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

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Abstract

Two prototype half-wave-resonators (HWR; 162.5MHz and β=0.12) for the RAON project were tested at Cornell University. In this paper, we report and analyse detailed results from vertical tests, including tests of the HWRs without and with helium tank. Surface preparation at Research Instruments is discussed, as well as the development of new HWR preparation and test infrastructure at Cornell.

INTRODUCTION

Two prototype HWRs (162.5MHz, β=0.12) for the RAON project [1, 2] are being developed by the Institute for Basic Science (IBS), Research Instruments (RI), and Cornell University. Fabrication and surface treatments of the prototype cavities (HWR-1 and 2) were completed by RI. The cavities were shipped to Cornell for the vertical tests to evaluate their RF performance. After fabrication, the bare HWR-1 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. The HWR-2 bare cavity followed an identical procedure as the HWR-1, but the helium tank welding has not been completed yet. In this paper, we report on the tests of 1) the HWR-1 bare and dressed cavity; 2) the HWR-2 bare cavity.

DEVELOPMENT OF TEST INFRASTRUCTURE

The new HWR infrastructure utilizes the existing SRF facilities at Cornell. We built two sets of input and pick-up couplers, HWR handling frames for both a bare and dressed cavity, and modified a 9-cell cavity vertical test insert for this project [3, 4].

Input and Pick-up Couplers

The HWR tests are done at temperatures of 2 – 4.2 K, 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 50 mm, and tune the external quality factor (Q_e) from $\sim 1\times10^7$ to $\sim 1\times10^{11}$. The pick-up coupler (Fig. 1 (b)) is a fix coupler with $Q_e \sim 1\times10^{13}$ to match the required power level of the LLRF system.

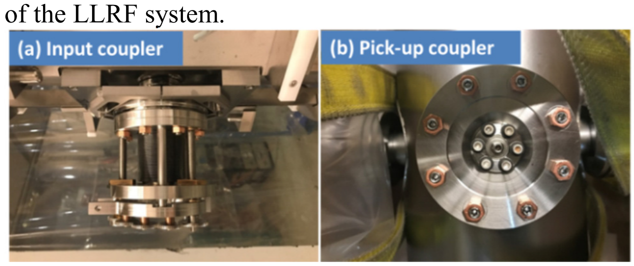

Figure 1: (a) Photograph of the input coupler; (b) Photograph of the pick-up coupler.

HWR Handling Frames and RF Insert

The photographs of the HWR cavity without and with helium tank are depicted in Fig. 2 (a) and (b) respectively. The bare-cavity weight is about 80 lbs; 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 cavity (b) the dressed HWR cavity. Both cavities are installed with the handling frames.

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During the tests, the HWR 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) shows a diagram illustrating the test set-up; Fig. 3 (b) and (c) are the photographs of the bare and dressed HWR on the insert respectively.

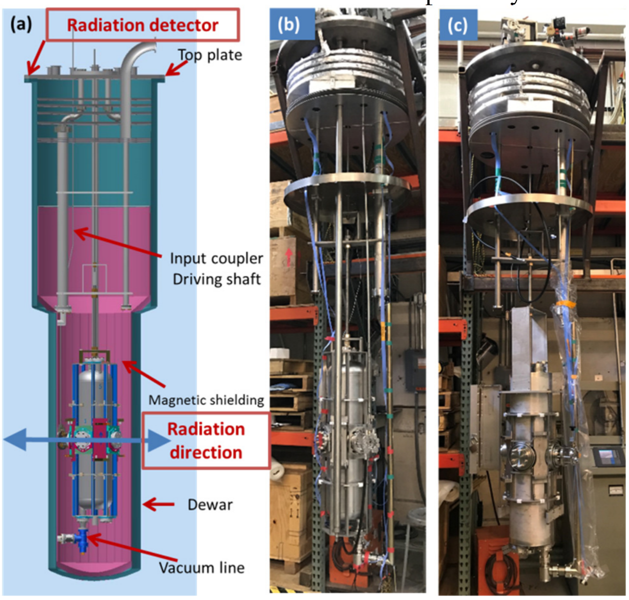

Figure 3: The HWR cavity on the insert. (a) Diagram of the HWR on the RF insert for the vertical tests with the view of the Dewar and magnetic-field shielding. b) Photograph of the HWR bare-cavity on the insert. c) Photograph of the HWR dressed-cavity on the insert.

VERTICAL TESTS AND RESULTS

HWR-1 Vertical Tests and Results

The bare HWR-1 cavity was cooled from room temperature down to 4.2 K in about 40 to 50 min, which is reasonable due to its larger cold mass. After reaching 4.2 K 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 4.2 K as is shown in Fig. 4 (red symbols). At low fields (0.5-2.4MV/m), Q_0 reached $\sim 2\times10^9$. The maximum E_{acc} was limited around 4 MV/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 2.4 MV/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 [5]. 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 15-20 μm BCP.

