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

M. Ge†, F. Furuta, T. Gruber, S. Hartman, M. Liepe, J. Maniscalco, T. O'Connell, P. Pamel, J. Sears,
V. Veshcherevich, Cornell University, Ithaca, New York, USA
B.H. Choi, J. Joo, J.W. Kim, W.K. Kim, J. Lee, I. Shin, Institute for Basic Science, Daejeon, Korea

Abstract

Two prototype superconducting half-wave-resonators (162.5MHz and $\beta = 0.12$) for the RAON project have been successfully tested at Cornell University. Detailed vertical performance testing included (1) test of the bare cavity without the helium tank, and (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, showing that the specifications for RAON were met.

INTRODUCTION

Cornell University has successfully completed the performance tests of two prototype half-wave-resonators (HWR-1 and HWR-2) for the RAON project [1, 2].

The two HWR cavities were fabricated and surface treated by Research Instruments (RI); after that, the cavities were shipped to Cornell for the cryogenic RF performance tests. The four vertical tests included (1) tests of the bare cavities without helium tank, and (2) tests of the dressed cavities with helium tank. For these tests, Cornell developed new infrastructure including modification of the RF insert, fabrication of a handling frame and two sets of input and pick-up couplers [3, 4].

VERTICAL TESTS PREPARATION

The HWRs were sent from RI under vacuum with an input coupler and pick-up coupler mounted. At Cornell, the cavities were dressed with the handling frame and mounted on an RF insert, as is shown in Fig. 1 (b) and (c) for a bare and dressed HWR cavity respectively. On the insert, the cavity was connected to an ion-pump which actively evacuated the cavity during the tests. Three Cernox sensors were mounted on the top, middle, and bottom of the cavity, as is shown in Fig. 2. The average temperature of the three channels was used to determine the helium bath temperature. Two fluxgate sensors were installed on the middle of the cavity, oriented vertically and horizontally (see Fig. 2). During the cool-downs, the magnetic-fields in the Dewar measured by the horizontal sensor were very small (<1mG), which indicates that magnetic fields caused by thermo-electric currents can be neglected. The vertical sensor detected the residual ambient magnetic-field, which was less than 2mG when passing the critical temperature of niobium. A variable coupler allowed tuning the external quality factor of the input coupler from 1×10^7 to 1×10^{11}.

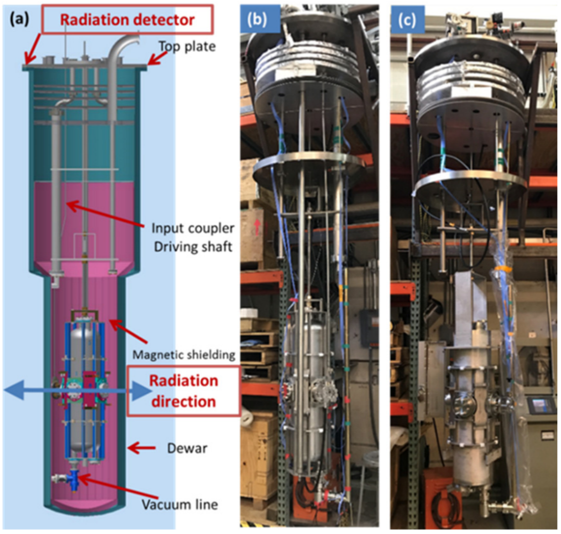

Figure 1: The HWR cavity on the insert. (a) Diagram of the HWR on the RF insert for the vertical tests with the view of the Dewar and magnetic-field shielding. (b) Photograph of the HWR bare-cavity on the insert. (c) Photograph of the HWR dressed-cavity on the insert.

