

CONCEPTUAL DESIGN OF A CRYOMODULE FOR COMPACT CRAB CAVITIES FOR HI-LUMI LHC

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Abstract

A prototype Superconducting RF (SRF) cryomodule, comprising multiple compact crab cavities is foreseen to realise a local crab crossing scheme for the “Hi-Lumi LHC”, a project launched by CERN to increase the luminosity performance of LHC. A cryomodule with two cavities will be initially installed and tested on the SPS drive accelerator at CERN to evaluate performance with high-intensity proton beams. A series of boundary conditions influence the design of the cryomodule prototype, arising from; the complexity of the cavity design, the requirement for multiple RF couplers, the close proximity to the second LHC beam pipe and the tight space constraints in the SPS and LHC tunnels. As a result, the design of the helium vessel and the cryomodule has become extremely challenging. This paper assesses some of the critical cryogenic and engineering design requirements and describes an optimised cryomodule solution for the evaluation tests on SPS.

INTRODUCTION

In order to extend the discovery potential of LHC, CERN has launched a major upgrade program “Hi-Lumi-LHC” (High Luminosity LHC) [1] to improve the luminosity performance of LHC, aiming for $L = 5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ from 2022. SRF compact crab cavities around the LHC detectors will be a key element in achieving this goal and three crab cavity designs [2] have been shortlisted for detailed studies. Such a technique has never been utilised for hadron beams before and so to mitigate any risks that may arise due to the complexity of the LHC, it is necessary to understand the interaction between the powerful LHC beam and the RF crabbing field prior to its final implementation. Therefore a prototype SRF cryomodule, consisting of two compact crab cavities is foreseen to be installed and tested on the SPS drive accelerator at CERN prior to the long shut-down period (LS2) to evaluate performance with high-intensity proton beams.

Preliminary Study

A series of complex boundary condition [3] has made the design of the helium vessel, as well as the cryomodule itself, an extremely challenging objective. A preliminary analysis [4] was undertaken to establish an approach to develop a concept cryomodule. SRF cavities have complex geometrical structures and each step towards assembling a complete cryomodule; from dressing with

the helium vessel, integrating with RF couplers to installing the tuners, is critical, costly and time consuming. Errors that may occur [5] during the assembly of individual components are typically realised only after assembly, during tests or in final operation. Traditional cryomodules, where the cavity string is rolled axially into a concentric module, can have limited access for addressing any issues discovered during the module commissioning phase. To overcome such difficulties, an open access cryomodule design [6] is proposed initially as shown in Fig. 1, to enclose the 4-Rod (4R) crab cavities for HiLumi-LHC.

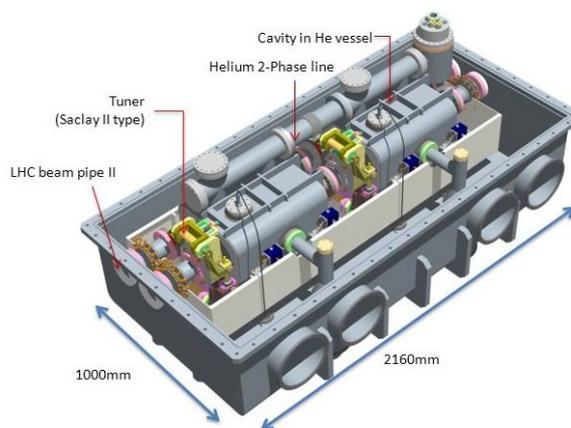


Figure 1: Open access cryomodule for 4R crab cavities.

Such a provisional design provides easy access to the internal components even after assembly and installation. It also simplifies the assembly process and minimises tooling requirements, which reduces the overall manufacturing costs. This particular design was based on the assumption that the RF power couplers will be inserted from the bottom of the cryostat. Subsequently, a refinement of the SPS requirements has modified this assumption [7] and the designs of the 4R cavities, the helium vessel and the cryomodule have also been adapted in response to the updated requirements and are hereby presented in this paper.

HELIUM VESSEL

Fig. 2 shows the helium vessel for a modified 4R [8] cavity design. Some important features of the helium vessel assembly are described below:

1. A dummy beam pipe to represent the second LHC beam pipe is included inside the cavity helium vessel.
2. The helium vessel is completely filled with superfluid liquid helium and is attached to a two-phase line via two interfacing chimneys.

