REPORT OF VERTICAL TEST OF THE $\beta = 0.12$ HALF WAVE RESONATOR (HWR) AT RISP*

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Abstract

The $\beta = 0.12, f = 162.5$ MHz half wave resonator (HWR) has been developed for the low-to-medium energy acceleration in RAON, the proposed heavy ion accelerator at rare isotope science project (RISP). Its first prototype was fabricated by Vitzro tech, and was sent to TRIUMF for a surface processing and vertical test. Despite some field emission, the cavity achieved the target value of $Q_0 = 2 \times 10^9$ at $E_{acc} = 6.3$ MV/m.

INTRODUCTION

A $\beta = 0.12, f = 162.5$ MHz half wave resonator (HWR) accelerates uranium beam in low-to-medium energy in RAON, the proposed heavy ion accelerator at rare isotope science project (RISP). The cavity is made to accelerate various ions ranging from proton to uranium in high intensity current of about 1 mA. In particular, the cavity will accelerate uranium beam from 2.5 MeV/u to 18.5 MeV/u. To accommodate high intensity current, the aperture was made as big as possible, reaching 40 mm. The first prototype was manufactured by Vitzro tech. with high purity $RRR \sim 330$ niobium. The fabrication of its first prototype by standard deep drawing and electron beam welding was complete (See Fig. 1) and the cavity was sent to TRIUMF for surface processing and vertical test. The detailed description of the design and fabrication are reported in [1], [2]. At TRIUMF, it was decided that high temperature baking at 800 °C will not be done and instead do "Q-disease test" to check if there is hydrogen leftover after BCP. The cavity will be operated at 2 K minimizing the helium press fluctuations, which is major cause for frequency shift.

In this paper, we report on the surface processing and the vertical test for the prototype HWR in detail.

SURFACE PROCESSING

The cavity was given a standard procedure of surface processing, i.e., buffered chemical polishing (BCP) followed by high pressure rinsing before the vertical test.

Buffered Chemical Polishing

Before BCP, cavity was degreased and cleaned with ultrasound for about 40 minutes (20 minutes in 1 % Liquinox, another 20 minutes in DI water). In BCP as shown in Fig. 2(a), the cavity was etched about 120 μm in total.

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Figure 1: HWR delivered from the vendor Vitzrotech.

(etching was done in 4 different treatments, 30 μm etching each treatment) The composition of an acid is as follows.

$$HF : HNO_3 : H_3PO_4 = 1 : 1 : 2 \quad \text{(volume ratio)} \qquad (1)$$

Being kept near 12 °C, the etching rate was maintained around 1 μm per minute. The rate drops rapidly when the concentration of acid exceeds 10 g/L. The frequency check before and after the etching gave frequency shift about 660 kHz/mm.

After etching, the cavity is immediately low pressure rinsed with DI water. The inner surface of the cavity was visually inspected after BCP, which is shown in Fig. 3

High pressure rinsing (HPR)

The cavity was rinsed in high pressure with DI water to clean the surface and eliminate possible field emitters. The pressure was controlled to be around 40 bar and the rinse was through 4 ports and took 325 minutes for each port .

After HPR, the cavity was kept for dry in class10 clean room over 48 hours.

Low Temperature Baking

Before the 2nd cool down, low temperature baking was done to see if there is any improvement on Q_0, high field slope in particular. The baking was done at 120 °C for 48 hours. The vacuum was in the range of 10^{-6} torr. There was some outgassing and one spike around 100 °C. It is known that low temperature baking decreases BCS resistance, while increases residual resistance.[3]

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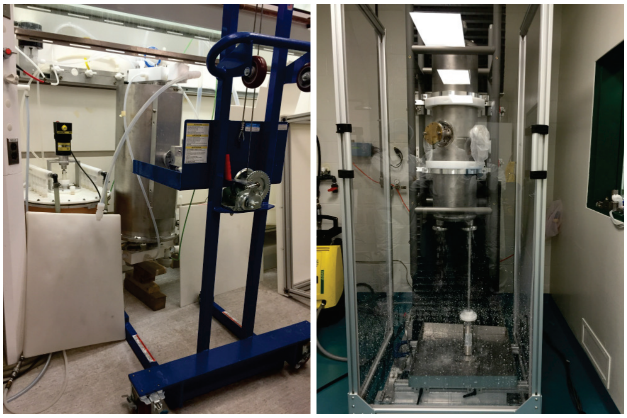


