DEVELOPMENT OF A SUPERCONDUCTING HALF WAVE RESONATOR FOR BETA 0.53*

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Abstract

A medium velocity half wave resonator has been designed and prototyped at the National Superconducting Cyclotron Laboratory (NSCL) at Michigan State University (MSU) for use in a heavy ion linac. The cavity is designed to provide 3.7 MV of accelerating voltage at an optimum beta = v/c = 0.53, with peak surface electric and magnetic fields of 32.5 MV/m and 79 mT, respectively. The cavity was designed for stiffness and tunability, as well as straightforward fabrication, assembly and cleaning. Measurements were performed to confirm Finite Element Analysis (FEA) predictions for modal analysis, bath pressure sensitivity, tuner stiffness and tuning range. A copper cavity prototype has been fabricated to confirm tolerances and formability. A tuner prototype has been built. The helium vessel and power coupler have been designed.

INTRODUCTION

The half wave resonator is being developed at MSU, and is proposed for use in the high energy section of the DOE national user facility called the Facility for Rare Isotope Beams (FRIB) [1, 2].

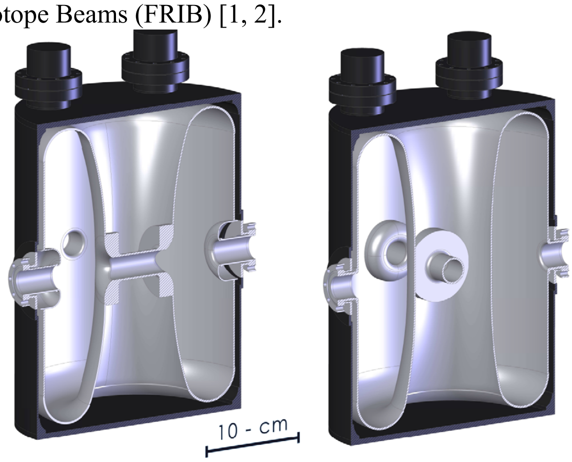

Figure 1: CAD representation of the beta 0.53 half wave.

The 322 MHz beta 0.53 half wave resonator has a 40 mm aperture in the drift tube and a 42 mm beam tube internal diameter. It will operate at 2 K with a conservative goal of 6 Watts helium load (dynamic). Frequency control will be provided by a mechanical tuner outside the helium vessel, which will perturb the cavity fields in the beam port region, actuated outside of the vacuum vessel by a stepper motor and piezo actuator in series. Ports perpendicular to the beam ports in the mid plane will be used for RF coupling with fixed probes, shown in Figure 1. Four ports have been added to the top shorting plate for ease of cavity processing, and may be used to provide fine tuning of the frequency via a superconducting plunger if needed.

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ELECTROMAGNETIC DESIGN

The RF performance of the cavity was optimized using a 3D field solver ANALYST [3] with the results shown in Table 1. In addition to the electromagnetic performance, FEA was used to predict multipacting, frequency shifts due to chemical processing, and to confirm the fundamental power coupler design.

Figures of Merit

During the evaluation of the half wave geometry to obtain optimum surface fields, care was taken to ensure that the cavity could still be easily fabricated, processed and tuned. Additional surface field optimizations are being explored.

Table 1: Electromagnetic figures of merit.

Parameter	Value
β_{opt}	0.539
V_{acc}	3.70 MV
E_{peak}	31.5 MV/m
B_{peak}	76.5 mT
U_0	31.0 J
G	101.2 Ohms

Fundamental Power Coupler

The FRIB application requires 4 kW RF power, with an external coupling of ~1E7. A power coupler which had been designed for higher power at 805 MHz [4, 5] has been verified using ANALYST as an appropriate option for the FRIB high beta cavities, though it will be optimized to reduce costs.

Multipacting

Multipacting barriers were predicted at several field levels using ANALYST. Cold testing of the niobium prototype will show to what extent conditioning of barriers is required.

