Poster No.: Wed-Af-Po 3.02.

MT25 25th International Conference on Magnet Technology
RAI - Amsterdam
August 27 - September 1, 2017

# Winding R&D for CFETR Central Solenoid Model Coil


Houxiang Han [1, 2], Yu Wu [1], Dapeng Yin [1, 2], Jinggang Qin [1], Yi Shi [1]

*1 - Institute of Plasma Physics, Chinese Academy of Sciences, PO Box 1126, Hefei, Anhui 230031, China*

*2 - University of Science and Technology of China,No.96,JinZhai Road Baohe District, Hefei, Anhui 230026, China*


ASIPP

## 1. Introduction

The central solenoid (CS) model coil is being developed to verify the large-scalar superconducting coil manufacture technology for China Fusion Engineering Test Reactor (CFETR) in ASIPP (Institute of Plasma Physics). The CS model coil composed of $Nb_3Sn$ (inner and outer coils) and NbTi (upper, middle and lower coils) hybrid superconducting magnet can reach to 12 T maximum magnetic field. All of five coils are the pancake coil composed of pancakes concentric circular turns, pancake joggles and upper & lower leads. For pancakes concentric circular turns, the minimum diameter is 1500 mm, the maximum diameter 3544.8 mm and the maximum height is 1545.4 mm. The high precision for coil continuous winding & forming must be acquired, which the innermost and outermost circular turn surface profile tolerance is 2 mm and the conductor feeding tolerance is 0.5‰L. The winding R&D activities, including the continuous winding for the pancakes concentric circular turns, the forming on-line for the pancake joggles, have been conducted to optimize and finalize the coil design and do the coil winding technology verification and improvement. The winding & forming for a 2×4 coil of the $Nb_3Sn$ inner coil have been finished.

## 2. Parameters for CSMC Windings

The $Nb_3Sn$ CICC will be used for the internal high magnetic field (12T) winding, and the NbTi CICC for the external low magnetic field (the maximum value < 6T) winding.

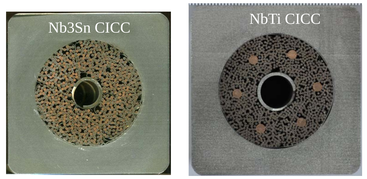



**Figure 1 Cross section of CICC for CFETR CSMC**

**Table 1 The specification of $Nb_3Sn$ and NbTi CICC**

| Items | $Nb_3Sn$ CICC | NbTi CICC |
|---|---|---|
| Jacket material | 316LN stainless steel | 316L stainless steel |
| External Dimension /(mm) | 49 × 49 | 51.9 × 51.9 |
| Diameter of inner bore /(mm) | 32.6 | 35.3 |
| Cabling pattern | (2sc + 1) ×3 × 4 × 4 × 6 | (3sc×4 × 4 × 4) + 1Cucore |
| Cable twist pitches | First Stage: 45±5mm<br>Second Stage: 85±8mm<br>Third Stage: 145±10mm<br>Fourth Stage: 250±15mm<br>Fifth Stage: 450±20mm | First Stage: 45±5mm<br>Second Stage: 85±8mm<br>Third Stage: 145±10mm<br>Fourth Stage: 250±15mm<br>Fifth Stage: 450±20mm |
| Petal wrap | 0.05 mm thick, 70% cover | 0.05 mm thick, 50% cover |
| Cable wrap | 0.08 mm thick, 40% overlap | 0.10 mm thick, 40% overlap |
| Core pattern | n/a | Cu strand: 0.73mm Cu core 3: 2.85mm |
| Number of sc strand | 576 | 1152 |
| Void fraction | 33.5% | 34.1% |
| Central spiral | 7 × 9 mm | 10 × 12 mm |

Five windings all are pancake coils wound by one conductor in hand, the vacuum pressure impregnation (VPI) for each winding will be made separately and then assembly them finally. The innermost radius is 750 mm, the outmost radius is 1772.4 mm, the maximum axial height for main winding is 1545.4 mm. Double positive arcs are designed to realize the concentric circular turns transiting.

**Table 2 Parameters for CSMC winding**

| Items | $Nb_3Sn$ Coil | | NbTi Coil | | |
|---|---|---|---|---|---|
| | Inner winding | Outer winding | Upper winding | Middle Winding | Lower winding |
| Winding type | Pancake | Pancake | Pancake | | |
| CICC dimensions /(mm) | 49×49 - Φ32.6 | | 51.9 × 51.9 - Φ35.3 | | |
| Turn / pancake insulation thickness /(mm) | 2.6/2.6 | 2.6/2.6 | 2.6/2.6 | | |
| Ground insulation thickness /(mm) | 3.1 | 3.1 | 3.1 | | |
| Clearance between windings /(mm) | 22.4 | | 50 | | |
| Num. of radial turns | 4 | 4 | 10 | | |
| Num. of axial turns | 30 | 30 | 8 | | |
| Total Num. of turns | 120 | 120 | 80 | | |
| Inner radius /(mm) | 750 | 976.2 | 1230 | | |
| Outer radius /(mm) | 953.8 | 1180 | 1772.4 | | |
| Height of main winding excluding insulation/(mm) | 1545.4 | 1545.4 | 433.4 | | |
| Operating current /(kA) | 47.65 | | | | |
| Maximum magnetic field /(T) | 12 | 8.42 | 6.10 | | |

