STATUS OF THE LINAC SRF ACQUISITION FOR FRIB*

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Abstract

The Facility for Rare Isotope Beams (FRIB) will utilize a high-intensity, superconducting heavy-ion driver linac to provide stable ion beams from protons to uranium up to energies of >200 MeV/u and at a beam power of up to 400 kW. The ions are accelerated to about 0.5 MeV/u using a room-temperature 80.5 MHz RFQ and injected into a superconducting cw linac consisting of 330 individual low-beta cavities in 49 cryomodules operating at 2 K. This paper discusses the current status of the linac SRF acquisition strategy as the project phases into construction mode.

INTRODUCTION

Due to the heavy mass and correspondingly low velocity of the accelerated ions the FRIB driver linac [1] utilizes four different low-beta SRF resonator designs as shown in figure 1 and figure 2. The status of SRF system designs and overall acquisition strategies have been summarized in [2]. For high-beta applications superconducting RF has become an established technology with a history of industrial optimization efforts. However, for low-beta structures, FRIB will most likely be the first facility requiring industrially produced components on a larger scale.

FRIB is a US$ 680 million construction project with an 8-year timetable: According to the current FRIB baseline schedule fabrication and procurement of linac components will start mid-2014. Actual linac installation will begin end of 2016 after completion of conventional facilities and cryoplant construction. Accelerator commissioning is scheduled to initially proceed in parallel with installation and to conclude at the earliest by end of 2019 (beginning of 2021 if schedule contingency is included). 2015 to 2018 will be the peak period for industrial SRF cavity and cryomodule production.

The FRIB project plans to place approximately 450 procurements above US$ 50,000 each. The sum of all technical equipment procurements (excluding conventional facility construction) issued to industry amounts to US$ 217 million. Roughly 30% of that procurement value will be spent on cryomodule components not including RF amplifier equipment.

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SRF PROCUREMENT SPECIFICS

A major challenge for the FRIB project is the need to develop, qualify, and industrialize four independent cryomodule and cavity types before start of construction. Optimization of the linac resulted in a design with 49 cryomodules incorporating 106 quarter-wave (QWR) and 224 half-wave (HWR) resonators (330 total) with four different optimum velocities as shown in figure 2. A detailed cavity count table can be found in [2].

Unlike prior superconducting low-β linacs, the large size of FRIB has required optimization of the resonator designs for both maximum performance and for low cost in the view of a large production. This requirement guided the choice of the resonator geometries, materials and mechanical solutions avoiding complicated shapes, minimizing the amount of electron beam welds, eliminating bellows, as well as optimizing construction and surface treatment procedures. The history of the resonator development and detailed FRIB cavity specifications are summarized in [3].

Cavity Procurement Status

Including development, pre-production, spare, and 10% excess cavities FRIB will procure more than 400 cavities within the next six years. FRIB can select from a highly qualified cavity supplier base due to world-wide strong, industrial interest in SRF cavity fabrication. Six vendors have consistently bid for FRIB cavity production: AES, Niowave, Roark, and Pavac on the American continent; Research Instruments and Zanon on the European continent. So far AES, Niowave, and Roark have produced physical cavity prototypes for FRIB.

β=0.53 Cavities:

The first and largest (several M$) FRIB cavity production contract (for a total of 160 undressed β=0.53 cavities: 2 development, 10 pre-production, 148 linac cavities) has been awarded to Roark, Inc. as a firm price contract. For FRIB procurement quantities the cost reduction between development cavities and mass-produced cavities falls around 3. The β=0.53 cavities are the largest and most expensive cavities used in the driver linac.

β=0.29 Cavities:

Due to federal funding delays FRIB has slowed down the procurement of the other cavity types. At present two

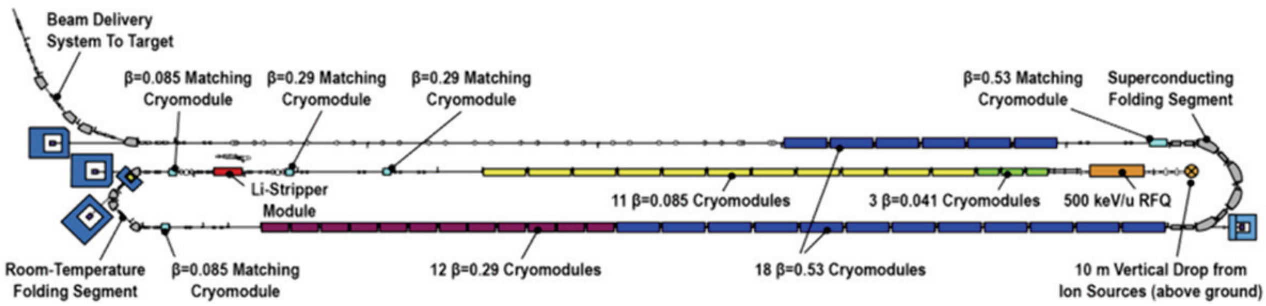

Figure 1: A schematic layout of the FRIB driver linac.

development β=0.29 cavities are being fabricated by Roark, Inc. with delivery expected in the beginning of 2013. Requests for proposals to deliver 10 pre-production cavities, 76 FRIB linac cavities, and 2 spare cavities will be issued in 2013.

