Performance and Q_0 Factor of a Half-Wave Resonator*

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Abstract

A half wave resonator (HWR) uses a radio frequency microwave along with superconducting radio frequency (RF) technology to accelerate protons or ions. In our experiment, we tested the performances of the HWR such as quality factor (Q_0) and accelerating gradients (Eacc) in ultra-low temperatures at 4.2K, 2K. This allowed an accurate assessment of the performance of the HWR which had of Q_0 ~10^9 at E_{acc} ~14MV/m at 2K. The purpose of this experiment is to provide details and performance data on the HWR cavity required for the RAON Project.

Introduction

The goal of this project was to test the Q_0 factor (RF performance) of the HWR cavity (figure 1) to ensure that specifications were met, and that the cavity would work as designed at low temperatures. The definition of Q_0 factor is the cavity resonate frequency (ω), which is fixed by the size and shape of the cavity, times the stored energy (U) divided by the power losses (resistance) on the cavity surfaces (P_c) shown in equation 1. This test is crucial because these cavities will be used in the new particle accelerator, the RAON project [1,2] being built for the Institute of Basic Science (IBS) in Daejeon South Korea and need to meet strict 2K performance requirements of Q_0 $2x10^9$ at 6.2 MW/m.

$$Q_0 = \frac{\omega U}{Pc} \tag{1}$$

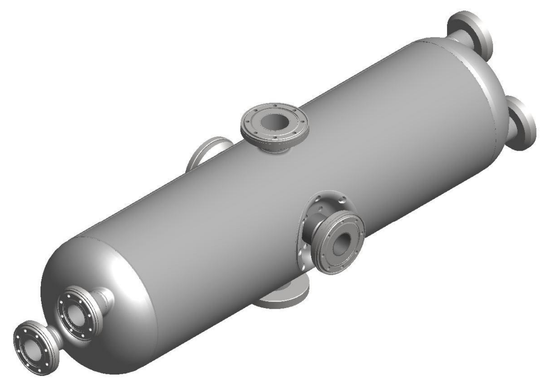

Figure 1: Niobium Half Wave Resonator Cavity

Preparation of the Cavity

A titanium frame was installed on the cavity for transfer onto the insert (figures 2 & 3a.) Special care was needed for this step because any accidents during this stage would change the set frequency of the cavity. Once the cavity was fixed to the insert, temperature sensors and a heater were attached (Figure 3b.) The insert was then lowered into the test pit, liquid nitrogen was filled into the insulation layer of the Dewar, and then liquid helium brought the temperature down to 4.2K. Before data taking, the cavity had to be processed to suppress multipacting. It took several days to process out all the multipacting to prepare the cavity for the rest of the experiment.

* Work supported by the Ministry of Science, ICT, MSIP and NRF.

Multipacting is a phenomenon that happens in RF applications where electrons hitting a surface can release additional electrons which can then be accelerated by the RF field and cause a runaway effect.

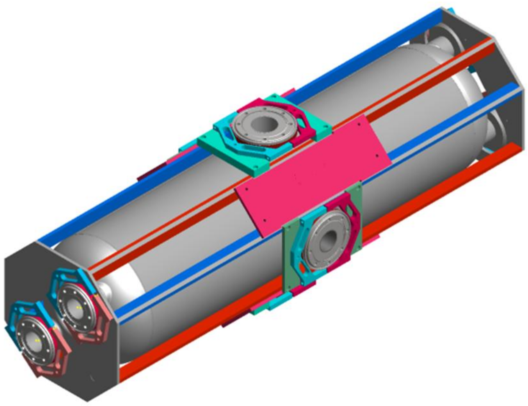

Figure 2: Titanium handling frame (shown in color). This frame was assembled and attached for the purpose of transporting the cavity safely onto the insert without disrupting the frequency of the cavity by deformation.

