Overview of a New Test Facility For the W7X Coils Acceptance Tests

T. Schild, D. Bouziat, Ph. Bredy, G. Dispau, A. Donati, Ph. Fazilleau, L. Genini, M. Jacquemet, B. Levesy, F. Moliné, J. Sapper, C. Walter, M. Wanner, L. Wegener.

Abstract-- **In the frame of the W7X stellerator project, an cooperation agreement between the Max-Planck-Institut für Plasmaphysik and CEA has been set-up in order to perform the acceptance tests of all the 70 superconducting coils that compose the W7X magnet system. The main purpose of these tests is to demonstrate that each coil can work at nominal operating conditions, with enough margin to ensure the coil safety during the stellerator operations. For that purpose, CEA has built a new test facility at Saclay. This paper presents a general overview of the test facility. It is mainly composed of two large cryostats (useful space of 5m diameter and 4.2m height), a cryogenic source to produce supercritical helium at 4.5 K and 6 bar with a power rating of 200W, and an electrical power supply of 25kA. Each cryostat can contain two coils. It is then possible to cool down two coils at the same time, and to warm up two others. But only one coil can be energized at the same time. As the assembly of the facility is now nearly completed, the first cryogenic tests with the prototype coil (DEMO) have started. The first conclusions of these tests and the facility performances will also be discussed in this paper.**

I. Introduction

The European industry has begun the manufacturing of the 70 superconducting coils for the W7X stellerator magnet system [1]. Prior to their installation at the Greifswald site, each of these coils has to be tested at room and operating temperatures. These tests will ensure that the performances of all the magnets are in accordance with the tender specifications.

The *Direction des Sciences de la Matière* from CEA Saclay is in charge, in the frame of a contract with IPP Garching and Greifswald, of these tests. To fulfill this task, CEA Saclay has built a test facility enabling the mechanical, electrical and thermal tests. Considering the tight schedule for these tests, the test station has been designed with two cryostats, each able to contain two magnets at a time. The first cool down cycle of the test station has been done without coils during june 2001. The second cool down has been made with the prototype coil, known as "Demo coil", made to demonstrate the manufacturing technique. This second thermal cycle will act as a commissioning test for the test station, and will be the first training for the CEA crews in charge of testing the further 70 coils.

Manuscript received September 24, 2001.

Th. Schild (corresponding author, telephone: 33 1 69 08 37 75, e-mail: thierry.schild@cea.fr, D. Bouziat, Ph. Bredy, G. Dispau, A. Donati, Ph. Fazilleau, L. Genini, M. Jacquemet, B. Levesy, F. Moliné, C. Walter are with CEA Saclay (Dapnia), F-91191 Gif-sur-Yvette, France.

J. Sapper, M. Wanner, L. Wegener is Max-Planck-Institut für Plasmaphysik, Wendelstein 7-X Aufbau, Teilinstitut Greifswald, Wendelsteinstrasse 1, D-17491 Greifswald, Germany.

II. Coil Overview and Tests requirements

Two types of coils have to be tested. The so-called "Non Planar" (NP) and "Planar" (P) coil. NP coils are made of 6 double layers, and P coils of 3 double layers. The average diameter of these coil is about 3 m. The conductor is a NbTi Cable-In-Conduit with a reinforced aluminum jacket. Coils are delivered to CEA with bare end. CEA has to install temporary connection to perform the electrical connection to its power supply [2].

The test facility has to demonstrate that each coil will work in nominal operating conditions, with sufficient operation margins. To reach such a requirement, the following tests have to be done:

① Dielectric rigidity between winding and casing at 10.4kV, at room temperature and cold temperature. In the final machine, 10 coils will be connected in serial. Then the last coil will experience 10 times the fast discharge voltage in case of quench. That is why such a high insulation voltage is needed.

② Check the turn-to-turn and layer-to-layer insulation by applying 1100VRMS on coil ends.

③ Check the layers pressure drop at room temperature and cold temperature.

④ Check the mechanical behavior of the coil during the cooling down and warming up, and also during coil energizing. For that purpose, coils are equipped with 4 "rosette" strain gauges, and 2 extensiometers.

