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Finite element analysis of copper–Nb_3Sn contact performance under transverse compression

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HIGHLIGHTS

- To build the 2D model of Nb_3Sn strand and analyze the copper strand influence on contact strain state with flat and concave plates.
- The two strand contact forms are (a) Nb_3Sn–Nb_3Sn contact model and (b) copper–Nb_3Sn contact model (the cooper on the top).
- The three strand contact forms are (a) Nb_3Sn–Nb_3Sn–Nb_3Sn contact model and (b) copper–Nb_3Sn–Nb_3Sn contact model (the cooper on the top).
- The average von-Mises strain of bottom Nb_3Sn in two strand or three strand contact forms (a) and (b) with flat or concave plates is the same.
- The copper on the top press construction has no more influence on the strain distribution in Nb_3Sn strand under the transverse compression.

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ABSTRACT

It turns out from recent researches on Nb_3Sn conductor that contact strain is important for Nb_3Sn conductor, as it could cause the degradation of the conductor itself. Few experimental results describing the behavior of Nb_3Sn sub cables under transverse load are available. Numerical modeling is one method to investigate the contact strain inside the cable. In this paper, finite element method was used to analyze the two- and three strand contact strains under two pressing configurations: flat and concave plates. From the finite element analysis, it is found that the average von-Mises strain of bottom Nb_3Sn in Nb_3Sn–Nb_3Sn–Nb_3Sn contact model and copper–Nb_3Sn–Nb_3Sn contact model is the same under flat or concave plates; the average von-Mises strain of bottom Nb_3Sn in two strand contact model is also the same. It is also verified that the shape of the top copper press has no more influence on the strain distribution in Nb_3Sn strand under the transverse compression.

1. Introduction

All superconducting coils with different dimensions used in ITER are made of cable-in-conduit conductors (referred to as CICCs). Two different types of superconducting strands are used in CICCs: one is NbTi and the other is Nb_3Sn. The differences in thermal contraction of the composite materials in the conductor will cause a contraction of the strands in the axial direction and also an enhanced bending and contact deformation of the strands when cooling to cryogenic operation temperature. During ITER magnet operation, the Nb_3Sn conductors are carrying large current in a magnetic field locally exceeding 13 T and suffer cyclic transverse loading from Lorentz forces, with cumulated loads from one strand transferred to other strand contacts. As the performance of Nb_3Sn is very sensitive to the strain, the contact strain will cause the degradation of transport current of the superconducting Nb_3Sn conductor [1].

At present, some numerical models on cable were developed to investigate the strain of single strands inside the cable [2–4]. However, it is difficult to simulate the strain state of whole cable accurately because of its complicate structure. Now several studies have used the finite element analysis (FEA) method to analyze the strain distribution and deformation of strands under transverse load [5–10].

The present research focuses on the numerical simulation of sub-cables, especially for a triplet. Wang [5,6] has investigated on the single strand and three Nb_3Sn sub-cables under transverse compression. For the toroidal field (TF) conductor and the central solenoid (CS) conductor whose first stage cable includes two superconducting strands and a copper one, the influence of the copper strand on the strain distribution in Nb_3Sn under transverse compression has not been investigated. In this paper, the finite element method is used to study the copper strand effect on strain distribution in the Nb_3Sn strand with flat or concave plates used to press

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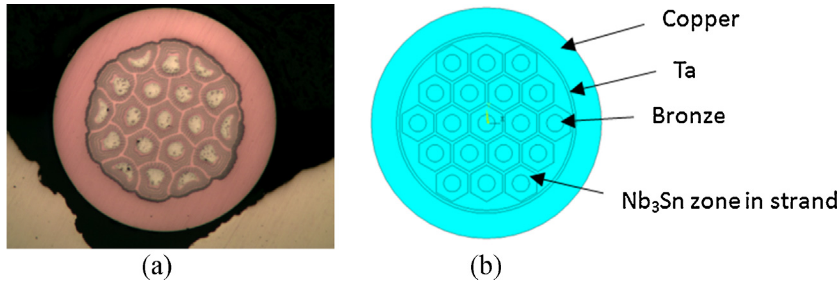

Fig. 1. (a) The cross section of the WST internal tin strand. (b) 2D model of the single strand.

Table 1
Dimension of the model internal tin WST strand.