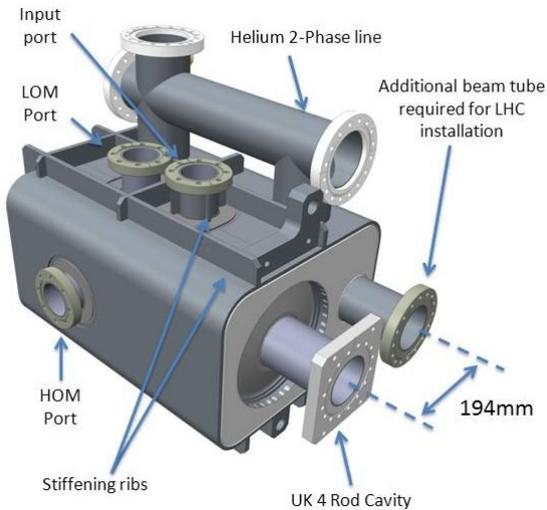


Figure 2: Helium vessel for a modified 4R cavity

3. Provision is made to incorporate modified Saclay-II tuners that have been successfully used on the ERL cryomodule [9] for ALICE and are shown in Fig. 3.
4. The helium vessel has 3 penetrations for three RF coupler ports (Input, HOM and LOM). 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 the cavity has been optimized for axial tuning and 2.6 bar differential test pressure (as required by CERN).

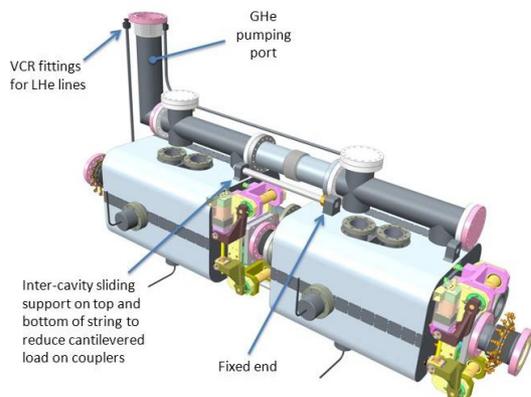


Figure 3: A string consisting of two dressed cavities with modified Saclay-II tuners.

CRYOMODULE

Side Loaded Design

The layout at the SPS test location requires that all the interfaces to the cryomodule, particularly the RF couplers and cryogenics, be located at the top of the cryostat. Keeping the basic approach of providing easy access to internal components, a new cryomodule concept design has been developed as shown in Fig. 4. Some of the key features are mentioned below but more details including preliminary mechanical analysis have been reported elsewhere [10].

1. It provides easy access to internal components from two sides.
2. It is proposed to use the outer wall of the RF coupler to support the dressed cavity mechanically inside the cryomodule, an approach similar to that taken in the case of SPL cryomodule design [11].
3. A three axis manual alignment mechanism has been developed to position the couplers and subsequently the cavity string within the cryomodule.
4. It is proposed to use the outer vessel frame of the cryomodule as tooling for assembling the cavity string and the RF couplers inside the cleanroom. Systematic assembly procedures to implement this are being developed and will be reported later.

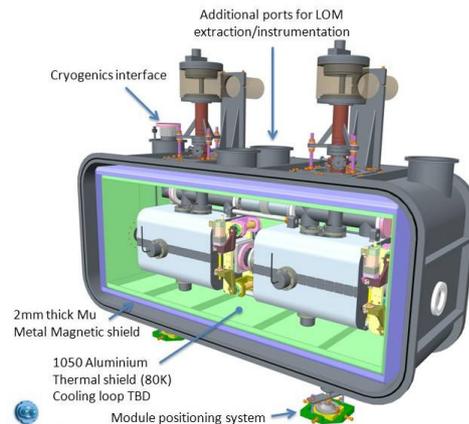


Figure 4: Side loaded cryomodule with full access to internal components after assembly and installation.

Integration with SPS Infrastructure

Fig. 5 demonstrates the compatibility of the side loaded cryomodule with the SPS layout. Overhead roof supports constrain the module in the vertical orientation. The module is also required to fit within a \square -chamber assembly which allows the module to be physically moved in and out of the SPS beamline with all external services connections being maintained. This adds constraints to the overall width of the module, particularly on the side of the SPS bypass line. The translation stage for moving the module will be developed by CERN, the requirements for which are yet to be determined.

