Manufacture and Test Results of a Prototype Nb_3Sn-NbTi Joint Sample for the CFETR CSMC

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1. Introduction

The CFETR CS Model Coil is a superconducting magnet of 12 T maximum magnetic field when the running current is 47.65 kA, which consists of two coaxial Nb_3Sn coils in the internal high field region and a stack of three NbTi coils in external low field region. All the windings of CSMC are a kind of pancake coil continuously wound one-in-hand by cable-in-conduit conductor (CICC), which are electrical connecting in series by superconducting joints. The five coils contain six joints due to two NbTi jumper lines are used to connect the three of them. The joint location and distribution are shown in Fig. 1 and Table I. The design resistance of the joint is below 5 nΩ in operating conditions. A Nb_3Sn-NbTi full-size joint sample has been manufactured and tested in the SULTAN facility. The design and manufacturing processes of the joint sample are presented, and the test result show dc resistance below 5 nΩ criterion.

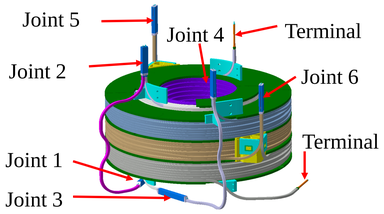

Fig. 1. The joints and leads location of the CSMC

Table I The joints distribution of the CSMC

	Nb_3Sn inner coil	Nb_3Sn outer coil	NbTi up coil	NbTi middle coil	NbTi low coil	NbTi jumper line	NbTi jumper line
Joint 1	●					●	
Joint 2		●				●	
Joint 3		●					●
Joint 4			●				●
Joint 5			●	●			
Joint 6				●	●		

2. Conductor specifications

The cross sections and specifications of CSMC CICC are shown in Figure 2 and Table II, respectively.

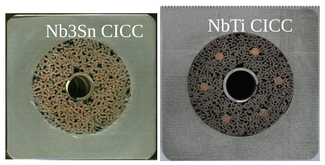

Fig. 2. Cross sections of CICC for CFETR CSMC

Table II The specifications 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	20/45/80/150/450	45/85/145/150/450
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	32.5%	34.1%
Central spiral	8 × 10 mm	10 × 12 mm

3. Joint sample Configuration

Fig. 3 shows the configuration of the prototype joint sample. The left leg Nb_3Sn CICC while the right leg is NbTi CICC. Each straight sample leg has two concentric terminations. Each upper termination is connected to a terminal of the facility transformer, and two lower terminations are soldered to a saddle copper block to close the electrical circuit. The overall length of the test sample at room temperature is 2826 mm. The lateral dimensions of assembled joint sample are within 142 mm × 92 mm. The dimensions of the assembled upper terminal cross section are 100 mm ×99.5 mm. Temperature sensors are installed on the jacket of conductors and helium inlet pipes. Voltage taps are arranged to collect the voltage drop across the joint.

