SUPERCONDUCTONG RESONATORS PRODUCTION FOR ION LINACS AT MICHIGAN STATE UNIVERSITY

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Abstract

Superconducting quarter-wave resonators and half-wave resonators are being prototyped and fabricated at Michigan State University (MSU) in effort to support the Facility for Rare Isotope Beams (FRIB) project. FRIB requires a 200 MeV per nucleon driver linac, operating 341 resonators at two frequencies (80.5 and 322 MHz) and four betas (0.041, 0.085, 0.29, and 0.53). FRIB cavity development work is underway, with the prototyping of all four resonators, including helium vessel design, stiffening strategy, and tuner interface. In addition, the acquisition strategy for FRIB resonators is being finalized, and the technology transfer program is being initiated. The status of the resonator production effort will be presented in this paper, including an overview of the acquisition strategy for FRIB.

INTRODUCTION

The Facility for Rare Isotope Beams (FRIB) at Michigan State University is an approved ~550M$ project funded by a cooperative agreement between Michigan State University (MSU) and The US Department of Energy (DOE) for advancement in the study of rare isotopes. The driver linac for the FRIB project is a 200 MeV/u superconducting linac with final beam power reaching 400 kW. There are four types of resonators used; two quarter-wave resonators (80.5 MHz, $\beta = 0.041$ & 0.085) and two half-wave resonators (322 MHZ, $\beta = 0.29$ and 0.53) [1]. The resonators are housed in rectangular, bottom loaded cryomodules with internally built focusing solenoids. In total, the FRIB linac will require 341 superconducting cavities, housed in 51 cryomodules.

FRIB continues to advance the design of the four cavities to be used in the FRIB driver linac. The cavity acquisition plan is in place with requests for proposals submitted to cavity vendors. FRIB will select vendors early in the project and work with the awarded vendors through development to production.

CAVITY ACQUISITION PLAN

A Request For Proposal (RFP) will be submitted for each of the four FRIB cavities. The RFP will lay out a path to production in three stages: fabrication of two complete cavities, a production run of 10 cavities, and final production of required number of cavities. Early vendor selection allows the FRIB project time to work with vendors and develop cavity fabrication procedures to ensure cavity quality and production rates. The first stage will require vendors to fabricate two cavities. The vendors will be supplied a cavity design based on the prototyping efforts prior to the RFP; as discussed further in the CAVITY STATUS section. Vendors will fabricate two complete cavities, working with FRIB technical staff to work through final frequency measurements and positioning. Stage one cavities will be fabricated with out helium vessels.

Stage two will require the fabrication of a small production run of 10 cavities. Cavities will be built to completion including helium vessels. It is also FRIB's desire to have cavity vendors perform the bulk chemical treatment to completed cavities. This will be handled as part of a separate RFP. Stage two also allows an opportunity to implement any necessary design changes realized in Stage one fabrication, as agreed upon by FRIB and vendor.

Stage three signifies the start of FRIB cavity production. Cavity fabricated during this stage will be shipped to FRIB and sequenced for cavity certification. Vertical test certification of FRIB cavities is required for all cavities prior to cold-mass assembly. Cavities will be inspected and tested real time with vendor delivery to ensure no deviations from production drawings and cavity performance.

Vendors will be required to fabricate all required dies and tooling to produce the awarded cavities at the agreed upon production rate. All high RRR niobium (>250) and helium vessel transition materials will be supplied by FRIB. FRIB scheduling will require vendors to supply cavities at a rate of 12 per month. This rate will support a cryomodule production schedule of two units per month. Cavity production will span 36 months with a 6 month ramp up. Production of Stage one cavities (two units) is scheduled to begin Q4 2011 with Stage three production to start in Q4 2013.

CAVITY STATUS

Prior to the RFP release, cavity development research initiated with the fabrication of 11 quarter-wave, beta=0.085 and 5 half-wave, beta=0.53 cavities. These cavities were fabricated using a step by step approach where commercial vendors were contracted to supply only cavity subassemblies. After receipt of the subassemblies, stack-up frequency measurements were completed by FRIB personnel. The subassemblies were then adjusted to meet frequency requirements, processed, and electron-beam welded to completed cavities.

The subassembly fabrication pre-step provided an opportunity to closely inspect cavity tolerancing and surface quality before features were hidden within the completed cavity. Cavities were then cryogenically tested to ensure vacuum integrity and cavity parameters (frequency, Q, gradient…).
This experience resulted in design changes that were later implemented to increase both fabrication and performance quality, as well as, reduce costs. A brief description of the major findings is discussed; including choice of helium vessel materials, material transition technology, vacuum seal technology, and RF interfaces. These design changes were used in drafting the FRIB cavity production RFP, as described in the CAVITY ACQUISITION PLAN section.

