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Fabrication and quality assurance of ITER TF conductor in China

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ABSTRACT

ITER-China TF conductor has been finished on schedule which met all technical requirements, passed all testing and acceptance inspections. Critical technologies for the ITER TF conductor, including cabling, jacket, welding, insertion, compaction, spooling, and acceptance tests have been fully developed and used on the TF conductor fabrication. According to the ITER quality assurance requirement, TF conductor is the quality class 1 component for ITER. To realize the quality assurance and control for manufacture of TF conductors, a quality assurance team has been established. The implements quality assurance (QA) and quality control (QC) work based on our quality system have been set up. Quality control has passed through the whole manufacturing process. The key technologies and QA process for successful fabrication all CN-TF conductors are given in this paper. Among all technologies for TF fabrication, the welding, insertion and compaction are the main critical processes performed at ASIPP. After welding and spooling, Non-Destructive-Examination (NDE), as a strict and important quality control method, is proceeded to control the quality of welding.

1. Introduction

The magnet system for the International Thermonuclear Experimental Reactor (ITER) tokamak consists of four main sub-systems: the 18 toroidal field coils, referred to as TF coils, the central solenoid coils, referred to as CS; the 6 poloidal field coils, referred to as PF coils; and the correction coils, referred to as CCs. All coils are superconducting using cable-in-conduit conductors, but wound by using the different superconductors according to their service requirements. Typically, the ITER TF conductor is composed of 900 Nb_3Sn strands and 522 pure copper strands [1,2]. As shown in Fig. 1, the cross-section view of ITER TF conductor indicates that the strands are assembled in a multi-stage cable around an open central cooling spiral. The cable is inserted into 316LN stainless steel jacket [3–6]. In working condition, the TF conductor operated with 68kA currents, providing a steady field of about 5.30 T at a radius of 6.20 m. Moreover, the TF conductors need to be cooled with supercritical helium at an inlet temperature of 4.5 K. According to the ITER quality assurance requirement, TF conductor is the quality class 1 component for ITER. The “Quality classification determination” was made as a standard, which has strict requirements on design, software, submitted documents, monitoring of performers, measurements, tests, equipment, inspection, personnel qualifications & training of special processes and QA, as shown in Table 1 [7]. Overall, in order to obtain the high quality TF conductor, the manufacture of TF conductors demands a careful evaluation of the production and quality assurance processes to fulfill the quality requirements.

The institute of plasma physics Chinese academy of sciences (ASIPP), as the main supplier of ITER TF conductor, has established the quality assurance team to implement the QA and QC relative works, such as procurement process control, manufacture process control, test and inspection, documents, traceability, training, equipment management & calibration, DR & NCR, quality audit, planning schedule, statistical analysis and so on, ensuring that quality control is passed through the whole manufacturing process. Based on that, the effective quality assurance and quality control programs are mandatory to obtain a high level of ITER TF conductors. So far, ASIPP has completed 13 unit lengths (ULs) of TF conductors manufacture and delivery, which is more than 7400 m long [6].

In this paper, we described the important steps during the manufacture of TF conductors, including welding, insertion, compaction and spooling. According to the experience of ASIPP, we also presented the quality control in detail during manufacturing process, concentrating on Non-Destructive-Examination (NDE) for TF conductors. Hopefully, the quality assurance processes and managements could provide the clues and references for the component fabrication of large scientific engineering equipment in the future.

2. ITER TF conductor manufacturing process

The manufacture of ITER TF conductor is a complex process,

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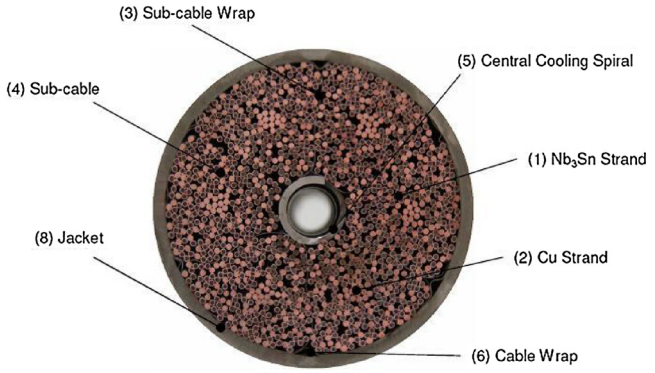

Fig. 1. Cross-section view of ITER TF conductor [8].

including cabling, jacket, welding, insertion, compaction and spooling. For ITER-China TF conductor, the welding, insertion, compaction and spooling are finished in ASIPP. In this section, we would describe each step of welding, insertion, compaction and spooling.

2.1. The welding of circular jacket

The whole length jacket is assembled by butt welding the 10–14 m stainless steel jacket sections, using gas tungsten-arc welding (GTAW) without filler. For the GTAW, the shield gas (Ar atmosphere) is requisited. The jacket section is shown in Fig. 2, and the characteristic information is listed in Table 2.

The welding procedure must be qualified as part of process qualification. The welded joints are considered as joints of category A, No.1 Type defined by ASME Sec. VIII, Div.2, and which are designed, fabricated and examined in accordance with ASME Sec. VIII Div.2 [8]. Based on this requirement, during the weld procedure, the adjacent jacket sections must be aligned on the central hole with a misalignment of less than 0.1 mm between each other, to avoid the tolerance effects appearing on the outside and the inner step resulting from position accuracy of the hole. In addition, to enable to get high quality welding without adjustment by a welding operator, the automatic welding with the appropriate equipment is used for orbital welding, as shown in Figs. 3, 4 and 5. After the welding, each weld is inspected by a go-gauge to confirm the absence of significant shrinkage or distortion relative to the main sections. Usually, the dimension of go-gauge used for the weld is a bit smaller than the jacket inner diameter. If the weld is checked failed by go-gauge, it was cut and re-welding.

2.2. Insertion

The insertion is also a key link in TF conductor fabrication, which ensures the performance of final conductors. The insertion is carried out by an insertion system which consists of pulling system, tension and length measuring system (Fig. 6).

Fig. 2. TF jacket section (316LN).

Table 2
Parameters of TF jacket.

No.	Item	Parameters
1	Material	316LN
2	Outer dimension	Φ 47 × 1.9 mm
3	Elongation at failure (300 K)	38.6%
4	Yield strength (300 K)	500 MPa
5	Ultimate tensile strength (300 K)	735 MPa
6	Young's modulus (300 K)	193 GPa

Fig. 3. The automatic welding for TF jacket.

During the insertion, the cable tension is monitored to confirm whether the abrupt changes occur. The abrupt change of the cable tension indicates snagging and possible strand damage. When the insertion force is bigger than 40 kn, the warning could ring. For all

Table 1
Action applicable to Quality Class1 [7].

No.	Items	Actions
1	Design	Design control including design reviews and verification
2	Software	Acceptance of software used for design and operation
3	Minimum documents and records to be delivered	Quality plan, Manufacturing& inspection plan, procedures, process qualification, operator qualifications, travelers, release note, certificate of conformity, material certification and inspection and so on.
4	Monitoring of performers	Audit of performers including qualification and surveillance
5	Measurements and Test Equipment	Controlled Calibrated measuring and test equipment
6	Inspection	100% visual, surface and volumetric inspection
7	Special processes personnel qualifications and training	Documented personnel qualifications and training
8	QA requirements	QA representative approvals of documents related to special processes and inspections are required