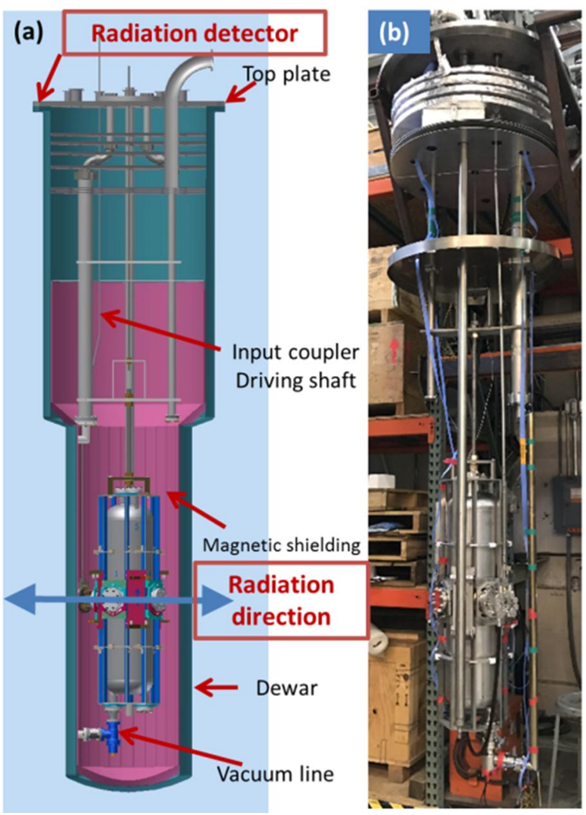

Figure 3: Insert with HWR Cavity in the test pit with liquid helium shown in pink (a) HWR cavity on insert fully dressed before insertion into test pit (b) [3]

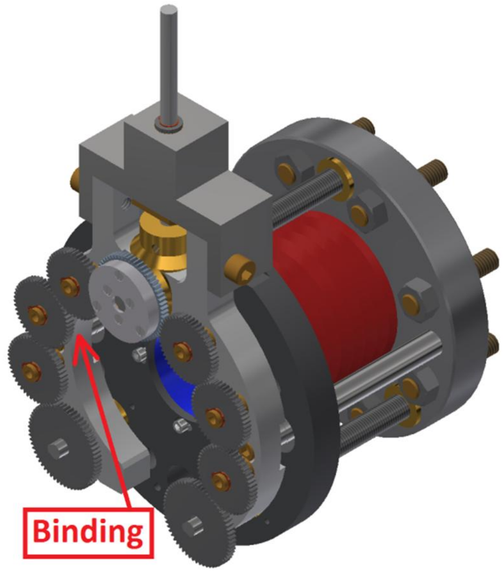

Figure 4: Gear Mechanism on Input Coupler. This mechanism moves the coupler antenna in and out of the cavity. This allows the user to excite the fields in a variety of ways to obtain desired application.

Obstacles

The input coupler antenna had to be moved in and out of the cavity for several measurements during the experiment. This was done by an electric motor on the top of the insert attached to a long drive shaft. During the test, the gear mechanism designed to move the input coupler in and out was significantly binding and caused stress on the electric motor. To solve this problem, the motor was disconnected and the drive shaft was moved manually from the top of the insert during the experiment. Once these problems were solved, measurements were then able to be taken at 4.2K and 2K, and data was collected.

