THE CRAB CAVITIES CRYOMODULE FOR SPS TEST*

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Abstract

RF Crab Cavities are an essential part of the HL-LHC upgrade. Two concepts of such systems are being developed: the Double Quarter Wave (DQW) and the RF Dipole (RFD). A cryomodule with two DQW cavities is in advanced fabrication stage for the tests with protons in the SPS. The cavities must be operated at 2 K, without excessive heat loads, in a low magnetic environment and in compliance with CERN safety guidelines on pressure and vacuum systems. A large set of components, such as a thermal shield, a two layers magnetic shield, RF lines, helium tank and tuner are required for the successful and safe operation of the cavities. The sum of all these components with the cavities and their couplers forms the cryomodule. An overview of the design and fabrication strategy of this cryomodule is presented. The main components are described along with the present status of cavity fabrication and processing and cryomodule assembly. The lesson learned from the prototypes and first manufactured systems are also included.

INTRODUCTION

A cryomodule is by definition an apparatus for maintaining a very low temperature. This condition is a requirement for all superconducting systems in an accelerator. Large sections of the LHC will be modified for its High Luminosity major upgrade [1]. In this frame, novel RF cavities aimed at reducing the crossing angle at the interaction points are foreseen based on 2 different designs, one for vertical (Double Quarter Wave, DQW) and one for horizontal interaction (RF Dipole, RFD). In general, this type of cavity is also called *crab cavity* for the drift motion they impose to the bunches of the beam. 16 crab cavities will be installed, 2 per each beam, on each side of both the ATLAS and CMS experiments.

Successful operation of the SRF crab cavities for HL-LHC requires them not only to stay at a temperature of 2 K, but also the magnetic field to be below 1 μT. Keeping a system at cryogenic temperature is a demanding task in terms of energy, therefore the heat transmitted from the outer environment must be minimized by careful design. This requirement must find a compromise with the need of structural strength, to comply with the mechanical loads and alignment stability.

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In this paper, we overview the main systems of the crab cavities cryomodule, previously seen in [2]. The main focus is the cryomodule for the DQW cavity type Fig. 1, which is more advanced in view of tests with high energy protons in SPS.

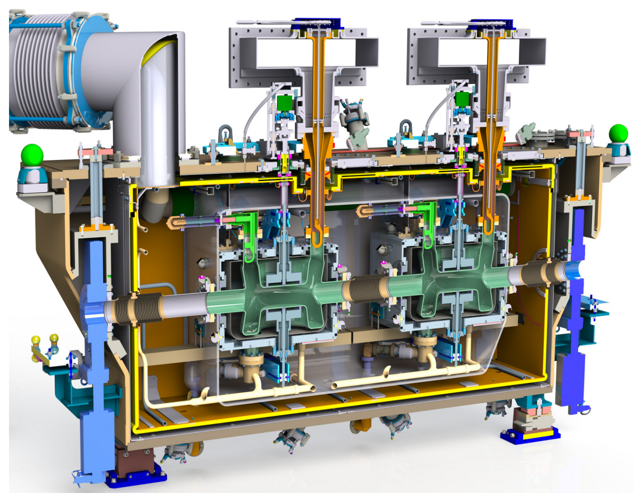

Figure 1: Open view of the cryomodule for the DQW cavity.

THE DRESSED CRAB CAVITY

At the core of the cryomodule there are two cavities. Each of them is enclosed by a set of systems including helium tank, High Order Modes suppressors (HOMS), pickup field antenna, Fundamental Power Coupler (FPC) and cold magnetic shield. The assembly of these systems, with the cavity, is called *dressed cavity* and is shown in Fig. 2 [3].

Each crab cavity has a complex geometry (i.e. not axisymmetric) made of 4 mm thick niobium sheets. Bulk niobium was chosen over coated copper, that would be challenging for such geometries. Two cavities have been fabricated at CERN for the SPS tests, Fig. 3. The shape is trim tuned before the final electron beam weld. Each cavity is then subjected to a chemical etching of 150-200 μm, heat treated at 650 °C, chemically etched for further 20 μm, rinsed with high pressure water and then conditioned and tested at 2 K.

The *helium tank* is built using thick (25-30 mm) titanium plates. In order to mitigate the deformation induced by the welding, we follow a design approach in which the structural

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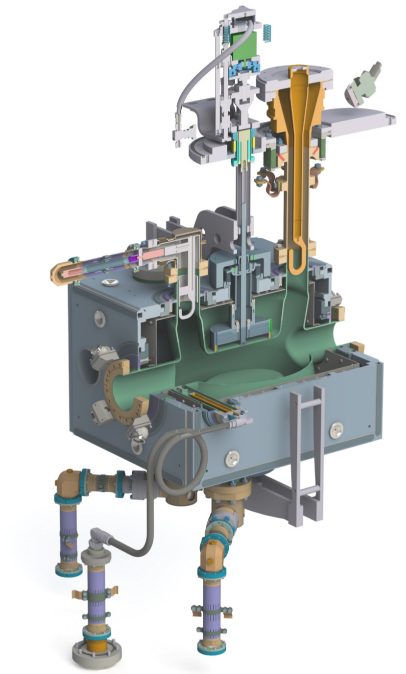

Figure 2: Open view of the dressed DQW cavity.