β=0.085 Cavities:

For the quarter-wave resonators, ten early β=0.085 cavity designs have been fabricated by Niowave, Inc. in 2010. They are utilized in the MSU Re-Accelerator project ReA [4]. FRIB is currently building two β=0.085 FRIB cavity prototypes in-house. An additional two development cavities have been purchased from Pavac Industries Inc. The request for proposal for 10 pre-production cavities, 94 FRIB linac cavities, and 11 spare cavities will be issued in 2013.

β=0.041 Cavities:

The initial section of the FRIB linac requires a small amount of β=0.041 cavities. Since these cavities are similar to cavities operational in the first two cryomodules of the existing ReA linac [4] 12 FRIB linac cavities plus 4 spare cavities will be purchased in 2014 without a development program.

Helium Vessels

All FRIB cavities are dressed in titanium helium vessels which are directly connected to the cavities through Nb-Ti transition pieces. No bellows are required in the designs. The helium vessels are designed according to the ASME pressure vessel code, but will not be code-stamped.

FRIB has successfully adopted the Jefferson Lab titanium-inert-gas (TIG) welding technique for titanium which utilizes oversize (~2 inch diam.) argon shielding gas nozzles made of quartz glass. That way the welding operator can work in direct contact with the equipment without requiring inert-gas chambers. As a result, welding times have been dramatically reduced. FRIB will work with vendors to transfer that knowledge.

Cavity Surface Preparation

Bulk cavity etching (~150 μm removal) will be performed by industry. Test results and cost considerations for a large production led FRIB to the choice of BCP (buffered chemical polishing) as surface treatment for the resonators. Once cavities are received and inspected at FRIB, 600°C heat treatment, final light etch, and high pressure rinse will be performed at MSU.

Niobium Procurement Status

The FRIB niobium procurement amounts to US$ 13 million and includes RRR>250 niobium sheets, plates, tubes, and rods, as well as Nb-Ti alloy material. The contract for thin niobium sheets used for deep drawing has been awarded to Tokyo Denkai Co. Ltd.; Ningxia Orient Superconductor Technology Co. will produce all niobium tubes, rods, and thick sheets; ATI Wah Chang is responsible for delivering all Nb-Ti material. Based on vendor capacity the delivery is phased according to the following schedule: 5% of material volume in Feb. 2013, 23% in Aug. 2013, 5% in Oct. 2013, 29% in Jan 2014, 38% in Oct. 2014.

Niobium will be accepted based on dimensional checks at MSU, confirmation of mechanical properties (tensile strength, hardness), profilometry, as well as thermal conductivity and chemical composition confirmation.

Cryomodule Status

After the conceptual design, the FRIB cryomodule design has evolved significantly from a “top-down”

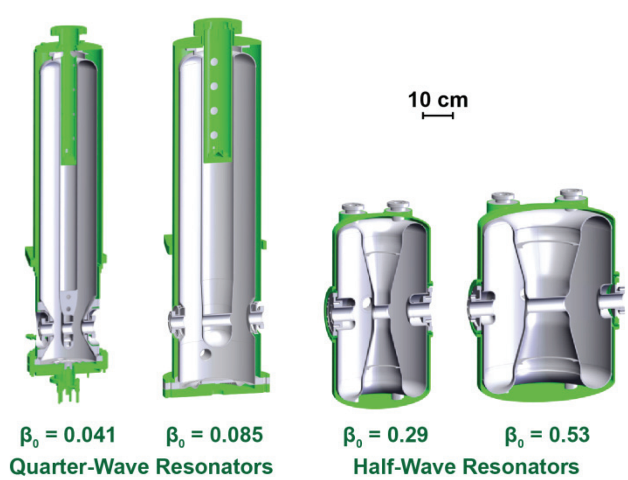

Figure 2: The FRIB driver linac requires four different low-beta cavity types as shown. Due to the large quantity of cavities in the driver linac the current development effort focuses strongly on minimization of fabrication costs [2].

