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Design of a multipurpose test facility (MTF) for HTS cables

Amalia Ballarino[1], Christian Barth[1], Marco Masci[1], and Diego Perini[1]*

[1] European Organization for Nuclear Research (CERN), Meyrin, Switzerland

*E-mail: Diego.Perini@cern.ch

Abstract. The High Field Magnet (HFM) program foresees, among others, the systematic measurement and assessment of mechanical, thermal, and electrical properties of high temperature superconductors (HTS) cables. These measurements are a key factor to characterize the conductor, verify its performance and control the production quality. These values are also necessary inputs to size the prototype magnets that will use HTS windings. Cable and coil properties must be measured at room temperature, in liquid nitrogen, in helium gas at 20 K – 30 K, and in liquid helium at about 5 K. Cable samples and small coils are tested at different temperatures, and under a given force or deformation. The mechanical and electrical loads can be applied simultaneously or in different combinations. The output data span over a large range of signals: strain measured by strain gauges, optical fibers, or digital correlation techniques, critical currents, displacements, and structural deformations. At the moment, any cable property can be measured individually. The proposed multipurpose test facility is a testing station capable of simultaneous measurements to facilitate the development of correlation laws: for example, by powering a small HTS coil at 20 K while measuring its deformation via digital image correlation; or measuring the critical current in a sample under a given mechanical pressure or after a certain amount of load cycles. Another important requirement is the flexibility and the short turnaround time to test samples. This note describes the multipurpose test facility designed at CERN and under construction. Some examples of possible measurements are given as well.

1. Introduction

Several projects to design and characterize HTS coils have started at CERN in the framework of the HFM programme [1]. They foresee the construction of several coils, their test in dedicated support structures and the evaluation of the performances.

Electrical, mechanical, and thermal properties of cables and coils are key parameters to assess the conductor quality, to carry out correct design computations and to control the manufacturing processes.

To characterize cables and insulations batches, it is necessary to measure the influence on the critical current of stresses and deformations (elastic or permanent). The loads simulating the conductor lifecycle need to be applied at different temperatures.

As input for magnet computations and manufacturing, it is important to know classical mechanical parameters like the Young's modulus, the thermal expansion coefficient, the Poisson's ratio, both at room and at cryogenic temperatures. This must be done both for the cable alone and for the cable plus insulation assembly.

Quality assurance processes need as well to reproduce and measure the effect of accidental loads on the cable performance.

Combined measurements are therefore necessary to understand the conductor behaviour during its lifecycle [2]: for example, measurement of critical current at a given temperature under a defined mechanical load, or measurement of thermal expansion coefficient on a sample under a defined compression.

To carry out all these multi-parameter measurements a dedicated test system has been designed and it is currently under construction. It combines in a single device different data acquisition elements, and it will allow the application of multiple loads to reproduce the real lifecycle of the conductors in a magnet.

2. Description of the testing facility (MTF)

The MTF is shown in figure 1, and a vertical section is given in figure 2.

