SUPERCONDUCTING TEST OF THE 56 MHz SRF QUARTER WAVE RESONATOR FOR RHIC

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Abstract

Our 56 MHz superconducting RF cavity will be the first quarter wave resonator (QWR) installed in a high energy storage ring. We expect it to boost the luminosity of the Relativistic Heavy Ion Collider by more than 50% thereafter. In this paper, we discuss the cavity's parameters and design features, and detail the results from our first vertical test of this cavity at 4 K.

INTRODUCTION

The design of the 56 MHz SRF cavity and its cryostat started several years ago. Being the first quarter wave resonator to be installed in a hadron collider, we designed the cavity to meet high demands. Thus, it will maintain a 2 MV voltage at its single gap during the operation of the 250 GeV proton bunches from both the yellow and blue rings of RHIC. To ensure bunch-to-bunch voltage stability, the cavity has its own dedicated feedback circuit and operates at low surface fields, viz., 88 mT peak magnetic field and 38 MV/m peak electric field at 2 MV gap voltage. Various papers and documents described our design and fabrication of the cavity and its components [1,2].

The cavity has a Fundamental Power Coupler (FPC), a Pick-up (PU), and four Higher Order Mode (HOM) couplers are attached to ports located in the high magnetic field region [3,4]. There also are two ports with zinc selenide windows in the same location. IR detectors are installed beyond these windows to capture light from the cavity or the coupler quench and provide signals for quench protection. All components therein are labelled in Figure 1. The cavity has a frequency tuning range of ±25 kHz. Tuning is achieved by deforming the flat plate forming a capacitive gap with an open end of the QWR. However, tuning is not large enough to cover the particle energy change during acceleration. Therefore, we inserted a fundamental damper to heavily damp the cavity during this period and extract it once the particles are put into store [5].

Figure 1 shows a layout of ports located on the cavity's shorted end (top), and a cross-sectional view of the cavity with helium vessel (bottom).

The 56 MHz SRF cavity, depicted in Figure 2, was manufactured by Niowave Inc., and delivered to Brookhaven National Laboratory in January of 2012.

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VERTICAL TEST FACILITY

Construction of the Large Vertical Test Facility (LVTF) at Brookhaven National Laboratory (BNL) was complete in 2012. It is a concrete block house enclosing a large vertical dewar, built with a sliding roof providing access to the dewar's top plate. The radiation shielding of the facility is rated up to an input RF power of 200 W.

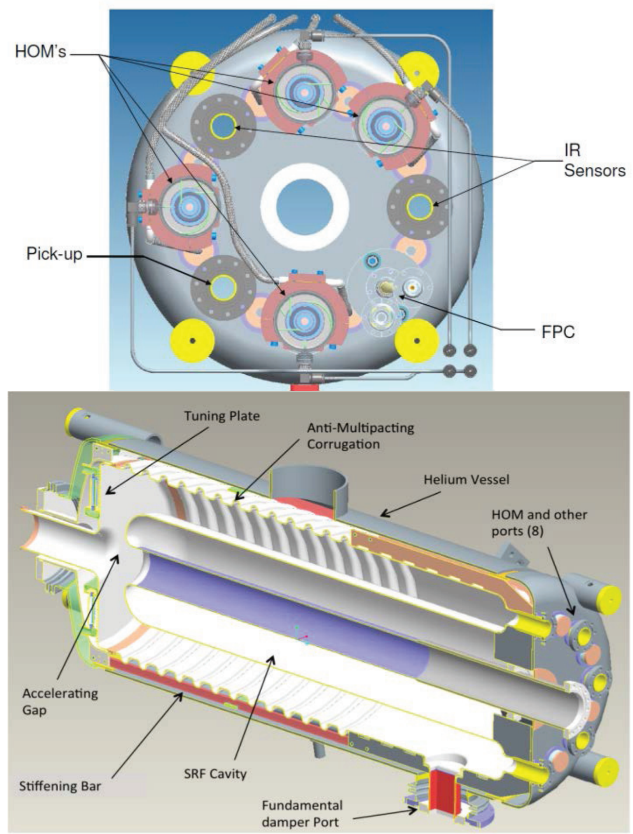

Figure 1: Top: Layout of ports for the 56 MHz SRF cavity for RHIC; Bottom: Cross-sectional view of the cavity with helium vessel.

