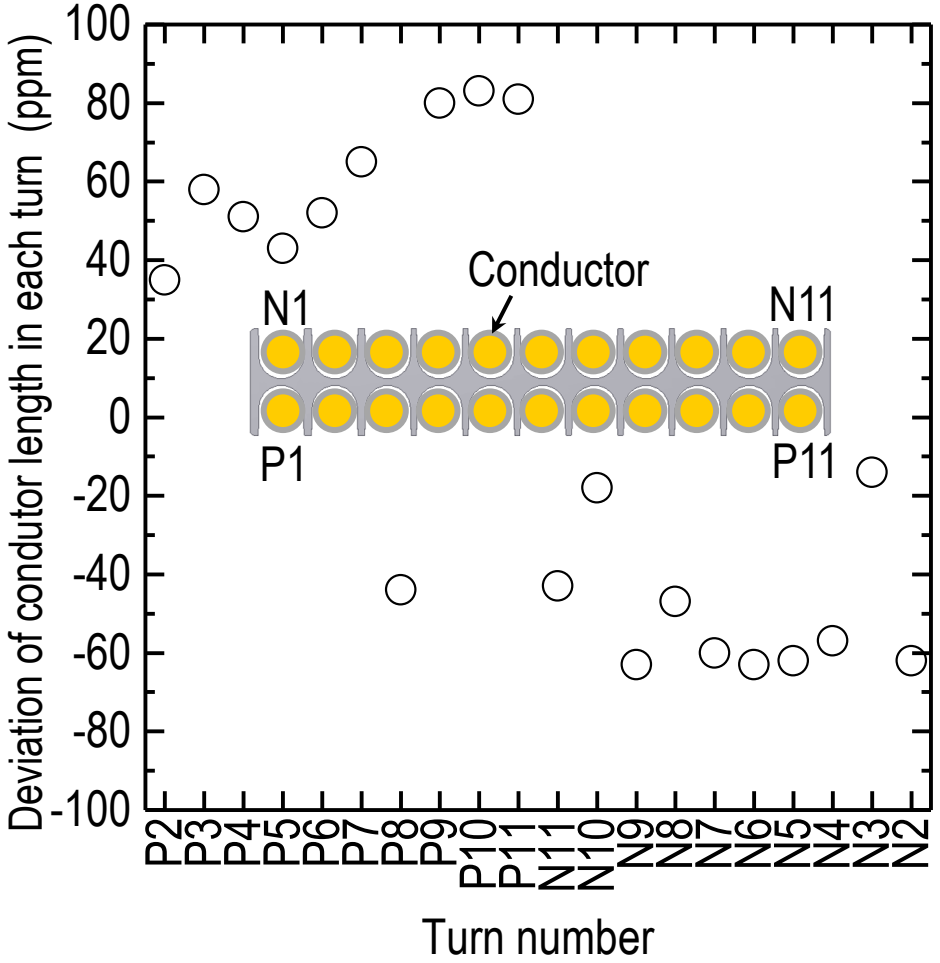
- Dummy regular DP (rDP) winding was successfully completed at beginning of November 2013.