⑤ Energize each coils at a pre-calculated test temperature, T_T, and nominal current (17.6kA for NP coils, and 16kA for P coils). T_T is equal to the theoretical current sharing temperature at the nominal current minus 0.3K.

⑥ Quench each coil. The procedure for that test is still open. Two ways are proposed : the first is to energize the coil at the nominal current, and then increase the temperature slowly up to the quench; the second is to increase the current up to the quench current, working at the test temperature.

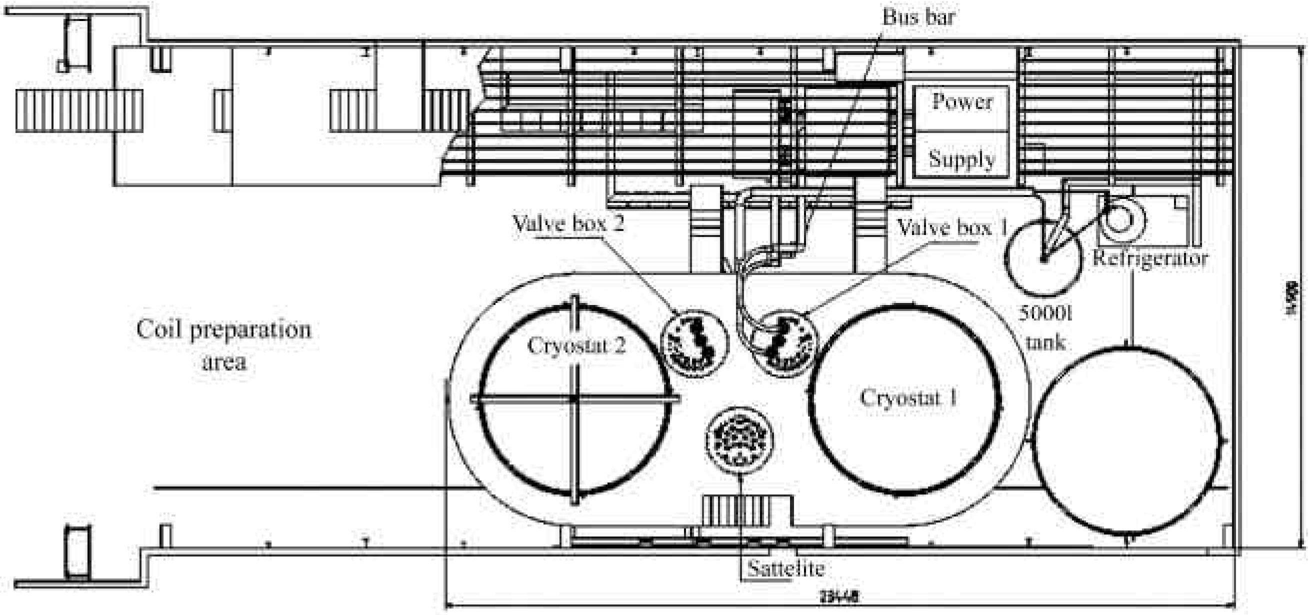

Fig. 1 Overview of the test facility

III. TEST FACILITY MAIN FEATURES

Fig. 1 gives an overview of the experimental set-up. This is a twin test facility with two cryostats able to contain two coils. At its arrival, the coil is installed on support ring (see Fig. 2). This ring will be used for outside cryostat tests and inside cryostat tests.

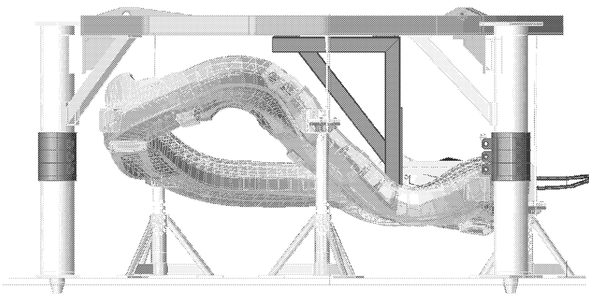

Fig. 2 View of a NP coil hung on its three-feet support ring.