(a) HWR in BCP (b) HWR in HPR

Figure 2: Standard surface processing of the HWR

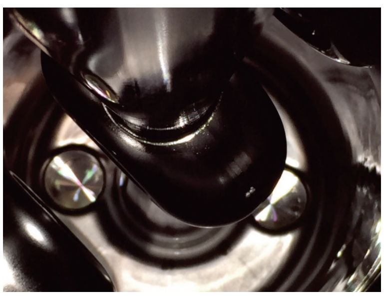


Figure 3: Inner surface of the cavity after BCP.

VERTICAL TEST

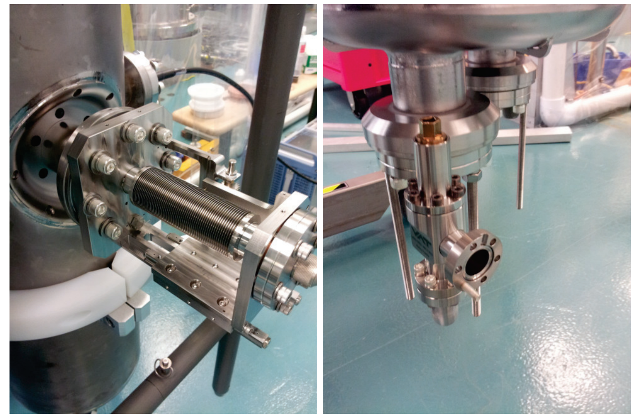
The test was done with 5 cool downs in total. After the first cool down with basic surface processing described in the previous section, additional treatment of low-temperature baking at 120 °C was done before the second cool down. Then "Q-disease test" was done, by warming up the cavity to parking zone and keeping for 9 hours before cool down for the third time. To improve on the field emission, we did additional 15 μm etch before the forth cool down without satisfactory result. Finally as another treatment for field emission, we rinsed the cavity with HF before the fifth cool down.

Clean Room Assembly

After the cavity was dried up, it was hermetically sealed in class 10 clean room. Adjustable power coupler is calibrated and installed (See Fig. 4(a)). All-metal cold valve and pickup coupler are installed (See Fig. 4(b)). Finally, leak check is done. The leak rate was measured to be 7.8×10^{-10} mbar·l/sec at the pressure 6.7×10^{-3} Pa.

Test Preparation

The cavity was taken out to vertical test stand and the level meter, temperature sensors are installed. The vacuum lines are connected to oil free turbo pump system and RF cables are connected to RF system. Helium purging is done



(a) Adjustable coupler to the cavity (b) Cold valve to the cavity

Figure 4: Clean assemblies

with room temperature helium gas. LN_2 is supplied to the thermal shield, the vacuum vessel is evacuated. RF measurements were made using data in Table 1.

Table 1: Figures of Merit of the HWR

Figures of merit	**Unit**	**Value**
E_{acc}	MV/m	6.6
E_p/E_{acc}	-	5.29
B_p/E_{acc}	mT/(MV/m)	7.95
G	Ω	40
Z	J/(MV/m)^2	0.131

The 1st Cool Down

The Q_0-E_{acc} excitation curve is shown in Fig. 5. The multipactions were encountered at low level, 30-60 kV/m, 80 kV, 160 kV and were processed at 4 K within a hour. based on the simulation, this is suspected to be two-point multipaction between re-entrant nose and drift tube.

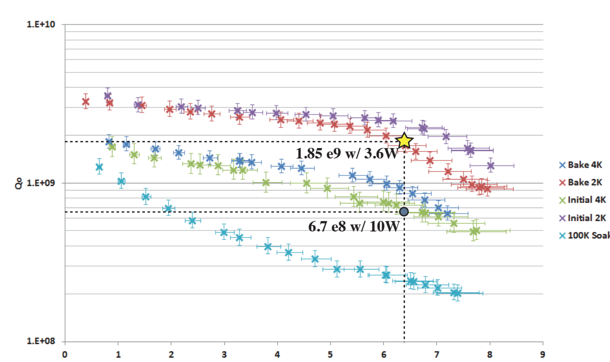


Figure 5: Q_0 vs. E_{acc} excitation curve

Higher level multipaction was around 3.6 MV/m to 5.6 MV/m, close to operating gradient, but the barrier was easier to condition. This is also predicted by the simulation as one-point multipaction at the toroids of the HWR. [4], [5]

