

SRF AND RF SYSTEMS FOR CeC PoP EXPERIMENT*

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Abstract

Efforts to experimentally prove the concept of coherent electron cooling are underway at BNL. A short 22 MeV linac will provide high charge, low repetition rate beam to cool a single ion bunch stored in RHIC. The linac will consist of a 112 MHz SRF gun, two 500 MHz normal conducting bunching cavities and a 704 MHz five-cell accelerating SRF cavity. The paper describes the SRF and RF systems, the linac layout, and discusses the project status, first test results and schedule.

INTRODUCTION

Coherent electron Cooling (CeC) is a technique promising significant luminosity improvement in high-energy hadron-hadron and electron-hadron colliders [1]. A Proof-of-Principle (PoP) experiment is under preparation at BNL to demonstrate its feasibility [2, 3]. This experiment aims to cool only one ion bunch stored in RHIC, requiring a high-bunch-charge (up to 5 nC), but low-repetition-rate electron beam. The bunch repetition frequency (78 kHz) is equal to the revolution frequency of ion bunches in RHIC. A short 22 MeV superconducting linac is being built to provide such beam [4]. The linac includes two superconducting RF (SRF) systems and one normal conducting RF system. The two SRF systems are a 112 MHz Quarter Wave Resonator (QWR) SRF photoemission electron gun [5] and a 704 MHz SRF booster cavity cryomodule. The normal conducting RF system comprises two copper bunching cavities [6] to provide velocity modulation for shortening the electron bunches between the two SRF cryomodules. The linac layout is shown in Figure 1. In this paper we describe the SRF and RF systems, report on the project status and test results, and discuss testing and commissioning plans.

112 MHz QWR SRF GUN

A superconducting 112 MHz quarter-wave resonator was developed by collaborative efforts of BNL and Niowave, Inc. [7, 8]. The gun operates at 4.5 K with liquid helium provided from a quiet helium source via the cryomodule cryogenic tower. We expect to achieve the

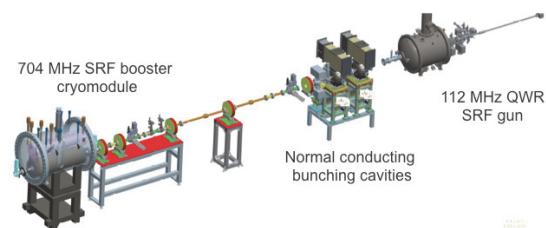


Figure 1: Layout of the CeC PoP linac.

cavity quality factor of 1.8×10^9 . The QWR's center conductor geometry naturally accommodates a half-wavelength choke joint and allows mechanical decoupling of the cathode assembly from the niobium cavity [9]. A low-RF-loss photocathode stalk operates at room temperature. It is hollow, allowing inserting a small photocathode pack via a load lock system. We plan to use multi-alkali (CsK_2Sb or NaK_2Sb) photocathodes illuminated with a green (532 nm) light from a laser to generate the electron beam.

The 112 MHz gun is equipped with a dual-purpose fundamental RF power coupler / fine frequency tuning assembly [9]. The fine frequency tuning with a range of about 3 kHz will be used for remote frequency adjustment. It will complement a larger range (> 78 kHz) tuner, which will be used only for an initial frequency set up. The mechanical design of the fundamental power coupler (FPC) is described elsewhere [10]. A focusing solenoid is placed on top of the FPC close to the cryomodule's beam exit flange.

After the first cryomodule cold test at Niowave in December of 2010 [7], the gun has undergone modifications. A new cryostat was designed and fabricated to be compatible with BNL's safety requirements and to have appropriate interfaces for installation in RHIC tunnel. The modified gun was cold tested again at Niowave in December of 2012 and February of 2013. During the tests we encountered multipacting zones at very low fields, which were processed only after we modified the RF input coupler to increase its coupling. Eventually, the gun reached an accelerating voltage of 0.92 MV, limited by an insufficient radiation shielding of the experimental set up. Figure 2 shows the gun cavity performance during the cold test.

