PERFORMANCE OF A SRF HALF-WAVE-RESONATOR TESTED AT CORNELL FOR THE RAON PROJECT*

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Abstract

A prototype half-wave-resonator (HWR) with frequency 162.5MHz and geometrical $\beta = 0.12$ for the RAON project is currently undergoing testing at Cornell University. Detailed vertical performance testing includes (1) test of the bare cavity without the helium tank; (2) test of the dressed cavity with helium tank. In this paper, we report on the development of the test infrastructure, test results, and performance data analysis.

INTRODUCTION

The $\beta = 0.12$ HWR for the RAON project [1, 2] is being developed by the Institute for Basic Science (IBS), Research Instruments (RI), and Cornell University. Fabrication and surface treatments of a prototype (HWR-1) were completed by RI. The cavity was shipped to Cornell for the vertical tests to evaluate its RF performance. The bare HWR-1, after the fabrication, received Buffer-Chemical-Polishing (BCP) of 150μm, then was baked in a high-vacuum furnace at 625°C for 10 hours, followed by a light BCP (5-10μm), High-Pressure-Water-Rinsing (HPR), and clean assembly. After the vertical test at Cornell, the bare cavity was sent back to RI for helium tank welding and re-cleaning. The dressed HWR-1 was shipped to Cornell again for a second vertical test. In this paper, we report on the tests of 1) the bare HWR-1 without helium tank; 2) the dressed cavity with helium tank.

DEVELOPMENT OF HWR INFRASTRUCTURE

The new HWR infrastructure utilizes the existing SRF facilities at Cornell. We built a new set of input and pick-up couplers, a HWR handling frame, and modified a 9-cell cavity vertical test insert for this project [3].

Input and Pick-up Couplers

The HWR testing is done at temperatures of 2-4.2K, and the input coupler should match the intrinsic quality factor of the cavity (Q_0) to keep the coupling factor (β) close to 1. If multipacting occurs during test, RF processing of the cavity is required. In this case, the input coupler needs to be set at a strong coupling, i.e. ($\beta \approx 100$). Therefore, we built a variable coupler which has a straight antenna and can be mounted in the middle section of the cavity. The input coupler (Fig. 1 (a)) can travel 50mm, and tune the external quality factor (Q_e) from $\sim 1 \times 10^7$ to $\sim 1 \times 10^{11}$. The pick-up coupler (Fig. 1 (b)) is a fix coupler with $Q_e \sim 1 \times 10^{13}$ to match the required power level of the LLRF system.

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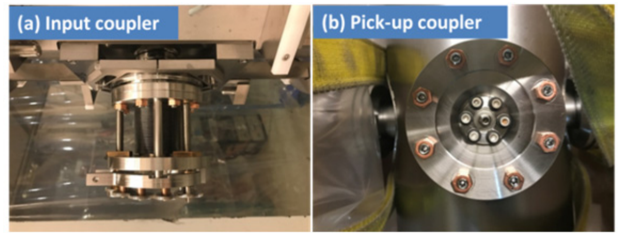

Figure 1: (a) Photograph of the input coupler; (b) Photograph of the pick-up coupler.

HWR Handling Frame and RF Insert

The photographs of the HWR-1 cavity without and with helium tank are depicted in Fig. 2 (a) and (b) respectively. The bare-cavity weight is about 80lbs; the dressed cavity is about 130 lbs with the helium tank. A handling frame is needed to hold the cavity on the RF insert for the cold tests. The frame for the bare cavity holds the cavity flanges instead of the cavity body, which will not deform the cavity; thus it will not shift the cavity frequency. The frame for the dressed cavity is attached on the helium tank without touching the cavity body as well.

Figure 2: Photograph of (a) the bare HWR-1 cavity (b) the dressed HWR-1 cavity. Both cavities are installed with the handling frames.