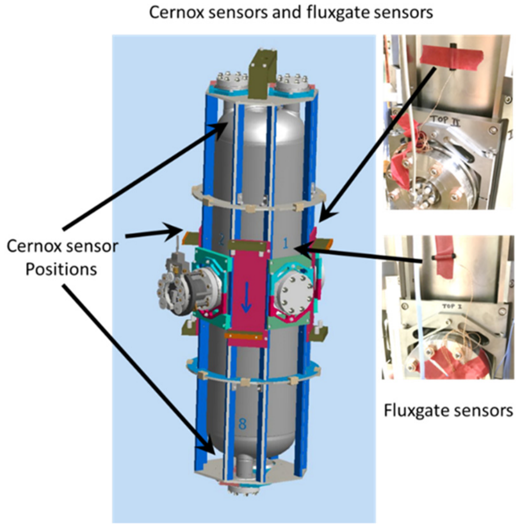

Figure 2: Cernox sensor and Fluxgate sensor locations.

VERTICAL TESTS RESULTS

HWR-1 Bare Cavity Test Results

At a temperature of 4.2K, it was initially difficult to lock the PLL system due to multipacting at very low fields. We spend ~10 hours to process through the multipacting. The intrinsic quality factor (Q_0) vs. accelerating gradient (E_{acc}) curves at 4.2K are shown in Fig. 3, in which Q_0 achieved $\sim 2 \times 10^9$ at low fields (0.5-2.4MV/m). The maximum

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† mg574@cornell.edu.

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field was limited to around 4MV/m by very strong field emission (FE) without hard quench. For comparison, the curves before and after processing are shown in Fig. 3. 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 (see Fig. 1 (a)).

After the 4.2K measurements, the cavity was cooled down from 4.2K to 2K. During the cool-down, we measured Q_0 vs. temperature, which has been converted to surface resistance (R_s) vs. 1/T, as shown in Figure 4, by $R_s = \frac{G}{Q_0}$. Here the geometry factor G is 36 Ω. The residual resistance (R_0) has been fitted with the model $R_s = \frac{A}{T} e^{-\frac{\Delta(0)}{T}} + R_0$, giving $R_0 = 4.6$ nΩ.

The 2K performance is quite similar to the 4.2K results, as is shown in Fig. 5. At low fields (0.5-2MV/m), Q_0 reached 6 to 7 × 10^9. Again, no hard quench was detected at 2K, and the gradient was limited to ~4MV/m by FE. Further RF processing, which lasted about 2 hours, did not reduce the FE.

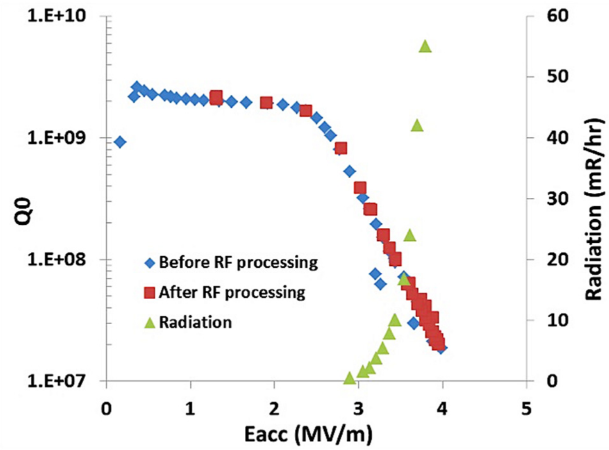

Figure 3: HWR-1 bare cavity Q_0 vs. E_{acc} curves at 4.2K.

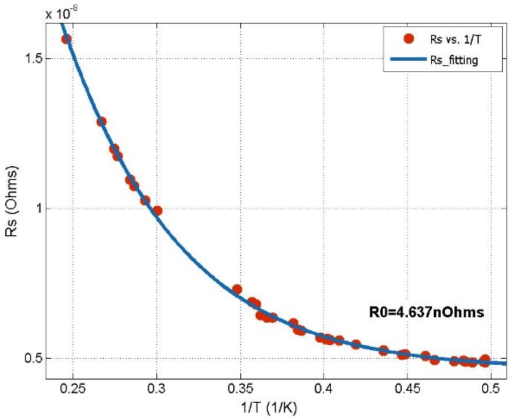

Figure 4: HWR-1 bare cavity R_s vs. 1/T curves.