Dummy side DP (sDP) winding

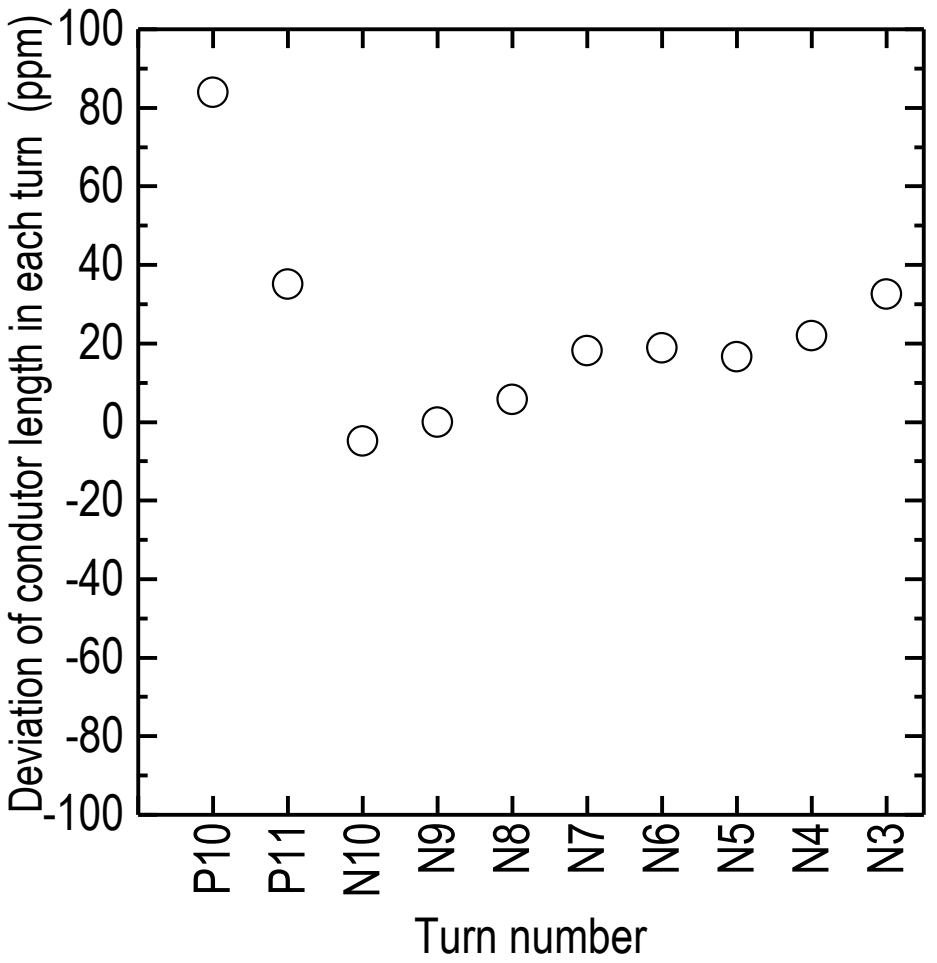


- Proto sDP winding was also successfully completed