DESIGN OF A COOLING SYSTEM FOR THE COLD TEST OF THE ITER TF COILS BEFORE INSTALLATION

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ABSTRACT

The ITER superconducting magnet system consists, besides six poloidal field coils and the central solenoid, of 18 toroidal field coils with the size of 16.6 m x 9 m and a weight of 400 t each. For each of these TF coils an intensive cold test is recommended prior to the installation into the torus in order to minimize the risk of malfunction which would cause tremendous costs and massive time delay. This paper presents the testing possibilities and a preliminary design of such a cold test facility including the process engineering of a cooling system.

INTRODUCTION

The magnet system of ITER consists of 18 toroidal field coils, the central solenoid, six poloidal field coils and several smaller correction coils. The construction principle of the large coils has been proven in a series of model coil tests, e.g. [1], where it was shown that such coils can be built with confidence from industry. However, from these experiments as well as from the construction of other actual front end superconducting coils it has been learned that tests with respect to high voltage, leak test, mass flow and current operation are indispensable for such coils. Therefore it is well accepted that superconducting coils of that challenge have to be tested before installation to ensure a proper functioning.

For a cold test of the ITER TF coils a large variety of test options exist, starting simplest with the test of TF coil parts e.g. a double pancake and ending with a possible test of a set of complete coils up to the rated current. Because for a test with rated current a massive reinforcement would be necessary [2] the most promising test is the test of one complete coil up to such a reduced coil current which does not require a reinforcement structure. This test allows checking high voltage toughness, leak tightness at cryogenic temperature, joint and forced flow cooling behavior. In this paper an outline for a cold test facility is presented based on the testing of a single TF coil at 4.5 K.

TESTING POSSIBILITIES

A cold test of one complete coil with reduced current offers the following test possibilities:

- Temperature-controlled cool-down and warm-up to check the temperature distribution
- Leak testing of the winding including the manifold region and the coil case
- High voltage insulation test at room and helium (He) temperature as well as in the “Paschen minimum” condition
- Investigation of the mass flow distribution and the pressure drop in the pancakes and the casing up to the reduced current to validate the operation parameters and to get the input for the simulation codes

- Measurement of the joint resistances
- Test of the sensors installed in the coil (temperature, pressure, pressure drop, balance of quench detectors, temperature compensation of strain gauges)
- Fast discharge from the maximum allowable current for a free standing coil

Parallel to the test of the ITER TF coils, components of ITER can be easily checked in the same cold test facility. In particular this could include:
- Test of ITER current leads with respect to He consumption and heat load at the cold end
- Test of components as cold He circulation pumps that still have to be developed for the required mass flow rate of the ITER cooling system
- Test of ITER current feeder system
- Test of the proposed control strategy of the ITER cooling system [3] as bypass system in the cooling circuit including heat load cycling tests

TEST FACILITY

The preliminary design of a vacuum vessel for vertical installation of a single TF coil is shown in Fig. 1a (left) and the arrangement of such a test facility in the required building in Fig. 1b (right).

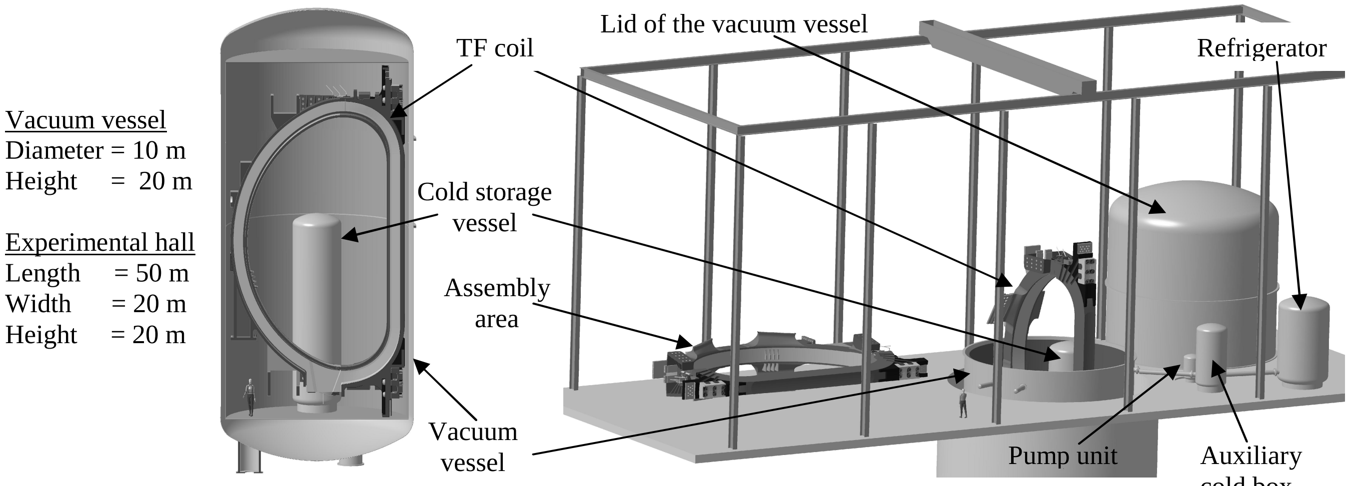

Figure 1 Preliminary design of a facility for the cold test of an ITER TF coil

The main components of the cold test facility are the vacuum vessel including liquid nitrogen shield for hosting the TF coil (Fig. 1a) and a cold storage vessel for the collection of the expelled He after a safety discharge, a He refrigerator/liquefier and an auxiliary cold box (ACB) for the distribution of the cryogenic supply from the refrigerator and for the heat load removal from the coil. Of course compressors, purifiers, warm gas storage and a control room are necessary.