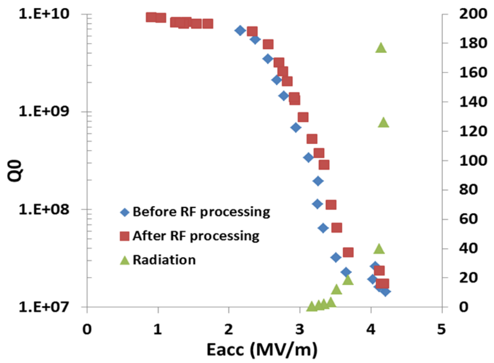

Figure 5: HWR-1 bare cavity Q_0 vs. E_{acc} curves at 2K.

HWR-1 Dressed Cavity Test Results

As during the HWR-1 bare cavity test, overcoming low-field multipacting required more than 10 hours of processing at 4.2K. However, initial strong FE at higher fields this time was dramatically reduced by RF processing (still light FE remaining after processing), with improved Q_0 after the processing. The cavity quenched at 6.3MV/m at 4.2K with Q_0 ~5×10^8. The residual resistance R_0 of the dressed HWR-1 was only 1.8 nΩ. which reaches the low levels typically only seen in an electroposlished cavity. At 2K, the cavity Q_0 achieved 2×10^{10} and the HWR quenched at 6.6MV/m. The high-field Q_0 at 2K was degraded by light FE, which could be reduced by an additional HPR. The test results from this test are shown in Fig. 6 and 7.

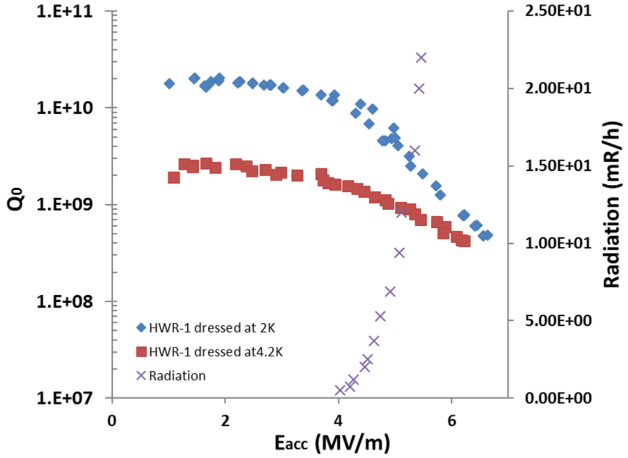

Figure 6: HWR-1 dressed cavity Q_0 vs. E_{acc} curves at 4.2K and 2K.

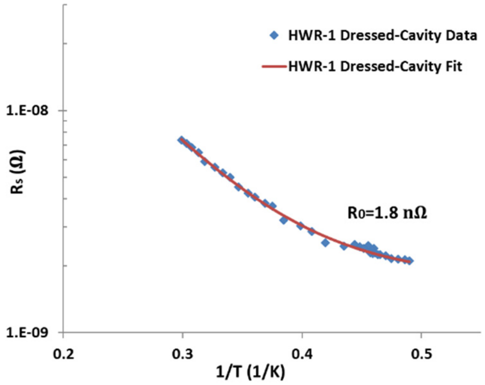

Figure7: HWR-1 dressed cavity R_s vs. 1/T curves.

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HWR-2 Bare Cavity Test Results

At 4.2K the low-field Q reached 3×10^9, which is quite similar to the HWR-1 performance. FE started at 4MV/m during the 4.2K measurement. The cavity gradient reached ~9MV/m with Q_0 ~2×10^8, limited by quench. The FE was conditioned at 2K, resulting in the maximum gradient to increase to 11MV/m with Q_0 dramatically improved; see Fig. 8. The Q_0 at 6MV/m reached ~4×10^9 which is two times higher than the RAON specification at 2K [5]. The test had to be stopped after the 2K Q vs E measurement, when a cold leak occurred. The input coupler did not move at low temperatures; hence we did not measure R_s vs. 1/T. But the HWR-2 bare cavity Q_0 vs. E curve is similar to the HWR-1 bare result, which indicates that the residual resistance of the HWR-2 bare was about 4-5 nΩ.