at end of November 2013.

Accuracy of winding dimension



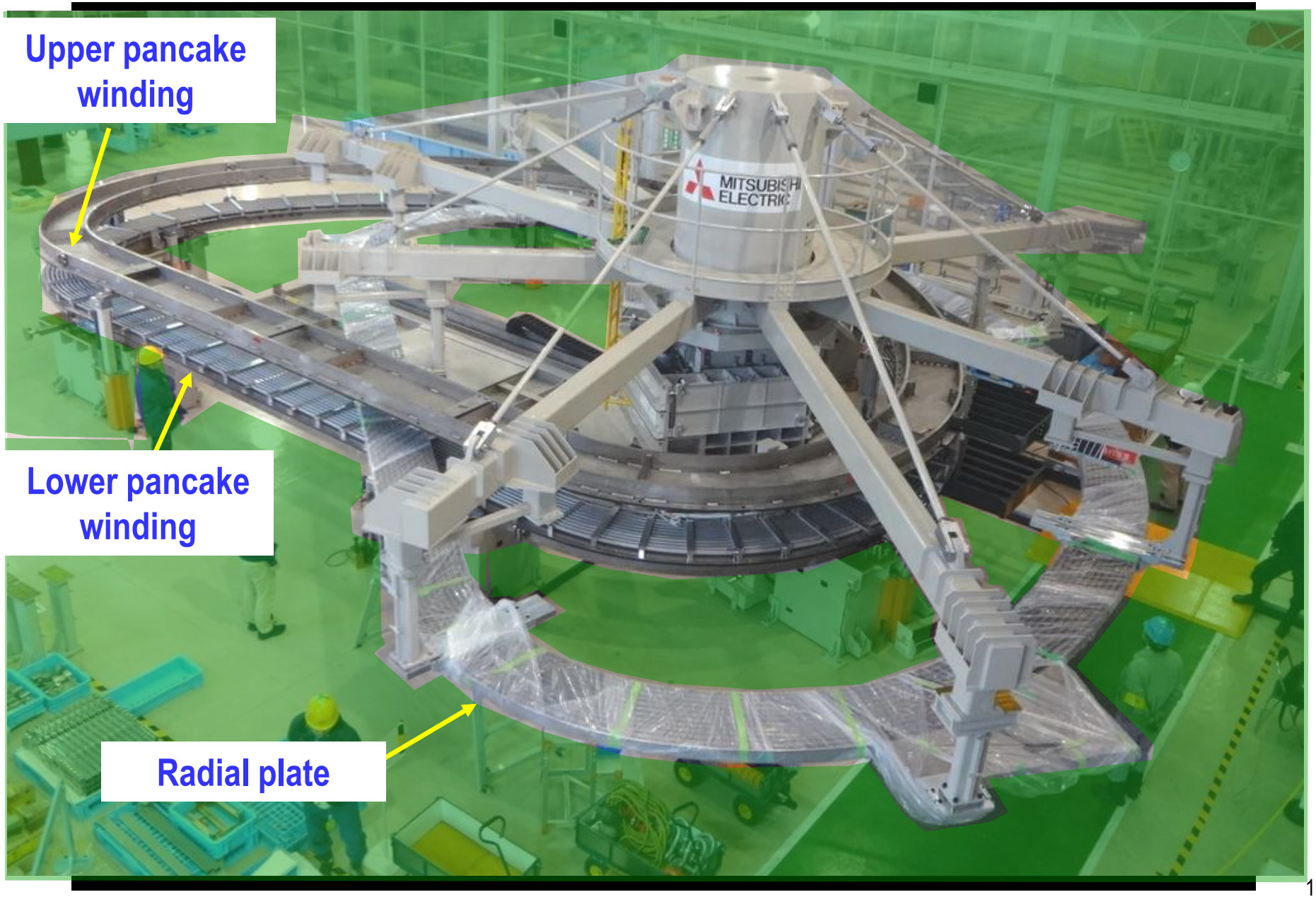
Dummy rDP (1st trial)