The 4.2K result of the dressed HWR-1 is depicted in Fig. 4 (blue symbols). The low-field Q_0 increased to $\sim 3\times10^9$. The FE had been dramatically reduced and the Q_0 at high-field was recovered to $\sim 4\times10^8$. The radiation level is again shown in Fig. 4. The cavity gradient was limited by the hard quench at ~6.5 MV/m, exceeding field specifications (6.2 MV/m).

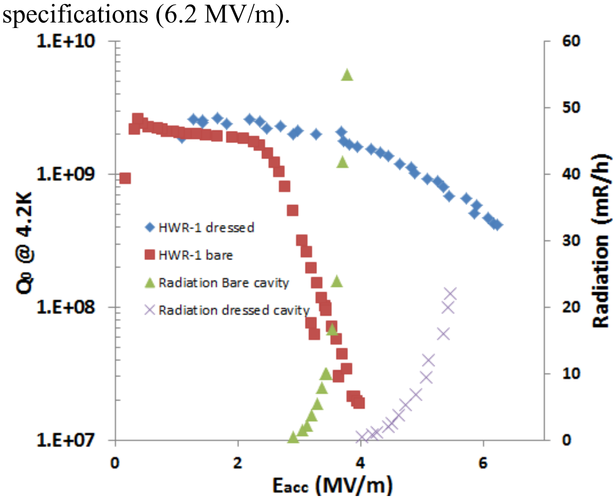

Figure 4: Q_0 vs. E_{acc} curves of the bare and dressed HWR-1 at 4.2K as well as radiation levels during the tests.

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 36 Ω. 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 [6].

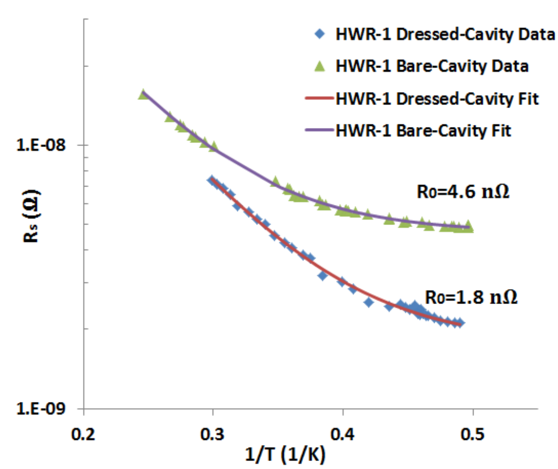

Figure 5: R_s vs. 1/T curves of the bare and dressed HWR-1 cavity during cooldown from 4.2 K to 2 K.

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Table 1: Summary of the Frequency Measurements

Frequency (MHz)	Simu. (IBS)	HWR-1 Bare-cavity	Δf Simu. – HWR-1 bare cavity	HWR-1 Dressed-cavity	Δf Simu.– HWR-1 dressed cavity	HWR-2 Bare-cavity	Δf Simu.– HWR-2 bare cavity
2K with Tuner	162.500	NA	NA	NA	NA	NA	NA
2K without Tuner	162.600	162.664	-0.064	163.104	-0.504	162.590	0.010
4.2K without Tu`ner	NA	162.646	NA	163.088	NA	162.500	NA
Vacuum @room temp.	162.310	162.382	-0.072	162.820	-0.510	162.325	-0.015
After 150um BCP	162.314	162.328	-0.014	NA	NA	162.316	-0.002

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 – 2 MV/m), the Q_0 of the bare HWR-1 reached 6 to 7×10^9. No hard quench was detected at 2K. The gradient was limited around 4 MV/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 very low R_0. The field of the dressed cavity reached 6.6 MV/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.

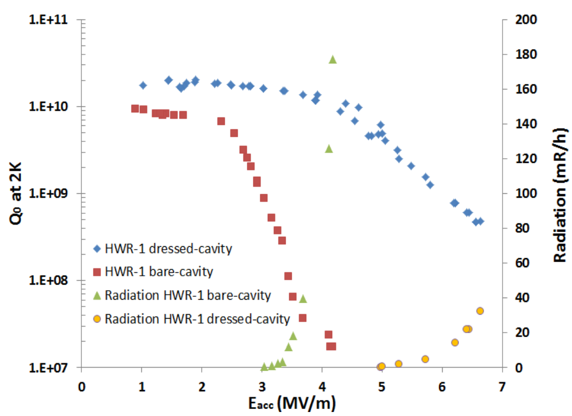

Figure 6: Q_0 vs. E_{acc} curves of the bare and dressed HWR-1 at 2K, as well as the radiation levels during the tests.