During the tests, the HWR-1 cavity was actively pumped by an ion-pump. A long drive shaft connects to the input coupler to move the antenna horizontally. The magnetic shield in the Dewar keeps the ambient magnetic-fields below 3 mG. Figure 3 (a) is the diagram illustrating the test set-up; Fig. 3 (b) and (c) are the photographs of the HWR-1 bare-cavity and dressed-cavity on the insert respectively.

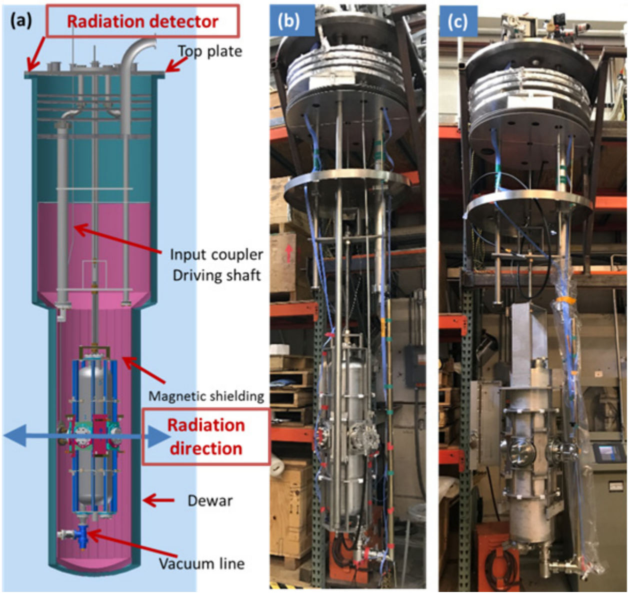

Figure 3: The HWR-1 cavity on the insert. (a) Diagram of the HWR on the RF insert for the vertical tests with the view of the Dewar and magnetic-field shielding. b) Photograph of the HWR-1 bare-cavity on the insert. c) Photograph of the HWR-1 dressed-cavity on the insert.

VERTICAL TESTS AND RESULTS

The bare HWR-1 cavity was cooled from room temperature down to 4.2K in about 40 to 50min, which is reasonable due to its larger cold mass. After reaching 4.2K and fully filling the Dewar, it was initially difficult to lock the PLL system due to multipacting at very low fields. We spend ~10 hours to process the multipacting. We then obtained the intrinsic quality factor (Q_0) vs. accelerating gradient (E_{acc}) curve at 4.2K as is shown in Fig. 4 (red symbols). At low fields (0.5-2.4MV/m), Q_0 reached $\sim 2 \times 10^9$. The maximum E_{acc} was limited around 4MV/m by very strong field emission (FE), also shown in Fig. 4 (green triangles); no hard quench was observed. The onset of the FE was around 2.4MV/m, beyond which the Q_0 dropped steeply with field, while the detected radiation (x-ray) increased exponentially. We spend ~2 hours trying to process the FE, but it could not be processed out. It has to be pointed out that the absolute level of the radiation was small (less than 1R/hr) because the position of the detector was not aligned to the cavity beamline where the maximum radiation is expected (depicted in Fig. 3 (a)).

After the bare-cavity test, contaminations were found inside, on the flange of the cavity beam port [4]. During the BCP of the bare-cavity, acid leaked into the flange braze-joint and corroded the copper of the brazing. These contaminations were later removed by a 15-20μm BCP.

The 4.2K result of the dressed HWR-1 is depicted in Fig. 4 (blue symbols). The low-field Q_0 increased to $\sim 3 \times 10^9$. The FE had been dramatically reduced and the Q_0 at high-field was recovered to $\sim 4 \times 10^8$. The radiation level is again shown in Fig. 4. The cavity gradient was limited by the hard quench at ~6.3 MV/m, exceeding field specifications (6 MV/m).

