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# The results of the second Chinese TF conductor sample☆

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ABSTRACT

In the framework of the ITER qualification tests the second Chinese sample (CNTF2) was tested in the SULTAN facility. The sample was made of two identical ITER TF type cable-in-conduit conductor sections. Internal Sn strands offered by Western Superconducting Technologies Company (WST) were used for the conductor fabrication. The main characteristics of the conductor and the strand are presented as well as the sample assembly details. The test was performed in accordance with the ITER International Organization specified program. In order to evaluate the conductor performance, the current sharing temperature was measured at specified electromagnetic load cycling steps. Few voltage–current characteristics were measured with the aim of n-value estimation. Before cycling load, both conductor sections of CNTF2 showed different performance, but after 1200 cycles and warmed up and cool down, they showed identical performance: the current sharing temperature ($T_{cs}$) was 6.36 K, which exceeds ITER requirement of 5.7 K.



## 1. Introduction

The specification of the critical current ($I_c$) of the $Nb_3Sn$ strands for the ITER Toroidal Field (TF) coils was upgraded, according to the test results of the ITER model coils. Institute of Plasma Physics Chinese Academy of Sciences (ASIPP) and Western Superconducting Technologies Company (WST) have been developing high performance $Nb_3Sn$ strands. Their $I_c$ specification at 4.2 K, 12 T more than 230 A for internal Sn method. The developed strands satisfied these specifications with sufficient margins. ASIPP fabricated the conductors using these high performance strands and the samples for testing at the SULTAN test facility in CRPP, Switzerland. The object of the test is to properly assess $T_{cs}$ of the tested conductors in operating conditions and to confirm that the conductor layout is appropriate for the TF coils. The qualification requirement is $T_{cs}$ ($E = 10\ \mu V/m$) > 5.7 K at 68 kA in the background field of 10.78 T [1,2]. The samples were tested from September 27th to October 15th, 2010.

## 2. $Nb_3Sn$ strand and conductor

### 2.1. Strand

The conductor tested in the SULTAN facility is composed of internal Sn strands with the main characteristics presented in Table 1. A cross-section of the strand before heat treatment (HT) and the filament bundle is shown in Fig. 1.

### 2.2. Conductor sample

The conductor sample CNTF2 is a cable-in-conduit conductors (CICC) with 43.65 mm outer diameter composed of 900 superconducting and 522 copper strands. The cabling was performed according to the ITER TF option 2 layout. The conductor terminations were manufactured according to the standard SULTAN sample manufacturing procedure. The main characteristics of the conductor are presented in Table 2. The heat treatment of the two conductor sections had been carried out at CRPP in a vacuum furnace, with purging Ar gas inside the conductors. The schedule for this treatment is shown in Table 2.

## 3. Test results and analysis

### 3.1. DC test results

The main direct current (DC) tests were performed with a background field of 10.78 T and $I = 68$ kA. In order to assess the performance of the conductors after repeated loads, 1200 electromagnetic load cycles were carried out ramping the current from 0 to 68 kA and back in a constant background field of 10.78 T. The samples had been further tested after a warm-up/cool down cycle with the aim of evaluating the impact of a thermal cycle on the conductor performance [3]. We used the electric method and calorimetric method to assess $T_{cs}$.

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**Table 1**
Strand characteristics.

| | 01CW0003 |
|---|---|
| Strand diameter (mm) | 0.82 |
| Cu:non-Cu in strand | 0.9 |
| Manufacturing technology | Internal Sn |
| Diffusion barrier | Ta |
| Non-Cu hyst.loss ±3 T (mJ/cm$^3$) | 666.7 |
| $I_c$ @ 4.2 K 12 T (A) | 273.8 |
| Strand n-index, @4.2 K, 12 T | 27.8 |
| RRR | 184.9 |

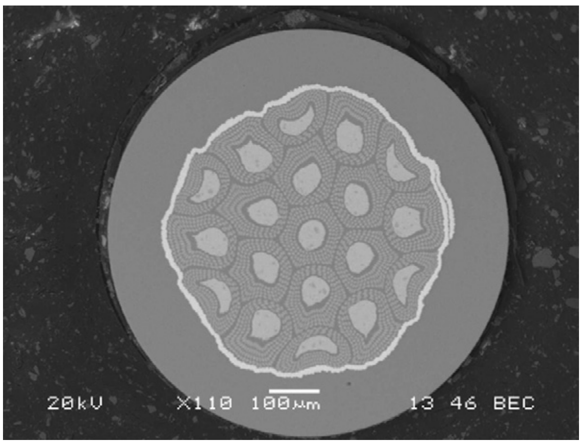


**Fig. 1.** Cross-sectional area of $Nb_3Sn$ strand before heat treatment.

*3.1.1. Electric method*

Because the effect of the joint, the early voltage is always not zero, such an offset may affect seriously on the assessed $T_{cs}$ value so that we cannot neglect or regard it as zero, because the critical level of $T_{cs}$ is defined as 0.1 µV/cm. The actual process is the linear fitting of early voltage data with respect to the current with initial 4 points (10, 20, 30 and 40 kA) excluding zero point in the early voltage. For such correction, an extrapolation of linear fitting for a cycle test is illustrated in Fig. 2.

