KEY DESIGN FEATURES OF THE CRAB-CAVITY CRYOMODULE FOR HI-LUMI LHC

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Abstract

Preparations have begun to demonstrate the crabbing technique by evaluating the performance of the compact crab cavities with high intensity proton beams using SPS drive accelerator at CERN. A prototype cryomodule consisting of two identical crab cavities is scheduled to be installed before LS2 (2^{nd} long shutdown in LHC operation). Several cryomodule designs corresponding to three different cavity designs; 4-Rod, RF Dipole (RFD) and Double Quarter wave (DQW), were considered and the side-loaded cryomodule design developed for 4-Rod cavities was chosen as the reference design for all three cavity types. This paper describes some of the key design features of the conceptual cryomodule design, current project status and future plans.

INTRODUCTION

Background

A series of complex boundary conditions [1] arising due to the layout of SPS has made the design of the cryomodule with two dressed crab cavities an extremely challenging task. A preliminary analysis [2] was undertaken to establish a design approach. Several variants of the cryomodule were presented at HiLumi CC-13 at CERN in 2013 and the side-loaded cryomodule developed for two, 4-Rod cavities (see Fig. 1) was chosen as the reference design for all three cavity types due to its open access and simplicity of assembly.

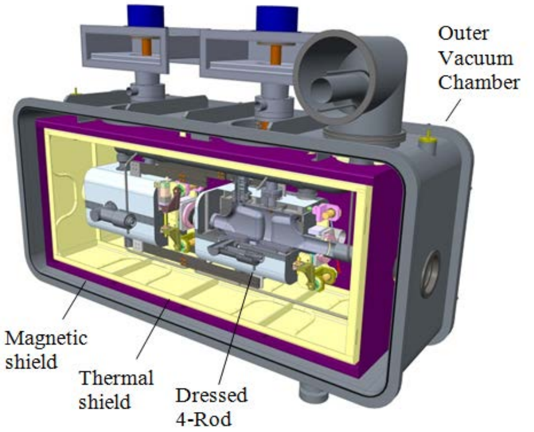

Figure 1: Open access cryomodule for 4R crab cavities.

The design provides easy access to the internal components from both sides even after assembly and installation. It also simplifies the assembly process and minimises tooling requirements, which reduce the overall manufacturing costs.

Figure 2: Three cavity designs under consideration (Left to Right: 4-Rod, DQW and RFD).

Figure 2 shows the three cavity designs [3,4,5] under consideration which are considerably different in terms of their electro-magnetic designs and geometrical shapes. As a result, optimising the designs for individual tuners, RF couplers and associated cryogenics is a challenge and is still work in progress. However, in order to share design effort, common features have been identified that can be used to maximize the functionality of the cryomodule to accommodate all three cavity types. Some of the key features of a conceptual cryomodule are described in the forthcoming sections for 4-Rod cavities but are also being extended to the DQW and RFD cavity implementation (See Fig. 3).

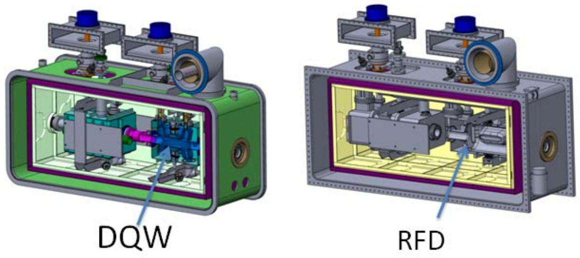

Figure 3: DQW module (left) RFD module (right).

DRESSED CAVITIES

Figure 4 shows the complexity of the 4R dressed cavity vessel, due to the number and position of ports on the cavities and the stringent pressure requirements. The dressed cavity has been designed to meet EN13458-2:2002 Cryogenic Vessels – Design, fabrication, inspection and testing protocol. The pressure sensitivity of the stiffened cavity is 18 Hz/mbar [6]. Lorentz force de-tuning of the stiffened cavity at full deflecting voltage (3.4 MV) is only 408 Hz, which is much lower than the other two cavity designs due to the inherently stiff design of the 4-Rod geometry.

The design of the helium vessel for the 4-Rod is also optimised to minimise the stress on the coupler ports experienced during tuning. This is achieved by incorporating a novel technique of welding ribs to the cavity which are then also welded to the helium vessel. These ribs then become the fixed points when tuning as opposed to the coupler ports. The ribs can also be fiducialised to give a positional reference from the electromagnetic centre of the cavity to outer vacuum chamber of the cryomodule.

