DESIGN FOR MANUFACTURE OF SUPERCONDUCTING HALF WAVE CAVITIES*

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Abstract

322 MHz medium velocity half wave resonators (HWR) with β = *0.29* and *0.53* have been designed at the Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) for use in a heavy ion linac. The β = *0.29* and β = *0.53* are to provide $1.9MV$ and $3.7MV$ of accelerating voltage with a peak magnetic field of $54mT$ and $77mT$, respectively. The cavities are designed for a peak surface electric field of $30MV/m$. The cavities were optimized for manufacturing recommendations based on previous design as well as for stiffness, tunability, assembly, and cleaning. Finite element analysis simulations were performed for mechanical modal frequency analysis, liquid helium bath pressure sensitivity, Lorentz force detuning factor and mechanical force to complete the tuning range. The helium vessel, fundamental power coupler (FPC), and frequency tuner systems which interface to the cavity have been designed and prototypes fabricated.

INTRODUCTION

The Facility for Rare Isotope Beams (FRIB) located at Michigan State University (MSU) is funded by a joint agreement between the US Department of Energy (DOE) and MSU for the advanced study of rare isotope beams[1]. The driver linac for FRIB is a $200MeV/u$ superconducting linac with a final beam power of $400kW$[2]. The superconducting linac will be constructed using four types of resonators[3]. Two quarter wave resonators operating at *80.5 MHz* with optimized β = *0.041* and β = *0.085*, and two half wave resonators operating at *322 MHz* optimized for β = *0.29* and β = *0.53*, shown in Figure 1. This paper will discuss the latter cavity type. A total of five β = *0.53* prototypes have been fabricated, one by FRIB and four by two different sources in industry[4]. Results from vertical dewar tests are presented at this conference[5].

Input from industry after manufacturing prototypes suggested revisions to geometry that simplify mass manufacture. These suggested adjustments can affect rf and mechanical performance. Since FRIB will use approximately 225 half wave resonators, small changes can greatly reduce cost for the project; however, sacrificing rf and mechanical performance is not desired so optimization is needed.

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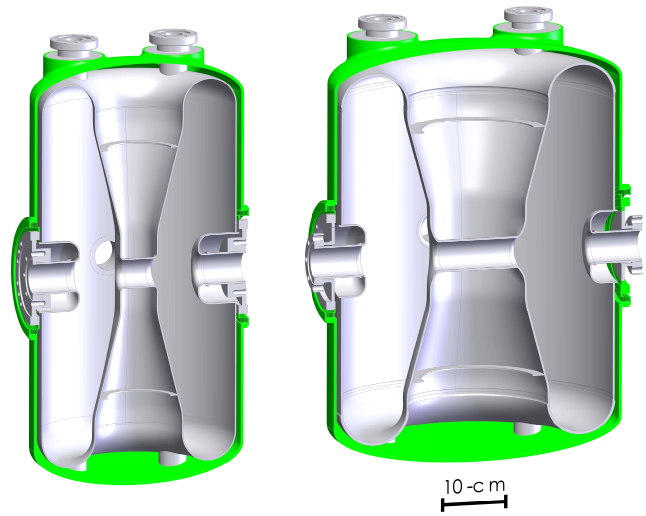

Figure 1: Optimized for production β = *0.29* and β = *0.53* resonators.

OPTIMIZATION

The cavity mechanical design is strongly influenced by the design of the helium vessel, FPC, and frequency tuner systems shown in Figure 2. The design is similar for the β = *0.29* and β = *0.53* resonators. The optimization focused first on the satisfaction of electromagnetic performance and then on manufacturing and cost. A cylindrical section between the short plate and inner conductor was added to solve machining mismatch and welding difficulties encountered in the prototype. A conical inner conductor, with an elliptical cross-section, is implemented for manufacturing convenience where previously a three dimensional profile was used. Moreover, the design of the beam port cup includes a flat surface that allows frequency tuning by means of beam port deformation without exceeding plastic limits.

SRF Optimization

The performance of a SRF cavity is determined by the electric and magnetic fields on the cavity. Optimization of the cavity involves changing its geometry to lower the peak electric and magnetic fields while maintaining the required accelerating voltage. The geometry had several constraints to optimize manufacture. For both resonators it was determined that a cylindrical interface between the short plate and inner conductor would need approximately *9.5 mm* to allow for a electron beam weld fit up and a smooth transition between parts after welding. The outer conductor diameter was increased as much as possible to decrease peak magnetic fields, taking into account available cryomodule space and cavity to cavity beamline coupling flange assembly. The maximum allowable radius is *222.25 mm* and *132.08 mm* for the β_{opt} *=0.53* and β_{opt} *= 0.29* respectively. To further increase the maximum diameter of the β_{opt} = *0.29* resonator the beam port flange was modified to minimize length extended from the helium vessel.