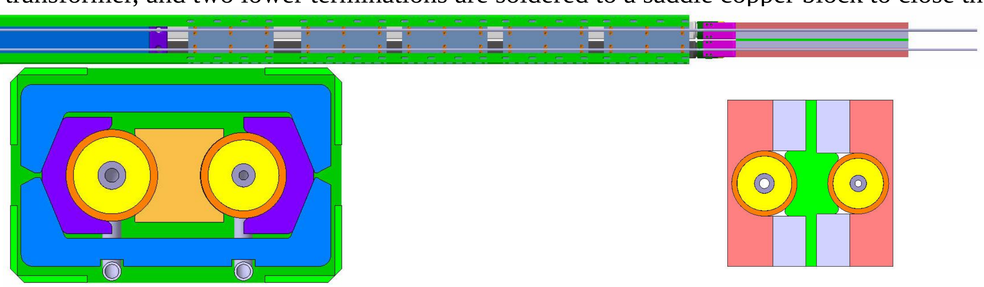

Fig. 3. Sketch of Nb_3Sn-NbTi full size joint sample

4. Joint sample manufacturing

A. Conductor termination manufacturing process

The key steps in fabricating the termination are: (1) preparing the vacuum brazed terminal sleeve sub assembly, (2) removing chrome plating from the cable surface for Nb_3Sn cable while Ni removal and silver plating for NbTi cable, (3) compacting the cable in the terminal sleeve to a small void fraction, (4) welding the stainless steel transition of the terminal sleeve to conductor jacket, (5) soldering NbTi cable and terminal sleeve, and (6) heat treatment for Nb_3Sn leg.

B. Joint Assembly

1) Lower tested joint: The lower joint was made by soldering two lower terminations with 60Sn40Pb (eutectic temperature: 183 ℃) to a saddle shape copper block. 2) The active terminal sleeve of each upper termination was soldered to a U-shape vacuum brazed SS-Copper block with a similar method used in making the lower joint. Fig. 4 shows the lower tested joint soldering results. The fabrication completed joint sample is shown in Fig. 5.

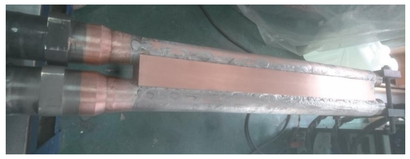

Fig. 4. Lower tested joint soldering

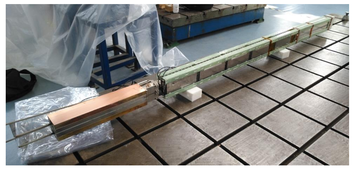

Fig. 5. Joint sample photograph

5. Joint sample test result

The measured resistance of the prototype joint are summarized in Fig. 6. The AC loss measurement are performed before and after 1000 loading cycles, see Fig. 7

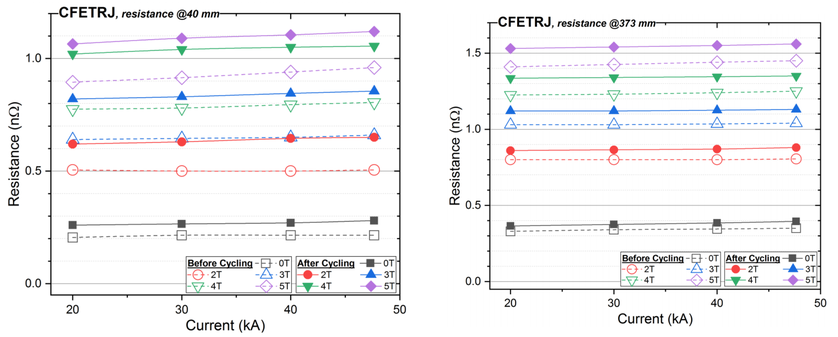

Fig. 6. DC resistance test results: Voltage taps 40 mm (left) and 373 mm (right) away from the joint

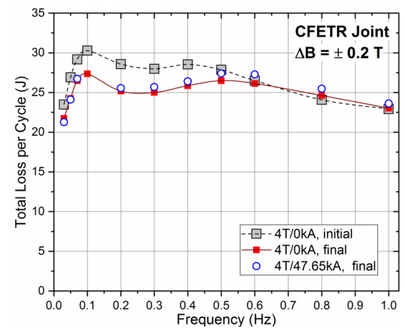

Fig. 7. AC loss results

6. Conclusion

A full-size joint sample has been designed and manufactured to verify the dc performance of the superconducting joint. The dc resistance of the full-size joint sample satisfies the criteria of below 5 nΩ. Most of the present joint manufacturing experiences and key parameters will be incorporated in fabrication of joints for the CS model coil.

Author: Guanghui Ma, E-mail: mgh@ipp.ac.cn, Title: “Manufacture and Test of a Prototype Nb3Sn-NbTi Joint Sample for the CFETR CSMC”.