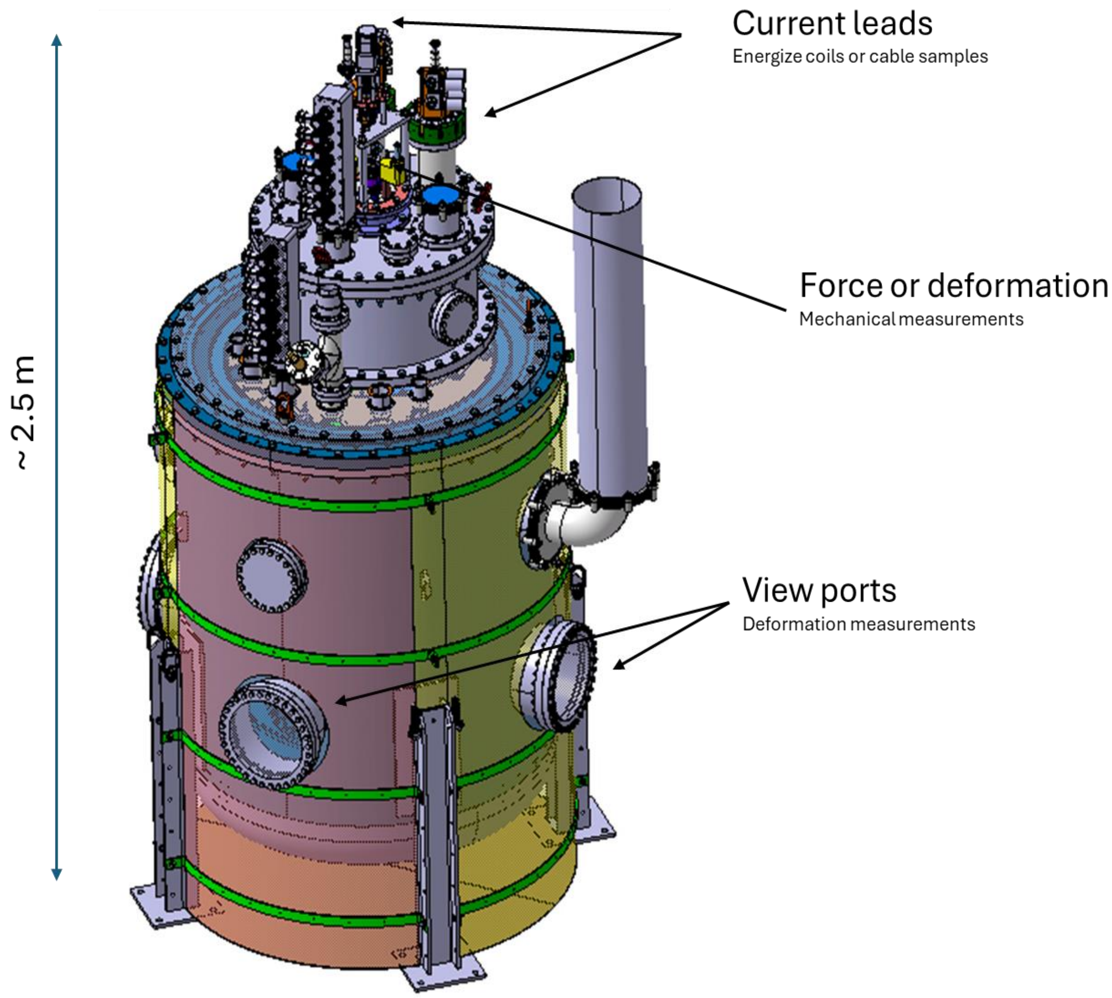

Figure 1. 3D view of the testing apparatus. It consists of a cryostat equipped with current leads, force or displacement application tools and view ports to see the samples under test. The cryostat can be cooled by liquid helium at 5 K or cold helium gas in the range of some tens of kelvin.

The system consists of a cryostat equipped with current leads to power cable or coil samples, access points to apply external loads or displacements, and ports equipped with optical glass to observe the elements under test and use digital image correlation techniques.

The cryostat has the standard configuration with three envelopes: the external vacuum tank, an intermediate thermal screen that can be actively cooled, and an internal pressure vessel [3].

The pressure vessel can be filled with liquid helium at about 5 K. A second option is to keep it under vacuum and cool it by conduction with a closed circuit of liquid or gaseous helium. In this case, a second independent circuit can be used to cool the sample.

The maximum sample size that can be housed in the structure is approximately 600 mm x 600 mm x 600 mm.

To summarize, tests can be carried out in vacuum or in a coolant bath, allowing a test temperature varying from five to few tens of kelvin.

The sample under test and the necessary services, such as cooling pipes, wires for signal transmission, current leads, and mechanical actuators, are supported by the top removable plate. The preparation of the experiment can therefore be completely done outside the cryostat. Safety valves, coolant feeding pipes and level control elements, reach the inside via dedicated ports on the cryostat and not through the top plate. Thus, they do not need to be modified or reassembled when changing the test sample or the test set-up.

3. Measurements of material properties

The simplest and most immediate use of the device is to assess material properties both of conductors and structural components.

Integrated thermal expansion coefficients can be measured via digital image correlation [4] through the view ports while the sample is conduction-cooled and in vacuum.

Mechanical properties such as Young’s modulus and elastic limit, at different temperatures, can be obtained by applying forces or displacements to the sample via the loading beams and measuring stresses or deformations via transducers or through the view ports.

The measurements can be carried out both on single HTS cables and on prototype small coils. In this second case, it is also possible to supply power via current leads integrated in the system. Existing elements, which can carry up to 2.5 kA are used for the first version of the MTF. If higher currents will be required in the future, new current leads will be manufactured and installed.

Through the loading beams, the cable can be loaded at a given level of stress and/or strain and the effects on the critical current can be recorded. These tests can be performed in a single cycle or in fatigue testing configuration.

4. Measurement of the performances of coils and magnets

The characterization of cables, insulations, and winding techniques for HTS coils is mainly conducted by manufacturing and testing relatively small coils with a total length of about 200 - 250 mm.

In this phase, the availability of a facility with flexible configuration and rapid turnaround times is crucial to evaluate rapidly numerous possible solutions.

