WAKEFIELD ANALYSIS OF THE 56 MHz SRF CAVITY*

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Abstract

The 56 MHz SRF cavity is a superconducting quarter-wave resonator installed in the common section of RHIC. Both beams share the cavity in an interwoven pattern over the entire store. The wake field excited in the cavity is the superposition of the two opposing bunches. This paper will discuss the wake field excited by both beams, and the higher order mode power as a result of the excited field.

INTRODUCTION

The 56 MHz SRF cavity installed in RHIC as a storage cavity is a quarter-wave resonator which has been discussed in various references [1][2][3][4]. The cavity is serving both beams in the common section with 180 degrees delay between bunches from the opposing beams. For this purpose, the location of the cavity is chosen to be 1.25λ from the interaction point 4.

The cavity will provide sufficient RF acceptance to long bunches, therefore less particles will be lost from inter beam scattering during rebucketing. Detailed studies have been discussed in previous papers [5]. The cavity was installed in January 2014 and started beam commissioning the same year later. Figure 1 shows the cavity installed in the RHIC beamline.

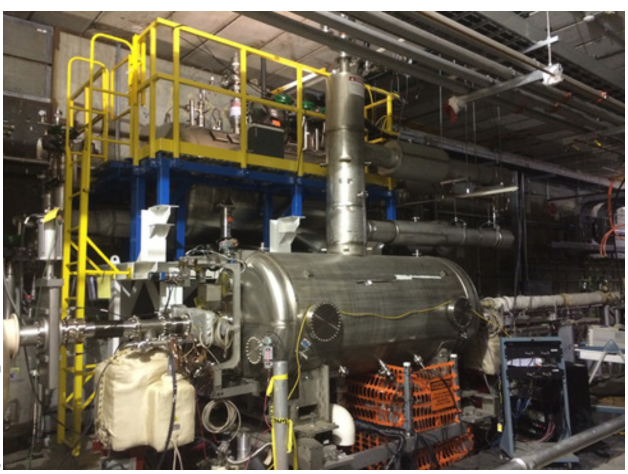

Figure 1: The 56 MHz SRF cavity installed in RHIC beamline.

During RHIC operation in 2014, with Au + Au collisions, the cavity has 1 higher order mode (HOM) coupler installed with a 3-stage high-pass filter. It is designed with -90dB attenuation at the fundamental frequency and <6dB on all HOMs below 700 MHz. From spectrum analyzer measurements out of the HOM coupler output, the wake field excited by RHIC beam inside the cavity is dominated by longitudinal wake potential. All monopole modes below 600 MHz are measured with gradually decreasing power, as shown in Table 1.

Table 1: Higher order mode power measured from 56 MHz cavity with full intensity Au + Au operation.

Freq. [MHz]	Qext_measured	P_measured [W]
56.313	3.46e10	2.52
166.233	6898	4.06
273.768	6313	0.03
376.756	17349	8.71e-4
474.204	2131	9.55e-4
573.541	11490	8.91e-4

The total power measured from the HOMs is 4.1W. With the filter transmission coefficient at 166 MHz to be –5dB, the actual power in the cavity should be 13W. The Au beam from both rings experience no degradation from the 56 MHz cavity [6], showing that the HOM damping was sufficient with only one HOM coupler.

SINGLE BUNCH

The RHIC bunches are relative long with rms bunch length of ~1.2m at store. When using CST Particle Studio [7] for wake field simulations, the impedance cut off frequency set to -20dB of the beam spectrum frequency. In our case, it limited the impedance spectrum to less than 500 MHz. To evaluate the impedance of the 56 MHz cavity, a short bunch of rms 6 cm was used to excite the wake field to reach a reasonable maximum impedance frequency of 1.7 GHz. The single bunch and the excited wake field are shown in Figure 2.

For function f(s) has only non-zero values in range of [0,L], sampled with N points evenly with step size $\Delta s = L/N$, we define $f[n] = f(n\Delta s)$. Discrete Fourier Transform for the wake field and the current would be:

$$W_k = \sum_{n}^{N-1} W_n e^{-i2\pi n/N}$$

$$I_k = \sum_{n}^{N-1} I_n e^{-i2\pi n/N}$$

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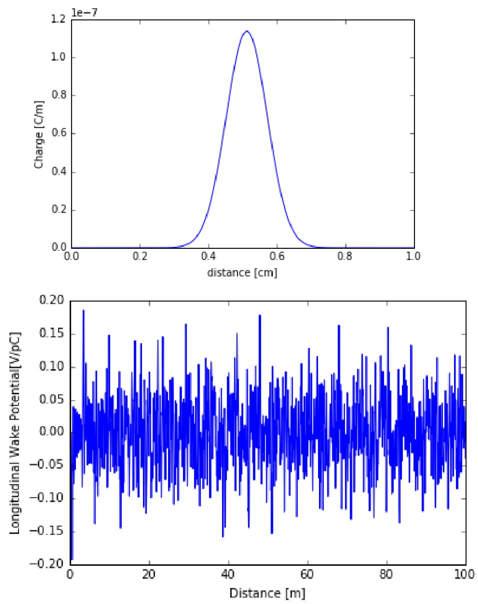

Figure 2: single bunch used for cavity impedance calculation over short distance.