Strand diameter (mm)	Inner diameter of Ta wall (mm)	Outer diameter of Ta wall (mm)	Length of the hexagon (mm)	Diameter of the Bronze (mm)
0.82	0.62	0.64	0.065	0.06

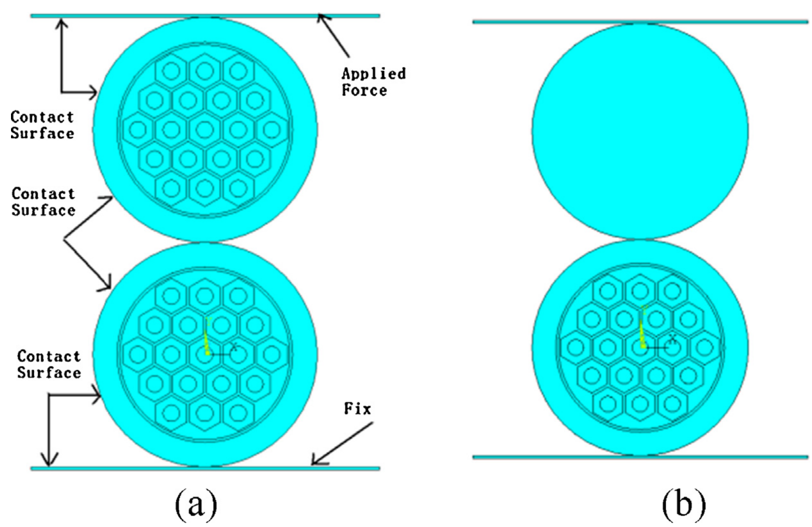

Fig. 2. Two-strand flat plate simulation model. (a) Nb_3Sn–Nb_3Sn contact model, (b) copper–Nb_3Sn contact mode (the copper on the top).

on two strand and triplet samples. The influence of copper wire is emphasized here.

2. Simulations

2.1. Model

The simulations are performed with a 2D model using ANSYS.14 program. Element PLANE183 with plane strain option is used to model the strand and Contact172 and Targe169 are used to simulate the contacts. The contact elements used in the analysis overlay all regions where a contact might occur [5–8]. The FEA model assumes that there are no voids in the strand and no sliding between different materials [5]. The internal tin strand made by Western Superconducting Technologies Company (WST) is chosen for modeling and analysis. The cross section of the sample and the finite element model are shown in Fig. 1. The dimensions of the model are listed in Table 1.

Two configurations in the two-strand simulations are considered. One is (a) Nb_3Sn–Nb_3Sn contact model, the other is (b) Copper–Nb_3Sn contact model (the copper on the top). The contact surfaces are created on two sides of the strands and between the two strands, the lower plate is fixed and the force is applied on the upper plate [7,8],as shown in Fig. 2. The pressing plates are flat or concave with a radius of 0.51 mm, as shown in Fig. 2 and Fig. 3.

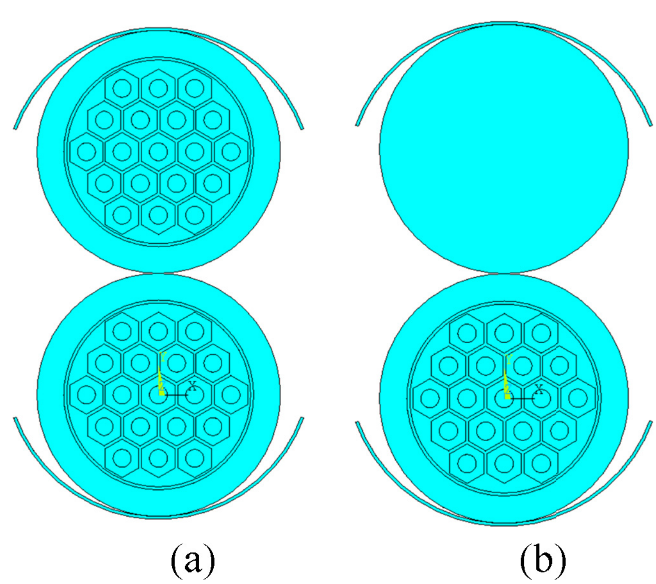

Fig. 3. Two-strand concave plate simulation model. (a) Nb_3Sn–Nb_3Sn contact model, (b) copper–Nb_3Sn contact mode (the copper on the top).