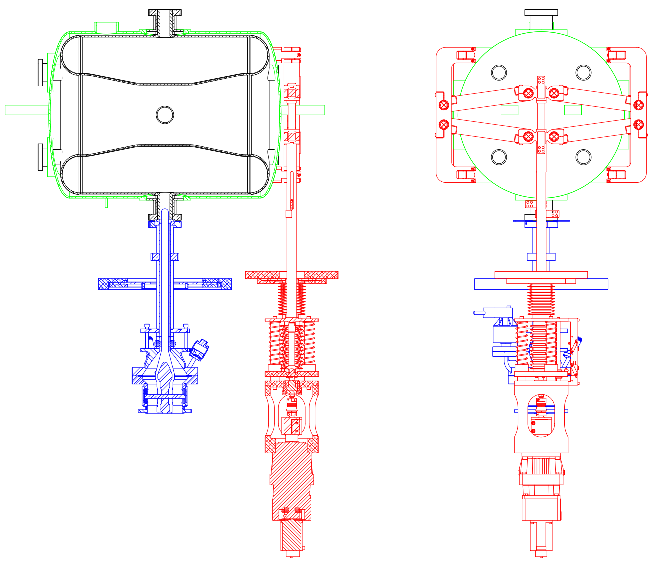

Figure 2: β= *0.53* HWR (black), with helium vessel (green), rf coupler (blue) and tuner (red).

The short plate to inner conductor interface diameter plays an important role on minimization of the peak magnetic field, especially around the rinse ports. After increasing as much as feasible the outer conductor diameter and designing the beam ports to reach the desired the β_{opt}, the peak electric field was lowered by decreasing the curvature of the beam port cup surface and the fillet between inner conductor and drift tube. Last, the frequency was adjusted by adjustment of distance between the shorting plates.

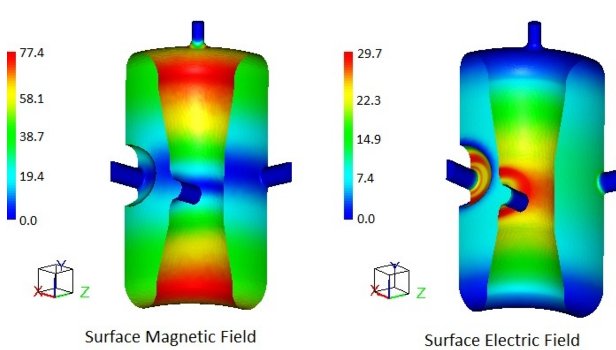

Figure 3: Magnetic and electric field plots.

A table of figures of merit compared with those of the original prototype cavity is listed in Table 1. For the same accelerating voltage, the production design has better electromagnetic performance as well as the manufacturing feasiblity than the prototype. The surface magnetic and electric fields plot shows that the peak magnetic field is uniformly distributed on the inner conductor, and the peak magnetic field is on the inner conductor around the drift tube, as shown in Figure 3.

Table 1: Figures of merit comparison

Parameter	Prototype		Production	
β_{opt}	0.541	0.293	0.541	0.290
f [MHz]	322.2	324.0	321.4	321.4
V_{acc} $[MV]$	3.70	1.90	3.70	1.90
E_{pk} $[MV/m]$	31.7	31.7	29.7	30.6
B_{pk} $[mT]$	78.1	75.9	77.4	54.4
U_o $[J]$	30.6	8.9	31.6	8.0
G [Ω]	98.4	61.5	96.3	77.9

Helium Bath Pressure Sensitivity

A target goal for cavity frequency sensitivity due to helium bath pressure for this optimization was *df/dp* $\leq$ *2 Hz/torr*. The prototype cavity had a design pressure sensitivity, *df/dp = 2.8 Hz/torr*. Initial simulation of the optimized resonator yielded *df/dp = 8.11 Hz/torr*. To achieve the design goal the following points were studied:

- Increasing the outer conductor cavity wall thickness.
- Addition of washer shaped stiffener disks to the inner conductor wall.
- Connections between short plate and helium vessel to introduce symmetry.

