

DEWAR TESTING OF COAXIAL RESONATORS AT MSU*

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Abstract

Michigan State University is currently testing prototype and production cavities for two accelerator projects. 80.5 MHz $\beta=0.085$ quarter wave resonators (QWR) are being produced as part of a cryomodule for ReA3. 322 MHz $\beta=0.53$ half wave resonators (HWR) are being prototyped for a driver linac for the Facility for Rare Isotope Beams. This paper updates the developments for the FRIB and ReA resonators as preparations at MSU are being made for production runs.

INTRODUCTION

Development is underway for the FRIB driver linac [1]. The FRIB driver linac consists of 330 quarter-wave ($\beta=0.041$, $\beta=0.085$) and half-wave ($\beta=0.29$, $\beta=0.53$) coaxial resonators. This development is being done in parallel with the construction of a 3 MeV/u re-accelerator linac (ReA3) for radioactive beams at MSU, with upgrade planning already underway for 6 MeV/u (ReA6). Differently from ReA, working at 4.5K, FRIB will work with superfluid helium at 2K.

The ReA superconducting linac consists of niobium QWRs optimised for $\beta = v/c = 0.041$ [2] and $\beta = 0.085$ [3]. The cavities are housed in rectangular box cryomodules. The first two cryomodules, containing a total of seven QWRs optimised for $\beta = 0.041$, have been installed and are operating in the ReA3 linac [4]. A third cryomodule, consisting of eight $\beta=0.085$ QWRs is needed to complete ReA3.

Five preproduction HWRs for $\beta=0.53$ have been fabricated so far. Three of the five cavities have been RF tested both with and without a helium vessel installed. Two have been selected for installation into a test cryomodule, where additional RF and systems tests are being performed.

CAVITY DESIGN GOALS

The cavity figures of merit and operating requirements are shown elsewhere in these proceedings [5], with the exception that the surface fields on the prototype and ReA3 resonators were not yet optimized before production began. The field and quality factor goals are consistent with FRIB (2K) and ReA (4K) specifications; however the surface field ratios for these cavities are somewhat different (the prototype resonators tested have

higher surface fields in the model) shown in Table 1.

Table 1: Surface field ratios for test results presented. The acceleration length is defined as $L_{\text{eff}}=\beta\lambda$.

Parameter	$\beta=0.085$ QWR	$\beta=0.53$ HWR
$E_{\text{peak}}/E_{\text{acc}}$	6.16	4.21
$B_{\text{peak}}/E_{\text{acc}}$ mT/(MV/m).	13.9	10.28

VERTICAL TEST CONFIGURATION

The vertical test configuration that is being used to certify ReA and FRIB resonators for acceptance is different from the traditional dunk methods. The resonators are certified with the helium vessel attached; the liquid helium only occupies the helium space plus a header volume sized appropriately for the additional helium required for 2K pumping and a few hours of RF testing (Figure 1). The remaining space in the Dewar is used to provide vacuum insulation. This vertical cryostat configuration, which is the preferred configuration for the vertical test certification at MSU, provides several benefits. These include a lower rate of use of liquid helium, early detection of cold leaks in helium vessel welds, and reduced time required for thermal cycling and 2K pump downs. In addition, the tests are performed under realistic thermal conditions.

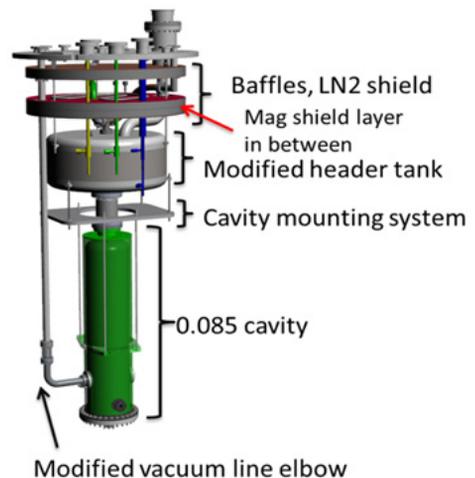


Figure 1: FRIB vertical test Dewar insert for ($\beta=0.085$ QWR shown); The insert can adapt to hold both ReA and FRIB QWRs and FRIB HWRs.

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DEWAR TEST RESULTS FOR FRIB HWR

Five prototype resonators of the half-wave type have been fabricated. One of them was formed and assembled completely in house, with the exception of e-beam welding, while the remaining four were fabricated in collaboration with industrial partners (two from each vendor).