MECHANICAL DESIGN

The outer conductor of the cavity is a straight cylinder, which provides stiffness to minimize the displacements caused by helium pressure fluctuations that lead to frequency detuning. The inner conductor is tapered such that it has a 48 mm larger diameter at the seam with the shorting plates, leading to lower surface magnetic fields. The beam ports, which are used for mechanical tuning, will be fixed to the tuning mechanism, providing a tuning mechanism without compromising stiffness.

Cavity Stiffness

Several analyses were performed to quantify the displacements and frequency detuning of the cavity in the liquid helium bath. Both COSMOS [6] and ANSYS [7] were used to verify the mechanical stability of the cavity. Figure 2 shows the ANSYS model: A contour plot of the displacement vector sums with 1 bar of pressure applied at both the external cavity walls and the internal titanium vessel walls. The model predicted the effect of displacement on the resonant frequency. Using ANSYS, a sufficiently small frequency shift coefficient was predicted (-2.2 Hz/mbar) without additional stiffening.

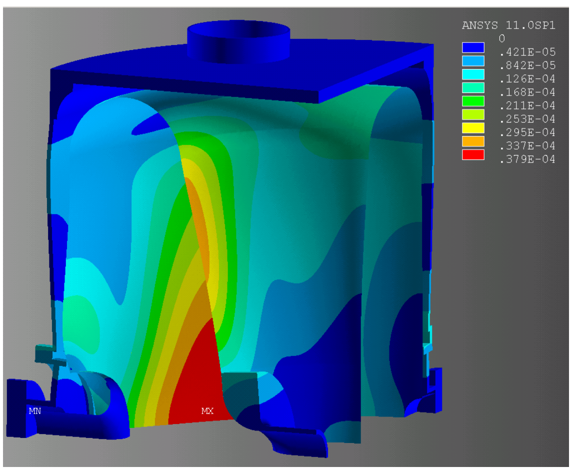

Figure 2: Displacement contours from the mechanical model in ANSYS.

Cavity Tuning

The implementation of beam port cups into the half-wave resonator design provides a less rigid structure at the median plane, facilitating cavity tuning by deformation at the beam ports. A tuning mechanism has been developed that enables both fine (fast) and coarse (slow) tuning through a single mechanical linkage. This is done by having two actuators connected in series; a piezo-electric actuator for fine tuning, and a stepper motor for coarse tuning.

The tuner mechanism, which is shown in Figure 3, has been designed to provide a mechanical advantage of roughly 20 to 1,i.e the force applied by the tuner to the resonator beam ports is 20 times than the force produced by the piezo-electric actuator and stepper motor. This produces very similar force and displacement characteristics, shown in Table 2, as the tuning actuators used for MSU's reaccelerator cavities [8].

The commercially purchased compliant joints [9,10], used as pivot points on the tuning mechanism, allow for simpler and fewer parts as well as a stronger, more definite transmission of motion throughout the joint without introducing vacuum degrading elements into the insulating vacuum space. All of the motion is realized through mechanical deformation of the joints instead of a rolling or sliding motion. Shrink fitting was chosen as the primary means of installing the flexural pivots.

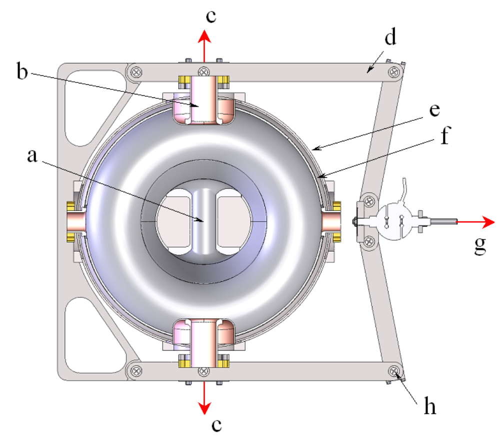

Figure 3: Section view of the tuner at the mid plane of the cavity: (a) drift tube; (b) beam tube; (c) resulting cavity; deformation force; (e) helium vessel; (f) outer conductor; (g) applied tuning force; (h) compliant pivot.