The facility is equipped with one refrigerator (only one cryostat can be cooled down at the same time), and one power supply (only one coil can be energized at the same time).

The satellite splits helium between valve box 1 or 2. Then the valve box splits helium and current between the first and the second coil within the cryostat

A. Data Acquisition System

One autonomous data acquisition system is associated to each cryostat. Each one measures all data needed for the coils assessment. It has been decided to fully dissociate control command measurements from the data acquisition needed for coils assessment for redundancy and safety reasons. Data acquisition software is based on an EPICS system.

Serial W7X coils are equipped with 21 sensors: 4 low temperature sensors (CERNOX), 3 PT100Ω sensors (4 are added on 7 coils), 12 strain gauges (i.e. 4 rosettes), two extensiometers. In addition to these, more sensors had to be added to check the coil behavior: inlet/outlet pressure sensors, inlet/outlet temperature, inlet/outlet mass flow, helium leak, vacuum pressure, protection voltage, and so on. In total 163 sensors are recorded for each cryostat.

All these sensors are divided in two groups: cryogenic sensors (temperature, pressure, strain gauges,...), and voltage taps. Cryogenic sensors and voltage drops are respectively acquired up 1 Hz and 10 Hz, in normal operation and 500 Hz and 20 kHz in case of quench event triggered by the magnet safety system (see §III.C).

It has to be noted that a special care has been taken for mass flow measurements. The principle is to measure a pressure drop through a venturi restriction. Due to the high sensitivity of the helium density versus the temperature and pressure parameters, online density calculation according to these parameters has been implemented for each flowmeter. This allows to have online mass flow measurements from room temperature to 4.5 K.

B. Room temperature tests system

Some tests have to be performed at room temperature with coils outside cryostat :

- All coil sensors are checked in order to verify the cabling and the isolation toward the coil casing (500VDC against the coil casing).
- Two insulation assessments are performed. A dielectric test is performed at 10.4kV against casing. The second test checks the layer to layer and turn to turn insulation by applying a 1100VRMS AC (2 kHz) voltage at coils end.

In order to facilitate these tests, an automatic device based on a computer system has been developed to control all these tests. This will generate automatically a report for each test, and therefore quicken the global assessment of the coil.

C. *Power supply and Quench Protection*

The power supply delivers a coil current of up to 25 kA at a maximum ramping voltage of 10 V. Current ramping rate is between 20A/s and 50 A/s. The electrical scheme is presented on Fig. 3.

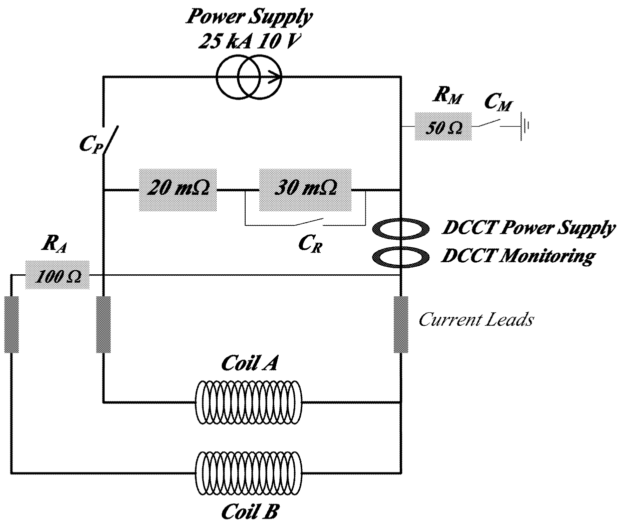

Fig. 3 W7X test facility electrical circuit scheme. One coil is energized and the second one is protected against overvoltage with the R_A resistor.

There are 2 modes for discharging of the coil current : in normal operation, a slow discharge will be performed by the power supply (different ramp values). The second mode is a fast discharge of the current into the resistor bank ; the value of this resistance depends on the value of the current in the coil as shown on table I. The resistance discharge for W7X coils will be 20mΩ.