HWR-2 Vertical Tests and Results

The test procedure of the HWR-2 bare cavity was quite similar to the HWR-1 cavity. At 4.2K, the RF processing took more than 2 days to suppress the multipacting at very low gradients. The Q_0 at 4.2 K reached $\sim3\times10^9$ which is quite similar to the HWR-1 cavity; and the gradient reached ~9 MV/m limited by quenches. There was light FE during the 4.2 K measurement. When the cavity was cooled down to 2 K, the FE was reduced by RF processing. As a result, the gradient was improved to 11 MV/m limited by quench; and the Q_0 at 6.2 MV/m achieved $\sim5\times10^9$, two times higher than the specification. The FE started at ~8 MV/m. Figure 7 shows the HWR-2 Q_0 vs. E_{acc} curves at 2K (blue symbols) and 4.2 K (green triangles) as well as the radiation levels at 2 K (red symbols).

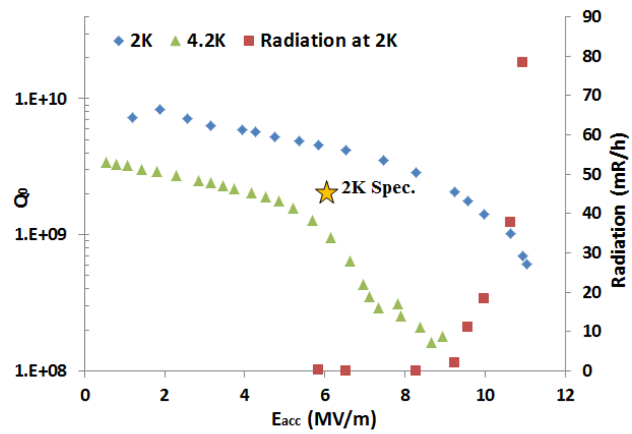

Figure 7: Q_0 vs. E_{acc} curves of the bare and dressed HWR-2 at 2 K and 4 K, as well as the radiation levels during the tests. Also shown are the 2 K field and Q_0 specifications.

FREQUENCY TRACKING

Reaching design frequency within specifications is important, and we measured the frequency of HWR-1 and 2 at each step, including (1) at room temperature and under vacuum; (2) at temperature 4.2 K; and (3) from 4.2 K to 2 K. Table 1 summarizes the measurement results of the bare and dressed cavities as well as the simulation results. The frequency of the bare cavities is close to the design value. The discrepancy is 60 – 70 kHz and 15 kHz corresponding to the HWR-1 and HWR-2 bare cavities respectively, which is within the tuner range. However, the HWR-1 dressed cavity has a ~500 kHz 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. 8 for the HWR-1 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 fast pressure fluctuations.

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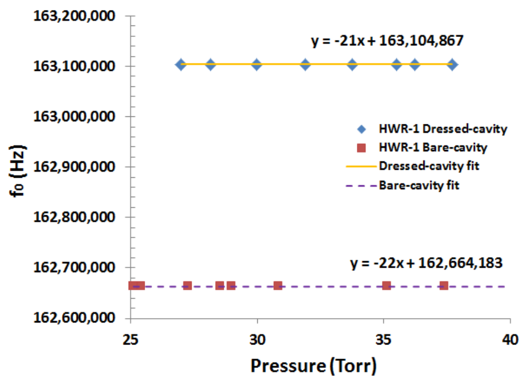

Figure 8: Frequency vs. LHe Pressure of the HWR-1 bare and dressed cavity during cool-down from 4.2 K to 2 K.

CONCLUSION

The HWR-1 and 2 prototypes have been successfully tested at Cornell University. The HWR-2 bare cavity significantly exceeded the 2K specification [5], i.e. the cavity quenched at ~11MV/m; and the Q_0 at 6.2MV/m reached $\sim 5\times10^9$. The HWR-1 dressed cavity quenched at ~6.5MV/m at 2K, achieving gradient specification. The quality factor was degraded by field emission at maximum fields to $Q_0 \sim 7\times10^8$, but the low-field Q_0 of the cavity achieved $\sim 1\times10^{10}$ at 2K, giving a residual resistance R_0 of 1.8 nΩ. Q_0 at operating field is slightly lower than the specification, but can likely be improved by another HPR. The results of the low-field Q_0 and the R_0 are very good for a chemical polished cavity, and are even comparable to those of an electropolished HWR cavity [6]. Frequency tracking shows that the HWR-2 bare cavity frequency is close to the design specification; but the HWR-1 dressed cavity has a ~500 kHz shift from the design value. The frequency to pressure sensitivity $\frac{df}{dP}$ is -22 Hz/Torr for the both HWR-1 bared and dressed cavity. The $\frac{df}{dP}$ measurements give a reference for further cavity mechanical optimization.

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