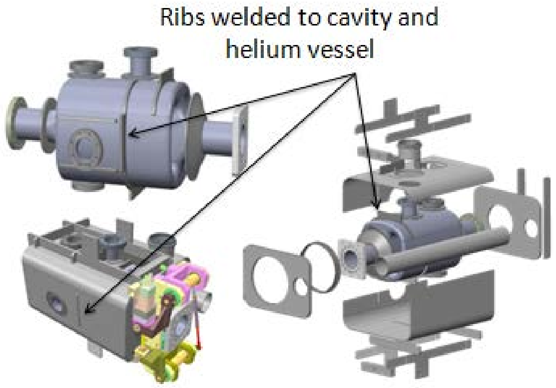

Figure 4: Components of the 4R dressed cavity.

The system uses a modified Saclay II style end lever tuner which has previously been developed as a part of the International ERL Cryomodule Collaboration [7]. This tuner has an increased stiffness of 320 kN/mm. Taking 7 kN as the limit for this tuner gives a total tuning range of +188 kHz for the cavity (see Figure 5). This is more than the required range of ± 60 kHz. Stress at the end of the range is 118 MPa which is well below allowable for Niobium at 2 K.

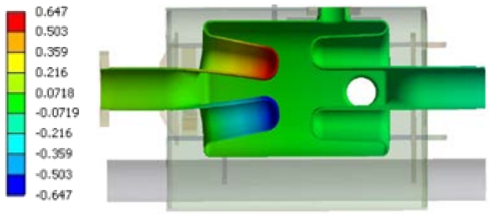

Figure 5: 4-Rod lateral deflection (mm) under 7 kN tuning load.

CAVITY STRING

The outer walls of the fundamental power couplers are used for supporting the cavity string in order to simplify the cryomodule design as shown in Figure 6. The total mass supported by the couplers is ~250 Kg. The 4-Rod cavity has the advantage of the cavity mass being balanced either side of the FPC. However, to deal with the offset load of the tuner mechanisms (~35 Kg each), a thermally neutral inter-cavity support system has been developed. The thermal contractions of Invar and 316 Stainless Steel compensate each other to ensure that the support structure maintains the same length at room temperature and when cold, a schematic of which is shown in Figure 7.

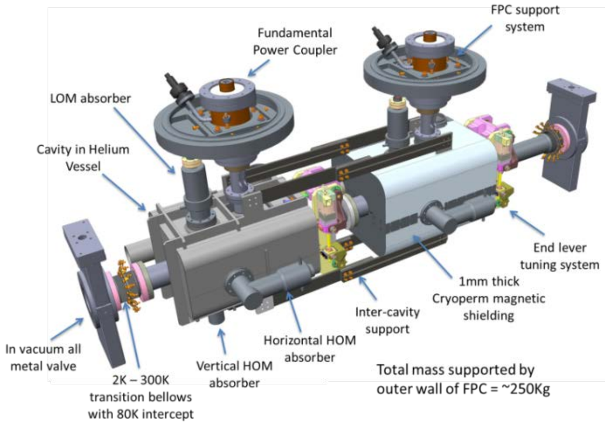

Figure 6: Cavity string.

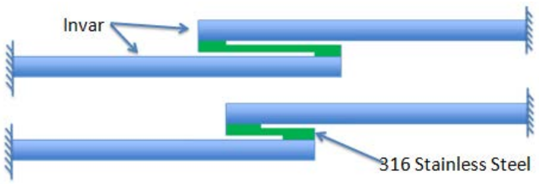

Figure 7: Thermally neutral inter cavity support principle.

The fundamental mode of vibration of the cavity string is low at 16 Hz, with a second mode at 22 Hz. These low modes occur due to flexibility in the outer wall of the FPC. A study is on-going to improve this support, either by increasing the stiffness of the FPC or adding an additional support rod to the structure. This system both stiffens the cavity string and reduces the stress in the FPC. At room temperature maximum deflection of the cavity centres is < 40 µm due to gravity. After cooldown maximum stress in the couplers is low at 12 MPa.

