Winding Deformation Caused by Reaction Heat-treatment for ITER TF Coil

T. Hemmi, H. Kajitani, K. Matsui, M. Yamane, K. Sakaguchi, M. Nakamoto, T. Saito, S. Ando, K. Takano, N. Koizumi

National Institutes for Quantum and Radiological Science and Technology (QST), 801-1, Mukouyama, Naka, Ibaraki, 311-0193, Japan

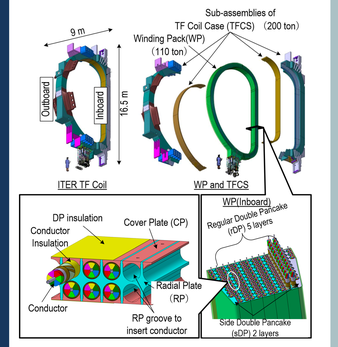
1.1 Background

The high mechanical and electrical reliabilities have to be ensured for the operation of the ITER. For this objective, the Radial Plate (RP) structure is employed to avoid accumulating the electromagnetic loading to the insulation layer around conductors. Since Nb_3Sn is brittle, the bending strain exceeding **0.1%** cannot be applied after the reaction heat-treatment. Thus, the conductor is wound to D-shape and then heat-treated before it is transferred into the RP groove.

1.2 Objectives

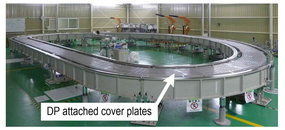
- **Demonstration of conductor transfer procedure for Korean (KO) conductors**.
- Evaluation of **the error in conductor length, the evaluated winding deformation and the bending strain**.

ITER TF Coil



4. Conclusion

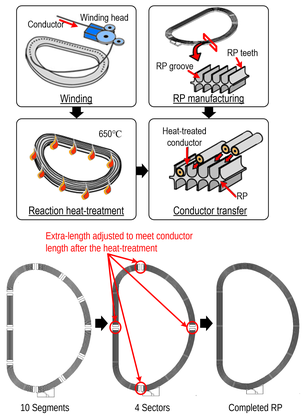
a) Insulated conductor inserted into RP groove



b) DP inserted conductor into RP groove and attached cover plates

- The approaches demonstrated for the Japanese conductors were applied to the conductor transfer of the **KO conductors**.
- **The target errors, 0.25% in total, were satisfied in the results of the winding accuracy, the estimation of the elongation caused by the heat-treatment and the error of the RP manufacturing.**
- In addition, the heat-treated conductor can be inserted into the RP groove **within the bending strain of 0.1%** even if the winding deformation caused by the reaction heat-treatment is occurred.
- Consequently, **the conductor transfer procedure has been established for the KO conductors**.

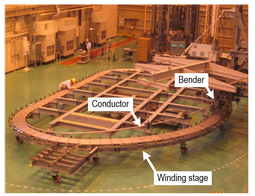
2.1 Conductor Transfer

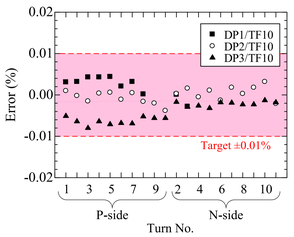


- To transfer heat-treated conductor into the RP groove, the accuracy of **±0.025%**, which is **±8.5 mm on 1-turn of 34 m**, in conductor length is necessary after the winding and the reaction heat-treatment.
- To solve the technical issue of the conductor transfer following approaches have been applied:

① **Development of winding procedure within the error of ±0.01% in conductor length,**
② **Estimation of conductor elongation by heat-treatment within the deviation of ±0.01% in conductor length,**
③ **Establishment of the manufacturing procedure of the RP within the error of ±0.01% in groove length.**

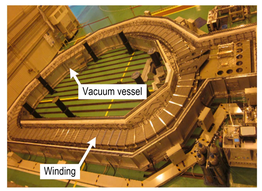
2.2 Winding

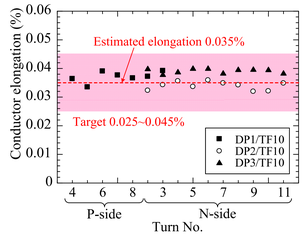




- The error in conductor length is **0.0013%** in average and **±0.0098%** in 3σ.
- **The target of ±0.01% in error of the winding has been satisfied.**

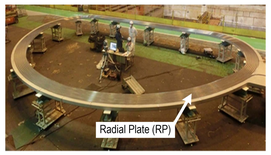
2.3 Reaction Heat-treatment

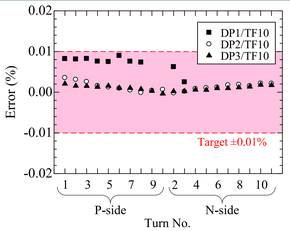




- The conductor elongation is **0.0366%** in average and **±0.0078%** in 3σ.
- **The target of ±0.01% in deviation from the estimated elongation has been satisfied.**

2.4 RP manufacturing



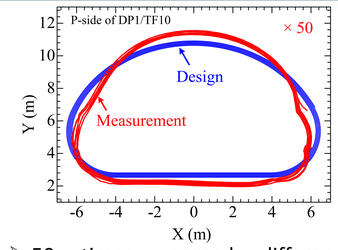


- The error of the groove length for the RP for DP1/TF10 is **0.0072%** in average and **±0.0054%** in 3σ.
- **The estimated welding shrinkage was reconsidered.**
- Then, the error of the RP groove length was **0.0010 ±0.0019%** for DP3/TF10.
- **Techniques for length measurement with high accuracy, temperature control in machining, welding with small shrinkage were developed by Toshiba.**

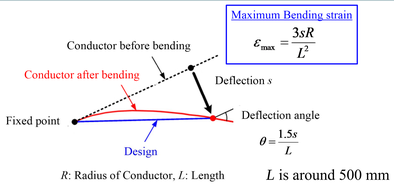
2.5 Total error in length

- The total error of length is **0.0004 ±0.0126%** in winding and heat-treatment for the **KO conductors.**
- As a worst case of RP manufacturing, the error of the RP groove length is 0.0072 ±0.0054%. Since the total error is **0.0076 ±0.0137%, the target of ±0.025% in the error of the conductor length was achieved**.
- In addition, the adjustment of the RP groove length in the RP assembling after the heat-treatment can be removed since the average error of 0.0004% in winding and heat-treatment is sufficient small.
- Consequently, the manufacturing schedule of the TF coils could be accelerated.

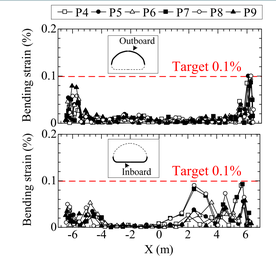
3. Deformation and bending strain



- 50 times zoomed difference between the measurement and the design of P-side of DP1/TF10 is shown.
- The maximum difference is 14.2 mm between the measurement and the design.



Model of the **continuous cantilever beams**



- The model of the **continuous cantilever beams** is considered to evaluate the bending strain to insert the heat-treated conductor into the RP groove.
- Since the conductor position inserted is fixed calculation, it is much conservative.
- **The calculated bending strain is less than the requirement of 0.1%. The positions of the bent conductor are located within the RP groove.**
- Note that the larger distance between bending points allows less bending strain since the bending strain is in inverse proportion to second orders of the its length.

Presented at MT25 Conference 2017, 30 August 2017, Amsterdam, Netherland; Session: Fusion Magnets: Manufacture and Joints; Program I.D. number: MT25-Wed-Af-Po3.02-11