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cryomodule style, widely used in the low-beta community, to a "bottom-up" design which has advantages for mass-produced applications. Figure 3 shows the current design incorporating a torque-resistant structural frame made of stainless steel. The design incorporates machined fiberglass compression posts supporting the coldmass in the cryomodule vacuum vessel. Three posts on linear roller bearings oriented towards the center of thermal contraction serve as 6-degree-of-freedom kinematic supports. This novel design maintains the alignment of the coldmass while allowing thermal contraction. Cavity and solenoid attachment points to the rails are all machined after welding and full annealing at 1100 °C to ensure assembly consistency.

The FRIB cryomodules contain separate cryogenic circuits at 4 K for the solenoids and at 2 K for the cavities with the 2 K heat exchanger residing inside.

The project schedule calls for a production rate of 1.5 cryomodules per month. Cavity processing, vertical tests and coldmass assembly are planned to be performed at MSU. The cryomodule thermal shield, magnetic shield, cryogenic plumbing, and vacuum vessel will be procured from industry as complete "plug-in" units ready for assembly in the cryomodules. Based on initial experience with vendors significant cost savings could be gained by ordering fully assembled subcomponents which are fit to tolerance at a single vendor instead of procuring individual parts from independent vendors requiring tight tolerances for overall assembly fits.

FRIB INDUSTRIAL ACQUISITION STRATEGY

Cost discipline has been strongly ingrained into the FRIB engineering culture since the overall project cost is capped. Designs are optimized towards low-cost manufacturability while still utilizing high-quality suppliers. In addition, MSU procurement overhead and labor rates are low compared to other national laboratories leading to 30% reduced cryomodule costs compared to similar projects.

Nevertheless, the most significant cost containment is achieved by a well-managed industrial acquisition strategy. Based on initial procurement experiences we can identify three main contributing factors to cost reduction:

(1) Actively reduce risks to the vendors. In dedicated engineering meetings designs are adjusted to allow suppliers to implement familiar or more cost-effective fabrication approaches. Components including cavities are accepted built-to-print instead of built-to-specification (e.g. electromagnetic or RF). Manufactures are given the option that high-risk manufacturing steps are performed at MSU. High-cost materials that are exposed to market fluctuations (e.g. niobium) are purchased by FRIB.

(2) Through FRIB-management vendor visits, a good rapport is developed with suppliers by ensuring that the project fits into the supplier's total capabilities and long-term business plans. For FRIB procurement volumes (50 to 200 production units) this favours suppliers with a strong "fabricator" background, contrary to smaller vendors with a R&D focused, more collaborative business model. Successful manufacturing companies with a long-standing manufacturing history are skilled in effective work-flow management (hence cost-reduction) and committed to solve manufacturing challenges and risks on the production floor together with their clients.

(3) Actively develop the vendor base with a goal of six to ten companies bidding after request for proposals. Vendor interest is assured by tailoring the request for proposal to long-term business plans of the vendor base. It is important to attractively size procurement packages and volumes. Phasing of procurements from prototypes to production prepares vendors to be able to successfully produce and attractively price the unique components required for FRIB.

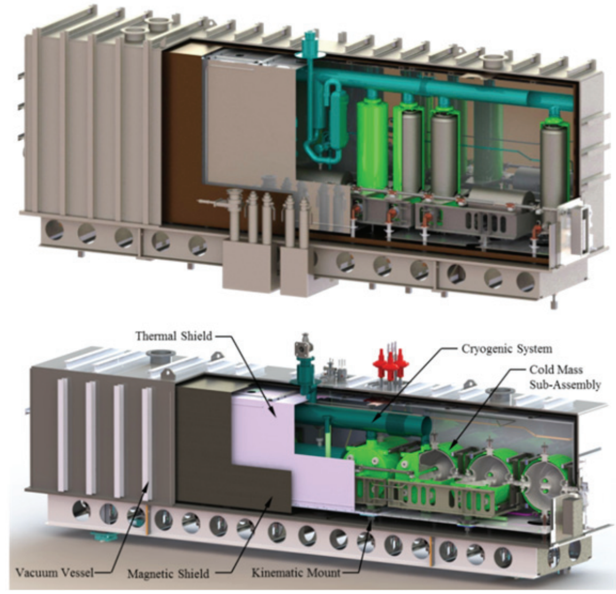

Figure 3: FRIB "bottom-up" cryomodule designs. The top cryomodule incorporates eight β=0.085 QWRs, three solenoids, and three cold beam position monitors; the bottom cryomodule incorporates eight β=0.53 HWRs and a single solenoid.

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