The facility has a 1800 liter dewar, 40" in diameter and 142" deep. Figure 3 shows a layout of the cavity inside the dewar.

A vertical test insert (a cavity under test connected to the top plate of the dewar) was assembled in a cleanroom. Baffles are installed between the cavity and the top plate, Figure 3. The insert assembly is then dropped into the dewar and connected to vacuum pumping, sensor cables, and helium supply lines.

The large capacity of the dewar ensures our capability to test large cavities. The vertical test of the 56 MHz SRF

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cavity was the first test performed in the newly commissioned LVTF.

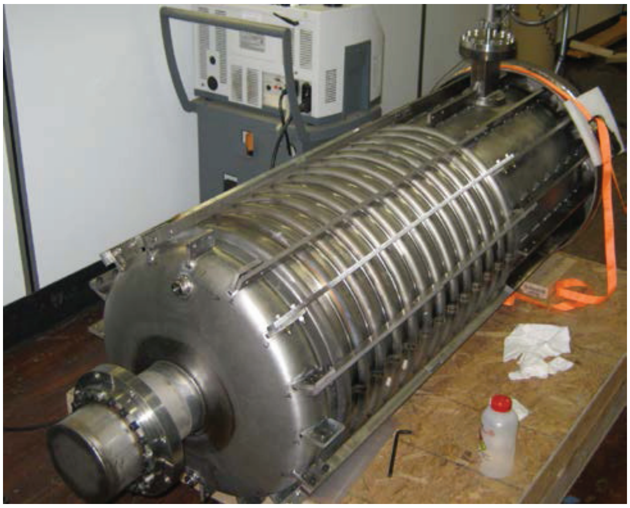

Figure 2: 56 MHz SRF cavity without helium vessel.

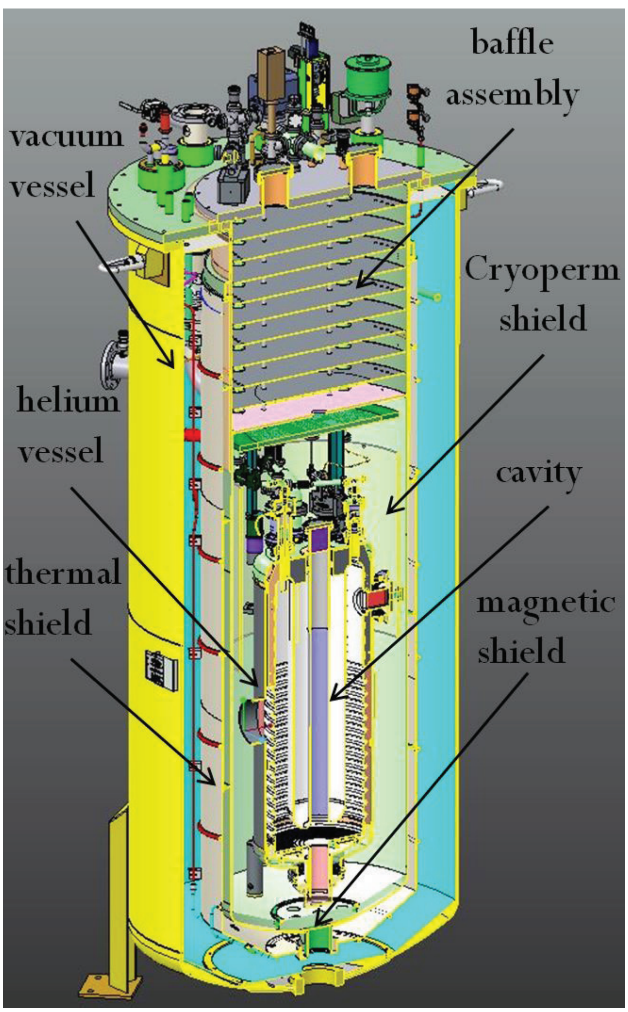

Figure 3: 56 MHz cavity assembly in the BNL's LVTF dewar.

