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Operational experience with forced cooled superconducting magnets

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HIGHLIGHTS

- Seventeen breakdowns happened in the fusion facilities with forced cooled superconducting magnets (FCSMs).
- The breakdowns always began on the electric, cryogenic and diagnostic communications (ECDCs) and never on the coils.
- In all the FCSMs the ECDCs were always insulated worse than the coils.
- For reliable operation of ITER organization team should essentially improve the ECDC insulation.
- Use of stainless steel grounded casings filled up with solid insulation over all the ECDCs is the best way to get reliable insulation.

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ABSTRACT

Force-cooled concept has been chosen for ITER superconducting magnet to get reliable coil insulation using vacuum-pressure impregnation (VPI) technology. However 17 breakdowns occurred during operation of six magnets of this type or their single coil tests at operating voltage < 3 kV, while ITER needs 12 kV. All the breakdowns started on electric, cryogenic and diagnostic communications (ECDCs) by the high voltage induced at fast current variations in magnets concurrently with vacuum deterioration, but never on the coils, though sometimes the latter were damaged too. It suggests that simple wrap insulation currently employed on ECDCs and planned to be used in ITER is unacceptable. Upgrade of the ECDC insulation to the same level as on the coils is evidently needed. This could be done by covering each one from ECDCs with vacuum-tight grounded stainless steel casings filled up with solid insulator using VPI-technology. Such an insulation will be insensitive to in-cryostat conditions, excluding helium leaks and considerably simplifying the tests thus allowing saving time and cost. However it is not accepted in ITER design yet. So guarantee of breakdown prevention is not available.

1. Introduction

Important merit of forced cooled superconducting magnets (FCSMs) is possibility to get a reliable magnet coil insulation using “vacuum-pressure impregnation” (VPI) technology. It was one of the main reasons of force cooling concept choice for the first tokamak with superconducting magnets (SMs) T-7 ($R = 1.25$ m, $a_c = 0.42$ m) constructed in 1969–1978. This tokamak operated till 1987 at Kurchatov Institute, Moscow [1,2]. After reconstruction into HT-7 it operates in the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP), Hefei, China, from 1994 up to now [3].

Among the tokamaks with SMs of the second generation constructed in 1980s only T-15 was forced cooled. It had a big Nb_3Sn toroidal magnet ($R_c = 2.5$ m; $a_c = 1.12$ m) which was constructed in Kurchatov Institute in 1988 and achieved rated magnetic field $B_0 = 3.6$ T in 1991 [1]. However after few experimental runs with the plasma current up to 1 MA it was “frozen” in 1995 due to financing

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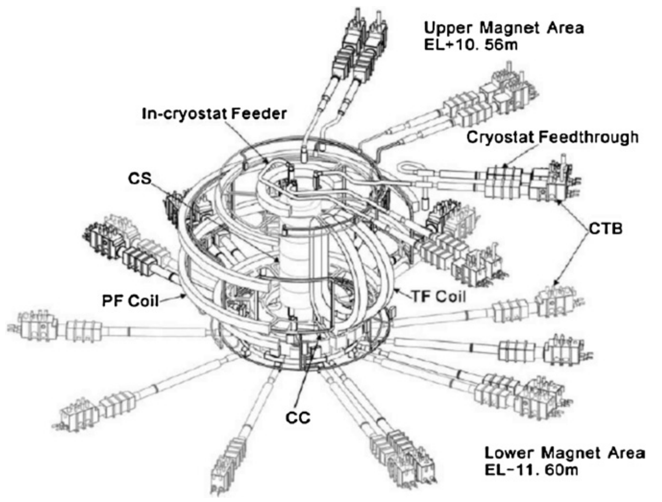

Fig. 1. An elevation view of the magnet coils and feeders in ITER: CTB – coil terminal box, TF – toroidal field, PF – poloidal field, CS – central solenoid, CC – correction coil, El – elevation [12].

cessation. Nevertheless just this device provides the most important experience for ITER together with recently constructed EAST, KSTAR and SST-1.

Two other tokamaks with SM of this generation TORE-SUPRA [4] and TRIAM-1M [5] and the main helical winding of Japanese stellarator LHD [6] were bath-cooled. They had high stability owing to effective cooling, but one of TORE SUPRA coils has got a shorting in the beginning of operation in spite of successful tests of all the coils before assembly. After this coil replacing the facility operates very reliably [7].

In the beginning of 1980s the concept of cable in conduit conductor (CICC) was developed. It seemed very attractive for FCSMs and in spite of small experience of its application was chosen for ITER and for Tokamak Physics Experiment project started in USA in 1990 to check technology for ITER. The latter was canceled in 1995, but had big influence on the third generation of fusion machines: Chinese EAST [8], Indian SST-1 [9], South Korean KSTAR [10], German W-7X [11] and Japanese LHD poloidal coils that used the forced cooled CICC.