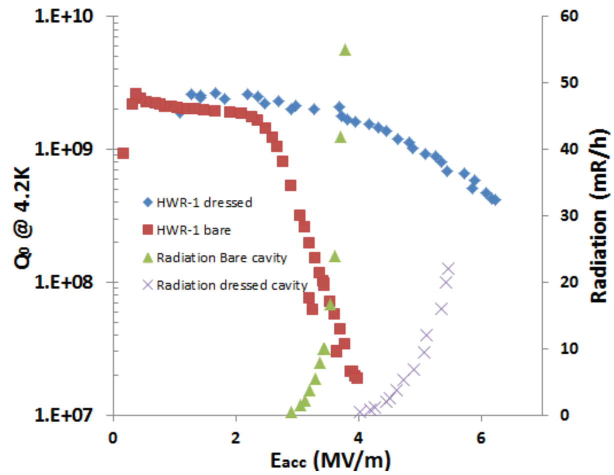

Figure 4: Q_0 vs. E_{acc} curves of the bare and dressed HWR-1 at 4.2K as well as radiation levels during the tests.

After the 4.2K measurements, the cavity was cooled down from 4.2K to 2K. During the cooldown, the Q_0 vs. temperature and frequency vs. temperature were measured. The Q_0 vs. temperature curve has been converted to surface resistance (R_s) vs. 1/T by $R_s = \frac{G}{Q_0}$, which is shown in Fig.5 for the bare and dressed cavity, respectively. Here the geometry factor G is 36Ω. The residual resistance (R_0) has been fitted using $R_s = \frac{A}{T} e^{-\frac{\Delta(0)}{T}} + R_0$. The results of the R_0 for the bare and the dressed HWR-1 are 4.6 nΩ and 1.8 nΩ respectively. It should be noted that the R_0 of the dressed cavity is quite low, reaching the level of an electropolished HWR [5].

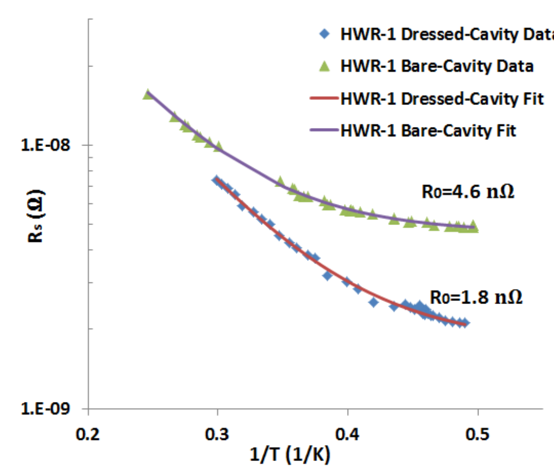

Figure 5: R_s vs. 1/T curves of the bare and dressed HWR-1 cavity during cooldown from 4.2K to 2K.

Table 1: Summary of the Frequency Measurements

Frequency (MHz)	Simulation (IBS)	Bare-cavity	Δf Simulation – bare cavity	Dressed-cavity	Δf Simulation– dressed cavity
2K with Tuner	162.500	NA	NA	NA	NA
2K without Tuner	162.600	162.664	-0.064	163.104	-0.504
4.2K without Tuner	NA	162.646	NA	163.088	NA
Vacuum @room temperature	162.310	162.382	-0.072	162.820	-0.510
After 150um removal	162.314	162.328	-0.014	NA	NA

The 2K measurements results are quite similar to the 4.2K measurements as is shown in Fig. 6 for the bare and dressed cavity. At low fields (0.5-2MV/m), the Q_0 of the bare HWR-1 reached $6\ to\ 7\times10^9$. No hard quench was detected at 2K. The gradient was limited around 4MV/m by the FE. Further RF processing, which lasted about 2 hours, did not process the FE in the bare cavity test. The low-field Q_0 of the dressed cavity achieved $\sim2\times10^{10}$ due to its ultra-low R_s. The field of the dressed- cavity reached 6.6MV/m limited by the hard quench. There was light FE during the 2K measurement of the dressed-cavity. The 2K radiation levels of the bare and dressed cavity are also shown in Fig. 6.