Location of the test facility

Two possible locations are considered for the test of the complete ITER TF coils.
- The first possibility is to perform the test at the manufacturer site. The main advantage of this option is the possible repair in case of any defect on the coil without additional shipment.
- The second possibility is to perform the test at the ITER site. This option is the most promising solution because the whole infrastructure, buildings and maybe one of the 4 refrigerators required for ITER can be used. Furthermore the ITER staff can be trained in this facility for the ITER operation and the coil test facility would be available after the coil tests for examination of other components.

CRYOGENIC COOLING SYSTEM OF THE COLD TEST FACILITY

The cooling system should be designed similar to the TFMC test facility at the Forschungszentrum Karlsruhe, including the gained experiences [4] and also to that of ITER [3, 5]. A supercritical He cooling circuit will be used for circulating the high mass flow rate of the TF coil with cold circulation pumps. The pumps can be included in the ACB or in a separate pump unit. A second pump planned for redundancy reasons may not be required if an exchange is possible without interruption of the coil cooling, but this depends on the design of the pumps. Fig. 2 shows a tentative flow diagram of the He cooling system required for the test of the TF coil.

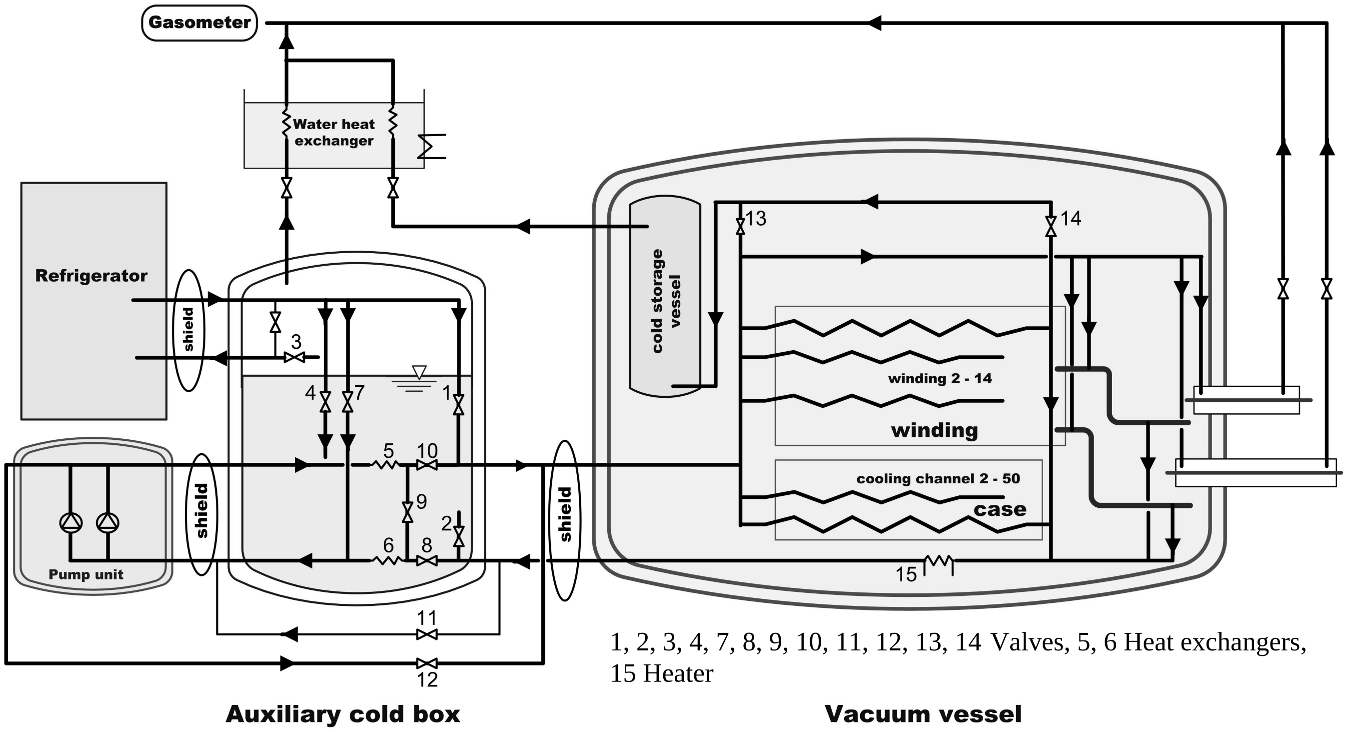

Figure 2 Preliminary design of a cooling system for the cold test of a single ITER TF coil

All operation modes mentioned hereafter are standard modes in the TOSKA facility and their safe and reliable operation was demonstrated during the coil tests (LCT, W7-X, ITER TFMC) over 20 years [4].