In addition to the mechanical tuner, a study was performed on the implementation of a superconducting plunger, similar to the ones used on Spiral2 [11] quarter waves. This option leaves some flexibility in the design for the final frequency of the cavity. The rinse ports can be blanked off, left filled with a static plunger or can be implemented as a (operating) tuner that may change the frequency without perturbing the beam ports.

Table 2: Cavity tuning parameters.

Parameter	**Design Goal**
Coarse Tuning Range	100 kHz
Coarse Tuning Resolution	10 Hz
Fine Tuning Range	3 kHz
Tuning Sensitivity	35 kHz / mm
Tuning Stiffness	150 N / mm
Plunger Tuning Range	16 kHz

FABRICATION

Prior to forming the niobium parts, a copper prototype was constructed to confirm the fabrication steps required for the niobium cavities. Aluminum die sets were used to form the two beam port cups, the two short plates, the inner conductor and the outer conductor. The drift tube, beam tubes and rinse port tubes were machined from copper tube stock. The drift tube was welded to the inner conductor, and then the inner and outer conductors were welded to the top short plate.

PROTOTYPE MEASUREMENTS

Bench measurements were performed on the copper prototype to confirm calculations made during the design study. A prototype tuner was built specifically for the copper cavity and tuner exercises were performed. The cavity stiffness was also checked by varying the internal and external pressures. A bead-pull measurement was performed to check the field flatness.

Frequency Checks

A preliminary frequency measurement was performed prior to welding the top shorting plate and the beam cups to the cavity assembly. At this point, the tuning sensitivity of the beam cups was verified and good agreement with the ANSYS model was obtained. In the future, the placement of the cups will be used as the final frequency tuning before they are e-beam welded. Figure 4 shows the adjustable fixture used to measure the frequency as a function of beam port cup position. Weight was added to the top of the top short plate (welded) to make good rf contact on the bottom short plate (not yet welded).

Figure 4: Copper prototype during assembly.

Pressure Sensitivity

Measurements were performed on the copper prototype to confirm its stiffness. The air in the cavity was pumped out and the external pressure was varied, using a Dewar as a vacuum chamber. Frequency measurements were done using a network analyzer, with two cases: fixed beam-ports (fixed to the prototype tuner) and free beam ports. The frequency shift coefficient for both cases was small, -2.2 Hz/ mbar (fixed beam ports) and -4.9 Hz/mbar (free beam ports).

Tuner Measurements

For stiffness testing the tuner prototype, a bar of stainless steel was installed in place of the RF cavity. A sufficiently rigid bar replicated the fixed boundary conditions of the finite element model so that a comparison could be made. A force transducer was attached to the rigid bar and tuner input to measure the force applied to the tuner (via a threaded rod and nut). As with the virtual model of the tuner, a series of different loads were applied to the tuner and the resulting locations of the tuner input and the tuner pivot centers were measured. These geometric measurements were made using an articulated coordinate measurement machine (CMM) arm. This test indicated agreement. Frequency measurements confirmed the model's prediction of tuning sensitivity for the copper prototype.

FUTURE WORK

Work on a niobium prototype is underway at MSU. Forming and machining is complete with the exception of the outer conductor. The parts are shown in Figure 6. Upon completion, cavity will first be tested without the helium vessel later this year.

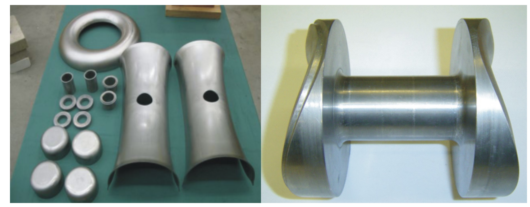

Figure 5: Niobium parts for the beta = 0.53 Half Wave Resonator (HWR) prototype.

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