To minimize material costs the inner and outer conductor wall thickness was set to *3 mm* and considered the base design. Various positions of a disk welded to the inner conductor wall determined an optimum location at *180 mm* above the beam centerline. The rinse ports introduce asymmetric distortion by fixing one side of the cavity. To make symmetry, four tubular extensions join the short plate to the helium vessel. The implementation of these items generate a final *df/dp = 1.5 Hz/torr*. Evaluation of the pressure sensitivity of the β_{opt} = *0.29* resonator is ongoing [6].

RF Resonance Frequency Tuning

The obtained resonance frequency tuning of the resonators is by compression of the beam port flanges. A drawing of the tuner connected to the cavity is shown in Figure 2. The system is composed of a scissor-jack and lever arm design with a driving stepper motor at room temperature. The tuner is rigidly mounted to the helium vessel and is bolted to the cavity beam port flanges. The drive system is composed of two concentric inner and outer stainless steel tubes working in compression and tension, respectively. The drive actuator uses a linear stepper motor capable of *1.25 Nm* maximum torque, a gear box with a 100 to 1 gear ratio, and a lead screw with a factor of *1 N/0.0012 m·N* for a total drive force of *105 kN*. The scissor-jack mechanism acts as a force multiplier increasing the total force to the cavity flange of *850 kN*. The tuning range requirement is *150 kHz*. The frequency sensitivity of the beam flange movement is *60.5 kHz/mm* with the force sensitivity of *1.7 kN/mm*, corresponding to *2.48 mm* of flange to flange displacement. The maximum stresses in the beamport flanges is *76.8 MPa* giving a safety factor at *2 K* of *8.5*. The ability to add a piezoelectric fine tuning actuator, at a later stage, is built into the design.

Mechanical Modal Analysis of the $\beta = 0.53$

The cavity was analyzed for the mechanical resonance modes. Low frequency modes around *60 Hz* or below lend to microphonics resonances and must be avoided. The lowest 4 modal Eigenvalues and Eigenvectors are shown in Table 2 and in Figure 4, respectively. The lowest mechanical frequency f_1= *346 Hz*, indicates there is minimal danger to microphonic resonances.

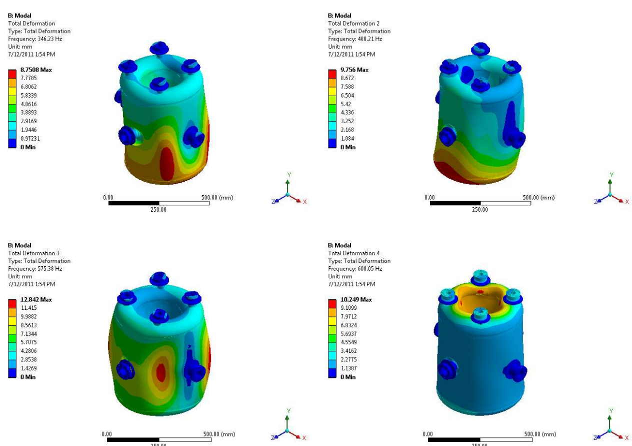

Figure 4: The lowest eigenvector modal shapes.

Table 2: Modal Analysis

Mode	Frequency (Hz)
1	346
2	400
3	575
4	608

Fundamental Power Coupler

The fundamental power coupler is designed to deliver up to *14 kW* of RF power at *322 MHz* to the resonator and the beam in CW, and to increase the resonators control bandwidth for stable operation [7]. A drawing of the FPC connected to the cavity is shown in Figure 2. The FPC includes an alumina vacuum barrier to allow the resonator to be under ultra-high vacuum. The FPC also serves as a thermal break between the room-temperature transmission line and the resonator at *2 K*, with *38 K* and *4.5 K* thermal intercepts designed to minimize the heat load to the cryoplant. The FPC design allows for some variation in the coupling, in case a larger bandwidth is needed to mitigate microphonic disturbances.

The cavity to FPC interface is a *3-3/8* inch Conflat® flange vacuum connection. The seal uses a custom gasket machined from *6.4 mm* thick sheet OFE copper to provide two additional functions over that of vacuum. The first is to seal the outer conductor and cavity flange surfaces making RF contact, similar to SNS power coupler gasket. Secondly, the gasket has two prolongations to thermal intercept to a *4.5 K* distribution header which uses bolted connection and Apiezon® Type N thermal grease to maximize heat transfer.

CONCLUSIONS

The mechanical design of the FRIB production cavities is near completion. Requests for quotes are underway for two production resonators. Once a vendor is selected, two will be fabricated. When received these resonators will be tested in a dewar to confirm RF performance which will be checked against the original resonator design. Mechanical analysis of the β_{opt} = *0.29* is ongoing and expected to be completed in Fall 2011.

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