4.1 Coils producing magnetic fields up to 1.5 T

Small, single HTS coils capable of reaching a field up to 1.-1.5 T can be directly positioned inside the cryostat on a simple support structure.

It is foreseen to measure through the view ports, the deformations of the coil during cool down and powering. This will give essential information concerning coil material properties and will allow to cross check and tune the values used in the finite element structural analyses.

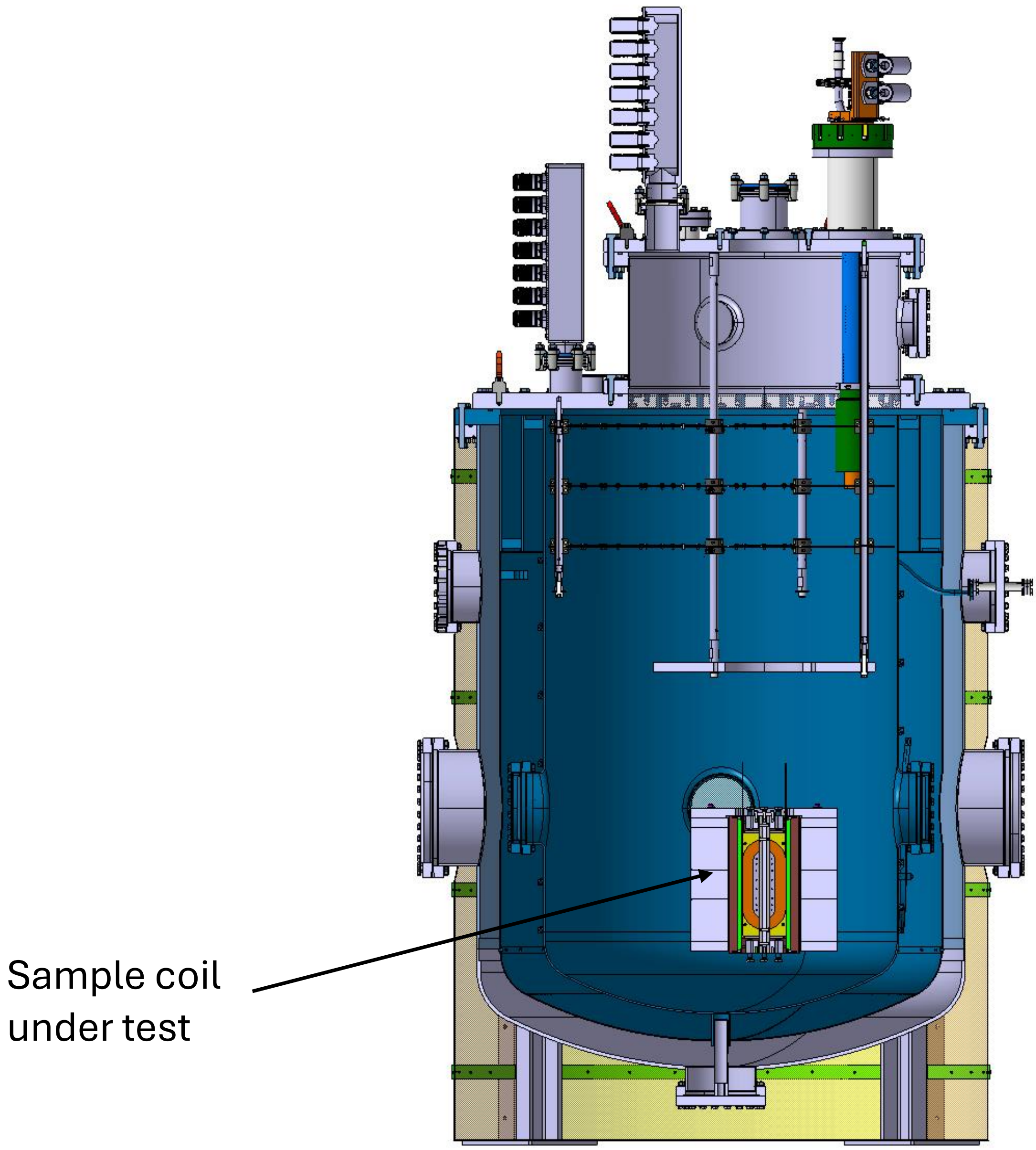

Figure 2. Vertical section of the cryostat with the HTS coil in the test configuration. The coil can be tested in liquid helium bath or in conduction cooled mode.

4.2 Systems of coils for high fields

In case of larger coils or systems of coils for higher fields, the electromagnetic forces in the windings reach values that could deteriorate the conductor if not properly supported. A modular structure has been designed to house and test flat double pancake HTS coils (racetrack coils). The structure can accommodate up to 6 racetrack coils positioned in the center of the iron cavity, or up to two pairs of coils facing each other in a 'common coil' arrangement [5]. In the first case the field that can be reached in the center is approximately 9 T at 5 K. In the second case, shown in Figure 3, the field in the center of the two 20-mm wide cavities is approximately 5 T.

