20th IMEKO TC4 International Symposium and
18th International Workshop on ADC Modelling and Testing
Research on Electric and Electronic Measurement for the Economic Upturn
Benevento, Italy, September 15-17, 2014

QA and QC for ITER magnet conductor production

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***Abstract* – Actually, the ITER (International Thermonuclear Experimental Reactor) project mission is to endow the scientific and engineering feasibility for fusion energy. Built LHC (Large Hadron Collider) at CERN, ITER has become the largest project in applied superconductivity and, besides its technical complexity, ITER represent a management challenge as it bases on a unique worldwide collaboration of seven partners (China, EU, India, Japan, US, Russia and South Korea), who provide 90% of the components as *in-kind* contributions. Among ITER components, magnet system for plasma confinement is one of the most complex and advanced superconducting magnet systems ever designed, and its production is involving six of the ITER partners (all but India).**

In the following, quality assurance/quality control programs that have been implemented by ITER Organization (IO) to ensure conductor production uniformity and full traceability of intermediate assemblies across numerous suppliers will be illustrated.

I. INTRODUCTION

The main goal of the ITER project is to demonstrate the scientific and technological feasibility of fusion power [1, 2]. In addition to its technological complexity, ITER represent a unique collaboration in terms of worldwide involved partners, thus requiring an exceptional effort to be managed, especially for the procurement of its components, which for 90% are given as *in-kind* contributions. In fact, the seven ITER members have agreed a procurement allocation, based on an overall agreed procurement value for the project's construction phase.

The project is managed by the ITER International Organization (IO), while each of the seven members have set up Domestic Agencies (DAs) to handle their contributions. The IO is responsible for overall design and integration, defines the technical requirements and issues Procurement Arrangements (PAs) with the DAs. The DAs carry out calls for tender (following domestic rules), procure the components and deliver them to the IO within the PA framework [3].

In this frame, effective quality assurance/quality control programs are mandatory to obtain a high level of homogeneity in the characteristics and features of ITER components produced by diverse suppliers all over the world. IO monitors and controls quality throughout the manufacturing process. This is fundamental because the IO takes responsibility for the ITER machine even though not all large components can be tested under nominal conditions before their acceptance. In what follows, quality assurance (QA) and quality control (QC) requirements and their management by IO for the ITER magnet conductor procurement are illustrated.

II. ITER MAGNET SYSTEM

The ITER magnet system is the largest and most integrated superconducting magnet system ever built [4]. Its stored magnetic energy is 51 GJ. As a comparison, the second largest superconducting magnet system is the Large Hadron Collider machine at CERN, which has a stored magnetic energy of about 11 GJ distributed over a magnet ring of 27 km in circumference.

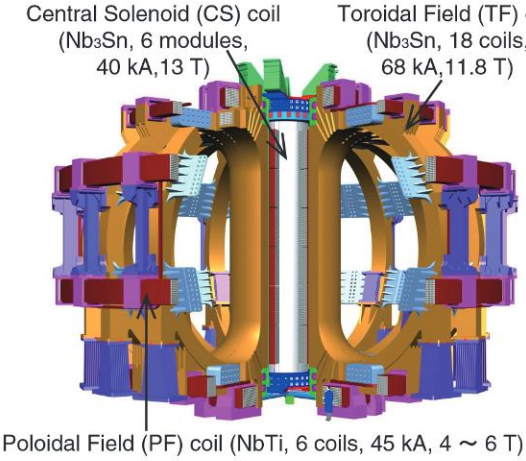

Fig. 1. ITER superconducting magnet system.

It consists of different type of magnets: 18 Toroidal Field (TF) coils, 6 Poloidal Field (PF) coils, a Central Solenoid (CS) coil, 18 Correction Coils (CCs) and a Feeder System.

Fig. 2. Views of the ITER TF conductors and of its components [5].

