Fusion Engineering and Design 98–99 (2015) 1094–1097

Contents lists available at ScienceDirect

Fusion Engineering and Design

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

Manufacturing design and development of the current feeders and coil terminal boxes for JT-60SA

Kaname Kizu[a,*], Haruyuki Murakami[a], Kyohei Natsume[a], Katsuhiko Tsuchiya[a], Yoshihiko Koide[a], Kiyoshi Yoshida[a], Tetsuhiro Obana[b], Shinji Hamaguchi[b], Kazuya Takahata[b]

[a] Japan Atomic Energy Agency, Naka, Ibaraki 311-0193, Japan
[b] National Institute for Fusion Science, Toki, Gifu 509-5292, Japan

HIGHLIGHTS

- Key components for current feeding system for JT-60SA were developed and tested.
- The joint resistance of feeder joint sample was 1.7 nΩ at 2 T, 20 kA.
- Trial manufacturing of crank shaped feeder showed the max. dimensional error of 3 mm.
- Feeder insulation samples showed >60 MPa in shear strength at 77 K.

ARTICLE INFO

Article history:
Received 17 September 2014
Received in revised form 24 March 2015
Accepted 8 April 2015
Available online 30 April 2015

Keywords:
Coil terminal box
Current feeder
Electrical joint
JT-60SA
NbTi

ABSTRACT

Feeders and coil terminal boxes (CTBs) of the superconducting magnets for JT-60SA have been designed. A small tool which can connect soldering joint with vertical direction in the cryostat has been developed. The joint resistance of the sample showed 1.7 nΩ at 2 T, 4.2 K, 20 kA which is within the requirement of <5 nΩ. A prototype feeder in CTB with crank shape was manufactured. The maximum dimensional error was 3 mm being within the requirement of ±10 mm. Feeder insulation samples showed a shear strength >60 MPa which is much higher than the requirement of 10 MPa as derived from analysis. Since all the manufacturing processes concerned have been proof-tested, the production of feeders and CTBs has been released.

1. Introduction

The superconducting coil system for JT-60SA consists of 18 Toroidal Field (TF) coils and 10 Poloidal Field (PF) coils [1]. PF coils include a Central Solenoid (CS) with 4 modules, and 6 Equilibrium Field (EF) coils. The current of TF and PF coils are 25.7 and 20 kA, respectively. The current feeding system consists of in-cryostat feeders and Coil Terminal Boxes (CTBs) [2,3]. CTBs contain feeders and High Temperature Superconductor Current Leads (HTS CLs) [4]. Because of the available space in torus building, five CTBs (CT01-05) are spread around the main cryostat as shown in Fig. 1. CTBs, in-cryostat feeders and superconductor for PF feeders [5] are procured by Japan. HTS CLs and superconductor for TF feeder [6] are procured by Europe.

There were several concerns for the production of feeder components. The first was the manufacturability of electrical joint in the narrow space in the cryostat after the coil installation. The second was the manufacturability of bent feeder to reduce the reaction force of HTS CL by thermal contraction. In this paper, the trial manufacturing and test results of feeder components are described.

2. Design of CTB and feeder

Fig. 2 shows the structure of CTB. Normal conducting busbars from power supply are connected to HTS CLs. Feeders consisting of superconductors are connected to the cold ends of HTS CLs, and are routed to main cryostat. Feeders in CTB are connected to the in-cryostat feeders through mid joints in the vicinity of cryostat wall. The in-cryostat feeders are connected to the terminal joints of coils.

Since the maximum (max.) allowable magnetic field of HTS CL is 33 mT, HTS CLs are 12 m away from the torus center. The max. allowable horizontal force of HTS CL that is perpendicular to the axis

* Corresponding author.
E-mail address: kizu.kaname@jaea.go.jp (K. Kizu).

http://dx.doi.org/10.1016/j.fusengdes.2015.04.030

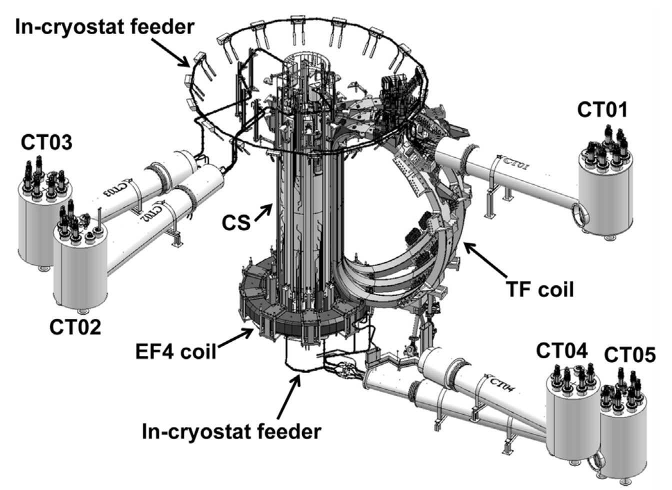

Fig. 1. The current feeding system of JT-60SA. Several TF and EF coils are invisible in this figure.

of HTS CL is 560 N. In order to reduce the horizontal force of HTS CL by the thermal shrinkage of feeder by cooling down, octagonal rings fixing feeders with four supports from room temperature are adopted.