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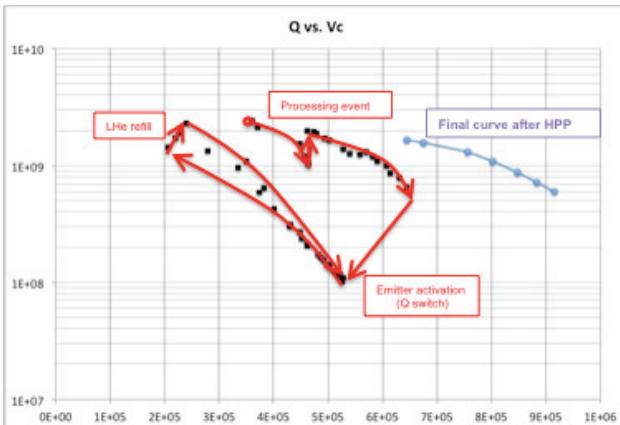


Figure 2: Q vs. V_c plot showing the gun cavity behavior during conditioning and the final curve.

After completion of the cold test, the gun was shipped to BNL and is currently installed in the RHIC tunnel. The commissioning will begin in early 2014.

500 MHz BUNCHING CAVITIES

Two single cell normal conducting cavities operating at 500 MHz will serve as bunching cavities, imprinting a velocity modulation along the electron bunch. The bunch will then shorten as they travel in the drift space between the two SRF cryomodules. The cavities are a contribution to the experiment from the Daresbury Laboratory, UK [6]. Formerly, they were installed in the now decommissioned SRS light source [11]. Figure 3 shows a cavity layout and Table 1 lists its parameters.

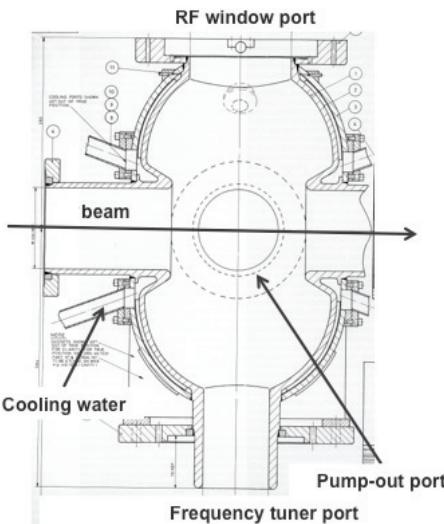


Figure 3: 500 MHz bunching cavity.

The fundamental power coupler is of a waveguide type coupled to the cavity via an aperture (port) at the cavity top, sealed with a disk ceramic window. The coupling is adjusted via moving a reflection plane in the waveguide. The original SRS configuration included a moveable waveguide short, which allowed adjusting coupling for different beam loading. As there will be very small beam

loading in CeC PoP, we will adjust the short position for unity coupling only once – no need for a moveable short. The two cavities will be powered in parallel from an IOT-based RF power amplifier.

The cavities were delivered from Daresbury to BNL in early 2012. They have been particulate-free cleaned and refurbished, vacuum baked. The cavities are installed in the RHIC tunnel and being prepared for high power commissioning.

Table 1: Parameters of the 500 MHz Bunching Cavity

RF frequency	500 MHz
Accelerating voltage	0.3 MV
R/Q	178.5 Ohm
Geometry factor	38.2 Ohm
Cavity Q_0	31,000
Frequency tuning range	1.5 MHz
Cavity wall losses at 0.3 MV	16.3 W
Available RF power from IOT amplifier	50 kW

704 MHz BOOSTER CRYOMODULE

The 704 MHz booster cryomodule will house one 5-cell SRF cavity of the BNL3 shape [12-14]. The booster will deliver an energy gain up to 20 MeV. It will operate at 2 K with an internal superfluid heat exchanger to better isolate the cavity from microphonic noise originated in the cryogenic system. The mechanical design of the cold mass is described elsewhere [15]. A sectional view of the cryomodule is shown in Figure 4. A fundamental RF power coupler (FPC) will be of a coaxial antenna type and will be able to transmit power up to 20 kW CW. The cryomodule design is being finalized and its production will begin soon at Niowave, Inc. with the delivery to BNL scheduled for summer of 2014. Table 2 lists main parameters of the booster system.

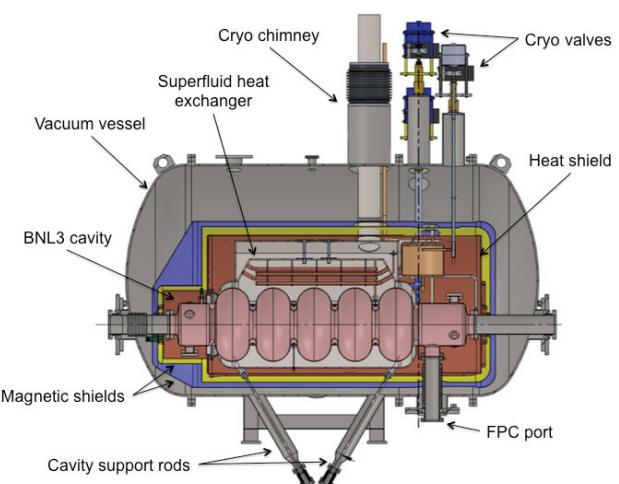


Figure 4: 704 MHz booster cryomodule for CeC PoP.

