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How should we test the ITER TF coils?

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Abstract

The international thermonuclear experimental reactor (ITER) toroidal field (TF) magnet system consists of 18 superconducting coils using a 68 kA Nb_3Sn conductor. In order to guarantee the performances of these coils prior to their installation, the test of at least one prototype coil at liquid helium temperature and full current is required. The test of all coils in the two-coil test configuration, with successive charging of each coil to nominal current is recommended. This requires a large test facility.

Keywords: ITER; Toroidal field; Nb_3Sn; Coils; Tests

1. Introduction

The international thermonuclear experimental reactor (ITER) will feature a completely superconducting magnet system [1]. The toroidal field (TF) magnet will be made of eighteen 350 tonnes D-shaped coils operating at a temperature of 4.5 K up to a maximum magnetic induction of 11.8 T, using a 68 kA cable-in-conduit Nb_3Sn conductor inserted in stainless steel radial plates. The manufacturing techniques to be used in the construction of these coils have been qualified by the manufacture and tests of the toroidal field model coil (TFMC) [2]. Nevertheless, this was achieved for a coil of a smaller size (1/3 scale) than the TF coils, which remains up to now as the single one of this type ever built. The tests showed evidence of the dependence of the critical performances of the conductor with the Laplace force [3]. Which final tests should be made on these coils and how they should be performed to ensure a reliable operation, is therefore, a crucial point to be addressed.

2. Test objectives and strategy

Changing a faulty coil in the torus would cause a major breakdown in the experimental programme and represents a considerable work, which makes compulsory to install only coils, the performances of which have been carefully checked. This means that sufficient knowledge should be acquired on their electromagnetic, thermal, hydraulic, mechanical and

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Table 1
Properties of the ITER TF coils

Properties	Measurement during manufacture	Measurement during a cold test at liquid helium
Critical electrical performances of the conductor	Performed on conductor samples in the SULTAN facility or equivalent. No measurement on the actual double pancakes	Cannot be performed at relevant magnetic field. Extrapolation needed from measurements at reduced field and higher temperature
Electrical resistance of joints	Performed on joint samples in the SULTAN facility or equivalent. No measurement on the actual joints of the coil	Minimum current in coil required to achieve enough precision on the sum of six joint resistances. No individual joint resistance measurement
Pressure drop of the double pancakes	Performed at room temperature with nitrogen gas flow. Extrapolation to supercritical helium flow requires model calibration on actual geometry	Can be performed in relevant conditions
Leak check of hydraulic circuits	Performed at LN2 temperature	Can be performed in relevant conditions
Electrical insulation tests (dc, ac, impulse and partial discharge)	Can only be performed at 300 K and LN2 temperature. Problems arising at lower temperature will not be seen	Can be performed in relevant conditions (300 and 4.5 K)
High voltage tests in Paschen minimum	Can be performed in relevant conditions	Can be performed in relevant conditions
Mechanical behaviour under in-plane and out-of-plane loading	Not performed	Single coil test allows in-plane loading only. Two-coil test allows both loadings
Thermal transfer of heat from plates to conductor	Not performed	Can be performed by a safety discharge
Instrumentation behaviour (temperature sensors, voltage taps at terminals)	Performed at LN2 temperature	Can be performed in relevant conditions
Operation of safety system	Not performed	Can be performed in relevant conditions

insulation properties and operating margins. In addition, the safety system in case of quench propagation should have been proved to operate correctly. Table 1 shows that very limited direct measurements will be available from manufacture due to the limitation of cold testing to LN2 temperature without current, whereas tests at liquid helium temperature with current would provide much more information. Consequently, the main characteristics can only be derived from the measurements performed on a relevant coil, assuming the reproducibility of the manufacturing process. This calls clearly for the cryogenic test of a prototype coil, built with the same geometry and materials as the series coils and on the same manufacturing line with the same procedures and toolings. The experience accumulated with the TFMC tests is not totally relevant, since the coil geometry is different, new manufacturing techniques are foreseen, as well as the use of new advanced conductors. Forgetting this step could lead to discover problems at a late stage of manufacture. Nevertheless, the measurement of the critical electrical properties of the prototype coil cannot be achieved in relevant conditions if this coil is tested alone, since the achievable magnetic field will be much smaller than in the toroidal configuration and could only reach a maximum of 6 T at nominal current. To reach the critical current, thus, needs to operate at temperatures above 9 K, assuming a thermal strain of −0.84%, according to the ITER design criteria and neglecting the electromagnetic strain (Fig. 1). It is therefore, necessary to

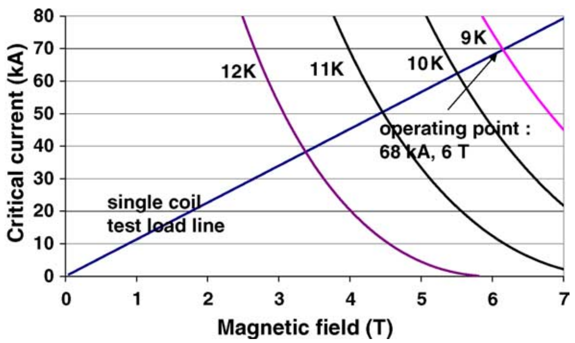

Fig. 1. TF coil critical current vs. magnetic induction ($\varepsilon = -0.84\%$).