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56 MHz SRF SYSTEM FOR SPHENIX EXPERIMENTS AT RHIC

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Abstract

The super Pioneering High Energy Nuclear Interatction eXperiment (sPHENIX) experiment is a proposal for a new detector at the Relativistic Heavy Ion Collider (RHIC), that plans to expand on discoveries made by RHIC's existing Solenoidal TrAckeR (STAR) and PHENIX research groups. To minimize the luminosity outside the 20 cm vertex detector and keeping the radiation to other detector components as low as possible, a 56 MHz superconducting RF (SRF) system is added to the existing RHIC RF systems to compress the bunches with less beam loss.

The existing 56 MHz SRF cavity was commissioned in previous RHIC runs, and contributed to the luminosity at a voltage of 300kV with thermal limitations from the Higher Order Mode (HOM) coupler at high field, and at 1MV while using its fundamental damper for HOM damping. In this paper, we will analyze and compare the effect of different RF systems at various scenarios, and discuss possible solutions to the Higher Order Mode damping scheme to bring the cavity to 2 MV.

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 at their 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, 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.

The 56 MHz SRF cavity is a quarter-wave resonator with beam passing through its symmetrical axis, as shown in Figure 1. 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 Reference [2]. Mechanical tuning is achieved by pushing or pulling the end plate of the cavity that is close to the gap, as labeled in Figure 1. The tuning capability of this mechanism is 46.5 kHz, which is 60% of the revolution frequency of RHIC beam. The cavity has loop shaped RF couplers inserted all from the cavity end

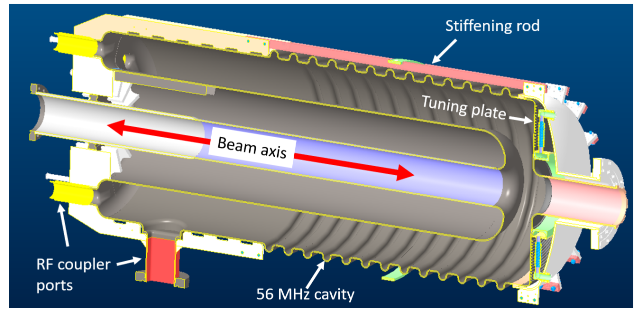

Figure 1: Crossection view of the 56 MHz SRF cavity.

far from the gap (magnetic field dominant region) for input power, pickup antena, fundamental mode damping during acceleration stage, and HOM damping [3–5].

RHIC OPERATION

The first operation of the 56 MHz cavity was in June 2014, with species Au + Au and He3 + Au. The cavity was in operation for 15 stores of over 130 hours with full intensity full energy beam. During the operation, the cavity voltage was limited at 330 kV by thermal quench at the HOM coupler sapphire window. The cavity operation switched to damping the HOMs by slowly extracting the fundamental mode damper (FMD) as tuning into the resonance. The FMD was designed for largely decrease the quality factor of the cavity during energy ramping period. Due to the location, the FMD couples well to all excited monopole modes in the cavity during operation, and also can tolerate the extracted RF power beyond 10 kW. With the FMD damping HOMs, the cavity can be tuned to closer to the resonance and provide 1 MV maximum [6]. The voltage was limited to 1 MV due to cooling to the FPC cable, which was improved later, and microphonics.