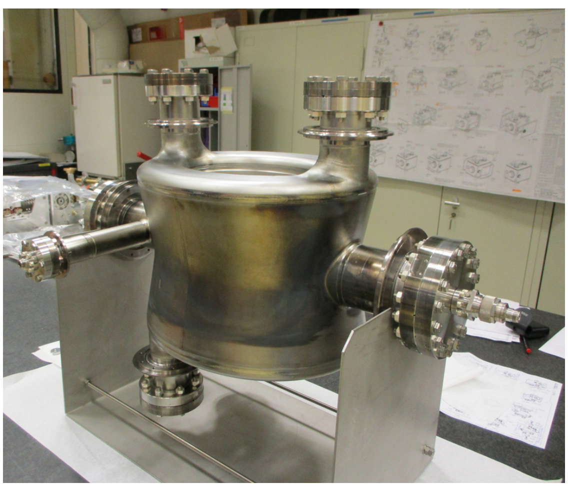

Figure 3: DQW cavity ready for dressing.

resistance is assured by a large set of bolts at the plates' edges. Thin welds are then performed to provide leak tightness.

This procedure, along with the mechanical strength and leak tightness, was tested on a prototype, i.e. a tank representative of the final design, but without any cavity inside. The tests were successful and showed a good agreement with the simulated deformations. The cavity deformation during tank TIG welding requires careful monitoring, but the measured values were sufficiently low both structurally and in terms of frequency, Fig. 4.

The RF performance is not determined by the cavity alone, but also by the HOMS, including the pickup field antenna shown in Fig. 5.

The *HOMS* design and fabrication is described in [4]. The mechanical performance is acceptable and with a high safety

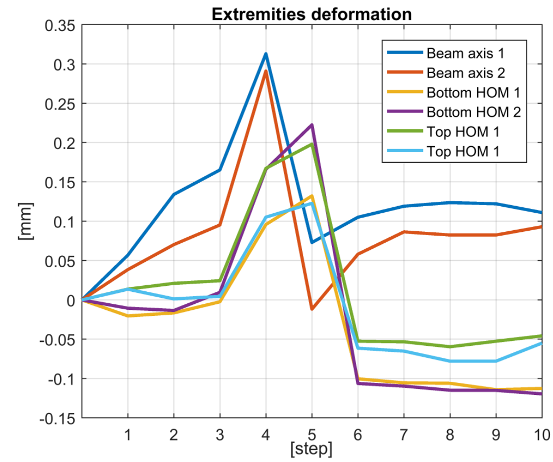

Figure 4: Deformation of tank prototype at the position of the cavity ports. Step 4 is the weld of the covers of the bolts on the plates edges. Step 5-6 are the covers of the bolts around the ports. The subsequent tests do not induce deformation.

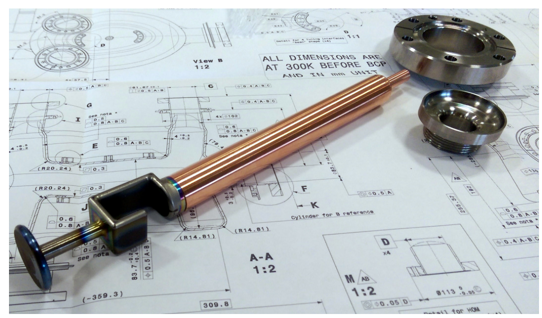

Figure 5: Pickup antenna for one of the DQW crab cavities.

factor. The fabrication is indeed more critical, in view of the tight tolerances. Five-axes milling machining and careful preparation of electron beam welding by means of tests were carried out.

The *pickup antenna* (that also acts as a HOMS) presents similar challenges, with the difference that there is no liquid helium and therefore the mechanical assessment is straightforward. To assess the thermal performance, the coupling between RF domain and thermal map is performed by means of a lookup table. Even in the worst case, however, RF is not a major source of heat and the peak temperature of about 5 K is determined by the static losses through the coaxial cable. The overall picture of the heat load on the cold mass is in [5].

Fabrication tolerances and uncertainty during processing as well as environmental effects during operation impose the use of a system capable of adjusting the cavity RF frequency. This device is called *tuning system* and is detailed in [6] and [7].

THE MAGNETIC SHIELDS

The surface resistance of a superconducting cavity depends also on the external magnetic field. In the case of the crab cavities a value below 1 μT is specified, against an environment of $\approx 60\ \mu$T. To guarantee compliance with such a limit, a two-layers approach is followed. Both shields have been produced and the measurements show an acceptable field reduction factor.

A so called *cold magnetic shield* is installed inside each helium tank. This shield is made of Cryophy® sheets, which provides good permeability also at 2 K [8].

