DESIGN OF A 4 ROD CRAB CAVITY CRYOMODULE SYSTEM FOR HL-LHC

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Abstract

The LHC requires compact SRF crab cavities for the HL-LHC and 3 potential solutions are under consideration. One option is to develop a 4 rod cavity utilising for quarter wave rods to maintain a dipole field. The cavity design has been developed including power and LOM/HOM couplers have been developed, as well as a conceptual design of a complete cryomodule system including ancillaries and this is presented. The cryomodule is designed to allow easy access during testing and uses a novel support system and contains the opposing beamline section to fit inside the LHC envelope.

INTRODUCTION

The LHC baseline programme has produced first results in the 2010-11 run aimed at an integrated luminosity of at least 1 fb^{-1} by the end of 2011. However in order to reduce the time required for statistical significance on rare decays the LHC has the goal of achieving 3000 fb^{-1} by 2035. All the hadron colliders in the world have so far produced a total integrated luminosity of about 10 fb^{-1}, while the LHC, as currently built, will deliver only about 200-300 fb^{-1} in its first 10-12 years of life. Therefore, the LHC requires a major upgrade to achieve the desired luminosity [1].

Crab cavities are a critical component in the LHC luminosity upgrade. In order to increase the luminosity, the magnets in the final focus will be upgraded to provide a smaller beta* (ie beam size). When the beta* of the beam is reduced to increase collisions, the beam becomes very sensitive to the crossing angle, and with no other intervention would lose around half the upgraded luminosity. Crab cavities can be used to align bunches in particle colliders to avoid this loss. This technique was recently demonstrated using electron beams at KEKB.

Because of their potential benefit, crab cavities are included as one of the major parts of the LHC luminosity upgrade. However, the technology must be verified before installation as crab cavities have never been utilised on Hadron beams.

A major constraint for the crab cavities is the available space between the incoming and outgoing beamlines. For a 400 MHz crab cavity there is not enough space to utilise an elliptical crab cavity hence a compact design is required. Several compact crab cavity designs have been proposed and three of these have been chosen to be taken to a prototyping phase [2]. One such cavity design is a 4 rod crab cavity (4RCC). This utilises two pairs of parallel quarter wave rods to support a dipole mode, as shown in Fig 1.

Figure 1: 4RCC cavity shape

In order to verify cavity performance and the effects on a hadron beam a test in SPS is proposed before long shutdown 2, and this paper discusses the cryomodule design for this test.

NEW CAVITY SHAPE

The 4RCC has been designed to have low surface fields, low multipole components to its deflecting field and a small transverse size [3]. The cavity shape has a higher shunt impedance than other designs for its dipole mode, while having less HOMs with lower impedance. It does however have its fundamental accelerating mode lower in frequency than the dipole mode, known as a lower order mode (LOM). However the LOM has a far lower impedance than the fundamental accelerating mode in competing designs.

The cavity is frequency tuned via a Saclay tuner on one end of the cavity which moves the rods closer together increasing the capacitive loading. However the initial design required 20 kN to achieve 0.5 mm of movement which likely to be more than the tuner can safely provide.

The cavity shape has been redesigned to reduce the force required to tune the cavity. A study of the cavity tuning in ANSYS showed that the base plate was very rigid with most of the shape occupied by either the large rods or the beampipe, due to the desire to make the cavity as compact as possible and to get the HOM and LOM couplers as close to the fields as possible for strong damping. The outer can was also very rigid to longitudinal forces as it had a constant cross section. In order to reduce the required force the surface area of the baseplate was increased by making the cavity wider in the vertical plane. This reduced the stiffness so that a force of 5kN is able to deform the cavity by 0.3 mm. The new baseplate shape and the old shape are shown in Fig 2.