2. Operating experience with FCSMs

FCSMs never had any troubles with the insulation of magnet coils themselves, because the reliable VPI insulation technology was applied to them, but their multiple ECDCs were always considered as less important and were isolated by simple wrap with different insulating tapes: teflon or capton and fiber glass (FG) tape filled up with fresh or precured epoxy, sometimes compressed by heat shrinking tapes. Therefore the most serious troubles which prevented successful start and reliable operation of some FCSMs were vacuum deterioration in cryostat and electrical breakdowns on magnet communications, which often happened concurrently.

2.1. Vacuum faults

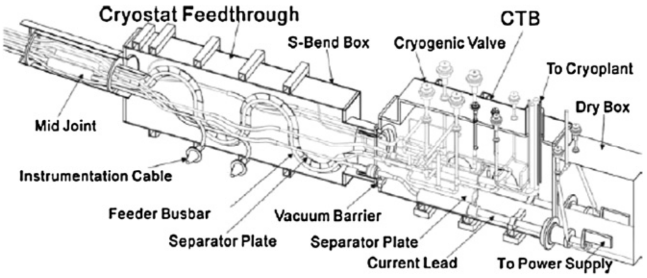

Fig. 2. Cryostat feedthrough and CTB with valves and current leads for ITER [12].

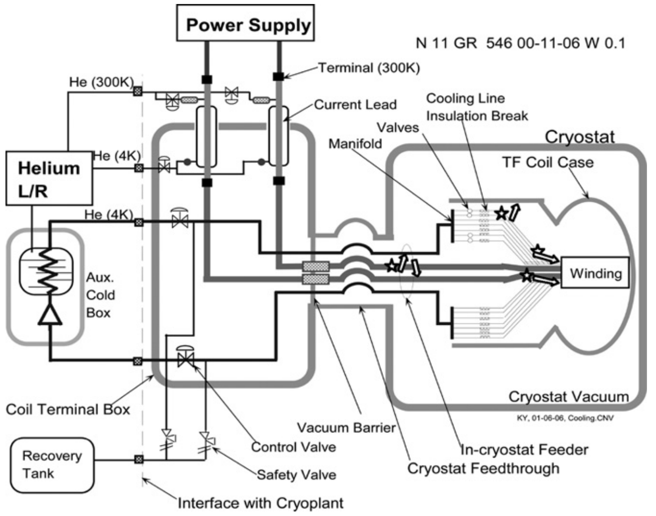

Fig. 3. Scheme of electrical and cryogenic communications of ITER TF coil: ☆ – high potential surfaces in the transmission lines at fast current variations, ⇧ – arcs during accidents.

Obtaining of vacuum in cryostat and keeping it for a long time of FCSM operation is not a simple task, since its effective cooling requests a lot of parallel cryogenic transmission lines with manifolds, leads and feedthroughs as well as a system for control of coolant flow distribution with many valves, temperature, pressure and flow sensors (Figs. 1 and 2). This complicated net of communications is located in cryostat vacuum and acquires high voltage (HV) at fast current variations (Figs. 3 and 4). Therefore it should be separated from grounded coolant manifolds by isolators. These isolators and many other parts of cryogenic communications (compensators of thermal deformations, regulating valves) are points with increased helium leak probability subjected not only to the stresses incipient at cooling down, but also to multiple mechanical perturbations: shocks, temperature jumps and vibrations during plasma pulses, especially strong at plasma current disruptions, as well as to pressure rise due to alternating current losses or quench. Therefore beside the leaks arising at cooling down, the “new” leaks

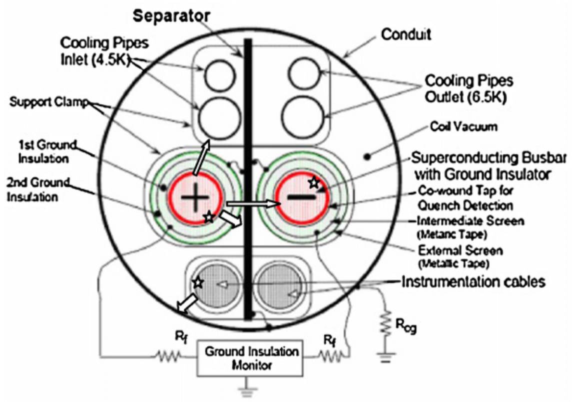

Fig. 4. Cross-section of ITER in-cryostat feeders’ duct with feeders, cooling piping and instrumentation cables: R_f – busbar insulation grounding resistor, R_{cg} – conduit grounding resistor, ☆ – high potential surfaces in the transmission lines at fast current variations, ⇧ – arcs during accidents [12].

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