ITER magnets rely on cable-in-conduit conductors (CICCs). As illustrated in figure 2, the main features of the ITER CICCs are [5]:

- Cr-plated Nb_3Sn or Ni-plated Nb-Ti superconducting (sc) strands mixed with segregated Cr-plated or Ni plated Cu strands,
- a multi-stage cable with stainless steel cable/sub-cable wraps and a central cooling spiral (save for CC and MB conductors),
- a circular, square or circle-in-square, austenitic stainless steel conduit made up of butt-welded jacket sections.

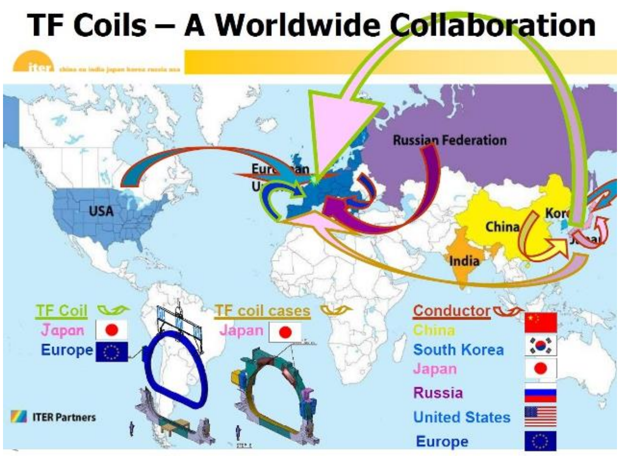

Fig. 3. View of the ITER TF coil production (from intermediate assemblies to final unit length) sharing.

ITER conductors are manufactured by all partner except India. As an example, in Fig. 3 is illustrated the world procurement distribution for the different stages of ITER TF coil manufacture.

III. QA/QC CONDUCTOR PRODUCTION MONITORING

As it is clear in the example in Fig.3, the large number of partners involved in ITER conductor manufacturing makes it crucial to ensure standardization and uniformity of production around the world. To this aim, IO defined through the 11 conductor Procurement Arrangements (PAs), detailed quality assurance (QA) and quality control (QC) requirements to be implemented by the DAs and their suppliers. Among others, these QA/QC requirements call for:

- qualification and certification of manufacturing and test procedures (e.g., orbital welding of jacket sections, local and global He leak tests),
- statistical process control (SPC) on critical parameters,
- benchmarking of cryogenic test facilities,
- systematic low-temperature measurements on strands (critical current, hysteresis loss, residual resistivity ratio): head/tail of every billet + statistical sampling of breakages,
- regular low-temperature measurements on full-size conductors at the SULTAN facility (see below): 25% of TF conductor unit lengths (ULs), 10% of PF conductor ULs, 25% of CS conductor ULs.

What's more, to monitor the production phases and to assure full traceability of the intermediate assemblies, the PAs define a number of control points where the suppliers and the DAs must seek clearance before proceeding to the next step.

With such a large procurement effort involving so many component pieces and suppliers, there is a clear advantage in establishing a centralized database to monitor component quality and uniformity during production, manage the business flow at the supplier, DA, and IO level, and assess production progress towards the Procurement Arrangement (PA) goals.

The tool to allow IO to implement such a monitoring is a web-based conductor database, developed by the IO basing on the successful CERN LHC conductor database [6], which is used by the DAs and their suppliers worldwide [7].

An example of how this tool is operated, is illustrated in Figure 4, where the monitoring of the production of one ITER TF conductor unit length is illustrated.

In total, for ITER magnets conductors, there are seven control points (see Figure 4): five authorizations to proceed ATPPs (strand lot, cable map, cable, jacket section lot, and jacket assembly), one notification point NP (jacketing) and one hold point HP (final conductor).