Cool down

During the cool down the He will be supplied from the refrigerator to all components in parallel through the ACB and valve 1. The return flow is expanded into the ACB through valve 2 and fed back to the refrigerator over valve 3. The ACB is cooled in parallel and after the cool down is completed, the refrigerator is liquefying into the ACB via the Joule-Thomson valve 4.

Steady state operation

For the steady state cooling of winding, case and current leads, a He mass flow rate up to 350 g/s will be circulated in the secondary cooling loop by means of circulation pumps. The He compression heat load will be transferred after the pumps to the liquid He in the ACB via the immersed heat exchanger (HX) 5 in order to provide He for the coil cooling at a temperature level of 4.5 K. In the immersed HX 6, the heat load of winding, case and transfer lines is also transferred to the liquid He in the ACB. This facilitates to obtain a stable inlet temperature to the pump unit. Valve 7 is foreseen for the stabilization of the pressure in the secondary cooling loop at the low pressure side to 3.5 bar, but the pressure can be increased to the design values of ITER. The stabilization at the outlet of the coil has the advantage that the pressure can be chosen at a low value independently of the pressure drop with no danger to run into the two phase region. For cooling the current leads the required He mass flow rate is subtracted from the secondary cooling loop inside the vacuum vessel with the advantage that no separate transfer line is necessary and the He is supplied at the same low temperature as for the coil. The main preliminary cooling requirements for reduced current operation of 30 kA are listed in the following Table 1. For comparison the corresponding numbers for rated current operation are also included.

Standby operation

In standby mode only the mass flow rate of the refrigerator will be used without running the pumps for cooling the complete test arrangement. The He is supplied via valve 7 into the secondary loop and is flowing through the pumps, the HX 5, then cooling the coil, returning to the ACB and expanded in valve 2 (valve 8 closed and 10 open) and finally liquefied into the ACB. Also a small portion (~1 g/s) of He is subtracted from the secondary loop for the standby cooling of the current leads.

Table 1 Preliminary cooling requirements for the cold test of a ITER TF coil

Operation	T	P	Mass flow rate						Heat load						
			W	C	FS	RS	CL	**Total**	W	C	RS	FS	PP	Facility	**Total**
Unit	K	bar	g/s	g/s	g/s	g/s	g/s	**g/s**	W	W	W	W	W	W	**W**
Rated (68 kA)	4.5	3.5	112	200	24	100	10	**446**	150	400	200	70	590	300	**1710**
Reduced (30 kA)	4.5	3.5	112	200	24	0	4	**340**	50	600	0	50	450	300	**1450**

T = temperature, P = Outlet pressure of the TF coil and inlet pressure of the pump, $\dot{m}$ = mass flow rate, $\dot{Q}$ = heat load
W = Winding, C = Case, FS = Feeder system, RS = Reinforcement structure, CL = Current leads, PP = Pumping power

Collecting and storing the expelled He after a safety discharge

The expelled He after a safety discharge or a quench, will be collected in a cold storage vessel and stored at low temperature by opening the valves 13 and 14 automatically with the quench or safety discharge trigger. This storage vessel will be installed inside the vacuum vessel and LN_2 shield as shown in Fig. 1.

Test of the cooling system as proposed for ITER

According to the ITER Design Description Document (DDD) [5] and also as explained in [3] the cooling system of the ITER TF coil is slightly different than proposed here for the cold test facility. In the secondary cooling loop no HX is foreseen in front of the pump. This operation can be simulated by closing the valve 8, opening valve 11 and bypassing HX 6. Furthermore, the ITER cooling system will be operated with a constant mass flow rate in the secondary loop also after ITER plasma pulsing with nuclear heat load fluctuations. This can be simulated to certain limits by introducing heat pulses using the heater 15 and bypassing partly HX 5 by opening the valve 12 in order to avoid an overloading of the ACB and the refrigerator.

Refrigerator/liquefier cryogenic plant

As listed in Tab. 1, the required cooling capacity is in the range between 1.5 kW and 2 kW. In the case of a test at the manufacturer site a suitable refrigerator has to be ordered. For a cold test facility at the ITER site the use of one of the four 18 kW, 4.5 K refrigerator cryogenic plants foreseen for ITER [3] can be considered. However, an adapted separate refrigerator/liquefier plant offers the advantage of low power consumption, the availability during ITER operation for pre-testing of components and the use of four identical plants for the ITER machine.

CONCLUSION

The cold test of a complete ITER TF coil at 4.5 K at a reduced coil current of about 30 kA is the most favourite option. This test scenario allows to detect high voltage, leak, joint, sensor and cooling failure before installation into the ITER machine and therefore to avoid enormous disassembly and re-installation work and as consequence large additional costs and delay. In addition the proposed cold test facility allows to prove the cooling circuit planed for ITER and will allow to train the ITER staff when the cold test facility is built on ITER site.

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