TABLE I
QUENCH PARAMETERS AND DETECTION

Differential Detectors	**5 (4 active)**	
Detection Time	**100 ms**	
Voltage Threshold	**500 mV**	
Contactor Delay	**85 ms**	
Maximal Current	**20 kA**	24 kA
Dump Resistance	**20 mΩ**	50 mΩ
$\tau_{\text{non planar coil}}$	**2.5 s**	1s
$\tau_{\text{planar coil}}$	**0.45 s**	0.2 s
Terminal Voltage	**400 V**	1200 V
Magnetic Energy	**10 MJ**	14.4 MJ
Hot Spot Temperature	**120 K**	

The main role of the coil detection system is to protect the coil in case of a defect serious enough risking to damage it. In particular, this is the case of a local transition from the superconducting to the resistive state (quench). This transition must be quickly detected and a fast discharge of the magnet activated, so as to dump the energy stored in the coil.

The role of the quench detection system is to detect that the differential voltage across 2 parts of the coil is above a voltage threshold for a duration longer than a given delay, ensuring that the detection is done on a real quench and not on external noise. The whole system is redundant for safety reasons.

The detection is performed by compensating the voltage drop against two adjacent double layers in order to remove the inductive voltage. For a current of 20kA, a delay of 0.485ms, and a threshold voltage 500mV, the expected hot spot is about 120K. It has to be noted that the discharge is not the same than in the final machine, as a variable dump resistance will be used [3].

D. *Cryogeny*

The main components of the cryogenic part of the test facility are the followings (see Fig. 1):

① *The helium refrigerator*. At 4.2K, the power rating is 200W and the flow rate is 15 g/s.

② *The satellite*. Inside the satellite, the helium fluid is prepare to cool down, keep cold then warm up the coils of one or the other cryostat.

③ *The 2 valves boxes* (one per cryostat). Each valve box contains 3 current leads and the different valves needed to split helium between the two coils.

④ *The 2 cryostats*. Inside each cryostat, it is possible to cool down one or two coils.

⑤ *The helium tank*. It contains 5 000 liters of liquid helium mainly used for the working of the current leads.

At the cryogenic test temperature, the helium at the outlet of the refrigerator has a pressure and a temperature of 16 bar and 5.5 K. Inside the satellite, a first valve checks the pressure of the helium supplying the different circuits, then go through a bath exchanger. At the outlet of the exchange, the helium has a pressure and a temperature rating of 6 bar and 4,7 K. It supplies the 3 hypercritical circuits: the winding coils, the coil casings and the superconducting bus bar. The flow rates are measured at the output of each circuit.

The bus bar cooling fluid reaches then the current leads tank whereas the winding and casing cooling fluid reaches the satellite tank
Three bath exchangers and heaters at the inlet of the different hypercritical circuits allow to regulate the helium temperature between 4.5K and 7.5K.

IV. FIRST CRYOGENICS TESTS

DEMO coil is the demonstration coil of the W7X magnet system [4]. It is a non-planar coil. This coil has already been tested at the Karlsruhe Forschungszentrum test facility (TOSKA). The goal of the CEA test is to validate the test facility.

A. *Cool down of DEMO coil*

The first cool down has started the 27th of July 2001 and required 17 days. It means an average temperature rate of about 0.7K/h. This cool down needs to be optimized in order to decrease the total time duration at about 10 days.

B. *First current ramping*

DEMO coil has been energized up to its nominal current, i.e. 14.7 kA. Fig. 4 presents the first current ramping up of the test facility. That is the reason why a plateau of about 10 minutes has been applied every 1 kA. It can be seen that stable condition was reached.

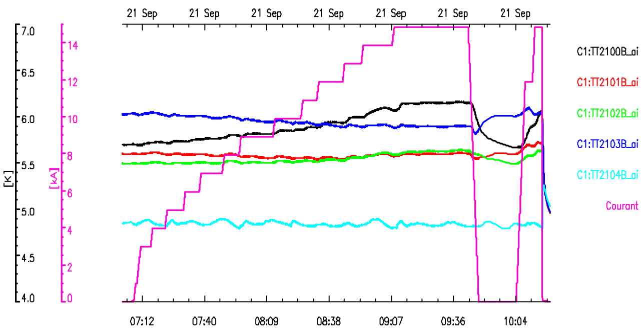

Fig. 4 Current ramping up to 14.7kA. TT2104B is the inlet temperature, all the others are the outlets temperatures.

