VERTICAL TEST RESULTS OF 704 MHz BNL3 SRF CAVITIES*

Wencan Xu[#,1], S. Belomestnykh[1,2], I. Ben-Zvi[1,2], H. Hahn[1], C. H. Boulware[4], T. L. Grimm[4], D. Holmes[3], G. McIntyre[1], R. Porgueddu[1], R. Than[1], D. Weiss[1]

[1)] Collider-Accelerator Department, Brookhaven National Lab, Upton, NY 11973, USA
[2)] Physics & Astronomy Department, Stony Brook University, Stony Brook, NY 11794, USA
[3)] Advanced Energy System, Inc., Medford, NY 11763, USA
[4)] Niowave, Inc., Lansing, MI 48906, USA

Abstract

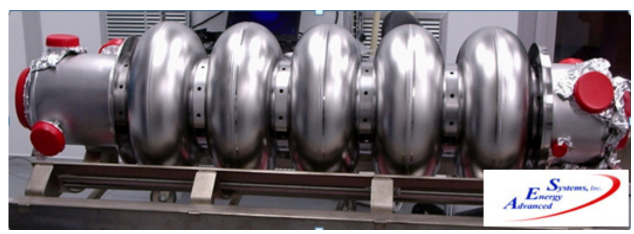
An electron-ion collider (eRHIC) proposed at BNL requires superconducting RF cavities able to support high average beam current. A 5-cell niobium SRF cavity, called BNL3, was designed for a conventional lattice eRHIC design. To avoid inducing emittance degradation and beam-break-up (BBU), the BNL3 cavity was optimized to damp all dangerous higher-order-modes (HOMs) by employing a large beam pipes and coaxial antenna-type couplers. Additionally, the cavity was designed for an acceptable cryogenic load and peak surface RF fields. Two BNL3 cavities have been fabricated and tested at a vertical test facility at BNL. This paper addresses development of the SRF cavities for eRHIC, including SRF cavity design, fabrication and test results.

INTRODUCTION

The Collider-Accelerator Department at BNL is working on the electron-ion collider (eRHIC) [1] R&D and coherent electron cooling [2]. Both machines require high current SRF linacs with extremely good HOM damping to preserve the emittance and have a high BBU threshold. The BNL3 cavity is a 5-cell 704 MHz SRF cavity designed for the high current SRF linacs with strong HOM damping capability. The HOM damping scheme with six coaxial-line HOM dampers allows high real-estate accelerating gradient, which is very important for long linacs. The RF measurements on a copper prototype of the BNL3 cavity verified the HOM damping capability [3]. Two Nb cavities were fabricated, one by AES [4] and one by Niowave [5]. This paper describes the vertical test results of these cavities.

NB BNL3 CAVITY DESIGN

The BNL3 cavity [6] was designed with integration of HOM damping scheme. It employs a concept that uses an enlarged beam pipe to propagate Higher Order Modes (HOMs) but attenuate the fundamental mode, by choosing the diameter of beam-pipe with cutoff frequency slightly lower than the first HOM. The HOMs are damped by three coaxial-line HOM couplers (separated azimuthally by 120º) located on the enlarged beam pipe. The HOM coupler groups at the two ends of the cavity are rotated by 60º relative to each other. Compared to the BNL1 cavity in the R&D ERL at BNL [7], the BNL3 cavity improves the fundamental mode performance, resulting in the *R/Q* and geometry factor increase of about 20% and 30% respectively. By avoiding a room-temperature ferrite damper on the beam pipe, the real-estate gradient of the BNL3 cavity has improved by about 50% as compared with the BNL1 cavity. To reduce the cross-talk between neighboring cavities, tapered sections to a reduced diameter beam pipe are added on both sides of the cavity. Figure 1 shows two Nb cavities made by AES and Niowave. The BNL3-Niowave cavity has become, unintentionally, made 2 cm shorter than the AES cavity.



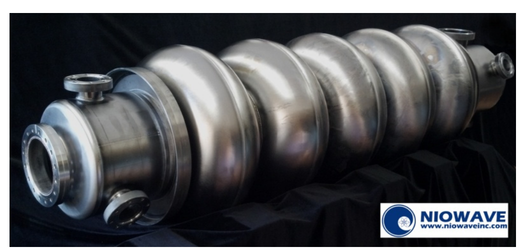


Figure 1: BNL3 cavities made by AES (top) and by Niowave (bottom).