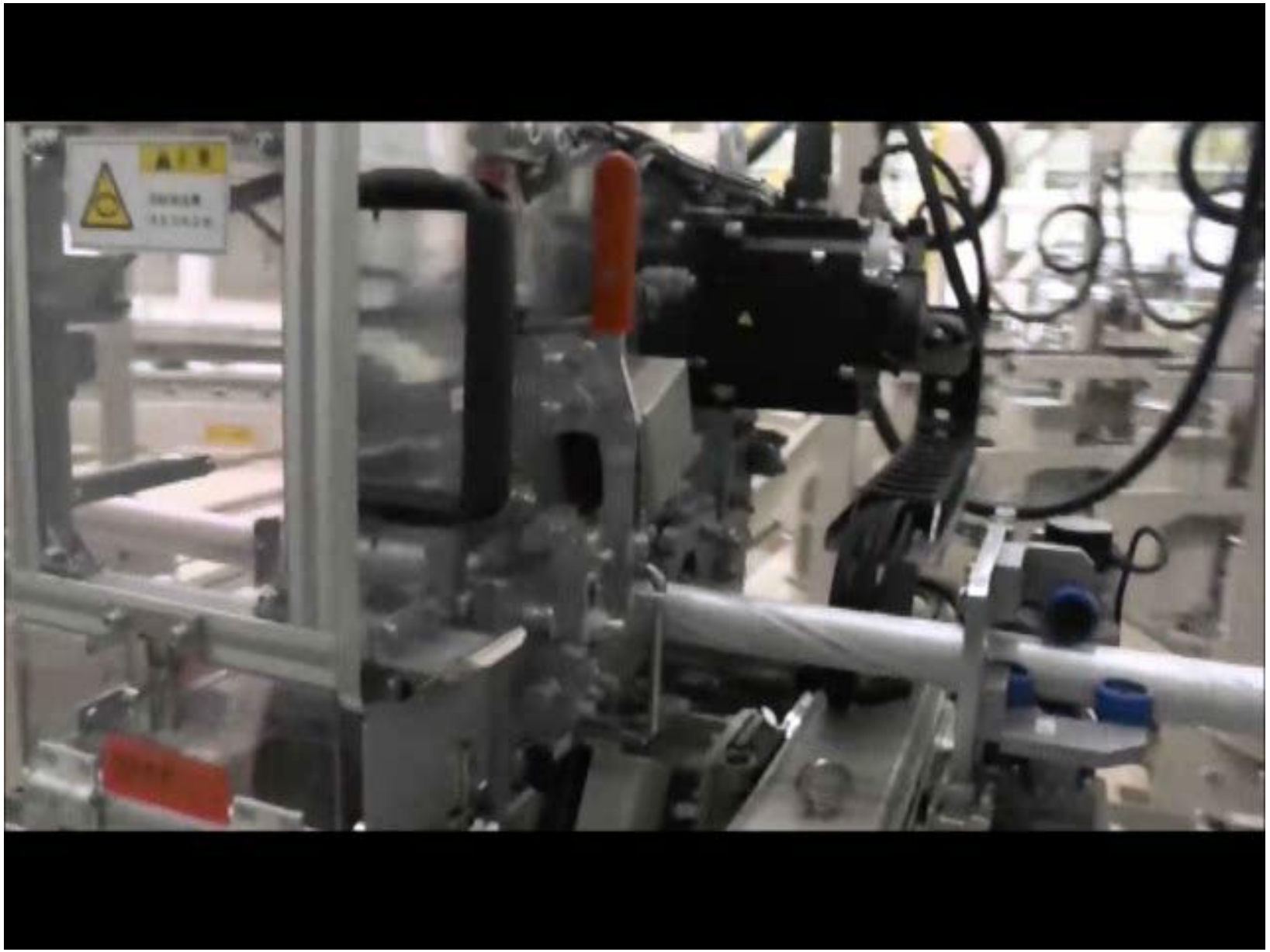
Proto sDP (2nd trial)

