PRODUCTION CAVITIES AND CRYOMODULES FOR A HEAVY ION RE-ACCELERATOR AT MICHIGAN STATE UNIVERSITY*

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Abstract

A superconducting linac for re-acceleration of exotic ions is being constructed at Michigan State University (MSU). The re-accelerator will initially be used by the MSU Coupled Cyclotron Facility; it will later become part of the Facility for Rare Isotope Beams at MSU. The re-accelerator will include two types of superconducting quarter-wave resonators (QWRs) to accelerate from 0.6 MeV per nucleon (MeV/u) to up to 3 MeV/u for uranium ("ReA3"), with a subsequent upgrade path to 12 MeV/u ("ReA12"). The QWRs (80.5 MHz, optimum $\beta = 0.041$ and 0.085, made from bulk niobium) are similar to the cavities used at INFN-Legnaro for ALPI and PIAVE. They include stiffening elements and passive dampers to mitigate fluctuations in the resonant frequency. Eight $\beta = 0.041$ QWRs have been fabricated; welding of the helium vessels and RF testing is in progress. Another eight $\beta = 0.085$ QWRs are needed. Three cryomodules are needed to reach 3 MeV/u. Fabrication and assembly of the first cryomodule (the rebuncher, with one $\beta = 0.041$ QWR and two superconducting solenoids) is complete. This paper covers production efforts, test results so far, and future plans.

INTRODUCTION

The National Superconducting Cyclotron Laboratory (NSCL) at MSU is building a re-accelerator for exotic ion beams [1, 2]. Stable ions are accelerated in the NSCL coupled cyclotron facility. The primary beam produces a secondary beam of exotic ions by particle fragmentation. The re-accelerator will consist of a gas stopper to slow down the secondary ion beam, a charge breeder to increase the charge of the ions, a multi-harmonic buncher, a radio frequency quadrupole for initial acceleration and focussing, and a superconducting linac to accelerate the beam to a final energy of up to 3 MeV per nucleon. Additional cryomodules can be added to increase the final energy to up to 12 MeV per nucleon.

The superconducting linac will consist of quarter-wave resonators (QWRs) optimised for $\beta = 0.041$ [3] and $\beta = 0.085$ [4, 5]. The cavities are housed in rectangular box cryomodules. The driver linac of the Facility for Rare Isotope Beams (FRIB) will make use of the same cavity and cryomodule design, with the QWRs operating at higher voltages [6]. This paper covers the production work on the cavities and cryomodules for the re-accelerator.

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CAVITIES

Design

The QWRs developed by Legnaro for ALPI and PIAVE [7] are the basis for the design of the QWRs for the re-accelerator. Some design modifications have been implemented. A larger aperture (30 mm) is used. Separation of cavity vacuum from insulation vacuum is implemented to reduce particulate contamination of cavity surfaces. Probe couplers [8] are used instead of loop couplers.

The cavity design has undergone some evolution since the first prototype cavity was fabricated and tested. For production QWRs, the shorting plate is formed from sheet niobium (3 mm thick) instead of being machined and the tuning plate (1.25 mm thick) is slotted to reduce the tuning force [8]. The shorting plate design is similar to designs used by Argonne [9] and SPIRAL 2 [10]. The tuning plate design is similar to designs for TRIUMF [11] and the ALPI upgrade [12].

The helium vessel is made of titanium. The vessel design includes a Legnaro-type frictional damper [7] inside the inner conductor to mitigate microphonic excitation of the cavity. Stiffening elements are incorporated into the cavity and helium vessel design, including a reinforcement rib in the center conductor, a ring connecting the top of the cavity to the helium vessel, and buttresses to strengthen outer conductor near the beam ports. The stiffening measures provide a significant reduction in the sensitivity of the resonant frequency to pressure, as indicated by numerical predictions and measurements [13].

The design intrinsic quality factor is $Q_0 = 5 \cdot 10^8$ for both cavities at the operating temperature of 4.5 K. The design fields are $E_p = 16.5$ MV/m for the $\beta_m = 0.041$ cavity and $E_p = 20$ MV/m for the $\beta_m = 0.085$ cavity, where E_p is the peak surface electric field. Detailed RF parameters for the cavities have been published previously [3, 4].

