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Qualification of ITER PF6 helium inlet

Shuangsong Du[a,b], Wei Wen[a,*], Guang Shen[a], Jijun Xin[a], Kevin Smith[c], Carlo Sborchia[c], Peter Readman[c], Yuntao Song[a], WeiYue Wu[a], Huan Wu[a]

[a] Institute of Plasma Physics, Chinese Academy of Science, Hefei, China
[b] University of Science and Technology of China, Hefei, China
[c] Fusion for Energy, Barcelona, Spain

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ABSTRACT

The Poloidal Field (PF) coils are one of the main sub-systems of the ITER magnets. The PF6 coil is being manufactured by the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP) as per the Poloidal Field coils cooperation agreement signed between ASIPP and Fusion for Energy (F4E). As one of the critical components, helium inlet locates on the innermost turn and supplies the coil with supercritical helium. During Tokamak operation, the helium inlet will undergo huge cyclic electromagnetic loads and thermal cycling during cooling down and warming up.

This paper focus on the main steps of ITER PF6 helium inlet qualification. Helium inlet hole drilling and stainless steel wrapping removal were firstly been carried out. Helium inlet welding with full penetration by automatic welding machine was then performed, followed by leak proof test, non-destructive test, fatigue test and tomography test. At the end, the samples were sectioned for micro and macro inspection. The results show ITER PF6 helium inlet qualification has successfully met the requirements of PF procurement agreement(PA) and was approved by ITER IO.

1. Introduction

The ITER PF system consists of 6 solenoidal coils, PF1 to PF6 (as shown in Fig. 1), which serve to shape and stabilize the position of the plasma in the Tokamak. The PF coils are all wound with NbTi conductors, and range in diameter from ~8 m to ~ 24 m.

ITER PF6 winding pack is composed by stacking of 9 double pancakes. The double pancakes are wound in a “two-in-hand” configuration. Two conductors are wound together to form a pancake layer with winding down from” outside-in” in one layer, and “inside-out” on the other. The two layers are connected by superconducting joint to form a double pancake. Joggling is needed in each layer to accomplish the proper positioning of the conductors during winding, as well as a joggle to make the transition from one layer to the next [1–3]. Each double pancake is supplied with supercritical helium by two inlet parts locate on the innermost turn, in the middle of the vertical joggles, as shown in Fig. 2.

Located in the high magnetic field region, the helium inlet will undergo huge cyclic electromagnetic loads and thermal cycling during Tokamak operation [4]. Full penetration weld under monitored welding temperature (below 250 °C to avoid strands degradation) is the primary requirement. According to the PA, full size samples to form the helium inlet shall be manufactured fully replicating the production conditions in order to qualify the manufacturing process, before it is applied on the dummy and series double pancakes winding.

This paper focus on the main steps of ITER PF6 helium inlet qualification. During qualification process, helium inlet hole drilling and stainless steel wrapping removal were firstly been carried out. Helium inlet welding with full penetration by automatic welding machine was then performed, followed by leak proof test, non-destructive test, fatigue test and tomography test. At the end, the samples were sectioned for micro and macro inspection.

2. Qualification of ITER PF6 helium inlet

The requirements of the ITER PF6 helium inlet manufacturing are listed in Table 1.

3 samples were manufactured for the qualification of ITER PF6 helium inlet. The strategies for each sample are as follows:

Sample #1: Welding → Visual inspection → Leak test → PT test → X-ray test → 5 cool-down cycles at 77 K (thermal shock) → Leak test → Tomography inspection → Sectioning → Visual and microscopic inspections.

Sample #2: Welding → Visual inspection → Leak test → PT test → X-

* Corresponding author.
E-mail address: wenwei@ipp.ac.cn (W. Wen).

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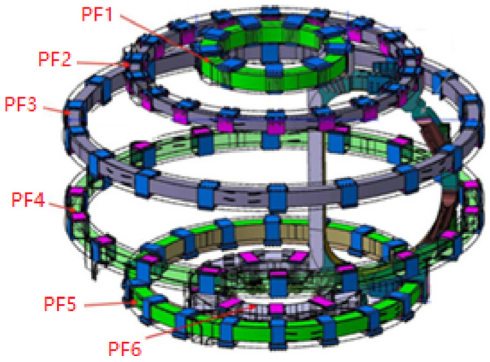

Fig. 1. The PF system of ITER magnet.

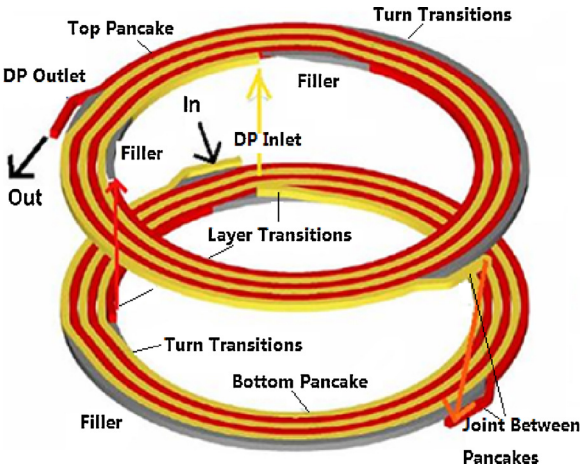

Fig. 2. Two-in-hand winding configuration.