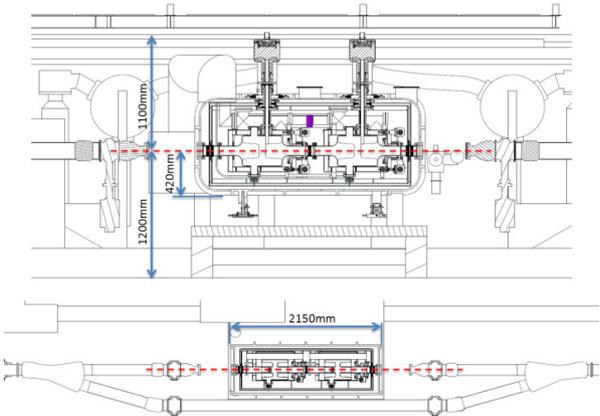
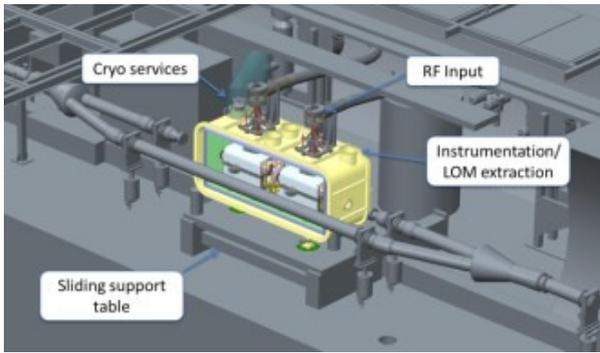


Figure 5: Side loaded Cryomodule in SPS

Schematic

Fig. 6 shows a schematic of the proposed cryogenic process for the cryomodule. Note that the use of 5K - 6K cooling circuit has been eliminated and all the thermal intercepts and the radiation shield will be cooled by liquid nitrogen. A 4K precool line is added to introduce better control over the cool-down process, whilst the SPL-RF coupler will be modified mainly to match the thermal performance with the cryogenic process. Although a separate interface is shown for liquid nitrogen, it will be integrated within the helium interface to simplify the external cryogenic infrastructure.

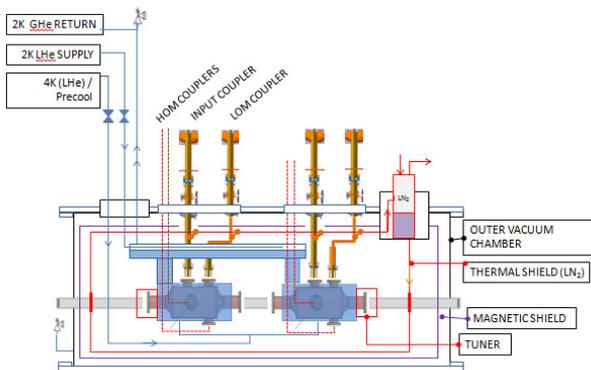


Figure 6: Cryogenic schematic of the cryomodule

FUTURE PLANS AND SUMMARY

Crab cavities are a critical component in the LHC Hi-Luminosity upgrade project. A prototype SRF cryomodule, consisting of two compact crab cavities is foreseen to be installed and tested on the SPS drive accelerator at CERN, prior to the long shut-down period LS2 to evaluate performance with high-intensity proton beams. As three cavity designs are under consideration, efforts are being made to identify common features that can be accommodated in a single plug-compatible cryomodule design in order to maintain the same infrastructure at the SPS test location. The cold side of the RF couplers and tuners for all the three cavity designs are quite different and accommodating them in the same cryomodule design will be a major challenge in its development process.

A concept design of an open access cryomodule with two 4R crab cavities has been developed, which meets all the basic requirements of the SPS tests. The assembled cryomodule is envisaged to be tested for cryogenic and RF performance at the SM18 facility at CERN prior to its installation at SPS and 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 additional RF couplers for damping the HOMs and LOMs. All of these will be addressed through a joint collaboration between CERN, STFC-UK and US-LARP.

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