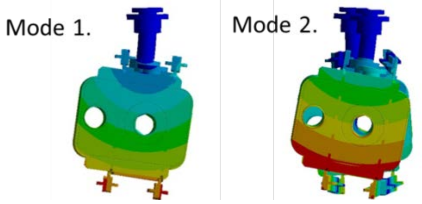

Figure 8: Cavity string modes of vibration.

CRYOMODULE

Figure 9 outlines the assembly sequence for the cryomodule. It is anticipated that the cavities will be centred on their EM centre, and then the positions of mounting holes for inter-cavity supports measured. The supports can then be machined to suit the cavity positions. Thermal and outer magnetic shields will be assembled after the installation of inter-cavity supports. Due to the limitations on the cryogenic services at SPS the use of a 5-6 K cooling circuit has been avoided and all thermal intercepts and the radiation shield will be cooled by liquid nitrogen. A 4 K pre-cool line is added to introduce better control over the cool-down process before the cavities are cooled to 2 K for final operation. The SPL-RF coupler is being modified to match the thermal performance with the cryogenic process. These fundamental RF couplers (FPCs) are used as rigid supports for the cavity string and therefore act as fixed point references for thermal contraction during cool-down.

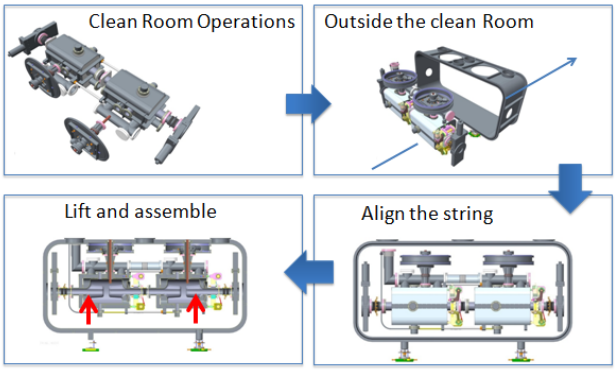

Figure 9: Sequence of steps for assembling the cryomodule.

WORK IN PROGRESS

In addition to the FPCs, the design of the multiple HOM couplers required for the cavities still remain a challenge. A combination of superconducting waveguide and coaxial couplers are being analysed. Design of the thermal intercepts and associated cooling techniques are in process [8]. Table 1 shows preliminary heat loads for the cryomdule with two cavities.

Table 1: Heat Load Estimates

STATIC	**2K (W)**	**80K (W)**
Radiation	0.6	35
CWT	3	12.6
Support	0.2	5
FPC	4	100
Instrumentation	1	
Hom/Lom/Pick-up	6.4	30
Total Static	15.2	182.6
DYNAMIC		
Cavities	6	
FPC	4	10
Hom/Lom/Pick-up	3.3	10
Beam	0.5	
Total Dynamic	13.8	20
TOTAL	**29**	**202.6**

Although not a fundamental requirement; attempts are being made to limit the total liquid helium volume in the cryomodule to 100 lts in order to keep the cryomodule in category-1or below of the European Pressure Enforcement Directive. Vessel geometry, multiple RF couplers and their locations make achieving this goal a difficult task.

One more challenge is to attenuate the stray magnetic field to 1 μT at the cavity in the presence of multiple coupler ports and their locations on the cavities. At least two levels of shielding; a mu-metal outside the radiation shield and the second of cryoperm around the dressed cavity are foreseen. Use of carbon steel for the main vacuum chamber and accommodating cryoperm shielding inside the helium vessel are also being considered.

FUTURE PLANS

Crab cavities are critical components in the LHC Hi-Luminosity upgrade project. Preparations are underway to develop at least two crab cavity cryomodules each consisting of two identical crab cavities [9]. The first cryomodule is scheduled to be installed on the SPS drive accelerator prior to the long shut-down period LS2 to evaluate performance with high-intensity proton beams.

The assembled cryomodule will be tested for cryogenic and RF performance at the SM18 facility at CERN prior to its installation at SPS. The requirements for these tests are being assessed. A number of issues also arise due to the critical alignment specifications, safety considerations and introducing interfaces for multiple RF couplers, for damping the HOMs and the LOMs. All these challenges are being addressed through collaboration [10] between CERN, UK (STFC and University of Lancaster) and LARP-US jointly.

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[10] http://hilumilhc.web.cern.ch/HiLumiLHC/activities/crab_cavities/WP4/