Two cavities have been fabricated: BNL3-1 by AES, Inc. and BNL3-2 by Niowave, Inc (Figure 5). Both cavities have undergone standard preparation for vertical acceptance testing (bulk BCP, vacuum bake at 600°C for 10 hours, light BCP, HPR). The tests will be performed in October/November of 2013.

Table 2: Parameters of the 704 MHz SRF Booster

RF frequency	704 MHz
Maximum energy gain	20 MeV
R/Q	506 Ohm
Geometry factor	283 Ohm
Cavity Q_0 at 4.5 K	2×10^{10}
Cavity RF losses at 2.0 MV	37 W
Frequency tuning range	78 kHz
Q_{ext} of FPC, min.	2.8×10^7
Available RF power from solid state amplifier	20 kW



Figure 5: BNL3-2 cavity at Niowave, Inc.

SUMMARY

A short 22 MeV linac for the CeC PoP experiment comprises two SRF systems and one normal conducting RF system. The 112 MHz SRF gun cryomodule has been fabricated and tested up to 0.92 MV, limited only by insufficient radiation shielding. It will be re-tested and conditioned to full voltage after installation in the RHIC tunnel is complete in January of 2014. This will be followed immediately by commissioning of the 2 MeV beam line. The beam line will include two single cell normal conducting bunching cavities operating at 500 MHz. The cavities were received from Daresbury in 2012, refurbished, vacuum baked and are currently installed in the RHIC tunnel. Two 704 MHz 5-cell

cavities have been fabricated. One of the cavities will be chosen for integration into the booster cryomodule after both are tested in a vertical cryostat at BNL. The booster cryomodule design is being finalized and its fabrication will begin soon at Niowave. Its delivery to BNL is scheduled for summer of 2014. Installation of the booster cryomodule will complete the CeC PoP linac.

REFERENCES

- [1] V. N. Litvinenko, Y. S. Derbenev, *Phys. Rev. Lett.* **102**, 114801 (2009).
- [2] V. N. Litvinenko et al., "Proof-of-Principle Experiment for FEL-based Coherent electron Cooling," *Proc. PAC'2011*, p. 2064.
- [3] I. Pinayev et al., "Progress with Coherent electron Cooling Proof-of-Principle Experiment," *Proc. IPAC'2013*, p. 1535.
- [4] D. Kayran et al., "SRF Photoinjector for Proof-of-Principle Experiment of Coherent electron Cooling at RHIC," *Proc. IPAC'2012*, p. 622.
- [5] S. Belomestnykh et al., "Superconducting 112 MHz QWR Electron Gun," *Proc. SRF'2011*, p. 223.
- [6] D. M. Dykes and B. Taylor, "Development of a High Power RF System for the Daresbury SRS," *Proc. PAC'1983*, p. 3475.
- [7] S. Belomestnykh et al., "Superconducting 112 MHz QWR Electron Gun," *Proc. SRF'2011*, p. 223.
- [8] S. Belomestnykh et al., "Developing of Superconducting RF Guns at BNL," *Proc. LINAC'2012*, p. 324.
- [9] T. Xin et al., "Design of the Fundamental Power Coupler and Photocathode Inserts for the 112 MHz Superconducting Electron Gun," *Proc. SRF'2011*, p. 83.
- [10] J. C. Brutus et al., "Mechanical Design of 112 MHz SRF Gun FPC for CeC PoP Experiment," WEPAC07, NA-PAC'13.
- [11] http://en.wikipedia.org/wiki/Synchrotron_Radiation_Source
- [12] Wencan Xu, et al., "High current cavity design at BNL," *Nucl. Instr. and Meth. A* **622** (2010) 17-20.
- [13] Wencan Xu, et al., "High Current SRF Cavity Design for SPL and eRHIC," *Proc. PAC'2011*, p. 2589.
- [14] Wencan Xu et al., "Progress on the High-Current 704 MHz Superconducting RF Cavity at BNL," *Proc. IPAC'2012*, p. 2486.
- [15] J. C. Brutus et al., "Mechanical Design of the 704 MHz 5-cell SRF Cavity Cold Mass for CeC PoP Experiment," WEPAC06, NA-PAC'13.