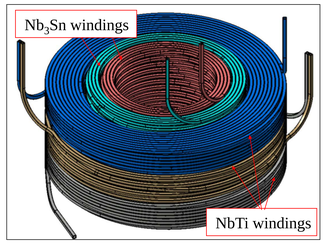



**Figure 2 CFETR CSMC windings**

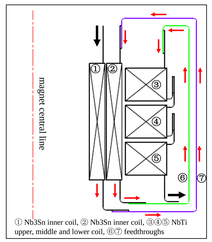



**Figure 3 Coil connecting scheme**

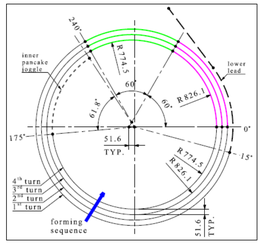



**Figure 4 1st Pancake for Nb3Sn inner coil**

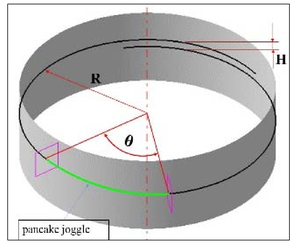



**Figure 5 Schematic diagram of pancake joggle**

## 3. Winding & Forming Method

A free tension bending method (Figure 5) is applied for continuous bending for the CS model coil winding including the concentric circular turns and turn transitions. The turns of different value radii are continuous bending by adjusting the pressing distance of the pressing roller and the conductor feeding by the feeding rollers, which the rollers are driven by servo motor.

The pancake joggle is formed by three processes, (1) the circular shape is formed by bending machine, (2) the axial height is gotten by the stretch bending tooling, and (3) the circular shape is reshaped by a three-points bending tooling.

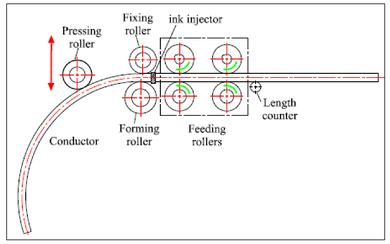
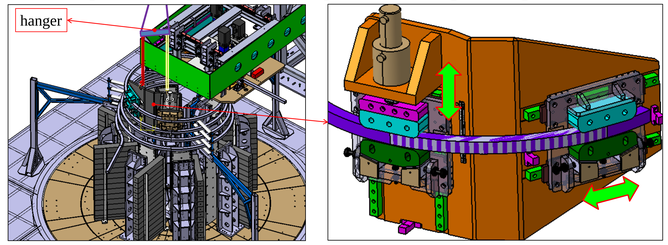



**Figure 6 Schematic diagram of continuous bending machine**




**(a) Forming statues on-line** **(b) Stretch bending tooling**

**Figure 7 Forming method on-line for pancake joggle**

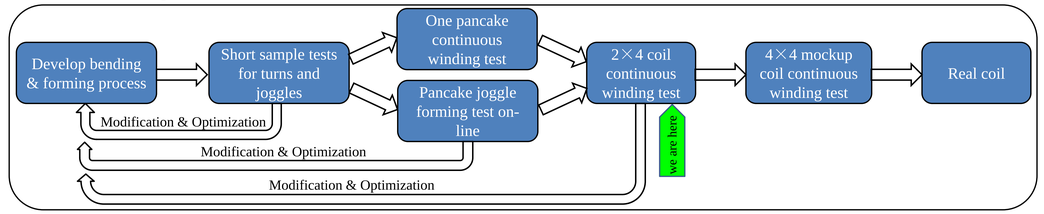



**Figure 8 Developing strategy for coil winding**

## 4. Results and Conclusions

2×4 coil of $Nb_3Sn$ inner coil has been wound continuously, the inner and outer circular surface profile is measured by laser tracker and the results indicate that the profile error is lower than 1mm within the requirement 2mm, the width and height error is lower than requirement (0.5mm), and the conductor feeding accuracy is within 1‰L not meet the design requirement 0.5‰L (can be adjusted by the modification of the servo motor driving parameters).

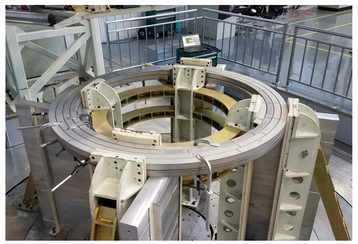


**Figure 9 2×4 coil wound**

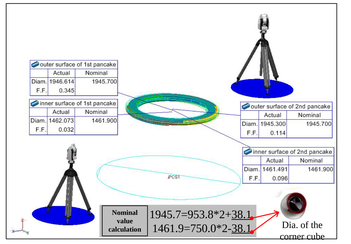



**Figure 10 Inner and outer circular surface profile**

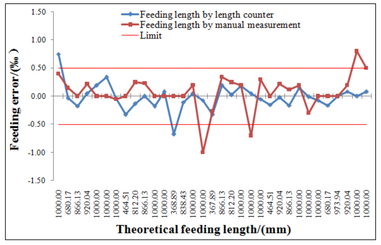



**Figure 11 Conductor feeding error**

2×4 coil wound successfully shows that the winding and forming process is feasible. The 4×4 mockup coil of $Nb_3Sn$ inner coil will be wound in next step.