VERTICAL TEST SETUP

Vertical tests of the BNL3 cavities were carried out at the vertical test facility in Bldg 912 at BNL. Figure 2 shows a vertical test setup. The fundamental power coupler (FPC) is located on the short-end side of the cavity. To assure critical coupling during 4 K and 2 K tests, the external Q of the FPC is designed to adjust in a range of 2×10^8 to 1×10^{11}, as is shown in Figure 3. The RF loss on the FPC components is minimized with a copper mask on the cavity flange. The total RF loss in the FPC (cavity flange, inner conductor and outer conductor) is

* This work is supported by Brookhaven Science Associates, LLC under Contract No. DE-AC02-98CH10886 with the U.S. DOE, and Award No. DE-SC0002496 to Stony Brook University with the U.S. DOE.
#wxu@bnl.gov

ISBN 978-3-95450-142-7

about 0.35 W (at the gradient of 20 MV/m). The tuning range of FPC was verified during the vertical tests.

The external Q of the pickup probe was designed to be 5×10^{11}, and measured as 4.36×10^{11} at the BNL3-AES cavity. The external Q of the Niowave's cavity's pickup was surprisingly high, 2.47×10^{15}. The reason, found after the vertical test, is that the pickup tube was 13 mm longer than that of the AES.

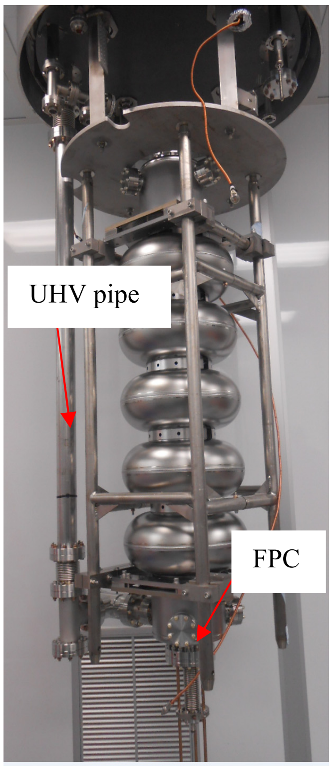


Figure 2: Setup of the BNL3 cavity vertical test.

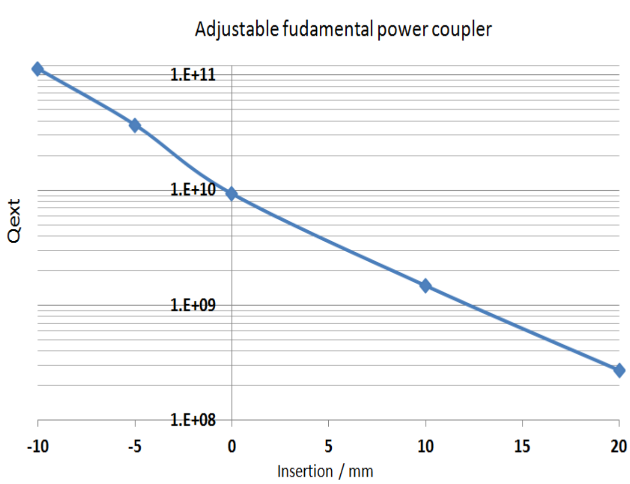


Figure 3: Adjustable fundamental power coupler.

CAVITIES' PREPARATION

The two Nb cavities followed the same post-processing procedure as shown in Figure 4. In short, the steps were: BCP to remove about 110 µm, 600°C heat treatment for 10 Hours, BCP to remove another 20 µm, HPR, and assembly in a cleanroom. Except that the 600°C heat treatment and FPC assembly was done at BNL, all other steps of processing (HPR, BCP) were carried out by AES or Niowave, respectively.

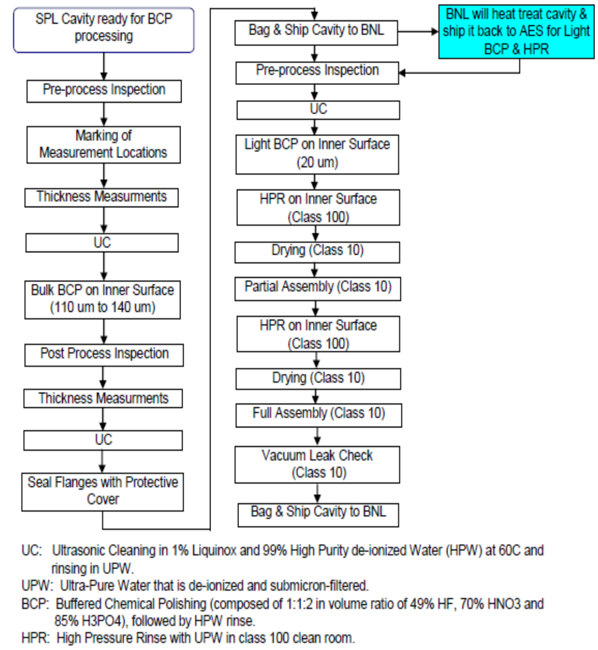


Figure 4: Post-processing procedure of BNL3 cavity.