A drawing of the $\beta_m = 0.041$ QWR is shown in Figure 1. The helium vessel is also shown.

Fabrication

Sheet Nb of thickness 2 mm and RRR ≥ 150 was used. The tip of the center conductor and the beam tubes were machined from solid Nb. The Nb tuning plate on the bottom of the cavity is held by a Nb-Ti to stainless steel flange. Forming was done at NSCL and in the local area, while

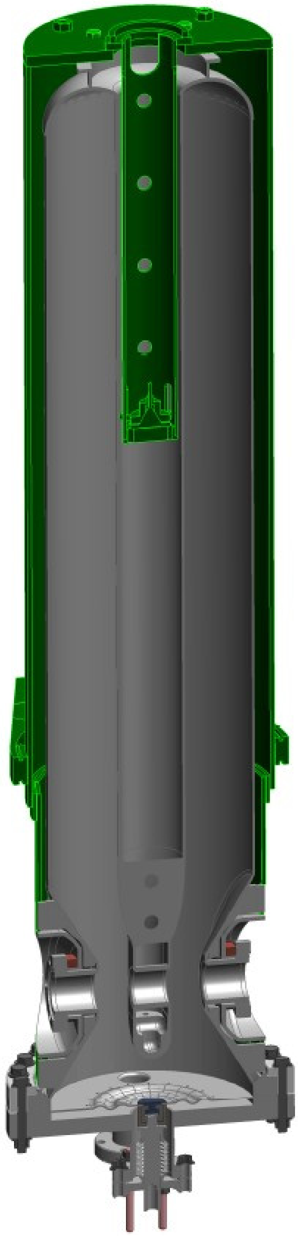

Figure 1. Isometric sectional view of the $\beta_m = 0.041$ QWR with its helium vessel, stiffening elements, frictional damper, tuning plate, and bottom flange. The helium vessel and damper are shown in green.

electron beam welding was done with industry. Indium joints were used to seal the bottom flange. Knife-edge seals were used for beam tube flanges. Between 120 and 150 μm was etched from the inner surface via buffered chemical polishing. High-pressure rinsing was done with ultra-pure water in a Class 100 clean room for 60 to 120 minutes.

A photograph of a production $\beta_m = 0.041$ QWR and tuning plate is shown in Figure 2. Etching, rinsing, and assembly photographs are shown in Figure 3.

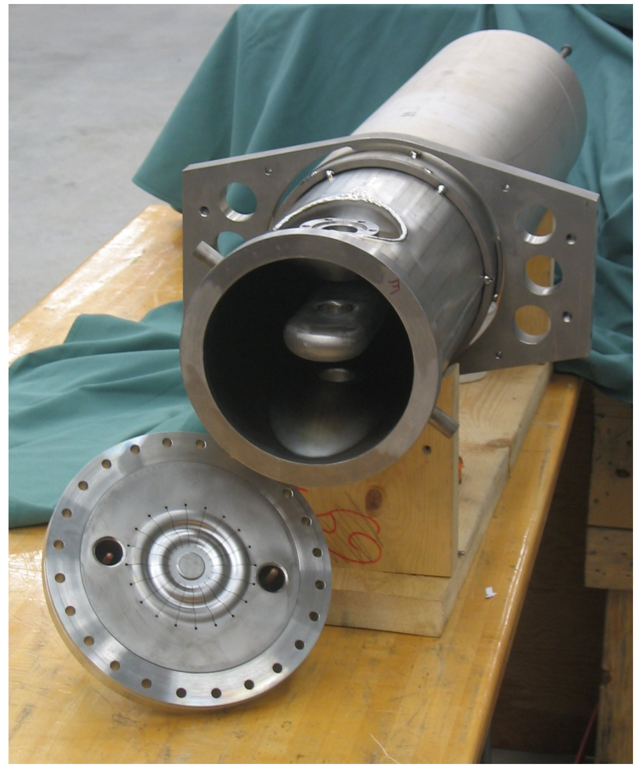

Figure 2. Photograph of a $\beta_m = 0.041$ QWR after tack welding of the helium vessel. The support flange is welded to the helium vessel. The niobium tuning plate and stainless steel bottom flange are visible on the lower left-hand corner.