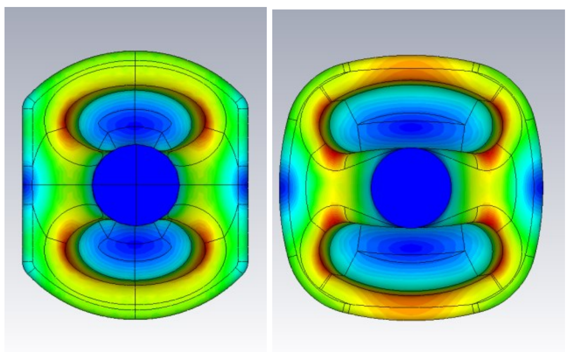

Figure 2: Original and new cavity cross sections

LOM AND HOM COUPLERS

As well as reducing the required force for tuning the rod shape was also optimised by increasing the rods width to reduce the shunt impedance of the LOM, and it is now approximately 2-3 times lower than competing designs with an impedance of 104 Ohms. However due to the high stored current in the LHC it is still necessary to provide strong damping of this mode to avoid longitudinal instabilities. While two HOM couplers will be utilised on the cavity it is not possible to have a high pass filter for the crabbing mode while still damping the LOM hence a separate narrow band LOM coupler is planned.

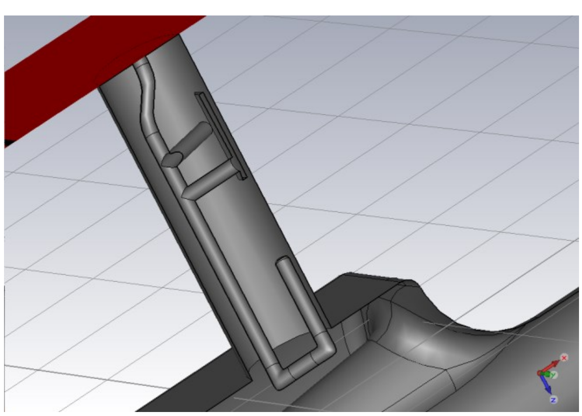

Figure 3: LOM coupler geometry

The LOM coupler will be placed in a location which shouldn't couple to the crabbing mode, however movement of the cavity and coupler during cool down means that the positioning alone cannot provide sufficient rejection of the crabbing mode, hence a resonant filter is also required. The difficulty arises in the small separation between the dipole mode and the LOM of only 30 MHz. A circuit with sufficient rejection and compensation can be achieved with a parallel inductance and resonant circuit. The parallel resonance provides a short circuit at the LOM frequency while becomes capacitive at the crabbing frequency, while the other inductance forms a tank circuit with this capacitance.

The coupler also has a loop added to couple to the magnetic field of the LOM and is shown in Fig 3 while its response when connected to a test quarter wave cavity with a variable length was simulated in CST and shows strong damping at 365 MHz and rejection at 400 MHz as shown in Fig 4.

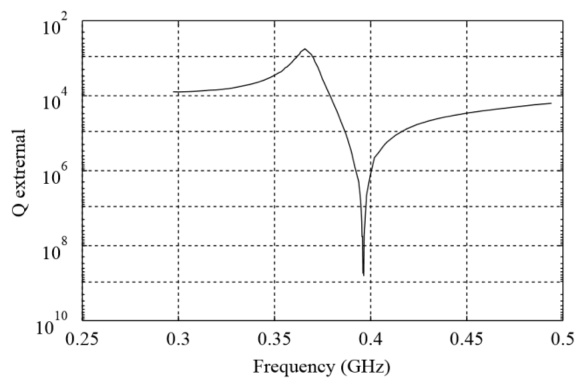

Figure 4: Q factor of the LOM coupler connected to a quarter wave resonator simulated in CST.

The HOM couplers will have a compact high pass filter designed by BNL [4]. One will be orientated horizontally and the other vertically in order to damp all HOMs.

LHE VESSEL

As the opposing beamline in the LHC is so close to the cavity there is insufficient space to have it outside the LHe vessel hence it must be inside. For SPS the opposing beamline is further away. Currently a dummy beampipe is included in the LHe vessel for SPS, although it is expected this will not be used in the final version.

