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THE FIRST OPERATION OF 56 MHz SRF CAVITY IN RHIC*

Q. Wu#, S. Belomestnykh, I. Ben-Zvi, M. Blaskiewicz, L. DeSanto, D. Goldberg, M. Harvey, T. Hayes, G. McIntyre, K. Mernick, P. Orfin, S. Seberg, F. Severino, K. Smith, R. Than, A. Zaltsman, BNL, Upton, NY 11973, USA

Abstract

A 56 MHz superconducting RF cavity has been designed, fabricated and installed in the Relativistic Heavy Ion Collider (RHIC). The cavity operates at 4.4 K with a "quiet helium source" to isolate the cavity from environmental acoustic noise. The cavity is a beam driven quarter wave resonator. It is detuned and damped during injection and acceleration cycles and is brought to operation only at store energy. For a first test operation, the cavity voltage was stabilized at 300 kV with full beam current. Within both Au + Au and asymmetrical Au + He3 collisions, luminosity improvement was detected from direct measurement, and the hourglass effect was reduced. One higher order mode (HOM) coupler was installed on the cavity. We report in this paper on our measurement of a broadband HOM spectrum excited by the Au beam.

INTRODUCTION

The RF system installed in RHIC includes two main accelerating cavities at 28.15 MHz and five storage cavities at 197.05 MHz for each ring, all operating at room temperature. The 197 MHz cavities are used to store bunches, after they have been accelerated to the top energy, for many hours. To accommodate the long ion bunches into the storage cavity bucket, which is ~50% shorter than the bunch length, rebucketing is adopted in the RHIC ramping procedure. However, longitudinal emittance increase due to nonlinearity and hardware complications during rebucketing will result in a 30% loss in the particles. A 56.3 MHz superconducting RF (SRF) cryomodule was installed near the interaction point (IP) 4 in RHIC, Figure 1, during the first quarter of 2014, to provide sufficient RF acceptance to long bunches [1].

To save cost on cryogenic system, the cavity location is in the common section of RHIC, and it is shared by ion bunches from both rings. The two colliding beams are synchronized at each IP. Therefore to achieve identical longitudinal beam dynamic effect, the cavity is installed at 1.25λ (6.66 m) away from IP 4.

CAVITY

The 56 MHz SRF cavity is a quarter-wave resonator with beam passing through its symmetrical axis, as shown in Figure 2. The cavity is designed to provide 2 MV at the 8.5 cm single gap, and the operation temperature is 4.4 K. Detailed cavity parameters can be found in Ref. [2].

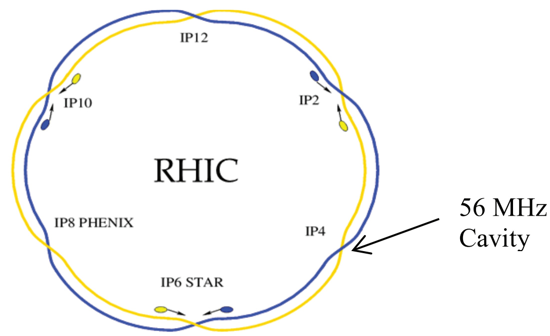

Figure 1: Location of the 56 MHz cavity in RHIC.

Mechanical tuning is achieved by pushing or pulling the end plate of the cavity that is close to the gap, as labeled in Figure 2 [3]. The tuning capability of this mechanism is 46.5 kHz, which is 60% of the revolution frequency of RHIC beam.

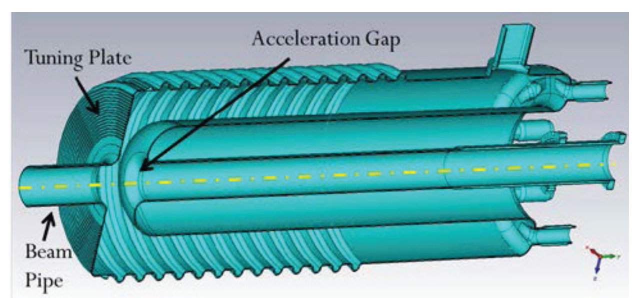

Figure 2: Crossection view of the 56 MHz SRF cavity.