When a conductor component (such as the superconducting strand, cable, jacket section, or jacket assembly) is fabricated and has passed the required acceptance tests, the DA issues to the supplier an Authorization to Proceed Point (ATPP), which clears that component for the next fabrication step. After all components for one conductor unit length (UL) have been cleared by ATPPs release by IO, the final jacketing supplier issues a Notification Point (NP) to announce the final assembly of the jacketed conductor. After the jacketing is complete (including conductor compaction, spooling, and acceptance testing), a Hold Point (HP) clearance request is submitted to the IO. At this stage, ITER reviews all the relevant performance and acceptance test data and decides whether to clear the HP. Such a clearance formally accepts the conductor unit length, and gives permission for the UL to be shipped to the coil manufacturer of the relevant magnet system.

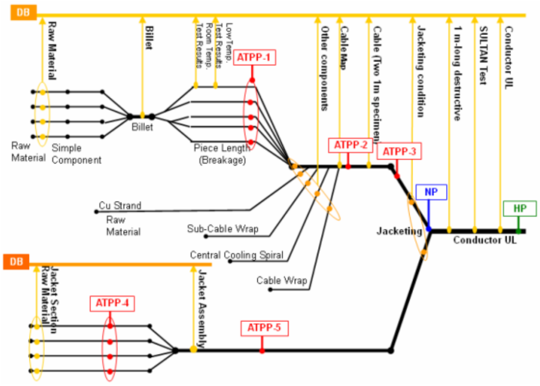

Fig. 4. Control points for monitoring the intermediate assemblies for ITER conductor production [6].

During manufacturing of the conductor components, testing is carried out locally by the suppliers and/or the DA.

By contrast, assessing the performance of a completed conductor section is significantly more complicated and expensive. This test, which consists in the determination of the current-sharing temperature of few meters of conductor length at full current and magnetic field, is currently conducted in the SULTAN facility (see below) at CRPP in Villigen, Switzerland [8]. The cost and limited availability of suitable facilities for such a test has led to the conclusion that not every produced conductor unit length would be tested. Rather, PAs foresee a statistical sampling of at least 1 out of 4 ULs (for TF) to undergo testing. The database will manage the logistics and scheduling of these tests, being even the interface to ensure that all other acceptance requirements are fulfilled across all unit lengths and all conductor components.

The implementation of the conductor dataset, which ensures strict confidentiality of the DAs and individual supplier data has been quite successful. Presently, there are ~20 suppliers/DAs and ~150 users registered to input and verify data. Over the course of the last four years, the IO has cleared ~6900 control points, which, for the strand lots, rely on ~27 000 critical current measurements [5].

IV. FINAL FULL SIZE CONDUCTOR TEST AT SULTAN

The most difficult and critical acceptance tests are the full-size conductor tests which are carried out at the SULTAN facility, located at CRPP in Villigen, Switzerland [8], the only facility in the world where full size, ITER-type CICCs can be tested at the extreme ITER operative condition.

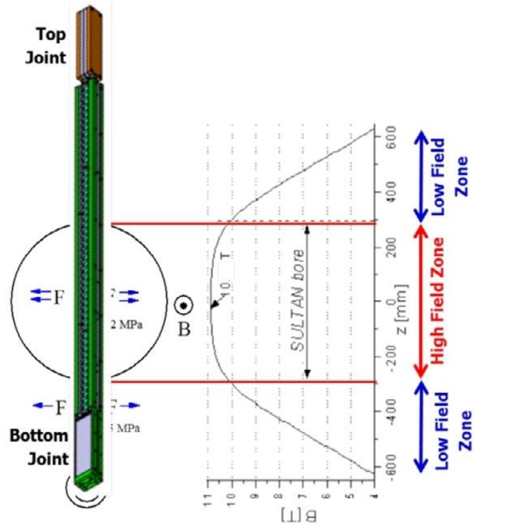

Fig. 5. Typical SULTAN sample sketch [8].