These configurations cover the first part of the coil test program. In a second phase, the structure will be scaled by approximately a factor two in size to house larger coils able to reach fields ranging between 15 T and 20 T.

The available working space inside the cryostat accommodates the tests envisioned for both phases of the program.

A massive single piece iron yoke with a pigeonhole-like cavity to house the coils is the way that was chosen to maximize the structural inertia and minimize the coil deformations and related stresses at powering. During the energization, the coils lean against the iron cavity walls and the electromagnetic forces are transferred to the rigid iron via intermediate plates (shown in figure 3).
To install the racetrack coils in the centre of the cavity and compress the coils to absorb the assembly clearances, a moderate pressure is applied with a press. The press force is transmitted to the intermediate plates via rods passing through holes in the iron yoke (see Figure 3); then keys are inserted to lock the position of the plates and the pressure is released. The holes reduce the iron yoke inertia in a negligible way.

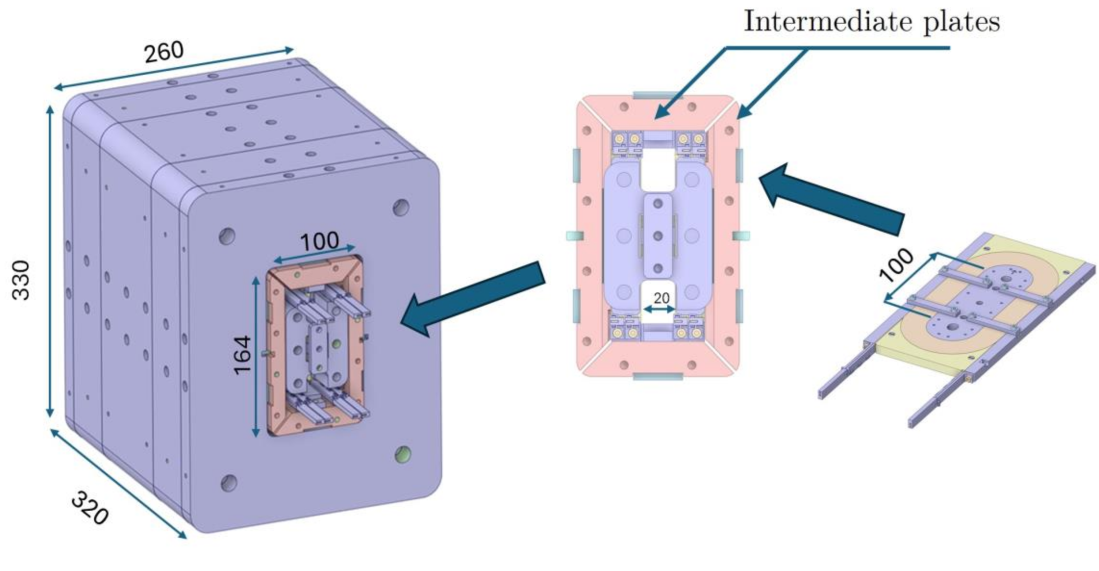

Figure 3. The PL (Pigeonhole Layout) magnet. On the right a racetrack coil. In the centre, four coils are positioned inside the intermediate support plates to form a common coil configuration. Then the system is inserted in the iron cavity and the cold mass is completed (on the left). In this arrangement, the field in the centre of the two cavities is about 5 T.

The intermediate plates offer the necessary longitudinal continuity and rigidity. The coils are connected to these plates via bullet gauges and a small bridge plate. The reaction to the electromagnetic longitudinal force is transformed into moderate tensile stress in the longitudinal plates.

The reduced number of components makes the structure less sensitive to tolerances, economically advantageous, and facilitates a quick disassembly and reassembly with different coil configurations.

5. Conclusions

In this phase of the HTS coil and magnet development, it is important to have a flexible and short turnaround time installation to quickly measure a large variety of cable samples and coils. In this way it will be possible to know from the beginning all the key parameters, which will allow the design, development, and test of high field magnets with HTS windings.

A multipurpose measuring facility has been designed and is under construction. The facility can contain cable samples or magnets up to 600 mm x 600 mm x 600 mm.

Scalable support structures, easy to install in the test device, have been designed. They can accommodate systems of modular coils and reach fields up to 15-20 T. These structures can be rapidly adapted to test a sequence of different coils in a reasonably short time.

6. References

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Acknowledgments

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