Dewar Tests

Dewar testing has been completed for the prototype $\beta_m = 0.041$ QWR [3] and the prototype $\beta_m = 0.085$ QWR [4], as well as two production $\beta_m = 0.041$ QWRs. RF test results for the $\beta_m = 0.041$ QWRs are compared in Figure 4. All three cavities exceed the design goals for the re-accelerator, as well as the FRIB design goals.

CRYOMODULES

Design

A rectangular box cryomodule design [14]is being used for the reaccelerator cryomodules. The cryomodule design accommodates QWRs and superconducting solenoids. A Ti rail system is used for support and alignment. Active and passive magnetic shielding is implemented. In the first cryomodule (the rebuncher cryomodule), the magnetic shielding consists of reverse wound coils at the ends of the solenoid, a Meissner shield (Nb can) around the solenoid, and μ metal shields around the Meissner shield and the cavities.

A drawing of the rebuncher cryomodule is shown in Figure 5. The rebuncher contains one $\beta_m = 0.041$ QWR and two solenoids.

Fabrication

Some of the steps in the fabrication of the rebuncher cryomodule are shown in Figure 6. To minimise particulate contamination of the cavity, the superconducting

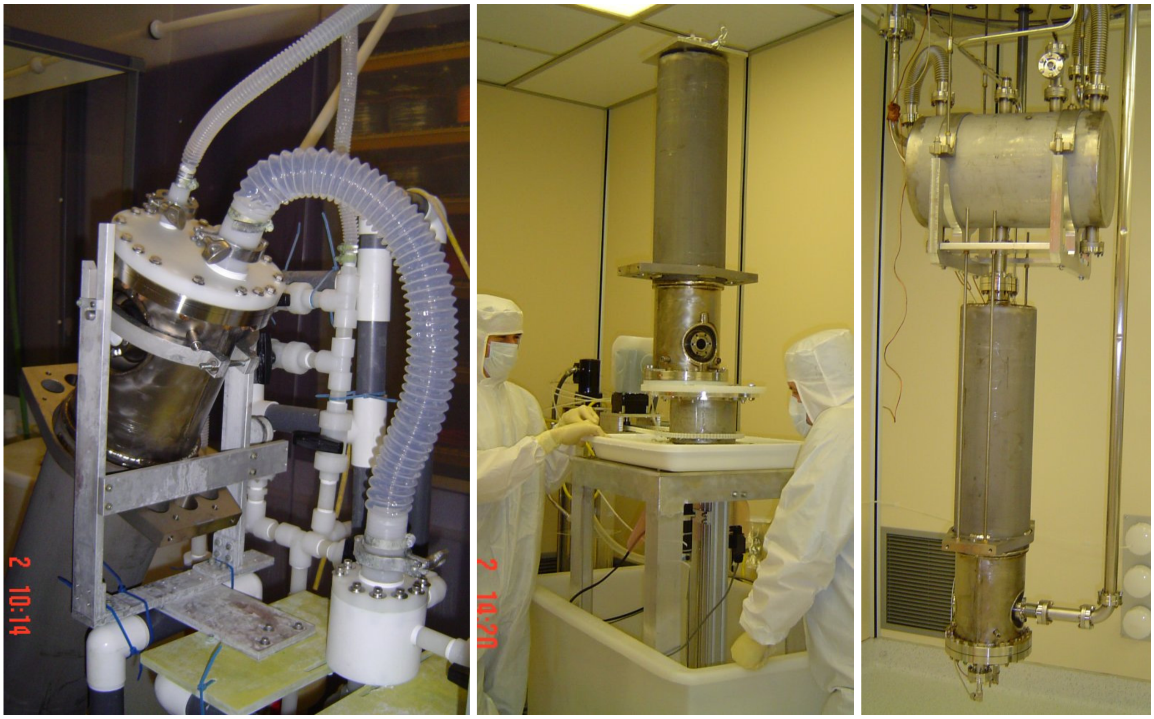

Figure 3. Left to right: etching, rinsing, and assembly of a $\beta_m = 0.041$ QWR onto the insert for Dewar testing.