After that ramping up, a fast discharge has been ignited. Fig. 5 presents the effect of that fast discharge on the casing temperature. The temperature increasing is about 2 K.

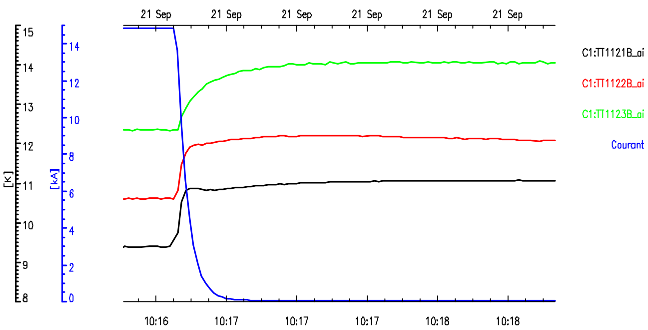

Fig. 5 Coil fast discharge, and coil casing temperature.

Fig. 6 is an example of the strain gauges measurements. On these measurements, we found back that the deformation is proportional to the square of the load current.

The next step will be to quench the coil. Two methods are proposed: either by increasing the temperature, either by increasing the current. DEMO coil tests will give us the experience needed to evaluate what is the best way for the coil safety, and for the global tests duration.

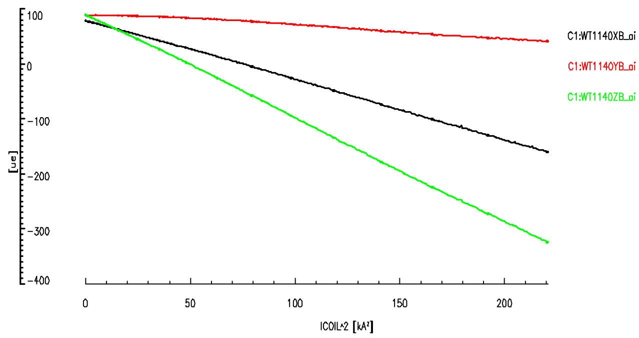

Fig. 6 Strain gauge measurements (micro deformation) as a function of the square of the coil current.

V. Conclusion

Two steps are required to achieve the full commissioning of the new double cryostat test facility. It is foreseen that the first cryostat will be ready for operation at the end of 2001, and then the second cryostat should be ready before June 2002. The commissioning of a cryostat is considered as fulfilled when the DEMO coil has been energized in the two positions of the cryostat.

The test facility has up to now demonstrated it can operate up to 15kA in stable condition in the lower position of the first cryostat. The control command, the magnet safety system and the data acquisition have also been checked successfully. Most of the technical choices have then been validated.

VI. Acknowledgment

The authors would like to acknowledge all the CEA staff that have participated to the design and the manufacturing of this test facility. In particular, we would like to thank J.B. Berton, A. Forgeas, P. Godon, M. Sueur, J. Proudowsky, for their work.

VII. References

[1] L. Wegener, “Status of the construction of the W7-X magnet system”, *IEEE Trans Appl. Superconduct.*, submitted for publication in the proceedings of MT’17 conference, September 2001.

[2] Th. Schild and al., “Current distribution in a reusable junction for W7X coil tests”, *IEEE Trans Appl. Superconduct.*, submitted for publication in the proceedings of MT’17 conference, September 2001.

[3] A. Nitsche, J. Sapper, “Power Supply and Quench Protection for the WENDELSTEIN 7-X Magnet, Proceedings of the 20th Symposium on Fusion Technology, Vol. 1, pp. 755-758, 2001.

[4] H. Kronhard, O. Dormicchi, J. Sapper, “Design and Manufacturing of a Wendelstein 7-X Demonstration Coil”, Proceedings of the 20th Symposium on Fusion Technology, Vol. 1, pp. 735-738, 2001.