Accuracy of winding < ±0.01%

RP transfer (RP insertion between pancakes)

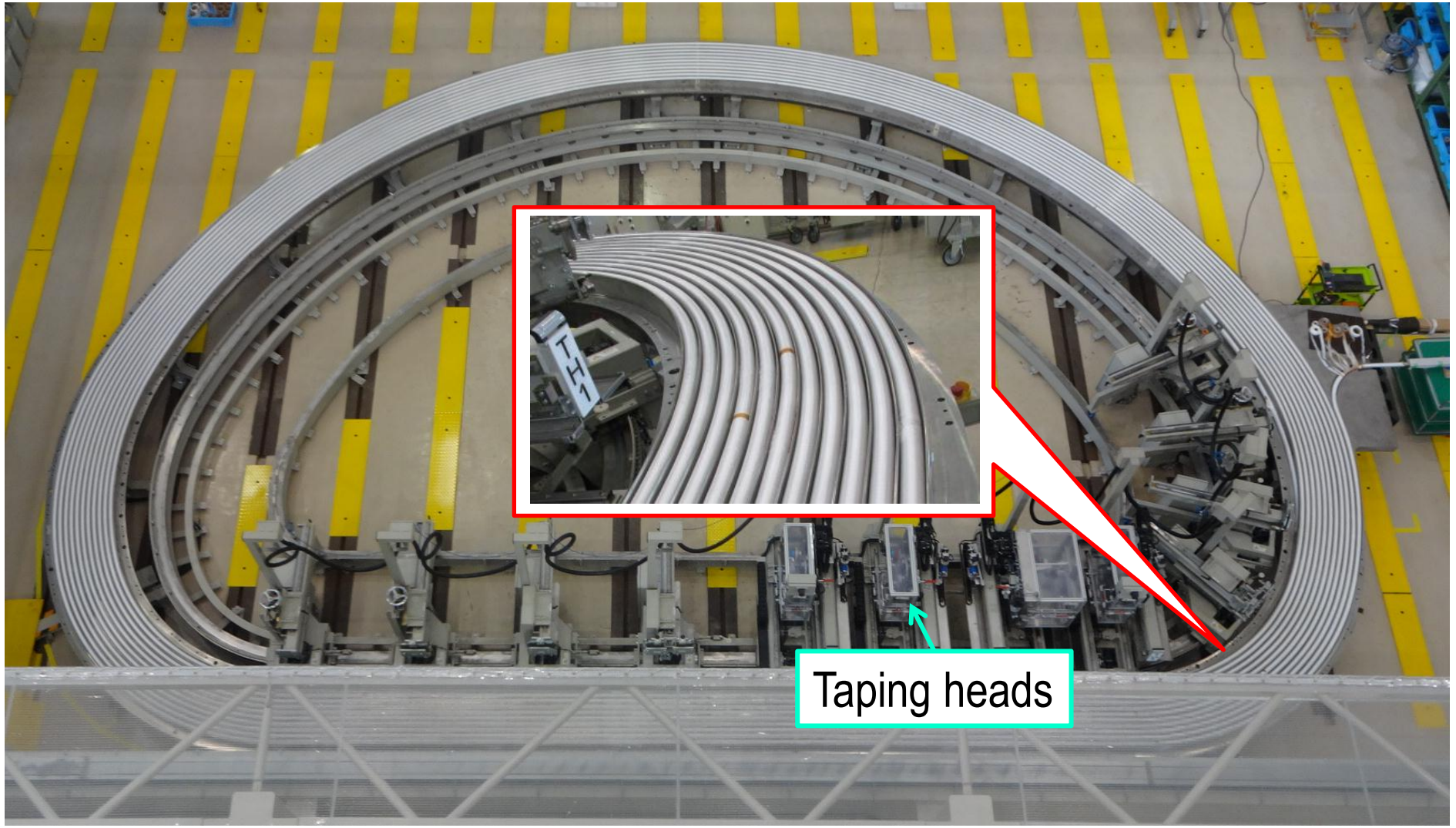


Turn insulation and insertion of conductor in RP groove



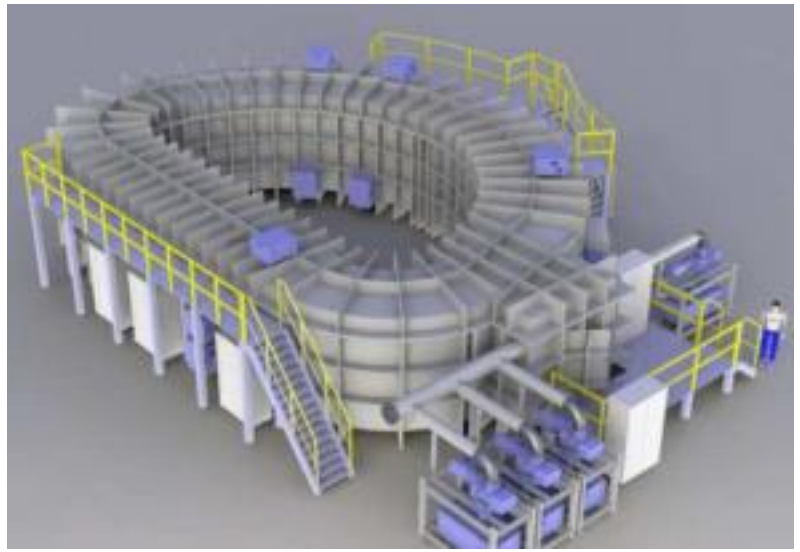
Dummy rDP transfer

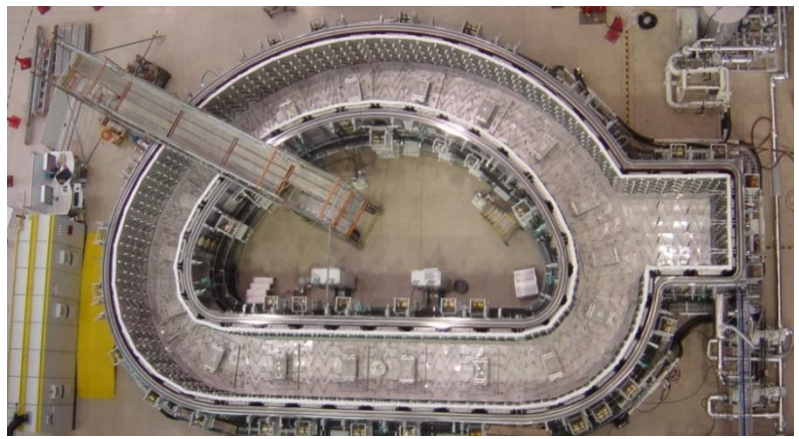
- Dummy conductor was inserted in RP groove after turn insulation.