PRE-TEST PREPARATION

After fabrication, the 56 MHz cavity was treated with Buffered Chemical Polishing (BCP) to remove a 150 micron layer from the inner surface. Then it was baked in a high temperature oven at 600°C for 10 hours followed by a light BCP and a High Pressure Rinse (HPR). Figure 4 shows the cavity set up for BCP. The cavity then was assembled for the cold test. We did not undertake a low temperature bake-out. We suspect this omission was the cause for significant Multipacting (MP) under very low field, as discussed in the next section.

A fundamental power coupler (FPC) was made especially for vertical testing. Unlike a FPC to be used in operations with $Q_{ext} = 2\times10^7$, the vertical test FPC has Q_{ext} of 5.8×10^8 for more efficient power coupling. It is tunable with a two orders of magnitude tuning range.

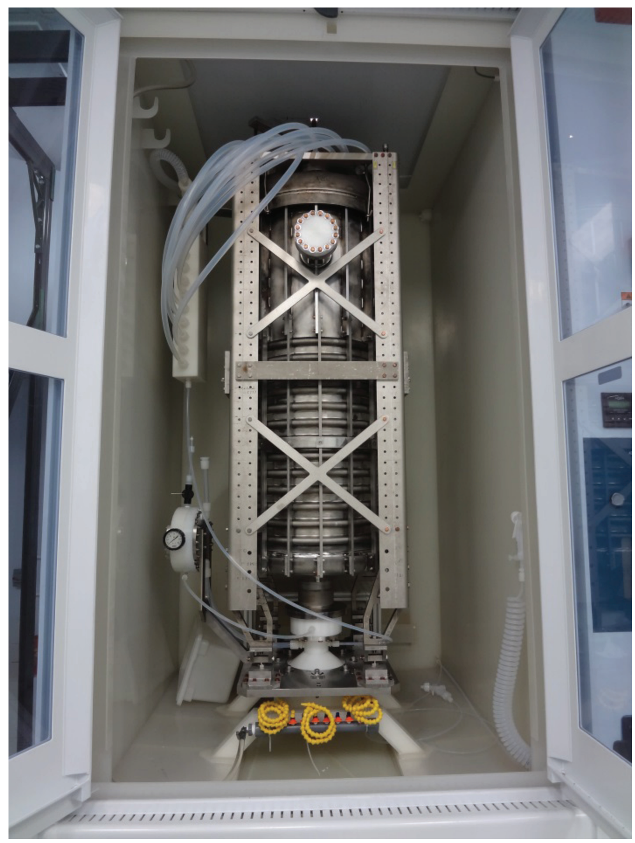

Figure 4: Cavity set up for BCP in the clean room.

CAVITY COLD TEST

At 4.5 K, with a small power input, i.e. 10 μW, we measured the frequency of the cavity as 56.278672 MHz, which is very close to the designed value. With the FPC external Q being close to 2e7, the bandwidth of the resonance is close to 1 Hz indicating that a superconducting condition was reached.

In the process of increasing RF power, we encountered a multipacting (MP) zone at a gap voltage around 1 kV, corresponding to a 19 kV/m peak surface electric field. At such low field in the cavity, the conditioning of the MP is very slow as it is very difficult to efficiently couple RF power to the MP-loaded cavity.

The quarter wave structures are vulnerable to MP due to the parallel surfaces. The 56 MHz cavity was designed with corrugations on its outermost surface to eliminate this phenomenon [6]. However, the analysis in [6] was performed only for relatively high RF fields. After encountering MP at very low fileds during the vertical test, we carried out additional 2D and 3D simulations of the MP with FishPact [7] and ACE3P [8] to re-investigate the situation.