And the impedance from the time domain calculation would be:

$$\Omega_k = W_k / I_k$$

The Impedance of the cavity is shown in the blue curve in Figure 3, and the loss factor of the 6cm short bunch in shown in red in the same plot.

The loss factor of the cavity with such bunch is

$$\begin{aligned} \mathrm{k} &= \frac{1}{Q^2}\int_0^L W(s)I(s)ds \\ &= \frac{1}{Q^2}\int_0^L \frac{1}{2\pi}\int_{-\infty}^{\infty} \Omega(k)I(k)e^{iks}dkI(s)ds \\ &= \frac{1}{2\pi Q^2}\int_{-\infty}^{\infty} \Omega(k)I(k)I(-k)dk \\ &= \frac{1}{NQ^2}\sum_0^N \Omega_n I_n I_n^* \Delta s \end{aligned}$$

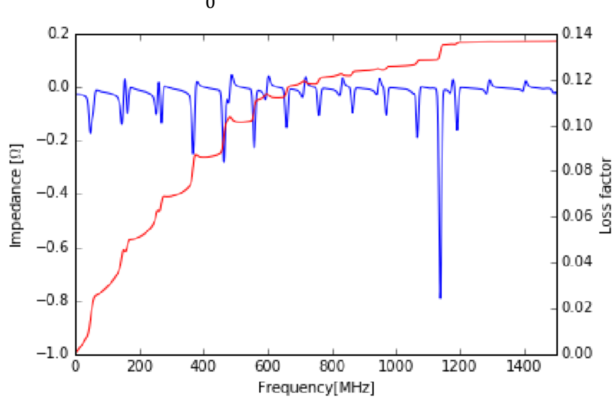

Figure 3: Cavity impedance (blue) and the loss factor of single 6 cm bunch (red).

MULTI BUNCH

Single Beam

The main cavity of RHIC is 28 MHz, which is the 360 harmonic of the beam revolution frequency. 111 bunches are injected evenly into a 120 bunch pattern, leaving 9 empty buckets as abortion gap.

RHIC beam from one ring is illustrated in Figure 4 with current normalized to 1 A. The beam parameter for RHIC Au+Au operation in 2014 is shown in Table 2.

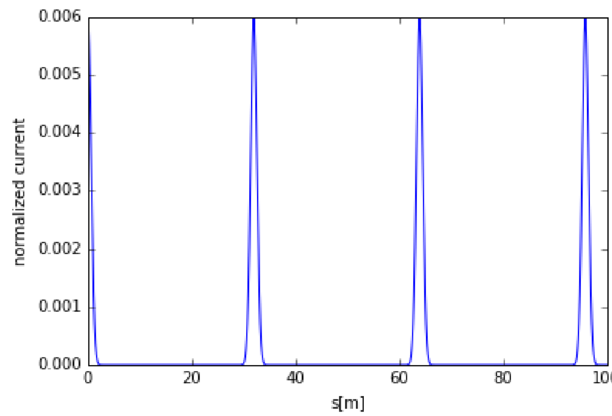

Figure 4: Bunch pattern in one RHIC ring over 100m.

Table 2: RHIC beam parameter in Au+Au run in 2014.

Parameter		Unit
Bunch number	111	
rms bunch length	75	cm
Harmonic	720	
Total Intensity per beam	200e9	
Revolution Freq.	78.2	kHz

The rms bunch length and total intensity are measured at the beginning of the RHIC store, which is the same time section when the HOM power measured in Table 1. Due to such long beam length, it is easy to conclude from the frequency domain plot that the only relatively low frequency modes can be excited in the cavity, Figure 5.

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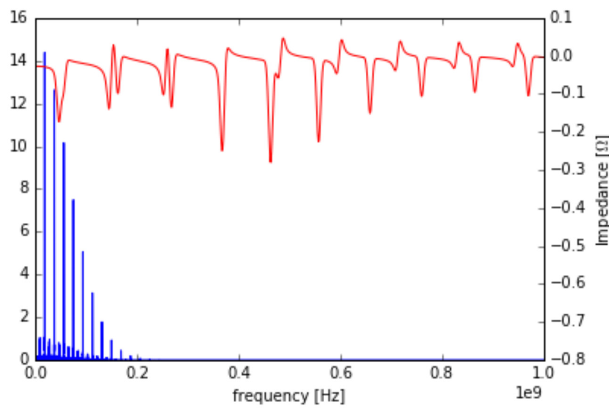

Figure 5: 75cm RHIC beam spectrum (blue) compare with cavity impedance (red).

The longitudinal loss factor for the 111 bunches in 120 train is 5.76e-6 V/pC, calculated with the same method as for single bunch. The HOM power in the cavity with one beam is 2.87 W.

Two Beams

The abort gap of Blue and Yellow beam in RHIC is synchronized for PHENIX at 8 o'clock on the ring. For 56 MHz, which is located 1.25 wavelength away from the interaction point at 4 o'clock, the two beams abort gap is shifted by 243 RF buckets. All beam parameters are the same for both beams.

The longitudinal loss factor for both beams is 2.35e-6 V/pC, and the corresponding HOM power is 4.67 W.

CONCLUSION

Any wake field simulated from a Gaussian beam can be used to calculate the single particle impedance of the cavity. The loss factor can be obtained from this impedance and the real beam current. The HOM power excited by RHIC both beams is calculated with this method, and it agrees with the measurement. The error mainly contributed from the measurement of the accuracy of the rms bunch length.

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