Heat treatment of proto sDP

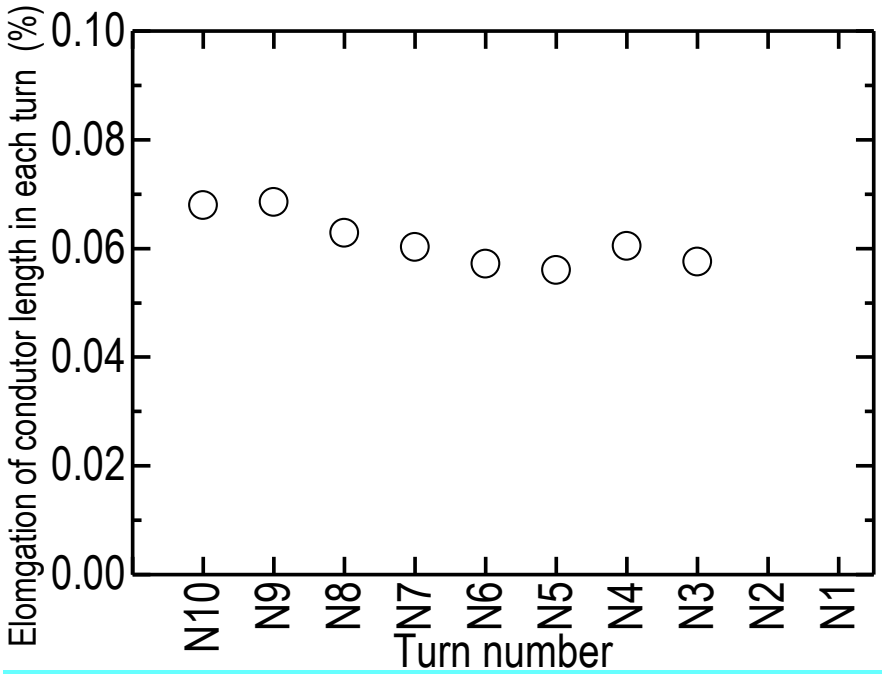
Heat treatment oven





- Dedicated oven was fabricated.
- ±5 °C at 650°C was demonstrated.

Conductor elongation



- Conductor elongation by heat treatment =0.061% +0.007/-0.005%.

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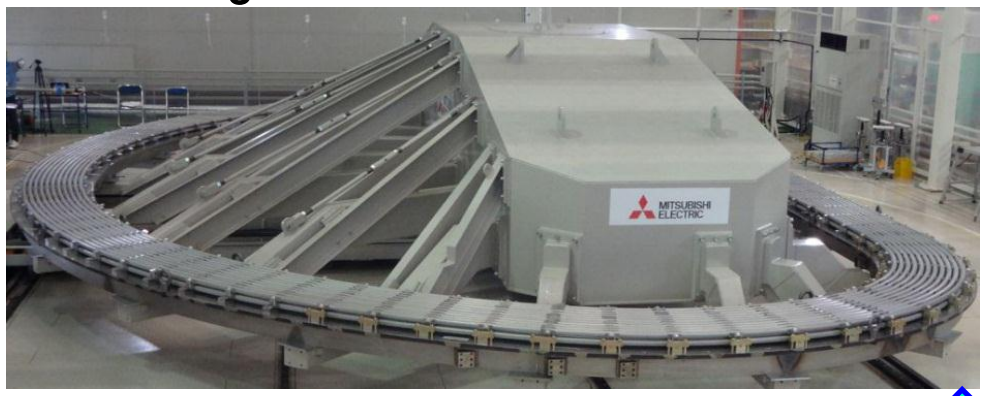
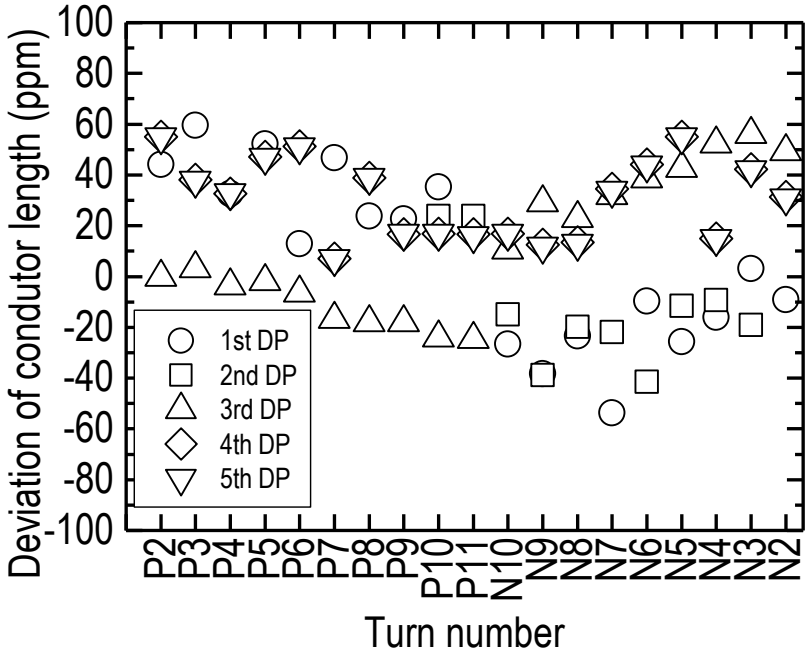
TF coil winding and heat treatment

❑ Winding of 5 DPs for the 1st TF coil was completed.