The vessel also includes ports for the input coupler, LOM coupler and two HOM couplers. All couplers are mounted on the cavity body and either come out horizontally or vertically. This allows space on the end which makes the use of a modified Saclay II type tuner successfully used on the ERL cryomodule [5] for ALICE as shown in Fig. 5. The helium vessel is completely filled with superfluid liquid helium and is attached to a two-phase line via two interfacing chimneys.

Stiffening ribs have been added to both the cavity and the LHe vessel to strengthen the cavity against differential pressure. At a differential test pressure of 2 bar, the Ti vessel experiences a maximum stress of 76 MPa, and a maximum deflection of 0.58 mm. The maximum stress in the Niobium cavity is 60 MPa, which is below the allowable stress limit. These figures will be revised once

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the cavity has been optimized for axial tuning and 2.6 bar differential test pressure (as required by CERN).

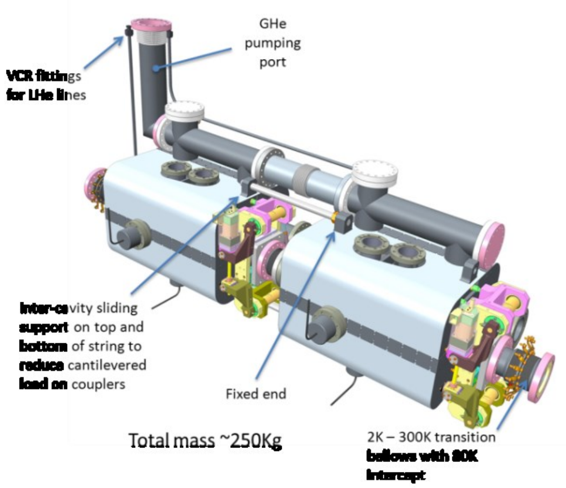

Figure 5: A string consisting of two dressed cavities with modified Saclay-II tuners.

CRYOSTAT DESIGN

Most problems in SRF systems occur after installation and almost certainly after integration of the SRF cavity into the cryomodule. This means that access to the cavity after integration is of paramount importance. With this in mind the 4RCC has a side loading cryomodule allowing access from both sides after integration, as shown in Fig 6. The couplers and other interfaces are all mounted on the top of the cryomodule and the dressed cavity is supported via the outer wall of the RF power coupler, similar to the approach taken for SPL [6]. A three axis manual alignment mechanism has been developed to position the couplers and subsequently the cavity string within the cryomodule.

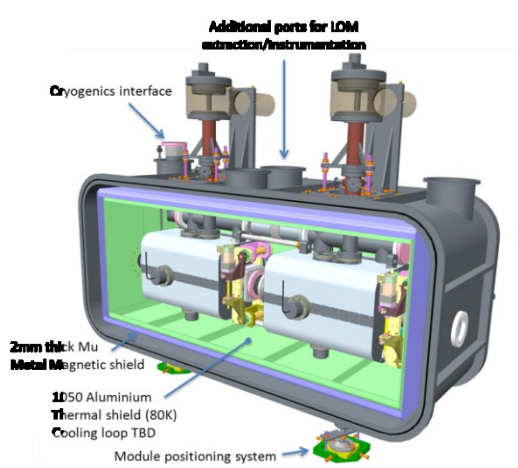

Figure 6: Side loaded cryomodule with full access to internal components after assembly and installation.

The module is also required to fit within a Y-chamber in SPS which allows the module to be physically moved in and out of the beam with all the services connected. This adds constraints to the overall width of the module, particularly on the side of the SPS bypass line.

All the thermal intercepts and the radiation shield will be cooled by liquid nitrogen and a 4K precool line is added to introduce better control over the cool-down process.

CONCLUSION

A full cryomodule system for the 4RCC is presented to meet with the requirements for both HL-LHC and the proof-of-principle tests within SPS. The design includes a modified shape to decrease the force required for tuning and to reduce the LOM impedance. In order to provide open access to the cavity after integration a side-loading cryomodule has been designed.

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