Use the raw voltage data subtract the extrapolation data at 68 kA, and then confirm the $T_{cs}$ at the 0.1 µV/cm. By using the same method, $T_{cs}$ versus number of cyclic loads is presented in Fig. 3.

From the test result, the two identical conductors have a different performance. A trend of $T_{cs}$ reduction is visible in both conductors. The $T_{cs}$ difference changes from 0.3 K to 0.1 K during cycling, and the $T_{cs}$ difference is not visible anymore after warm-up and cool down. The final $T_{cs}$ is 6.365 K for the left leg and 6.36 for the right leg.

**Table 2**
Conductor characteristics.

| | CNTF2 |
|---|---|
| Cabling layout | ((2 sc + 1 Cu) × 3 × 5 × 5 + core) × 6 |
| Core | 3 × 4 |
| Cu strand diameter triplet (mm) | 0.82 |
| Cu strand diameter in core (mm) | 0.82 |
| Final outer diameter (mm) | 43.65 |
| Void fraction (%) | 29.29 |
| Twist pitch sequence (mm) | 80/140/185/300/440 |
| Number of sc strands | 900 |
| Number of copper strands | 522 |
| Jacket material | 316LN |
| Sub-cable wrap | 15.02 mm width, 0.095 mm thick, 45.6% open surface, left hand, Material 316L |
| Cable wrap | 39.93 mm width,0.099 mm thick, 38.1% overlapped, left hand, Material 316L |
| Central spiral | 6 mm width,1 mm thick, diam 10.03 mm, twist pitch 8.57 mm,Material 316L |
| Heat treatment schedule [°C/h] | 210/50 + 340/25 + 430/25 + 575/100 + 655/100 |

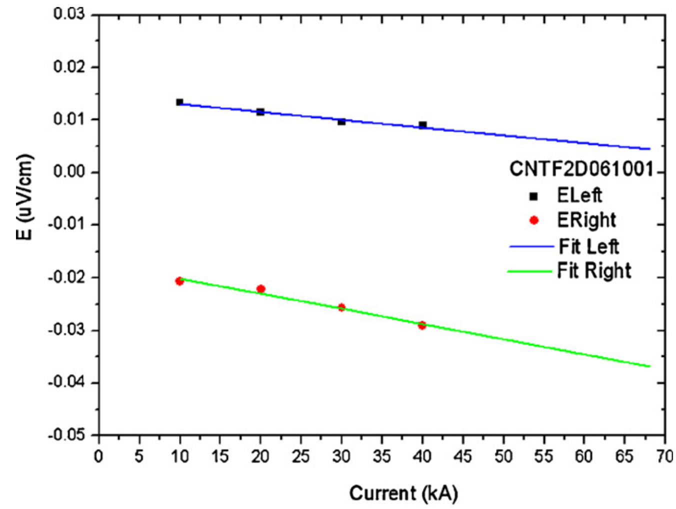


**Fig. 2.** The early voltage linear offset with current on both legs.

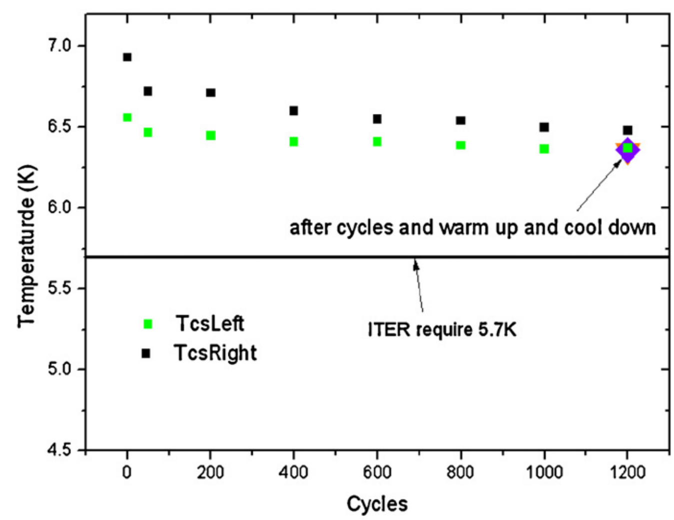


**Fig. 3.** $T_{cs}$ versus number of cyclic loads for CNTF2 sample.

*3.1.2. Calorimetric method*

The Joule heating due to operation in the current sharing regime is assessed by the heat power derived from the change of enthalpy at a given mass flow rate (*1*), and measured between the two temperature probes located upstream and downstream of the high field zone as shown in Fig. 4 [4,5].

$$EI\Delta L = \frac{dm}{dt}(H(T_d, P) - H(T_u, P)) \quad (1)$$

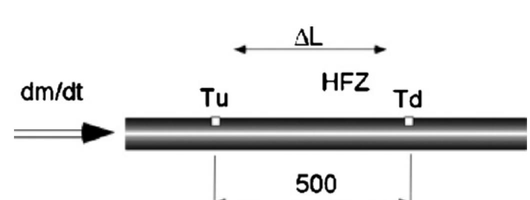


**Fig. 4.** Calorimetric method model.