Thirteen corrugations are added to the outer wall of the cavity to supress multipacting [4]. During the conditioning of the cavity, multipacting was encountered at 90 – 140 kV gap voltage, and was easily conditioned through after 30 minutes. During operation with beam, the cavity never encountered any multipacting issues.

Couplers

Since the cavity does not have sufficient tuning range to follow the large revolution frequency change during acceleration, it must be turned off during the energy ramp. In addition to full frequency detune from the tuning plate, a fundamental mode damper (FMD) is inserted into the cavity from a rectangular port. The port is opened perpendicular to the beam axis on the outer wall of the cavity, as shown in Figure 3. More information on the FMD can be found in Ref. [5].

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#qiowu@bnl.gov

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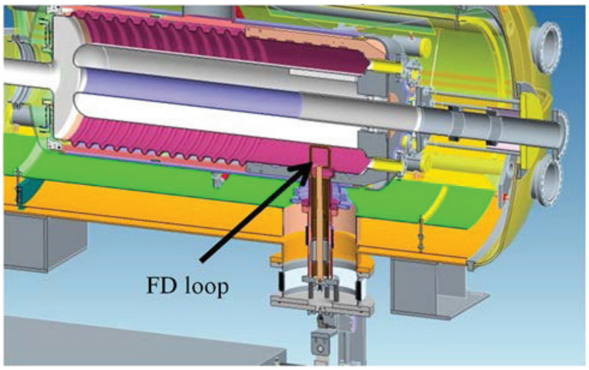

Figure 3: Cross section view of the 56 MHz cavity cryomodule with the FMD fully inserted.

A 1 kW amplifier is connected to the cavity through fundamental power coupler (FPC) located in the maximum magnetic field region, and it is used to:

- Achieve required amplitude and phase stability.
- Provide conditioning capability.

The external quality factor of the FPC is 3×10^7, and it can be tuned one order of magnitude up or down. More information on the FPC can be found in Ref. [6].

According to previous impedance studies, four higher order mode (HOM) couplers were designed for the cavity. All HOM couplers are geometrically identical and located at the cavity's shorted end in a specific configuration. Each HOM coupler loop is followed by a Chebyshev high-pass filter to reject the fundamental mode in the cavity while providing strong broadband damping for all other modes. As the most complex and critical RF element, substantial physical and mechanical studies were done on the HOM couplers [7]. Due to the delay in fabrication, only one HOM coupler (a prototype) was installed onto the cavity for RHIC Run14 [8]. A picture of the HOM coupler with high pass filter is shown in Figure 4.

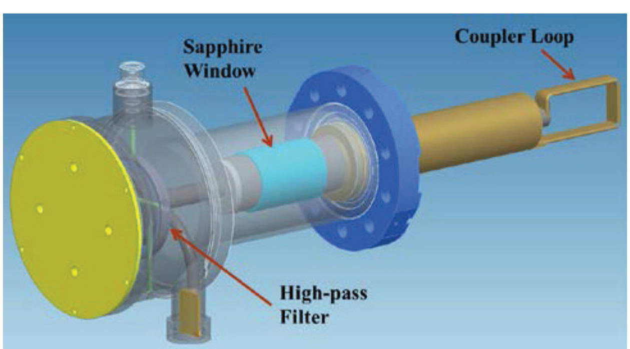

Figure 4: The HOM coupler with high pass filter for 56 MHz cavity.

Cryogenic System

The cavity cryomodule is operating at 4.4 K with cryogenic supply from a quiet helium source. This system provides a helium bath with very small fluctuation of pressure, [9]. Figure 5 shows the cryomodule installed in the RHIC tunnel.

Figure 5: The 56 MHz cryomodule in RHIC tunnel.

OPERATION

The first operation of the 56 MHz cavity was in June 2014, with species Au + Au and He3 + Au. The RHIC operation parameters with 56 MHz cavity installed are listed in Table 1.

The cavity voltage was limited at 330 kV by quench at the HOM coupler sapphire window. The cause of the quench was investigated and traced to RF heating of the braze alloy used during fabrication of the sapphire window. This initiated a coupler redesign. The production set of the couplers will not have these windows.

