Fusion Engineering and Design 88 (2013) 2773–2776

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Joint resistance measurements of pancake and terminal joints for JT-60SA EF coils

Tetsuhiro Obana[a,*], Kazuya Takahata[a], Shinji Hamaguchi[a], Toshiyuki Mito[a], Shinsaku Imagawa[a], Kaname Kizu[b], Haruyuki Murakami[b], Kiyoshi Yoshida[b]

[a] National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan
[b] Japan Atomic Energy Agency, 801-1 Mukoyama, Naka, Ibaraki 311-0193, Japan

HIGHLIGHTS

- To evaluate the joint fabrication technology for the JT-60SA EF coils, joint resistance measurements were conducted with a joint sample.
- The joint sample was composed of pancake and terminal joints.
- The measurements demonstrated that both joints fulfilled the design requirement.
- Considering the measurements, the characteristics of both joints were investigated using an analytical model that represents the joints.

ARTICLE INFO

Article history:
Received 18 September 2012
Received in revised form 8 April 2013
Accepted 8 April 2013
Available online 17 May 2013

Keywords:
Cable-in-conduit conductor
JT-60SA
NbTi
Joint resistance
Shake-hands lap joint

ABSTRACT

To evaluate the joint fabrication technology for the JT-60SA EF coils, joint resistance measurements were conducted using a sample consisting of pancake and terminal joints. Both joints are shake-hands lap joints composed of cable-in-conduit conductors and a pure copper saddle-shaped spacer. The measurements demonstrated that both joints fulfilled the design requirement. Considering these measurements, the characteristics of both joints were investigated using analytical models that represent the joints. The analyses indicated that the characteristics of the conductors used in the joints affect the characteristics of the joints.

1. Introduction

The magnet system in the JT-60 Super Advanced (JT-60SA) fusion experiment is composed of 18 toroidal field coils, 4 stacks of central solenoid (CS) coils, and 6 plasma equilibrium field (EF) coils [1,2]. The procurement of the CS and EF coils is being undertaken by the Japan Atomic Energy Agency. In the EF coils, two types of cable-in-conduit (CIC) conductors are utilized because of the difference of the maximum magnetic field in the coils. The EF coil for high field (EF-H) conductor is composed of NbTi strands, and the EF coil for low field (EF-L) conductor is composed of NbTi strands and copper wires. The joint between the EF conductors is a one box-type joint that is suitable for a NbTi joint without using a bonding plate of copper and stainless joint. A joint can be assembled using a 60Sn-40Pb solder and covered by a simple case with closure welding. The EF coil has a “pancake joint”, which is the joint between pancake coils, and a “terminal joint” which is the joint between the pancake coil and the current feeder [3].

The sample, including the pancake and terminal joints, was developed to evaluate the fabrication technology of the joints. Using the sample, joint resistance tests were conducted at the National Institute for Fusion Science (NIFS) test facility [4,5]. In this paper, the results of the joint resistance measurement are described, and the characteristics of the pancake and terminal joints are discussed.

2. Sample of the pancake and terminal joints

Fig. 1 shows the configuration of the joint sample. It has a racket shape and is 300 mm in diameter at the circular section. The pancake joint is composed of the shake-hands lap joint between the EF-H coil conductors, and the terminal joint is composed of the shake-hands lap joint between the EF-H and EF-L coil conductors. The EF-H and EF-L coil conductors are CIC conductors equipped

* Corresponding author. Tel.: +81 572 58 2137; fax: +81 572 58 2616.
E-mail address: obana.tetsuhiro@LHD.nifs.ac.jp (T. Obana).

0920-3796/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.fusengdes.2013.04.022

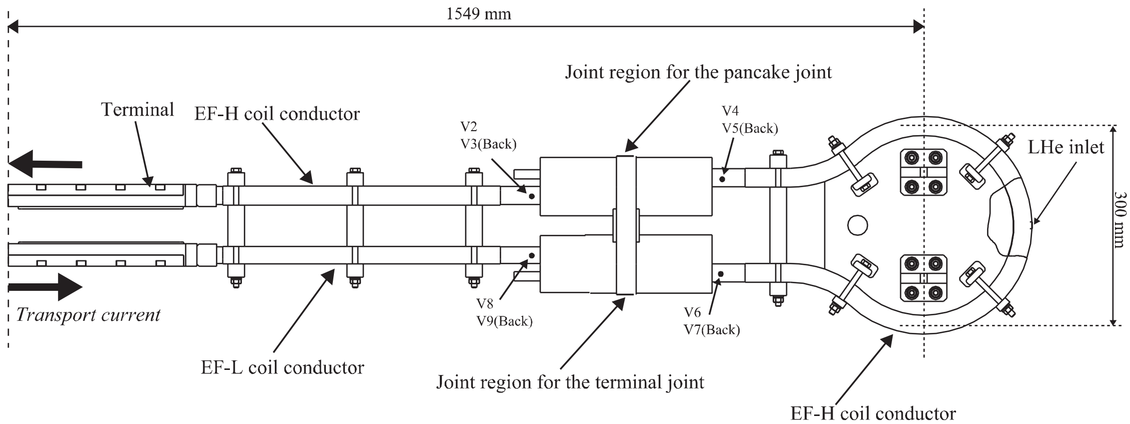

Fig. 1. Schematic view of the sample. V2–V9 indicate the position of the voltage taps.