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Experimental Results

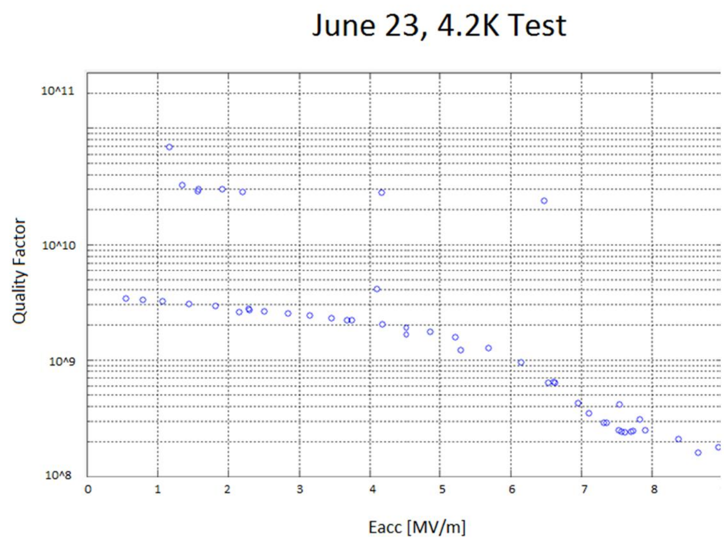

Figure 4: Measurements taken at 4.2K showing a Q_0 Factor of ~$3x10^8$ at ~7.5 MV/m

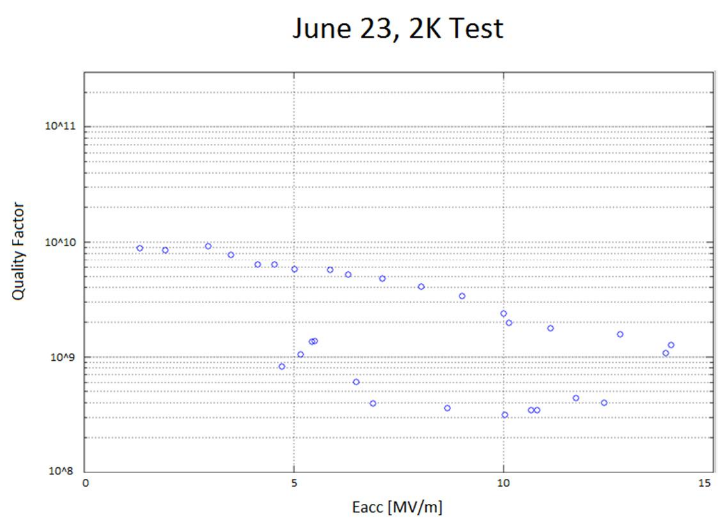

Figure 5: Measurements taken at 2K showing a Q_0 factor of ~10^9 at ~14MV/m

Data Analysis

Figures 5 and 6 show the Q_0 factor as a function of the accelerating gradient. In equation 1, Q_0 factor is inversely proportional to P_c (power dissipated) therefore the higher the Q_0 the lower the power dissipated. This is especially crucial in this application because at 2K, 1 Watt of heat takes 800 W of power for the refrigeration to keep the system at the same temperature, so any means of raising the Q_0, and therefore lowering the power dissipated, means a huge savings on refrigeration costs.

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Conclusion

The RAON project stated that the cavity must be able to obtain a Quality Factor of $2x10^9$ at 6.2MW/m at temperature 2K. The cavity greatly out-performed this minimal requirement by a factor of 2, reaching roughly $5x10^9$ at the same 6.2 MV/m. The cavity operated at a maximum 2K measurement of Q_0 ~10^9 at E_{acc} ~14MV/m. Although the team experienced a couple of issues with miltipacting and the binding of the gear system for the input coupler, everything else ran smooth and the experiment was a success. This experiment was able to prove that the HWR cavity meets and exceeds expectations of quality factor and accelerating gradient required for the RAON project.

References

[1] S. K. Kim, "Rare Isotope Science Project: Baseline Design Summary", 2012, http://risp.ibs.re.kr/orginfo/info_blds.do

[2] H. J. Kim, *et al*., "Progress on superconducting Linac for the RAON heavy ion accelerator", in *Proc. IPAC'16*, Busan, Korea, May 2016, paper MOPOY039, pp. 935-937.

[3] M. Ge, et al., "Performance of SRF half-wave-resonators Tested at Cornell for the RAON project" SRF Conference, Beijing, China, July 2017

Acknowledgments

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