Fusion Engineering and Design 121 (2017) 70–74

Contents lists available at ScienceDirect

Fusion Engineering and Design

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

Mechanical performance characterization of the insulation strap of the ITER PF coil tail

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HIGHLIGHTS

- Thermal contraction from 300 to 77 K of the tail strap of ITER PF coils was measured.
- The elastic modulus of the strap was measured at 77 K.
- Fatigue performance of the strap at 77 K was verified in the working condition.

ARTICLE INFO

Article history:
Received 29 October 2016
Received in revised form 3 May 2017
Accepted 6 June 2017

Keywords:
ITER
PF coil tail
Strap
Thermal contraction
Elastic modules
Fatigue property

ABSTRACT

International Thermonuclear Experimental Reactor (ITER) is a full superconducting coil tokamak. The strap composed of fiber glass composite materials is an important component of Poloidal Field (PF) coil tail. The main function of the strap is to maintain the electrical isolation and mechanical connection between the last turn and the last but one turn. The thermal contraction of the strap shall be measured to assess the mismatch between the strap and adjacent conductor while the coil is cooled down, and further, in order to balance the thermal stresses, pretension on the strap is needed while the elastic modulus of the full-size strap shall also be measured. In addition, the fatigue performance of the strap shall be examined in consideration of the cyclic electromagnetic load on the tail in the tokamak operation condition. In this paper, the thermal contraction test, the elastic modulus test and the fatigue test on the full-size strap for ITER PF coils were carried out. The test results show that the thermal contraction from 300 K to 77 K is 0.19% and the elastic modules is about 60 GPa at 77 K. The fatigue results indicate that the strap can meet the requirement of ITER and can be utilized to the practical applications.

1. Introduction

International Thermonuclear Experimental Reactor (ITER) is based on the tokamak concept of magnetic confinement. The aim of the ITER is to demonstrate the scientific and technical feasibility of fusion power [1,2]. The ITER magnet consists of 18 toroidal field (TF) coils, six poloidal field (PF) coils, a central solenoid (CS), and 18 correction coils (CC). The PF system consists of six coils, namely PF1 through PF6, which is designed to control and stabilize the plasma position inside the vacuum chamber of the thermonuclear reactor.

The ITER PF coils are composed of a stack of double pancakes (DPs), which is connected in series by joints. The ends of the conductors of the top and bottom pancakes are coil terminations which will be joined to the terminations of the superconducting bus bars of the feeders. In order to guarantee the reliability of mechanical property of the PF coil, the terminations mechanically connect to the last but one turn by a tail. The main function of the tail is to transfer the longitudinal tensile (or compression) forces from the last turn to the last but one turn by a mechanical connection composed of two legs, one welded to the last turn (weld type 2) and the other to the last but one turn (weld type 1) [3,4]. The electrically isolation between the two legs is performed by a strap made of insulating composite. The mechanical connection between the strap and adjacent stainless steel is achieved by two pins as shown in Fig. 1.

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http://dx.doi.org/10.1016/j.fusengdes.2017.06.010
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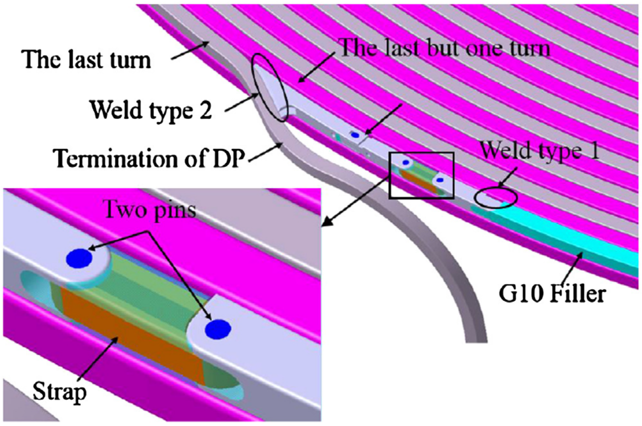

Fig. 1. The layout of strap of the PF coil tail.

All the main elements of the adjacent conductor jacket are manufactured by 316L stainless steel except for the strap, which is made of fiber glass/epoxy composite materials. After the vacuum pressure impregnation (VPI), the tail will be bonded to the adjacent conductor jacket by turn insulation. While the mechanical property of 316L stainless steel has been well documented [5–7], the properties of the specific fiber glass composite need to be characterized to figure out the mismatch between these two when they are cooled down side by side from room temperature to cryogenic temperature. Once we know the mismatch, we can apply a preload during the tail assembly at room temperature on the strap to stretch it to the extent which can balance the mismatch expected down to cryogenic temperature. We thus further need to determine the elastic modulus of the strap to generate the preload by expected extension. In addition, because of the PF coil is operated under the condition of cyclic loading and low temperature, the fatigue property of the strap should also be obtained in consideration of the cyclic electromagnetic force of superconductor magnet.