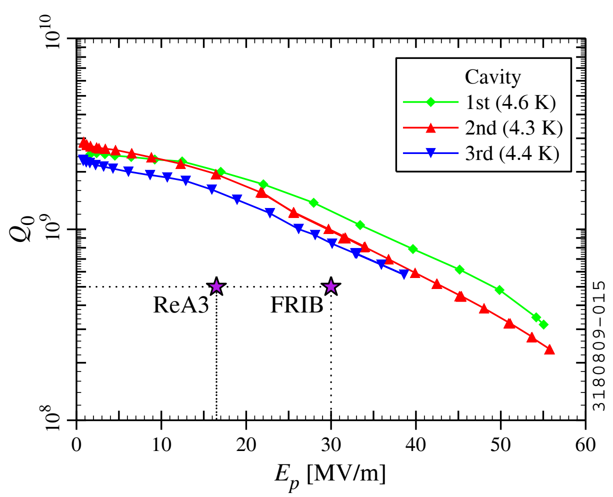

Figure 4. Dewar test results for the first three $\beta_m = 0.041$ QWRs. The tests on the second and third cavities were done after the installation of the helium vessel.

solenoids were cleaned and their beam tubes were high-pressure rinsed with ultra-pure water in a Class 100 clean room before assembly onto the cold mass. The cold mass, including the QWR, the solenoids, the beam line, and the support rails, was assembled in the clean room. After the beam line vacuum was sealed and leak checked, the cold mass was removed from the clean room for assembly of the cryogenic plumbing, thermal shield, and vacuum vessel. Multi-layer insulation was installed between the 77 K thermal shield and the 300 K vacuum vessel.

Rebuncher Testing

The rebuncher cryomodule has been installed on the re-accelerator deck and cooled down. Below 150 K, the cryomodule was cooled rapidly to minimise the risk of surface hydride formation ("Q disease"). The measured static heat leak of the module at 4.5 K is about 8 W ± 1.2 W.

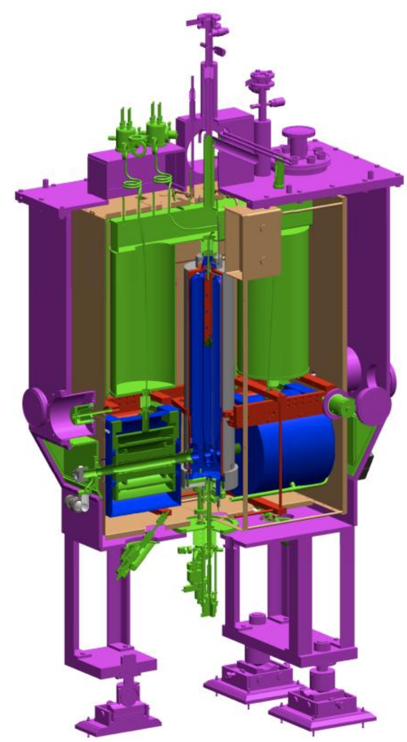

Figure 5. Isometric sectional view of the rebuncher cryomodule.

RF testing of the cavity is in progress. The testing is being done with a direct connection from the RF amplifier to the coupler, and also with a sliding short to set up a standing wave on the rigid copper coaxial transmission

Figure 6. Construction of the rebuncher cryomodule. Top left: cold mass in the clean room; Bottom left: cold mass under top plate; Top right: 77 K shield; Bottom right: completed cryomodule after installation on the ReA3 deck.

line. The sliding short configuration provided less mismatch and mades it easier to infer the intrinsic Q of the cavity (Q_0) from the RF measurements; simple loop couplers are used to couple into the transmission line through the short and monitor the field in the line. The measured QWR input coupling strength is $Q_{ext} = 1.2 \cdot 10^6$ with a direct connection. This corresponds to a cavity bandwidth of 67 Hz (the design goal was 42 Hz). Preliminary RF measurements indicate that a field level of $E_p = 36$ MV/m can be reached with a forward power of 500 W with a direct connection.

The tuner has been operated over its full range of about 28 kHz in frequency, corresponding to about 6 mm in tuning plate motion, with a force magnitude of 950 N or less. Measurements of the dynamic load and measurements with the solenoids are in progress.

CONCLUSION

The NSCL re-accelerator requires 3 cryomodules, with a total of 15 cavities and 8 solenoids. Fabrication of the $\beta_m = 0.041$ has been completed; the installation of helium vessels and Dewar testing is in progress. The first cryomodule, containing one cavity and two solenoids, has been installed and is being tested. The second cryomodule is currently being fabricated.

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