As illustrated in figure 5, SULTAN samples are 3.6 m long, with a high field zone (HFZ) of about 400 mm (of the order of the last-stage cable twist pitch). Samples are tested in pairs with joints at the top and bottom and are instrumented with voltage taps and temperature sensors. Measurements are carried out either at fixed temperature and field, by increasing the transport current (I_C run) or at fixed current and field (figures 6, 7and 8), by increasing the temperature (T_{CS} run) (figures 6, 7and 8). The T_{CS} runs are the ones used to assess the conductor performance [9], which reserves 100% of the SULTAN usage for three years.

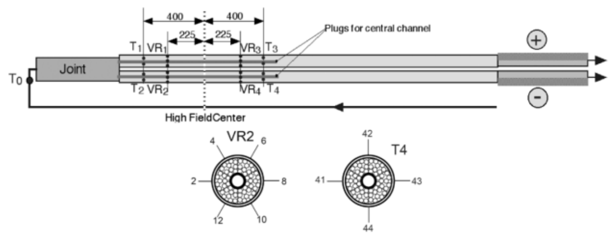

Fig. 6. SULTAN sample voltage and temperature sensor location

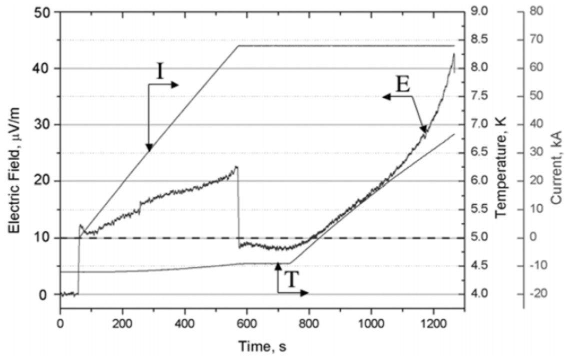

Figure 7. Example of 'voltage slope', i.e. potential building up during the current ramp in a T_{CS} run.

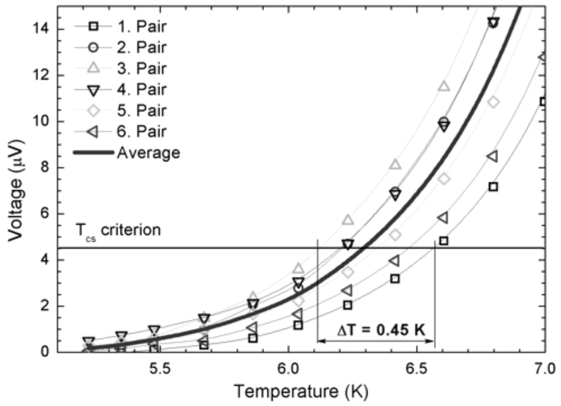

Figure 8. The T_{CS} measurements from individually post-processed voltage compared with the averaged signal.

Suppliers have been qualified on the basis of SULTAN samples which are used as references for assessing the results of QC samples which are now being tested as part of production monitoring.

V. SUMMARY

IO manages quality assurance (QA) and quality control (QC) requirements for the procurement of conductors for the ITER magnet system by means of the ITER Conductor Database tool, a web-based relational database developed for the scope. The database is the interface for executing the control points of the relevant conductor PAs. The users can share uploaded information and communicate according to their privileges.

The ITER Conductor database ensures full traceability and real-time monitoring, and allows the effective use of the stored data in the project lifecycle. The database performs both data completeness and conformance assessment with respect to the registered specification dataset in advance of the control point clearance.

Crucial tests for the acceptance of the ITER magnet system conductors to assess the required performances, is the final full-size conductor tests which are carried out at SULTAN, the only facility able to reproduce, even if on a limited conductor sample length, the extreme operative condition in ITER.

The difficulties in terms of cost and schedule to perform such a test, led IO to the decision of foreseeing a statistical sampling of at least 25% of ULs (for TF) to undergo SULTAN testing. Again, logistics and scheduling of SULTAN tests is managed through the ITER Conductor database.

VI. DISCLAIMER

The views and opinions expressed herein do not necessarily reflect those of the ITER Organisation.

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