Fusion for Energy (F4E) will provide the PF2-6 coils to ITER Organization (IO), in which PF2-5 coils will be manufactured by ASG Superconductors and PF6 by Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP). In this paper, the mechanical test on the full-size strap for all PF2-6 coils designed and manufactured by ASG Superconductors was performed by ASIPP under a cooperation agreement coordinated by F4E. The test methods and configuration were described. The mechanical performance characterization of the strap composed of the thermal contraction, the elastic modulus and fatigue property was carried out. The test results were also reported and discussed.

Table 1
Final dimensions of the strap after the curing.

Parameter	Dimension(mm)
H-height of strap	35.1
D-width of the strap	56.2
L-length of straight part	207.6
T1-tickness of middle section	20.2
T2-tickness of 1/4L section	19.1
R-radius of external surface	27.9
r-radius of internal surface	11.7

2. Sample preparation

The tested full-size strap is shown in Fig. 2 on the left. The strap was designed as a racetrack structure and composed of fiber glass/epoxy composite materials, which were wound with glass roving loops with the fiber aligned in the circumferential direction. The strap was made by the wet wrapping technique, and the external dimensions were defined by a customized mold. The final dimensions on each position throughout one tipical strap are shown in Fig. 2 on the right and listed in Table 1. It can be found that the dimension of the strap is not homogeneous in the thickness from the middle section going to the ends. The strap in the middle section is thicker than two ends. As the glass content is constant throughout the cross-section of the strap, the fraction of epoxy in the middle of the strap is much higher than at the end positions. The fractions of glass/epoxy and the density at each key cross-section throughout the strap have been measured by burning method, the sampling positions on the strap are shown in Fig. 3, and the test results are indicated in Fig. 4.

3. Measurement method

The mechanical performance was carried out by collecting the value of the strain gagues. As the structure of the strap was symmetrical, six working strain gauges attached on key positions of the strap would be continuously monitored during the test. The gauges 3, 4 and 6 were attached at the middle of the strap, the gauges 1, 2 and 5 were 60 mm away from the center of the strap, and all the gauges were located at the center of the width of the strap surface as shown in Fig. 5.

For the thermal contraction test, the 1/2 Wheatstone bridge was used to measure the thermal contraction of the strap, with the working strain gauges attached to the strap on one arm and the reference gauges attached to the quartz chips on another arm. One thermometer was attached to the strap to monitor the temperature of the strap during the cooling. The strap and the quartz chips were both placed on one epoxy plate (G10) closely. All of them

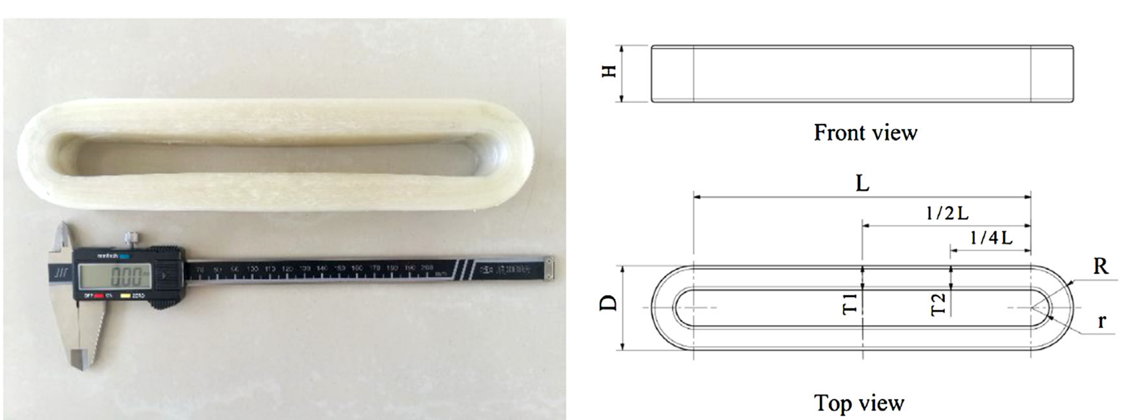

Fig. 2. The full-size strap (left) and its dimension (right).