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 2. 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 [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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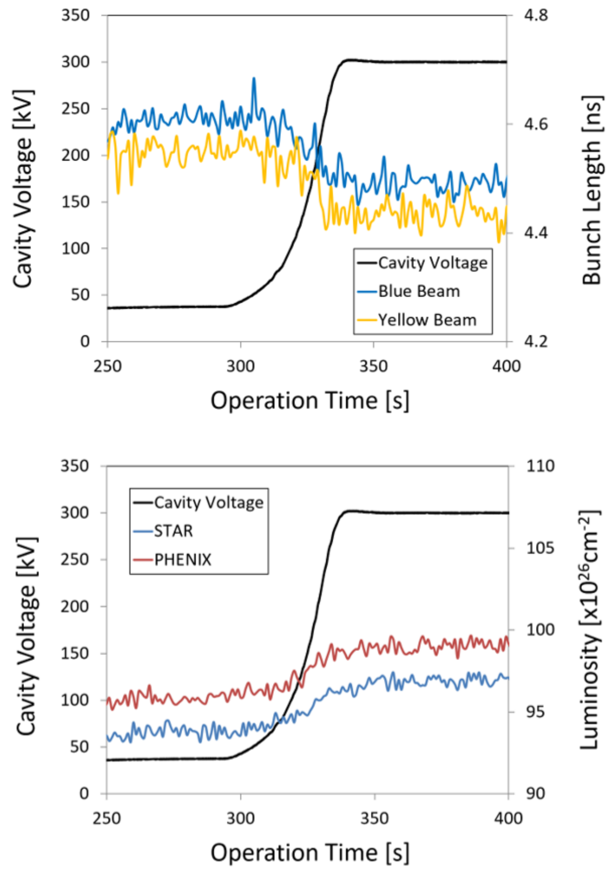

Figure 2: Bunch length decrease (left) and luminosity increase (right) directly related to 56 MHz cavity in operation.

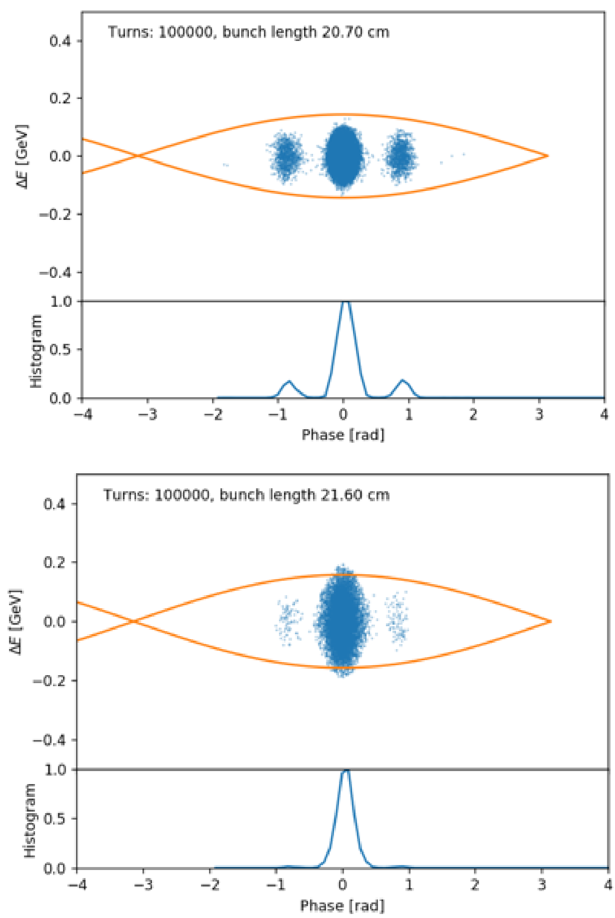

Figure 3: Particle distribution in 28 MHz torus with 56 MHz cavity turned off (left) and at 2 MV (right). The orange line outlines the 28 MHz cavity bucket.

BEAM STUDY

Adding the 56 MHz cavity, the RF system for RHIC operation is setting up a 3-harmonic combination which decreases the particle loss and bunch length at the same time compares to with 28 MHz and 197 MHz alone. The 56 MHz cavity provided an increase in the acceptance of the storage RF bucket. At RHIC injection energy, the Au bunches have a typical emittance of S95% = 0.3 - 0.5 eV-s/nucleon. The emittance is growing during the ramp up, and reach an emittance of 0.8 - 1.0 eV-s/nucleon at the store energy [8]. This final emittance corresponds to a full bunch length of 9.7 ns with the 28 MHz RF, which is too long for the 197 MHz cavity bucket. In order to squeeze in more particles into the center bucket of the 197 MHz cavity, the bunches are rotated via RF gymnastics before turning on the higher harmonic cavities. However, during this rotation, a large percentage of the particles are spilled into the neighboring buckets, as shown in Figure 3, causing a large reduction of the center bunch intensity. The percentage of the particle loss can go up to 30%. Figure 3 compares the particle distribution with 56 MHz cavity turned off and at 2 MV after the 197 MHz cavities turned on.