Dunk Tests and Quench Detection

The Q_0 vs. E_{acc} plots shown in Figure 2 indicate that the prototype resonators can achieve the desired acceleration and Q_0 with margin.

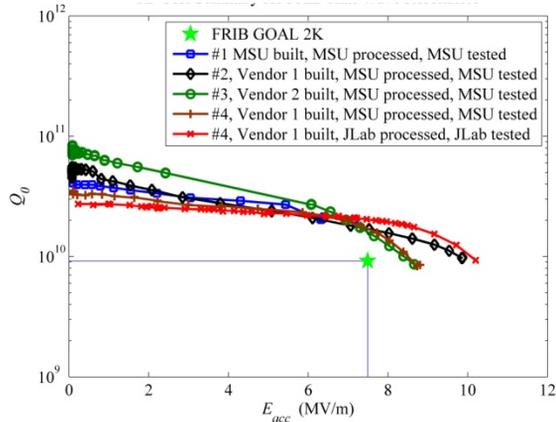


Figure 2: HWR Dunk Test Results.

The maximum field in all the tests was limited by a thermal breakdown and an associated drop in Q_0 . A quench detection scheme was adopted, which shows, in Figure 3, the quench locations were in the high magnetic field region. This location contains an e-beam weld between the tapered inner conductor and short plate. To address this issue, the production design of the resonator was changed to reduce the B_{peak}/E_{acc} by 10%, and the taper in the weld region was removed [6].

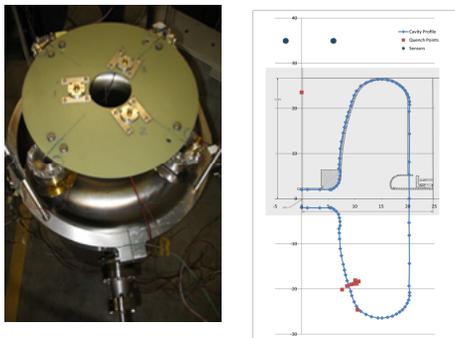


Figure 3: Quench detection set-up (left) and results from second sound (right).

Processing & RF Testing at JLAB

One of the five HWR's was shipped to JLAB to process, assemble and conduct vertical tests. The results shown in Figures 2 and 4 suggest that the existing infrastructure at JLAB is capable of producing similar

performance in the RF tests. Additional development work was done at JLAB, which includes an investigation of the effect of a low temperature bake. The bake was performed (120 °C, 48 hrs) at JLAB and the resonator was retested. The results, shown in Figure 4, indicate that there is not a substantial benefit from the low temperature bake.

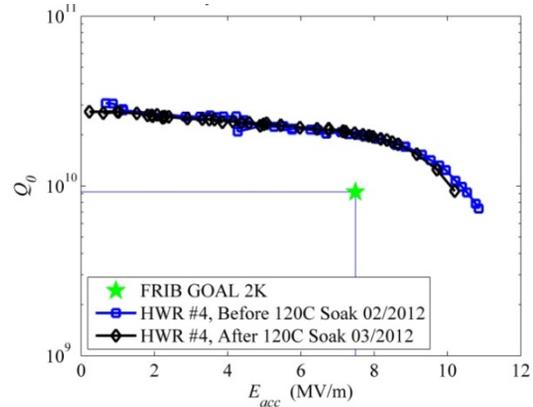


Figure 4: HWR low temperature bake performed at JLAB.

Vertical Cryostat Configuration

Three of the four resonators dunk tested have been equipped with a helium vessel. Using this configuration, a cold leak in the helium vessel was discovered, revealing an unreliable titanium bellows on the resonators. The bellows were removed on two of the resonators, and then re-tested. Figure 5 shows a comparison of one cavities dunk tested, tested with a helium vessel in the vertical cryostat configuration, and then re-tested after rework on the helium vessel.

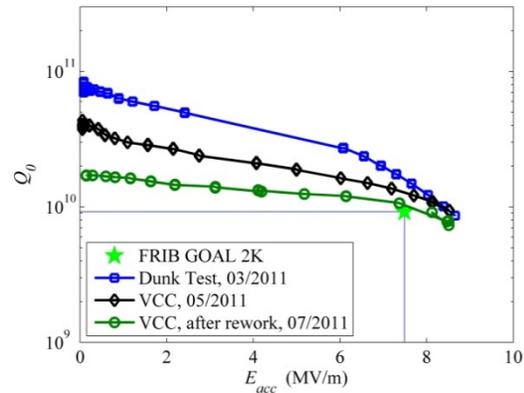


Figure 5: Sequential vertical tests of a FRIB HWR, dunk test, helium vessel test, then after a helium vessel rework.