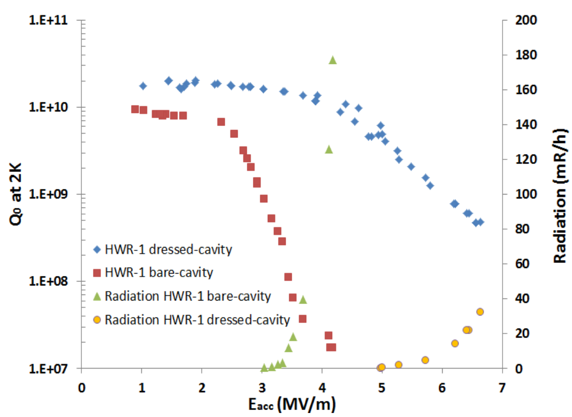

Figure 6: Q_0 vs. E_{acc} curves of the bare and dressed HWR-1 at 2K, as well as the radiation levels during the tests.

FREQUENCY TRACKING

Reaching design frequency within specifications is important, and we measured the frequency of HWR-1 at each step, including (1) at room temperature and under vacuum; (2) at temperature 4.2K; (3) from 4.2K to 2K. Table 1 summarizes the measurement results of the bare and dressed cavity as well as the simulation results. The frequency of the bare-cavity is close to the design value. The discrepancy is 60-70 kHz, which is within the tuner range. However, the dressed cavity has a ~500kHz shift from the design value. The reason of the large frequency shift needs to be investigated further.

The measured frequency vs. LHe bath pressure is plotted in Fig. 7 for the bare and dressed cavity, from which the sensitivity $\frac{df}{dP}$ can be calculated. The bare-cavity's $\frac{df}{dP}$ is -22 Hz/Torr. The dressed cavity has a very similar value of -21 Hz/Torr, as is expected since bellows are located at all interfaces between the HWR and its LHe tank. The $\frac{df}{dP}$ value is important, as it determines the level of microphonics from pressure fluctuations.

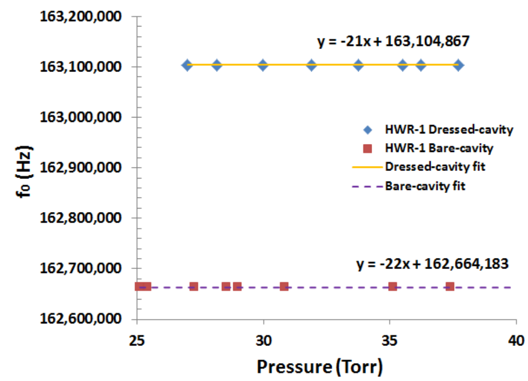

Figure 7: Frequency vs. LHe Pressure when the bare cavity was cooled from 4.2K to 2K.

CONCLUSION

The HWR-1 prototype has been successfully tested at Cornell University. The Q_0 of the bare cavity at low fields reached $\sim2\times10^9$ at 4.2K and $\sim7\times10^9$at 2K; the dressed cavity Q_0 at low-fields achieved $\sim3\times10^9$ at 4.2K and $\sim2\times10^{10}$at 2K. The residual resistance of the bare and dressed cavity are $4.6n\Omega$ and $1.8\ n\Omega$ respectively, which is very good for a BCP'd cavity.

The Q-values and the residual resistance manifest that the surface preparation recipe used is appropriate. The gradient of the bare-cavity was limited by strong FE to ~4 MV/m, which has been reduced by the light BCP. Therefore, the dressed cavity gradient reached ~6.6MV/m, limited by the hard quench. The gradient at 2K achieved the gradient specification for the RAON HWR [4]; but the Q_0 is slightly lower than the specification due to FE, and can be improved by another HPR. The frequency measurements at each step show that the bare cavity frequency is close to the design value; the discrepancy is about 60-70 kHz, close to the maximum tuning range of the frequency tuner. However, the dressed-cavity now has a ~500kHz frequency shift, which needs to be investigated further. The $\frac{df}{dP}$ of the bare HWR is -22 Hz/Torr and the dressed cavity has -21 Hz/Torr. The $\frac{df}{dP}$ measurement gives a reference for further cavity mechanical optimization.

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