The over-all curve does not show significant slope and maintains $Q_0 \sim 2 \times 10^9$ at its accelerating gradient limit $E_{acc} \sim 6.7$ MV/m. Around $E_{acc} \sim 4$ MV/m field emission starts to develop, ultimately leading to quench around $E_{acc} \sim 8$ MV/m.

In addition, frequency sensitivity df/dp against helium pressure fluctuations, Lorentz force detuning (LFD), were measured. During the cool down from 4 K to 2 K with $E_{acc} \sim 4$ MV/m, assuming the frequency shift due to thermal contraction is negligible, the frequency shift was measured over 1 bar to 0.03 bar. The measured frequency shift sensitivity is -8.1 Hz/mbar. The measured LFD coefficient is -8.8 Hz/(MV/m)^2. From Table 1 and using the relation $R_s = G/Q_0$, one also measures R_s as temperature goes down from 4 K to 2 K, which is shown in Fig. 6. Three-parameter fitting gives us an estimate for residual resistance $R_{res} = 14\,\mathrm{n}\Omega$.

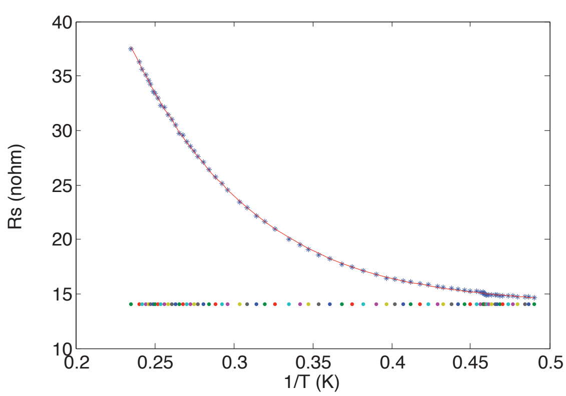


Figure 6: R_s fitting curve of the HWR

In Fig. 6, a small bump around $1/T \sim 0.4\,\mathrm{K}^{-1}$ is a lambda point for a transition of LHe to superfluid. The data was fitted to a curve

$$R_s = \frac{Af^{1.8}}{T} e^{-\Delta(0)/T} + R_{res} \qquad (2)$$

A normalized zero-point band gap energy is determined as $\Delta(0)/kT_c = 1.848$ compared to the known value of 1.8. A constant A is determined as $A = 9.06 \times 10^{-21}$ compared to the known value of 2.4×10^{-21}.

The 2nd Cool Down

Low-temperature baking was done at 120 C four over 12 hours. Although the benefit of the baking with the low-beta cavities are not as obvious as elliptical cavities, the decision was made in favor of the baking for research purpose. The result, shown in Fig. 3, shows the baking worsened the high field slope, although somewhat improved Q_0 value in low-medium field at 4 K. The baking also worsened multipactions. A new barriers around 2.3 MV/m to 3.5 MV/m, lower than 60 kV/m emerged taking longer time to condition.

The 3rd Cool Down

In Q-dsisease test, one warms up the cavity to parking zone, i.e., temperature range between 50 to 100 K and leave it there for 9 hours so that the hydrides could develop if any and cools down again to cryogenic temperature. Parking zone is known to be temperature range hydrides can form from leftover hydrogen from BCP. In Fig. 2, Q_0 value shows a rather significant difference between the first two cool downs and the disease test even at low gradient, suggesting there were indeed hydride formation.

More Cool Downs

After third cool down, the HWR was given additional 15 μm etching only to show little difference in its performance. Finally, the cavity was HF rinsed.

SUMMARY

- The surface processing of the HWR was done successfully, while leaving the possibility for high temperature annealing.
- The vertical test result shows the cavity achieved $Q_0 = 2 \times 10^9$ at $E_{acc} = 6.3$ MV/m in 2 K operation. The field emission and multipaction near operating range are issues for more improvement.

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