$\beta=0.530$ Frequency Sensitivity

During the cold tests with the helium vessel and beam ports fixed, the Lorentz force detuning (LFD) coefficient was measured to be -4 ± 1 Hz/(MV/m)² (per E_{acc}) with a frequency sensitivity to bath pressure (df/dP) of 10 Hz/torr. The LFD without a helium vessel was similar, while the df/dP was quite different (-11 Hz/torr).

DEWAR TEST RESULTS FOR REA QWR'S

A complete refurbishment of the original ReA3 $\beta=0.085$ QWR was done in 2011 to prepare for production [3]. In the final steps of the refurbishment, tests were performed to determine the appropriate material for the bottom flange, which is the thermal path from the liquid helium to the conductively cooled niobium tuning plate. The comparison was done using a high RRR niobium bottom ring and the NbTi of the original design. The high RRR niobium bottom ring yielded very high Q's and high fields (shown in Figure 6), while the NbTi bottom ring had lower Q and the tuning plate temperature rose well above 9.2K, while temperature in the high RRR case stayed superconducting. Therefore, the high RRR niobium material is needed to provide the most effective heat transfer from the tuning plate, however a lower cost solution is being developed for FRIB.

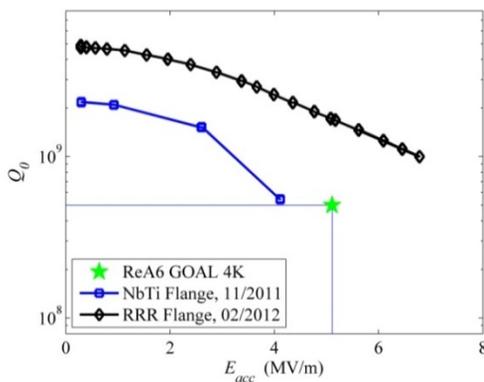


Figure 6: QWR niobium versus NbTi bottom flange results.

Test results show similar performance at 2K in both a dunk test and the vertical cryostat configuration (Figure 7). This is a clear indication that the tuning plate cooling is sufficient with the modified flange. The high field Q drop at 2K, which corresponds to several tens of watts, was not straightened by a low temperature bake.

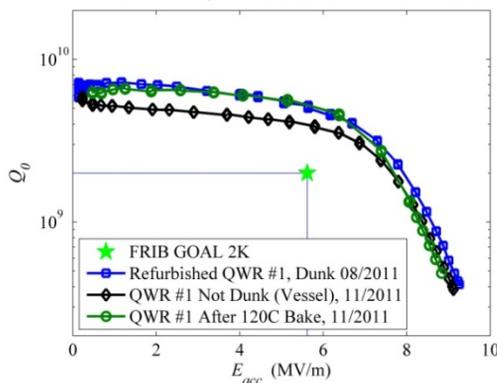


Figure 7: 2K comparisons of dunk test and the vertical cryostat configuration and again after a 120 C bake.

The results of low temperature bake, 120 °C for 48 HRs, are also shown in Figure 8. There seems to be a substantial benefit at 4K, and thus this treatment has been

incorporated into the ReA3 production processing plans. This low bake can also be very useful for FRIB as a method to recover marginally performing resonators. This is beneficial because the low temperature bake can be performed while attached to the Dewar insert, and the performance recovery can be done without the expense of doing a complete disassembly and reprocess.

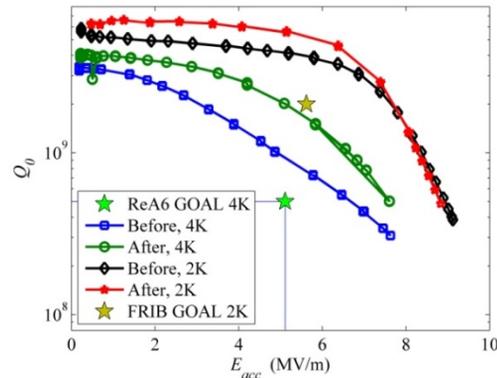


Figure 8: 4K and 2K comparison of the 120 °C for 48 HRs low temperature bake.

$\beta=0.085$ Frequency Sensitivity

During the cold tests with the helium vessel and beam ports free, the Lorentz force detuning coefficient for the refurbished resonators was measured to be -5 ± 5 Hz/(MV/m)² (per E_{acc}) with a frequency sensitivity to bath pressure (df/dP) of -2.3 Hz/torr.

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