BREAKTHROUGH IN PERFORMANCE DEGRADATION OF ITER CENTRAL SOLENOID CONDUCTORS OWING TO SHORT-TWIST-PITCH CABLING AND SUPPRESSION OF BENDING STRAIN

[1]Tomone SUWA, Takaaki. ISONO, Keiya. TAKEBAYASHI, Yasuhiro. UNO, Tsutomu. KAWASAKI, Masaru. KAWABE, Tsutomu HEMMI

[1]National Institutes for Quantum Science and Technology, 801-1 Mukoyama, Naka-shi, Ibaraki 319-0193, Japan

Email: suwa.tomone@qst.go.jp

The National Institutes for Quantum Science and Technology (QST) procured all 49 conductors for the ITER central solenoid (CS). Because the critical current of Nb_3Sn strands degrades due to strain and deformation, the current sharing temperature (T_{cs}) of the CS conductors should be maintained for 60,000 electromagnetic loading cycles (30,000 plasma burns) over the lifetime of ITER. To prevent Nb_3Sn strands from deforming due to electromagnetic loading cycles, a short-twist-pitch conductor having stable performance against electromagnetic loading cycles was developed. This study is the first to identify the internal strain state of Nb_3Sn strands in a short-twist-pitch conductor by using neutron diffraction measurements and strain analysis, and the first to clarify the mechanism of improvement owing to the short twist pitch.

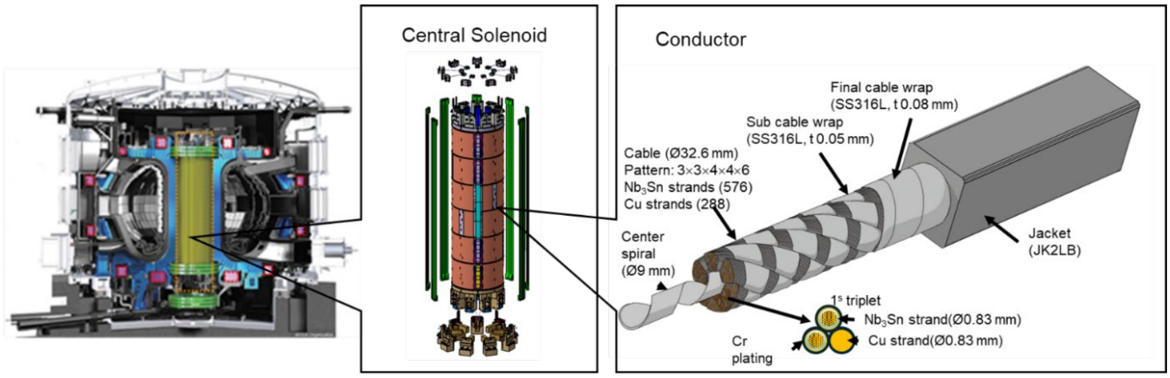

Fig. 1 ITER central solenoid (CS) and CS conductor

The CS conductors are cable-in-conduit conductors, 918 m (613 m) in unit length for a hexa(quadri)-pancake coil and are composed of 576 Nb_3Sn strands, 288 Cu strands, a central spiral, and JK2LB stainless steel jackets, as shown in Fig. 1. A peak magnetic field of 13 T is generated by a 40-kA current flowing in the CS at the start of discharge (SOD). The CS conductor is composed of a five-stage cable having Nb_3Sn and Cu strands, whose cable pattern is crucial in protecting the Nb_3Sn strands from strain and deformation. In the beginning phase of CS conductor manufacturing, several 3.6-m-straight samples using trial CS conductors were tested in the SULTAN facility. The trial conductors had a long twist pitch, and the test conditions were selected to reproduce maximum electromagnetic loading in the ITER CS by using a background field of 10.85 T and current of 45.1 kA. However, T_{cs} degradation was observed after less than 10,000 electromagnetic loading cycles [1]. This raised concerns that T_{cs} had decreased below the ITER requirement. Bent and buckled strands were observed in visual inspections of the trial CS conductors whose T_{cs} degraded. Moreover, large local bends of Nb_3Sn strands and their positions in the trial conductors were found by using neutron diffraction measurements. To prevent the strands from bending and buckling and to improve the stiffness of the cable to supress T_{cs} degradation, a short-twist-pitch CS conductor