Table 1: Parameters for RHIC Run14

	Unit	Au + Au	He3 + Au	
		Au (b/y)	**He3 (b)**	**Au (y)**
Peak Intensity	$\times10^9$	180	5000	150
Energy	GeV	100	103	100
Bunch length	ns	2.5	2.2	2.5
beta*	cm	70	100	

During the first cavity test with Au-Au beam, the voltage was increased slowly to 300 kV in the middle of the store. We observed 3% increase in the luminosity and 4.5% decrease of bunch length in both rings as shown in Figure 6.

We also observed hourglass factor increase with the cavity turned on.

During the asymmetrical collision events, the bunch profile changed with the 56 MHz cavity. The population of Au beam in the satellite buckets is squeezed toward the center as illustrated in Figure 7.

After commissioning with beam, the cavity was routinely operated. It was automatically turned on after the beam reached the store energy at every RHIC fill, and the voltage was parked at 300 kV by Low Level RF (LLRF) controls. We kept 10% of voltage safety margin for the cavity operation.

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The cavity operated for 13 full stores of RHIC in 2014. The voltage fluctuation during the operation was controlled within 1 kV.

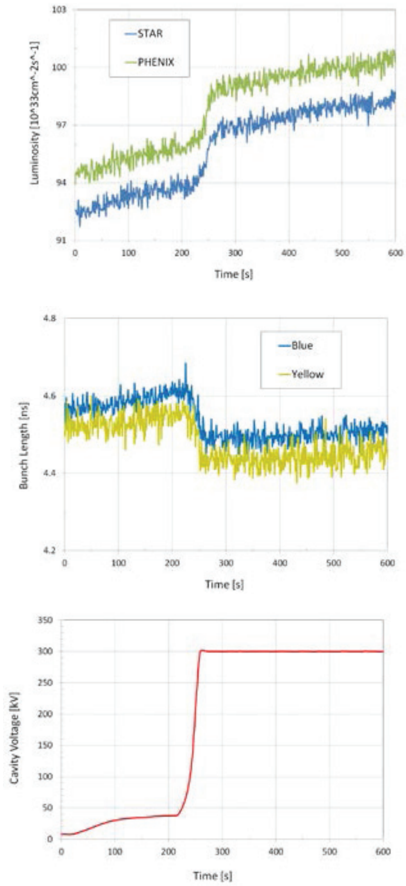

Figure 6: Luminosity increase and bunch length decrease due to the 56 MHz cavity turned on.

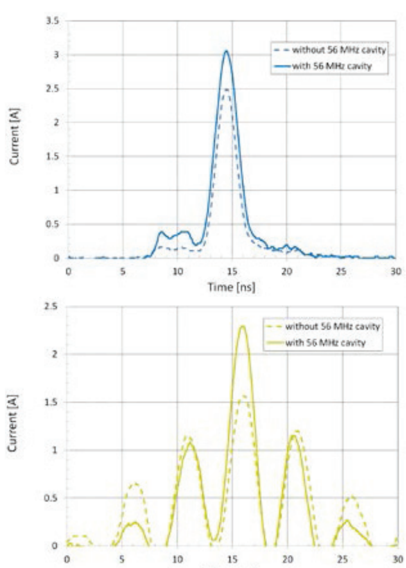

Figure 7: Beam profile comparison for 56 MHz cavity turned on and off. Top: Blue ring with He3 particles. Bottom: Yellow ring with Au particles.

Despite the quench in the HOM coupler which limited the cavity voltage, the HOM damping provided by a single coupler was proved to be sufficient for current RHIC run. The beam did not experience measurable instability during the tune in of the cavity, when the cavity frequency would scan over multiple resonance lines of the HOMs.

FUTURE PLANS

During the RHIC shutdown in summer of 2014, the HOM coupler was extracted from the cavity cryomodule. Thermal studies show that the quench of the coupler was due to the braze alloy used to bond the sapphire window and the Nb sleeve. Non-superconducting material, CuSil, was used for brazing and RF losses were high enough to over heat and quench the local region.

A new design of the HOM coupler without a sapphire window or any non-superconducting material was proposed at BNL. Five of these new couplers are currently under fabrication at Jefferson Lab. One to three couplers will be installed onto the cavity during the shutdown of 2015, to allow the cavity operation with beam during RHIC Run16.

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