TEST RESULTS

Figure 5 shows the 2 K test results of the BNL3-AES cavity. BNL3-AES cavity was the first cavity tested at 2 K tests at the BNL vertical test facility. The administrative limit (radiation safety concern) for the first test was set to 20 MV, which limited the BNL3 cavity's gradient at 20 MV/m. Field emission was observed. After conditioning, the field was up to 19.7 MV/m. Notably, the Q_0 value of 3.23×10^{10} at low field indicates a residual resistance is 4.5 nΩ. The performance of the BNL3-AES cavity should improve with additional HPR.

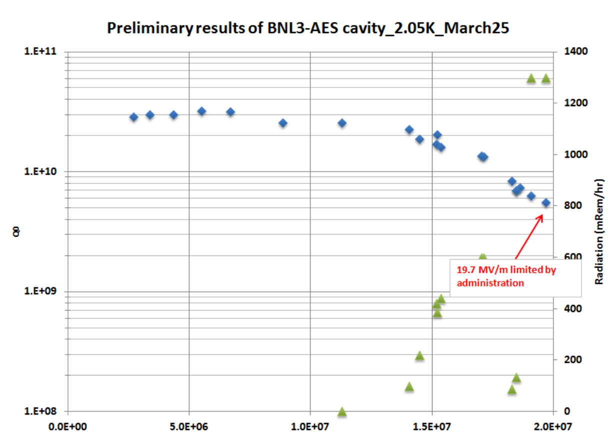


Figure 5: Vertical test results of the BNL3-AES cavity.

The BNL3-Niowave cavity encountered severe field emission during the vertical test, which we were unable to condition. After the cavity was pulled out from the vertical test dewar and inspected, cracks were found in electron beam weld seams at the equators.

The BNL3-AES cavity will be used in the Proof-of-Principle Coherent electron Cooling (PoP CeC) cryomodule [8], which is shown in Figure 6. The cryomodule is being fabricated by Niowave Inc.

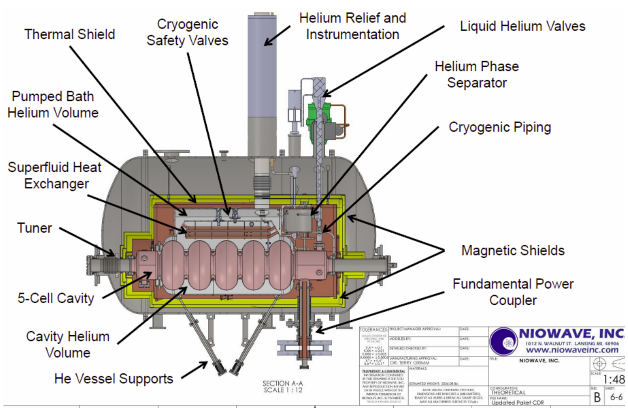


Figure 6: The BNL3-AES cavity in a cryomodule under fabrication at Niowave.

CONCLUSION

The BNL3 cavity was designed for high current SRF linac applications. The design addressed the fundamental mode optimization as done in a conventional cavity design as well as the HOM damping, which is important for high beam current operation. Two Nb BNL3 cavities were fabricated by AES and Niowave. The vertical test results show promising performance of the BNL3-AES cavity, with gradient up to 19.7 MV/m limited by field emission and administrative limit. The BNL3-Niowave cavity performs much worse due to bad electron-beam welding at the equator. The BNL3-AES cavity will be used in the PoP CeC SRF linac.

REFERENCES

[1] eRHIC, http://www.bnl.gov/cad/eRhic/eRHIC_ZDR.asp

[2] V. N. Litvinenko, "Coherent electron cooling-perfect tool for high luminosity RHIC and eRHIC," http://www.cad.bnl.gov/MAC/MAC_08/PDF/15_VL_CAD_MAC_February_2008.pdf

[3] Wencan Xu, et al, "Progress on the high-current 704 MHz superconducting RF cavity at BNL", *Proc. IPAC2012*, pp. 2486-2488.

[4] Advanced Energy Systems, Inc., http://www.aesys.net/

[5] Niowave, Inc., http://www.niowaveinc.com/

[6] Wencan Xu, I. Ben-Zvi, R. Calaga, H. Hahn, E.C. Johnson, J. Kewish, "High current cavity design at BNL", *Nucl. Instr. and Meth. A* **622** (2010) 17-20.

[7] R. Calaga, PhD Thesis, http://www.agsrhichome.bnl.gov/people/rcalaga/thesis.html

[8] J. C. Brutus, et al., "Mechanical design of the 704 MHz 5-cell SRF cavity cold mass for CeC PoP experiment," *Proc. IPAC2014*, pp. 2678-2680.

ISBN 978-3-95450-142-7