Quarter-wave Resonators

Multiple quarter-wave resonators have been cryogenically tested and shown to have good performance in both Q and gradient. Early tests, however, discovered a reliability issue with the assembly of the bottom flange. This assembly provides the vacuum seal on the open end (bottom) of the resonator, while also making both the RF and thermal connections from the tuning plate to the outer conductor. Tests with poor contact, as confirmed with pressure film tests, had shown significantly lower Q values and gradients, well below FRIB parameters. Three main mechanical issues were redesigned to mitigate the problem in the bottom flange connection, as shown in Figure 1.

First, the joint location was moved by extending the length of the outer conductor (~70mm). This reduced the current at the joint, as well as, reduced electric fields seen on the tuning plate. Second, the RF coupling was removed from the bottom flange and positioned radially on the outer conductor, 90 degrees from the beam ports. This significantly decreases the heat load seen by the tuning plate, reducing the required cooling. Third, the material of the bottom flange and clamping ring were changed from stainless steel to titanium. The change in material decreases the radial thermal contraction difference between the bottom flange and niobium material of the cavity. The stainless steel bottom flange of the old design resulted in a significant contraction difference that altered the applied load to the RF joint. By changing to titanium, the thermal contraction will be nearly equal to what is measured in niobium. Further details and tests results are presented in [2].

Half-wave Resonators

Multiple half-wave resonators have been cryogenically tested and shown to have good performance in both Q and gradient. Subassembly fabrication and final cavity stack-up measurements resulted in design changes to address tolerance issues (electron-beam welding interfaces) and reduce production costs. Tolerance issues were observed in weld joint interfaces, resulting in "ledges" along the electron-beam welds between the outer and inner conductors to the toroids. This issue was mitigated by implementing a straight section to the inner conductor interfaces and removing the weld preps on the outer conductor interfaces, as shown in Figure 2.

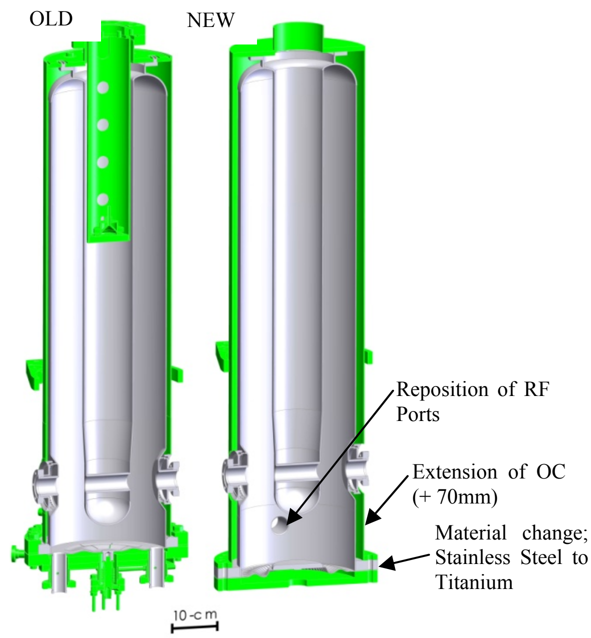

Figure 1: FRIB quarter-wave resonator old and new design.

The fabrication costs for the different subassemblies were analyzed. A major cost was noted in the inner conductor subassembly, associated with the drift tube interface. The subassembly required a complex machining operation, requiring many hours of work. This was mitigated by redesigning the curvature to allow a larger region of forming (deep drawing) while reducing the required machining. Further details and tests results are given in [3].

An additional concern was discovered during assembly of the completed cavities. When examining copper gaskets used in vacuum assembly of the cavities, one can observe irregularities in the formed knife-edge groove. The marks appear to be pitting, suggesting the knife-edges may have been exposed to chemistry during fabrication. Quality control producers will be implemented to secure and protect vacuum seals at all stages of production.

Helium Vessel

FRIB cavities are constructed with isolated vacuum systems and individual plumbed cryogenic vessels. Multiple fabrication materials were studied for potential use in helium vessel fabrication. Materials under consideration included low-purity niobium, titanium (Grade 2), and stainless steel (316). Of the three materials, each one provides both positive and negative attributes. The low-purity niobium and titanium both have similar coefficients of thermal expansion as RRR niobium (~0.14%), allowing the vessel to move with the cavity during cool-down. Stainless steel contraction is nearly double (~ 0.27%) requiring a design approach that mitigates the displacement (bellows). Niobium can provide additional magnetic shielding when properly cooled. When considering costs, stainless steel is the clear economical choice, with a savings of nearly 4 times the cost of titanium. In fabrication, niobium and titanium are problematic as they require vacuum or inert environments for welding.