The external layer, or *warm magnetic shield* is located just inside the vacuum vessel and therefore operates at 300 K. The sheets are made of mu-metal. The main challenge is to limit the flux leaks due to the holes and gaps between plates due to several large interfaces. To mitigate this effect, a 100 mm overlap between top plate and bottom assembly is foreseen. Patterns of deformable small plates are mounted at the interfaces that cannot be screwed due to lack of access during assembling. They provide material continuity in those locations. The overall expected magnetic field is shown in Fig. 6. We considered the simulations in this domain non-conservative and we therefore aimed at a high margin.

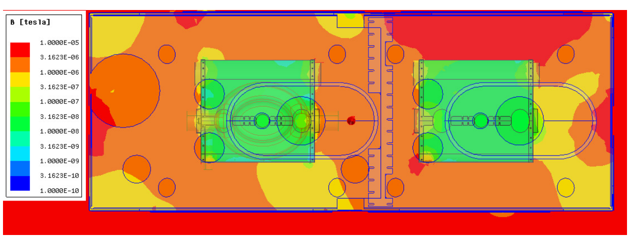

Figure 6: Magnitude of magnetic field on the mid-plane of the beam pipes.

THE THERMAL SHIELD

The *thermal shield* (see Fig. 7) is the layer that prevents the cold mass to receive direct radiation from 300 K and is located inside the magnetic shield. The thermalisations, which mitigate the heat on the cold mass [5], are also attached to the shield that is cooled with helium gas at a temperature between 50 K and 70 K.

The design is based on the HIE-ISOLDE experience [9] and employs copper sheets with a copper pipe brazed on them. The system is suspended by the vacuum vessel top plate by means of titanium blades, that allow thermal contraction. A multi-layer insulation is foreseen both between thermal and warm magnetic shield and around each dressed cavity.

THE VACUUM VESSEL AND THE ALIGNMENT SYSTEMS

The *vacuum vessel* is the outer layer of the cryomodule and is the system that contains and supports most of the devices and encloses the insulation vacuum.

In order to comply with the tight magnetic and mechanical requirements, the vessel is made from stainless steel 316LN. The thickness of the plates and the configuration of

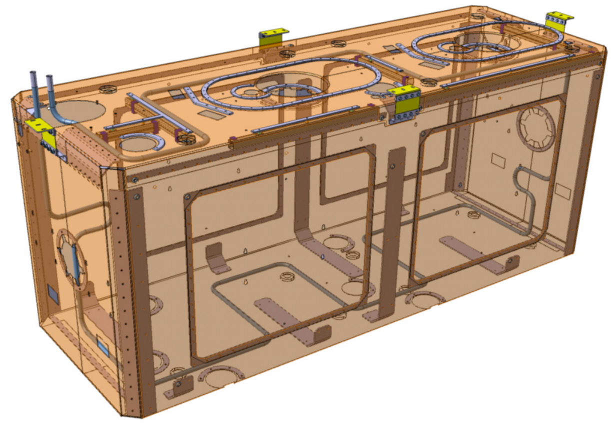

Figure 7: View of the thermal shield.

the stiffeners are optimized in order to mitigate the deformation of the top plate, when the vessel is under vacuum. This is aimed at keeping a good alignment of the cavities and accuracy of position monitoring system.

The cavities position is adjusted by means of a plate mounted isostatically at 3 points. Each dressed cavity is rigidly connected to this plate and the vacuum volume is confined by some bellows. A combinations of optical sensor systems [10, 11] provides redundant monitoring of the cavities position and orientation for the SPS installation and tests.

Figure 8 shows the philosophy followed for cryomodule assembling, that foresees for all the systems to be mounted below the top plate and then to lower the sub-assembly in the bottom part of the vacuum vessel.

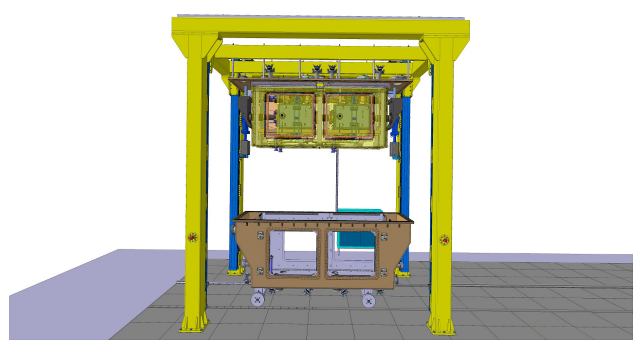

Figure 8: View of the cryomodule during the last steps of the assembling.

CONCLUSION

HL-LHC will include 16 crab cavities to compensate for the crossing angle and contribute to the increase of luminosity. Each pair of cavities will be enclosed in a common cryomodule. A test cryomodule for installation in SPS in 2018 is being prepared and will allow for compact deflecting cavities to be validated with the highest energy protons for the first time in the world.

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