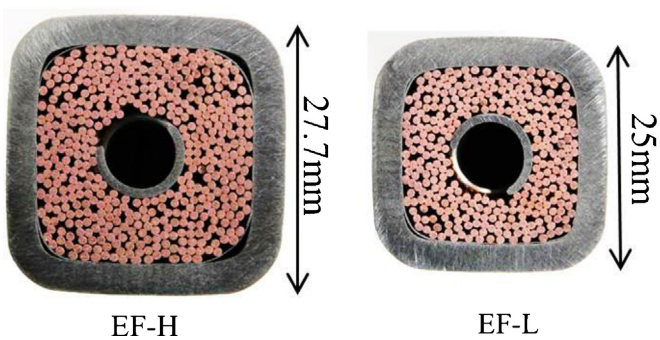

Fig. 2. Cross-section of the EF-H and EF-L coil conductors.

with a central spiral. The EF-H conductor's cable is composed of only 450 NbTi strands, and the EF-L conductor's cable is composed of 216 NbTi strands and 108 copper wires. The NbTi strands are plated with Ni. Fig. 2 shows the cross-sectional view of the EF-H and EF-L coil conductors. Specifications for the conductors are described in Refs. [1,2]. As shown in Fig. 3, a saddle-shaped spacer of pure copper (C1100) is located between the conductors in the joints of the sample, removing a conduit and the Ni plating of the conductor surface. To reduce AC loss, the saddle-shaped spacer is divided into seven sections in the longitudinal direction using 1-mm-thick polyimide sheets. The spacer and conductors are electrically connected with a 60Sn-40Pb solder and clamped with SUS304. Additionally, the central spiral is replaced with a stainless tube. The connected length is 160 mm in the longitudinal direction. This length is the same as the final pitch of the conductors. The conductors are compacted in the joint, and the void fraction of the conductors is 25%. There is a liquid helium (LHe) inlet located at the circular section of the joint sample.

3. Experimental setup

The joint resistance of the sample was tested at the superconducting test facility of NIFS. The test facility can accommodate the testing of superconductors cooled by LHe, under an external field generated by a superconducting split coil. Details of the test facility are described in Refs. [4,5]. The joint sample was installed into the gap of the split coil so as to fit the center of the joint sample with that of the split coil. The joint sample was subsequently immersed in LHe. As illustrated in Fig. 1, the joint sample was equipped with voltage taps attached to the conduit. To measure the joint resistance properly, two pairs of the voltage taps were used for each joint such as the pairs (V2–V5, V3–V4) for the pancake joint and those (V6–V9, V7–V8) for the terminal joint.

4. Measurements

Electrical resistances were measured at the joints of the sample. For these measurements, the sample was energized to 20 kA at a ramp rate of 100 A/s, and was maintained for 500 s. The sample was then degaussed.

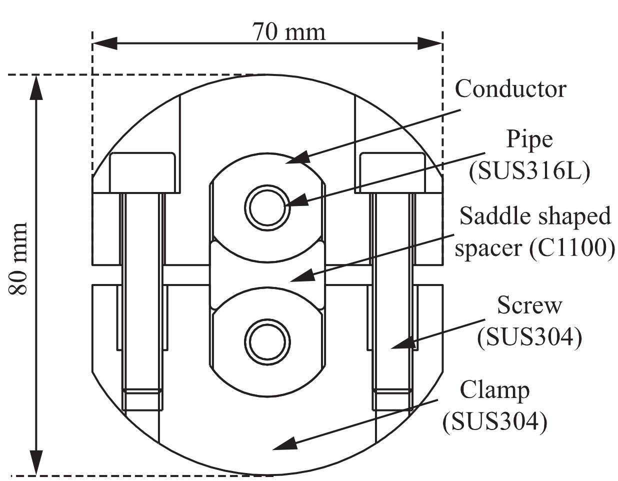

Fig. 3. Cross-section of the sample at the joint.

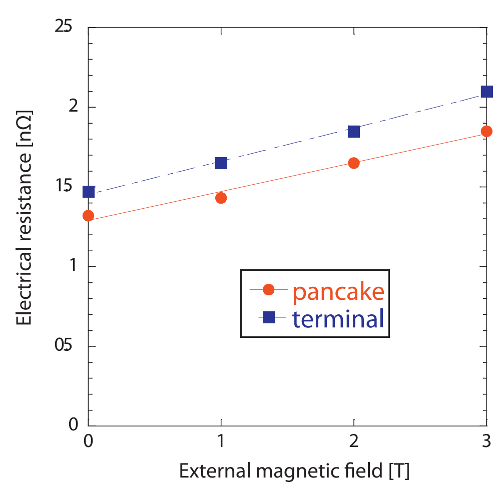

Fig. 4. Measurement result of the joint resistance.