With a scan over a large energy range of primary electrons from 5 eV to 3000 eV and the entire surface of the cavity, the results from both codes show that no resonance electrons are found in the cavity under such a low field. Nevertheless, some electrons generated on the surface with corrugations have trajectories that bounce between the two parallel surfaces while slowly moving towards the peak magnetic field region. Along these trajectories, electrons frequently impact on the cavity inner surface, generating secondary electrons along their way. We concluded that the cavity surface has a high secondary emission yield (SEY) that allows a dense electron cloud to build up within a short period, i.e. tens of RF periods.

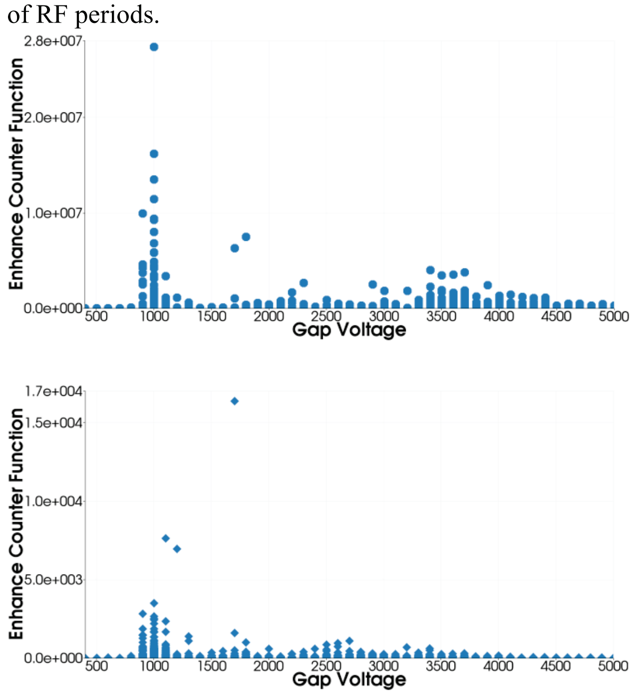

Figure 5: MP simulations in the 56 MHz with poor (top) and standard (bottom) Nb surface.

Figure 5 shows the 3D simulation results obtained with ACE3P. The Enhance Counter (EC) function was calculated for the cavity gap voltage up to 5 kV. The top figure gives the result for a "wet" Nb surface, where SEY is above 1 for primary electron energy from 5 eV to 3000 eV, which is typical for cavities with multiple monolayers of water accumulated on the surface. The EC peaks to 10^7 at 1 kV. This agrees with our experimental observations, where the first MP zone was located at ~1 kV. As the voltage increases, the possibility of MP is still high, although lower than at the 1 kV peak.

In the bottom figure, we show the result from a treated Nb surface where water is eliminated. The peak in the entire voltage range has fallen to below 2×10^4.

We *in situ* baked the cavity continuously for eight days. Warm helium gas was purged through the liquid helium supply line and recycled. The temperature of the cavity was held under 110ºC, which left the Indium sheet underneath the thermal couples undisturbed.

After baking of the cavity, we resumed the conditioning. Within two hours under pulse mode RF power, the gap voltage has reached 17 kV, which is outside the Enhance Counter Function plot, Figure 5. We are in the process of MP simulations to cover the broader gap voltage range. The prediction of MP zones from ACE3P simulation agrees with the experiment for the first peak.

CONCLUSION

Water adsorbed on the surface of the 56 MHz SRF cavity greatly increased the secondary electron yield, and led to multipacting at low field. With a high SEY surface, the electrons would build up quickly even without satisfying the resonance condition. Baking of the cavity is essential to avoid prolonged conditioning time. We plan to bake the cavity further at higher temperature, as well as apply higher power.

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