The sPHENIX is a planned expriment at RHIC specially designed for measurements of jets, quarkonia, and other rare processes originated from hard scattering created in collisions of Au ions at 100 GeV [9]. In the current sPHENIX detector design, the physcis requires to minimize the luminosity outside of the vertex detectors which are +/- 10 cm in longitudinal space. This is to minimize the pileup in the Time Projection Chamber (TPC) and MVTX, which is a vertex detector for open heavy flavor measurement with CMOS sensors. With large collision losses outside the +/- 10 cm detector range, the TPC will be confused with extra hits and drift in. Therefore, the experiment requires short bunch length of 20 cm and small particle losses.

Table 1 shows a comparison of bunch length and particle loss under various RF scenarios with 3-harmonic system and no intra-beam scattering and cooling taking into account. As shown from the table, the voltage of the 197 MHz defines the final bunch length. At the maximum achievable value, the bunch length can reach ~21 cm, which is very close to the requirement.

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Table 1: Bunch Length and Particle Loss with 3-Harmonic RF System Comparison

28 MHz	56 MHz	197 MHz	rms bunch length [cm]	particle loss %
300 kV	0	0	72	0
300 kV	0	2.5 MV	19	28
300 kV	2 MV	2.5 MV	26	3
600 kV	2 MV	5 MV	22	2
300 kV	2 MV	5 MV	22	2
600 kV	2 MV	2.5 MV	25	2
600 kV	1 MV	5 MV	21	4
300 kV	1 MV	2.5 MV	25	6

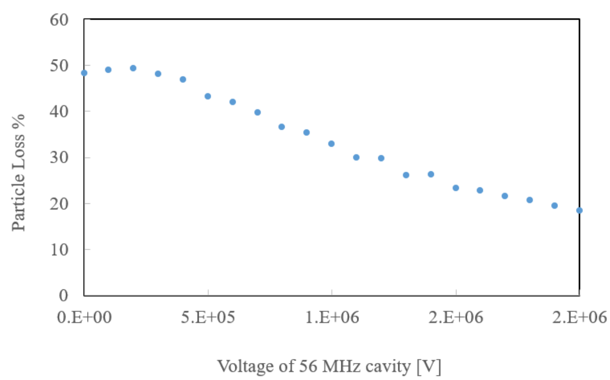

Figure 4: Particle loss with 56 MHz at different voltage.

Taking IBS and stochastic cooling into consideration, the particle loss decreases with the increase in the 56 MHz cavity voltage. Simulation performed using Fortran code developed for RHIC stochastic cooling analysis [10]. Figure 4 shows the particle loss at various voltage on the 56 MHz cavity, with 197 MHz RF system providing maximum voltage of 5 MV. The 28 MHz RF system is not considered in the simulation, because with the two higher harmonic RF systems, the bucket of the 28 MHz affect is negligible in the center bunch.

CURRENT STATUS

The 56 MHz cavity cryomodule has been dissembled from the tunnel installation site and moved to the SRF processing building for further treatment. Figure 5 shows the cavity on its stand after dissembled from the cryomodule.

The inner surface of the cavity was exposed to outside for HOM coupler in-situ assembly and dissembly under a temporary cleanroom. The cavity will have a high pressure water rinse (HPR) as the first treatment before setting cryogenic vertical test beaseline. The HPR and cold test will be done with the helium vessel attached. The HOM coupler will be redesigned to avoid thermal quench in the early field stage, and multiple couplers will be installed to share the transmitted power.

Figure 5: 56 MHz cavity with helium vessel after dissembled from cryomodule.

SUMMARY

After successful operation of the 56 MHz cavity at 300 kV in RHIC for more than 130 hours, the cavity will be reprocessed and have HOM couplers redesigned to push for higher voltage. Simulation results show that with the 56 MHz cavity reaching its design voltage of 2 MV, the RF system will significantly decrease the beam loss and bunch length in RHIC during sPHENIX experiments.

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