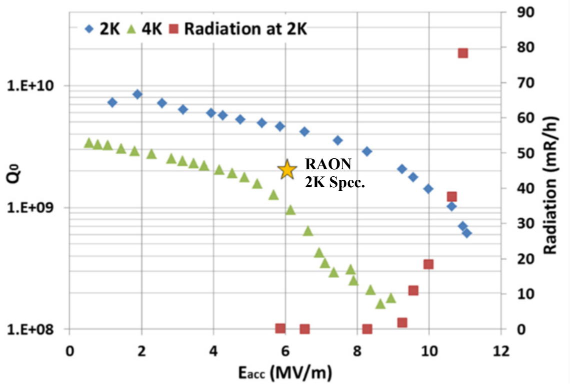

Figure 8: HWR-2 bare cavity Q_s vs. E_{acc} curves measured at temperature 4.2K and 2K. The yellow star symbol indicates the gradient and 2K Q specifications.

HWR-2 Dressed Cavity Test Results

At 4.2K, the cavity quenched at 10.0MV/m. The FE started at 4.7MV/m, and the low field Q_0 was ~2.5×10^9. At 2K the cavity had a cold leak, and data taking at low field was skipped. The 2K measurement started at ~3MV/m with Q_0~7×10^9, and then we measured at 6.7MV/m, giving Q_0 of 2.2×10^9. The maximum gradient reached was 9MV/m, which is not the quench field of the cavity; because of the cold leak we were unable to measure at higher fields. Again, the cavity performance achieved the RAON 2K cavity specification. The dressed HWR test results are shown in Fig. 9.

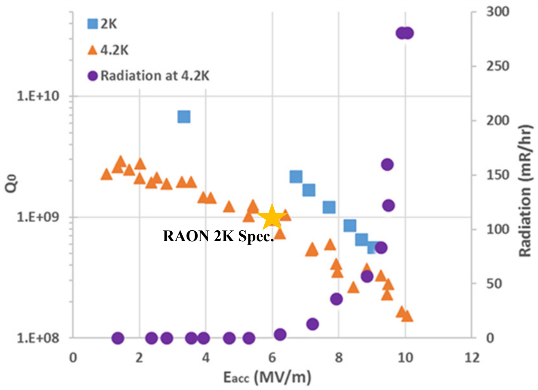

Figure 9: HWR-2 dressed cavity Q_0 vs. E_{acc} curves measured at temperature 4.2K and 2K.

SUMMARY AND CONCLUSION

The HWR performances from the four vertical tests are summarized in Table 1. The HWR-2 exceeds the RAON specification of Q_0~2 × 10^9 at 2K and 6MV/m. The bare cavity quenched at ~11MV/m; and Q_0 at 6.2MV/m reached ~5 × 10^9. The dressed gradient can reach higher than 9MV/m with Q_0 at 6.2MV/m reaching ~2.2 × 10^9. The HWR-1 dressed cavity quenched at ~6.5MV/m at 2K, achieving gradient specification. The quality factor was degraded by strong field emission at maximum fields to Q_0 ~7 × 10^8, but the low-field Q_0 of the cavity achieved ~1 × 10^{10}at 2K, giving a residual resistance R_0 of just 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 chemically polished cavity.

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Table 1: Summary of HWR Performance During Vertical Tests

Cavity	Quench field at 2K (MV/m)	Quench field at 4.2K (MV/m)	Q_0 at 6 MV/m & 2K	Low field Q_0 at 2K	Low field Q_0 at 4.2K	R_0 (nΩ)
HWR-1 bare	4 (FE)	4 (FE)	NA	~7×10^9	~2×10^9	4.6
HWR-1 dressed	6.6	6.3	~6×10^8	2×10^{10}	2.5×10^9	1.8
HWR-2 bare	11	9	~4×10^9	~7×10^9	3×10^9	~5
HWR-2 dressed	>9 (cold leak)	10	2.2×10^9	~7×10^9	~2.5×10^9	NA