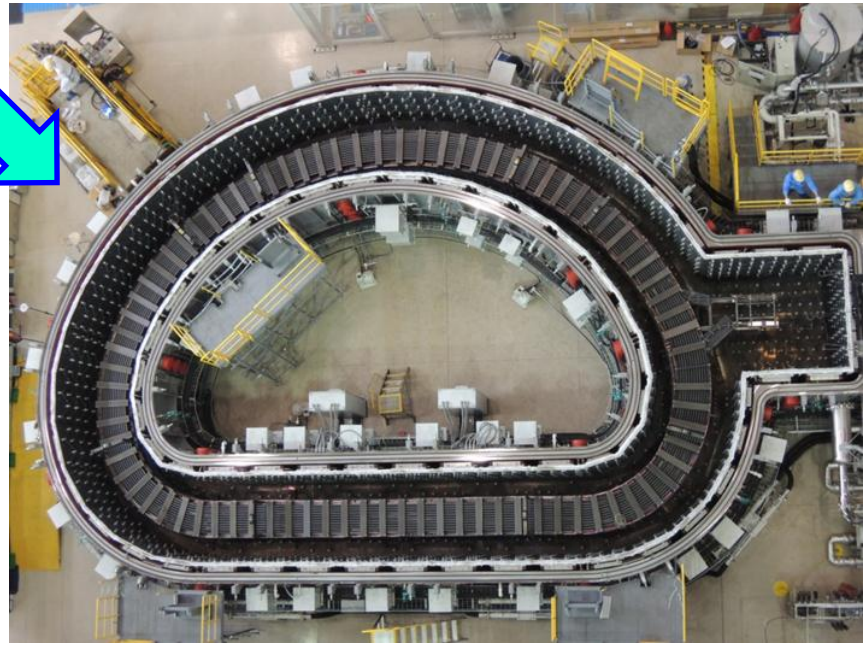


Winding of 1st DP of JA 1st TF Coil



❑ Winding accuracy < ±0.01%

❑ 1st DP was heat treated.



Heat treatment of 1st DP of JA 1st TF coil

(Elongation = 0.07% +0.006/-0.008%)

❑ Elongation < Prediction(0.06%)±0.02%

Summary

Full-scale trials are performed to qualify the optimized manufacturing plan of ITER TF coil WP manufacture in Japan. The major achievements and progress are as follows:

- High accuracy of winding to control conductor length with ±0.01% was demonstrated.
- Heat treatment oven was developed with highly accurate temperature control and conductor elongation is predicted to be 0.06%±0.02%.

From these successful achievements, JADA started series production of TF coil. The present achievements are as follows:

- 5 DP winding was completed with satisfying target accuracy of ±0.01%.
- 1st DP was heat treated and elongation of conductor is within target accuracy of ±0.02%.

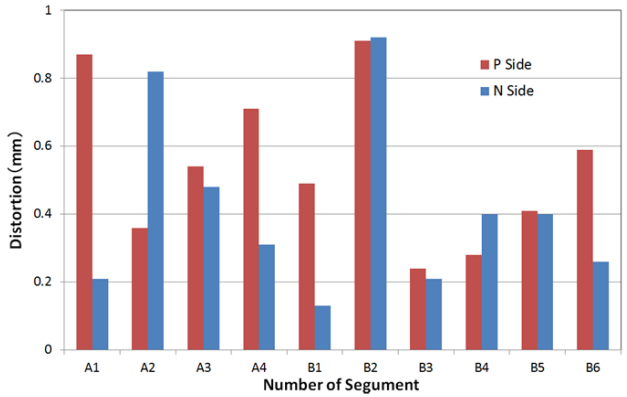
In addition, the delay from 2011 is being recovered.

Dummy sRP trial manufacture

Machining RP section

Welding between RP sections

Final assembly



Flatness of RP sections
for dummy sRP

After welding (RP sub-assembly)

Completed RP