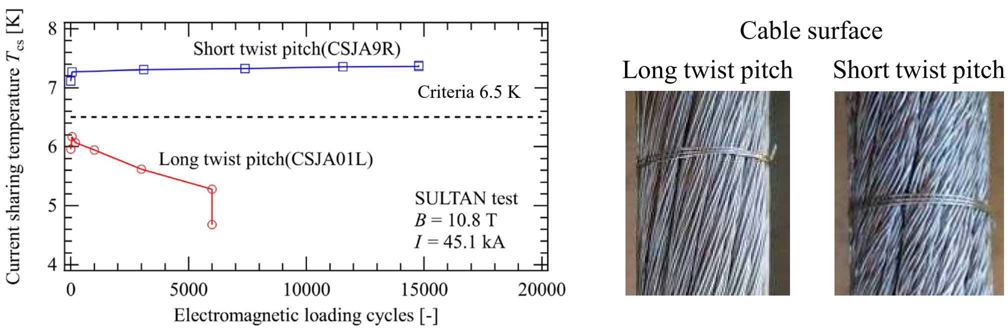

Fig 2. Current sharing temperature (T_{cs}) against electromagnetic loading cycles for SULTAN test

was developed [2]. The twist pitch of the short-twist-pitch conductors was nearly half the twist pitch of the long-twist-pitch trial CS conductors, the cable surfaces of which are shown in Fig. 2. In general, critical buckling load is inversely proportional to the support length (i.e. twist pitch), with deflection of the strands being a function of the support length. The shorter the twist pitch, the higher the critical buckling load and the lower the deflection. Therefore, the twist pitch of the short-twist-pitch conductors was nearly half the twist pitch of the long-twist-pitch conductors (with the exception of the five-stage cable). Using the newly developed short-twist-pitch CS conductors, T_{cs} no longer degraded due to elctromagnetic loading cycles, but T_{cs} did increase slightly [3], as shown in Fig. 2.

To evaluate T_{cs} under simulated operating conditions of the ITER CS (13 T), a solenoid CS insert coil having a 40-m, short-twist-pitch conductor was tested by using a CS model coil (CSMC) to apply a background field. The reason for this is that the SULTAN test facility cannot fully simulate the operating conditions of the ITER CS due to its maximum magnetic field of 10.85 T and lack of hoop stress on the samples owing to their straight shape. As a result of the CS insert test campaign, the T_{cs} of the CS insert satisfied the ITER requirement (5.2 K) after approximately 10,000 electromagnetic loading cycles, and T_{cs} did not degrade [4]. In contrast, the T_{cs} of the CS insert was higher than that of the SULTAN test because compressive strain on Nb_3Sn strands due to differences of thermal contraction between the components of the CS conductor was reduced owing to hoop stress (tensile direction).

The results of the SULTAN test and the CS insert test on short-twist-pitch CS conductors showed the effectiveness of a short twist pitch for improving conductor performance, however, the quantitative influence of a short twist pitch on the strain state of Nb_3Sn strands in the conductor was not understood. To investigate the effects of twist pitch on T_{cs} degradation and strain state of Nb_3Sn strands, neutron diffraction was performed and a new strain analyis by using deconvolution of diffraction profiles was developed [5]. Through this strain analysis, suppression of the bending strain was observed in only the short-twist-pitch conductor, as shown in Fig. 3. Moreover, compressive strain relaxation owing to electromagnetic loading cycles was observed. Therefore, the T_{cs} of the short-twist-pitch conductors was improved by improving the critical current of Nb_3Sn strands.

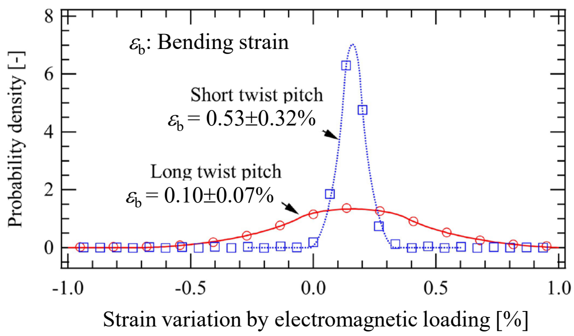

Fig 3. Strain variation by electromagnetic loading in analysis of neutron diffraction profiles

These results are evidence that a short twist pitch is effective for improving T_{cs} by supressing bending strain and relaxing compressive strain on the ITER cable-in-conduit conductors, and could be applied to future fusion devices such as DEMO.

Dislaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

REFERENCES

[1] Hemmi T., et al., Test Resultsand Investigation of Tcs Degradation in Japanese ITER CS Conductor Samples, Supercond. Sci. Technol. 26 (2013) 084002.
[2] Devred A., et al., Status of Conductor Qualification for the ITER Central Solenoid, IEEE Trans. Appl. Supercond. 23, (2013) 6001208.
[3] Bresch M., et al., Performance tests of ITER CS conductor samples from series production, Supercond. Sci. Technol. 36 (2023) 035007.
[4] Martovetsky N., et. Al., ITER Central solenoid Insert Test results, IEEE Trans. Appl. Supercond. 26 (2016) 4200605.
[5] Suwa T., et al., Strain analysis by neutron diffraction on Nb_3Sn strands in ITER central solenoid conductors of short and long twist pitch, Supercond. Sci. Technol. 38, (2024) 015008.