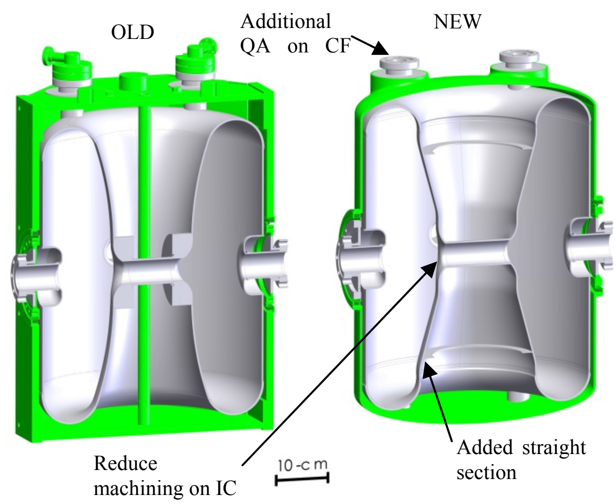

Figure 2: FRIB half-wave resonator old and new design.

Transitions

When considering helium vessel materials, a suitable transition material must also be selected that can be welded to the high RRR niobium of the cavity. For low-purity niobium and titanium, the material choice is an Nb-Ti alloy (45-55%). This material has been successfully demonstrated in operating facilities, such as the SNS project. In more recent advances, a niobium to stainless steel transition has been developed and used in current accelerator projects (Jlab's 12 GeV upgrade). This joint uses a copper alloy braze between the niobium and stainless steel. Transition locations in the half-wave resonators are similar diameters to what has been demonstrated in other projects. As for the case of the FRIB quarter-wave resonators, the bottom flange diameter is large, requiring a sealing flange >13 inches. This diameter joint has not been demonstrated and requires additional development.

In a parallel development, FRIB is also investigating the use of niobium to stainless annular explosion bonded transitions.

Vacuum Seals

Cavities and focusing elements along the cryomodule strings will be assembled using Conflat® technology with copper gaskets. Proposed sealing transitions are being studied prior to production to prove sealing reliability and draft fabrication specifications. Multiple materials are still being considered for possible use in helium vessel fabrication. The final vessel design will define the flange material to be used in the vacuum assembly.

As part of this study, flanges of different materials and sizes were fabricated with standard Conflat® seals. The flanges were paired in different configurations and vacuum tested (all using copper gaskets); including ten thermal cycles from 300K to 77K. Torque settings on bolts, before and after cycling, where also monitored and recorded. Table 1 provides the material combinations, sizes, and results.

In additional to the beam line and coupler flanges, the quarter-wave resonator bottom flange seal is also being reinvestigated. The current design requires an indium seal (0.060 inch wire) for vacuum. These indium seals have demonstrated multiple thermal cycles while maintaining vacuum integrity. However, the indium does present a different problem in that it is not easy to remove and can produce particulate if the seal is broken. This has raised issues concerning a final high-pressure rinse of production cavities; after vertical certification before string assembly. In an investigation to remove the indium seal, a titanium Conflat® seal is under development at the size required for the quarter-wave resonators (13.25 "), results are provided in Table 1.

Table 1: Table showing vacuum test results of multiple flange material combinations and sizes

Material 1	Material 2	Gasket	Flange Size (OD)	Vacuum Test
Nb-Ti	Stainless Steel	Copper (CF)	3.375"	Yes
Nb-Ti	Nb-Ti	Copper (CF)	2.75"	Yes
Titanium	Titanium	Copper (CF)	13.25"	Yes
Niobium	Titanium	Indium	13.25"	Yes
Nb-Ti	Niobium	Indium	13.25"	Yes
Nb-Ti	Titanium	Indium	13.25"	Yes
Nb-Ti	Stainless Steel	Indium	13.25"	Yes

ACKNOWLEDGEMENTS

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REFERENCES

[1] M. Leitner *et al.*, in *Proceedings of the 15th International Workshop on RF Superconductivity, Chicago, IL, USA, 2011, MOPO009.*
[2] J. Popielarski *et al.*, in *Proceedings of the 15th International Workshop on RF Superconductivity, Chicago, IL USA,* Paper TUPO060.
[3] S. Miller *et al.*, in *Proceedings of the 15th International Workshop on RF Superconductivity, Chicago, IL USA,* Paper MOPO051.