The positive and negative conductors of feeders are clamped to withstand the repulsive force. Feeders in CTB are bent shaped to reduce the thermal stress of octagonal rings. Because of the limitation of the space for CTB vessel, large loops of feeder inside CTB vessel could not be adopted. Fig. 3 shows the cross section of conductors. TF and PF feeders are manufactured from TF coil conductor and EF coil conductor, respectively. Table 1 shows the major parameters of conductors. The conductor in feeder is insulated by Glass/Kapton/Glass (GKG) tapes with epoxy resin.

3. Confirmation of terminal joint

Terminal joints of PF coils and mid joints of TF and PF feeders are the lap type joints connected by solder. The joint is surrounded by stainless steel can. He from one conductor flows out in the can, then flows into another conductor. The design is based on the pancake joint of EF coils [1]. The void fraction and pressing force of cable during soldering are 25% and 140 kN, respectively. However, because the direction of terminal joint is vertical, it was required to confirm that the solder connection can be done appropriately. In the case of EF coil joint, the press is conducted by hydraulic pressure. On the

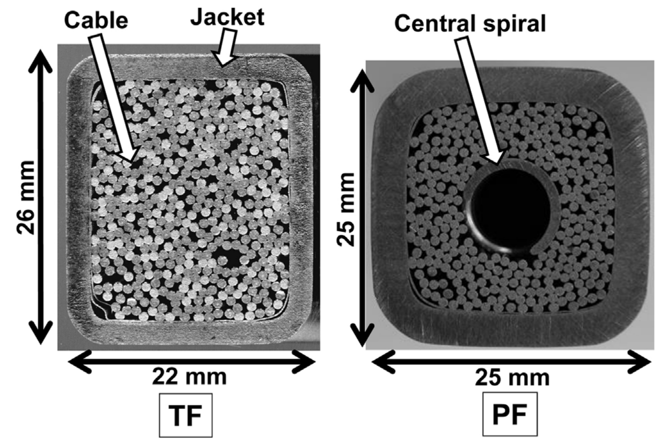

Fig. 3. The cross section of feeder conductors.

Table 1
Major parameters of feeder conductors.

	TF	PF
Type of strand	NbTi	NbTi
Max. Current (kA)	25.7	20.0
Number of NbTi strands	324	216
Number of Cu wires	162	108
Central spiral (id × od) (mm)	NA	7 × 9
Cable dimensions (mm)	22.0 × 18.0	19.1 × 19.1

other hand, in order to reduce the size of tool for terminal joint, the developed connecting tool equips bolts (M12 × 8) to press the joint and sheath heaters embedded to melt solder (50 Pb/50 Sn). Fig. 4(a) shows the photograph of the tool during the connection work. Fig. 4(b) shows the manufactured joint.

A terminal joint sample connected by the tool was fabricated in order to confirm the resistance of joint at operational condition at 2 T, 4.2 K and 20 kA. Fig. 5 shows the schematic drawing of sample. The PF feeder cable and EF coil cable were connected. After removing the nickel coating of NbTi strands and copper (Cu) wires, PF feeder cable, Cu saddle and EF coil cable were soldered and clamped by SS clamp with bolts. The connecting length was 160 mm which is equal to the final twist pitch of cables. This sample was installed in the superconducting coil at National Institute for Fusion Science (NIFS) [7] to apply the external magnetic field. The sample was cooled to 4.2 K. The joint resistance was derived from the electric current and voltage between voltage taps installed at both ends of joint.

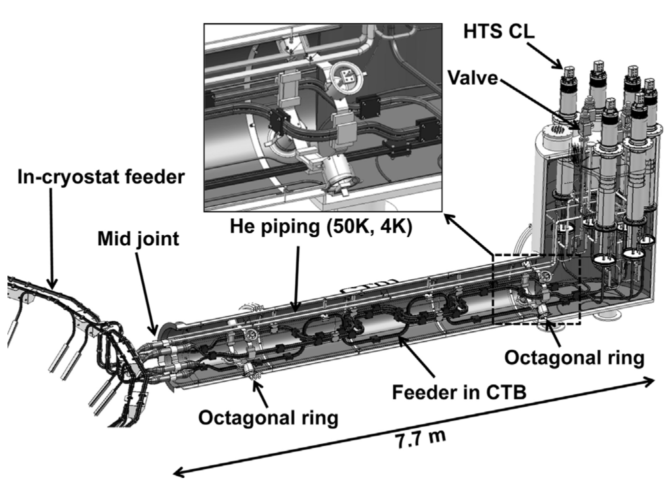

Fig. 2. The structure of CTB.

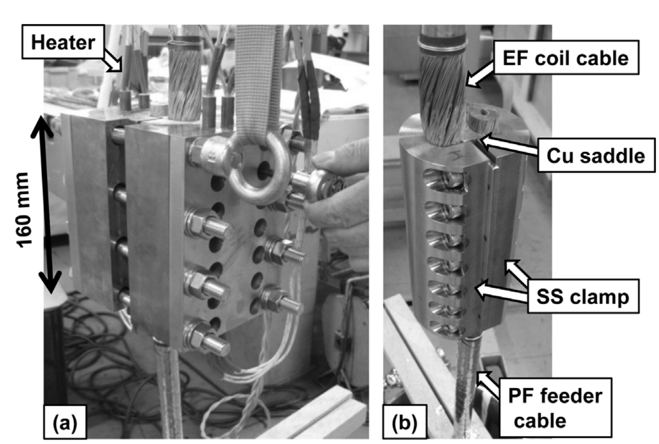

Fig. 4. (a) The connecting tool and (b) the manufactured joint.