Table 1
ITER PF6 helium inlet requirement.

Item	Requirement
Temperature control	Cable temperature shall remain below 250 °C
Weld joint	Full penetration (ISO 5817_B level)
Leak rate	$< 10^{-9}$ Pa*m^3*s^{-1}, under 3 MPa
Fatigue test	77 K, strain range 9.5×10^{-5}–9.5×10^{-4} during 600,000 cycles or 1.9×10^{-4}–1.9×10^{-3} during 30,000 cycles.

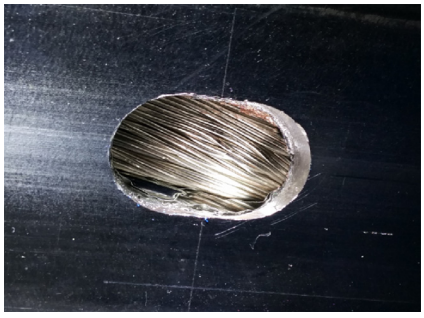

Fig. 3. Helium inlet hole drilling and wrap removal.

ray test → 5 cool-down cycles at 77 K (thermal shock) → Leak test → Fatigue test at 77 K → Leak test.

Sample #3: Welding → Visual inspection → Leak test → PT test → X-ray test → 5 cool-down cycles at 77 K (thermal shock) → Leak test → Tomography inspection → Fatigue test at 77 K → Leak test → Tomography inspection.

Among them, Sample #3 is a backup of sample #2, in case sample #2 failed during fatigue test. If sample #2 survived in fatigue test, no tomography inspection and following tests will be performed on Sample #3.

Sample #1 was bent to the internal radius of the double pancake, simulating geometry of the turn. Samples #2 and #3 were straight. All the manufacturing of the above qualification samples started with helium inlet hole drilling by a portable milling machine and stainless steel wrapping manual removal, shown in Fig. 3. The clearance of the hole root is vital to reduce the stress concentration and pressure drop.

Welding temperature measurement on the cable was required on sample #1. To do this operation, 6 thermocouples were planted from the back, as shown in Fig. 4. The thermocouple joints were planted under the weld in the point of the highest temperature during welding.

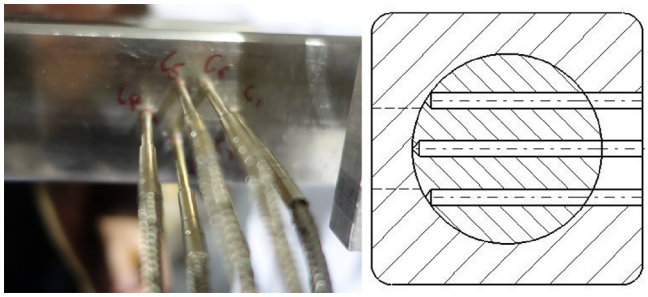

Fig. 4. Thermocouples planting.

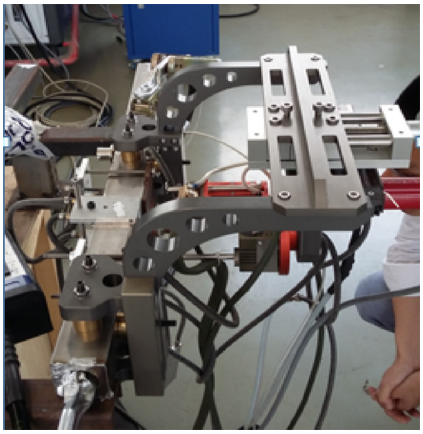

Fig. 5. Automatic welding machine.

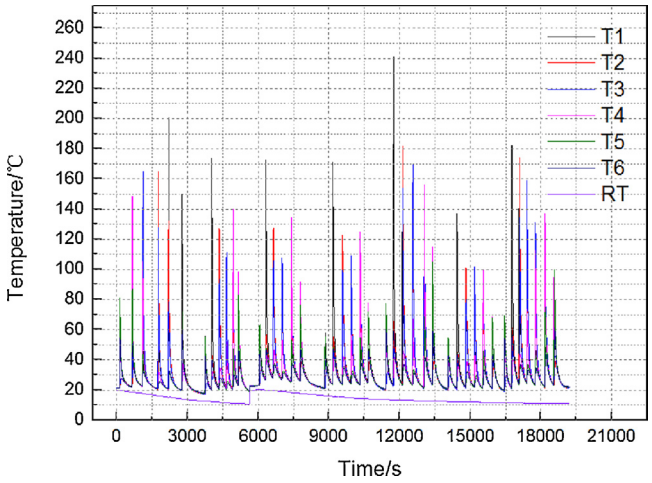

Fig. 6. Temperature curve of welding.