RF DESIGN AND OPERATING PERFORMANCE OF THE BNL/AES 1.3 GHZ SINGLE CELL SUPERCONDUCTING RF PHOTOCATHODE ELECTRON GUN *

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Abstract

Over the past several years Advanced Energy Systems and BNL have been collaborating on the development and testing of a fully superconducting photocathode electron gun. Over the past year we have begun to realize significant results which have been published elsewhere [1]. This paper will review the RF design of the gun under test and present results of its performance under various operating conditions. Results for cavity quality factor will be presented for various operating temperatures and cavity field gradients. We will also discuss future plans for testing using this gun.

INTRODUCTION

Over the past several years AES, BNL, and JLAB have been collaborating on SRF electron gun development. One of the projects we have been working on is a 1.3 GHz single cell gun that has recently been producing significant results [1]. The gun cavity was designed and fabricated by AES and has been tested at JLAB and BNL. This paper will briefly review the RF design of the gun including anticipated the Q_0 at various temperatures. We will then review RF performance of the cavity under test both at JLAB and at BNL.

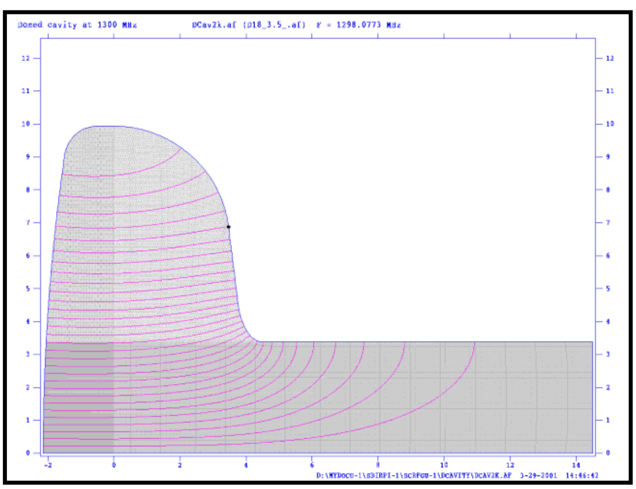

Figure 1, RF Configuration of Single Cell SRF Gun Cavity

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SRF GUN CAVITY RF DESIGN

Figure 2, Two SRF Gun Cavities Fabricated by AES

Cavity Configuration

The SRF gun cavity consists of a single ~half (0.6) cell. Figure 1 shows the field configuration in the cavity as calculated with SUPERFISH. The cavity is fabricated entirely from Nb. It has a single beam pipe port and two additional coupler ports on the beam pipe [2]. Two cavities were fabricated and are shown in figure 2. Do to the configuration of the cavity and cryostat it was impossible to include a permanently mounted valve on the cavity. The standard practice of maintaining the cavity as a sealed unit following cleaning could not be followed. During integration the cavity was open to air in a temporary clean room, installed, and pumped down.

Cavity Design Parameters

Table 1, Cavity RF Parameters

Cavity Frequency	1298.060 MHz
Max Design E Field at Cathode	43.779 MV/m
Max Design E Field at Iris, E_{peak}	45.684 MV/m
Max Design H Field at Wall, H_{peak}	80038.30 A/m or 8.004 mT
Max Design Stored Energy	4.440 Joules
Residual Resistivity used in SUPERFISH (nΩ)	10 nΩ
Q_0 at 2K	7.06621×10^9
Q_0 at 4K	3.29610×10^8

The SRF gun cavity was designed using SUPERFISH, major RF parameters are shown in table 1. The gun cavity was not designed with a rigidly specified operating point. It was designed primarily a proof of principle device and the operating fields are limited by the cleanliness that can be achieved as discussed previously. The residual resistivity of 10 nΩ used in SUPERFISH is a conservative estimate of what should be achievable using normal fabrication practices.

VERTICAL TEST RESULTS

Following fabrication at AES both cavities were cleaned, reassembled, and underwent VTA testing at JLAB. The cavities were originally supplied to JLAB using aluminum input and output coupling probes. These probes were cleaned and installed in the JLAB clean facilities during assembly. They were originally designed for beam operation in which nearly 200W of power would be transmitted by the coupler.

Tests of cavity #1

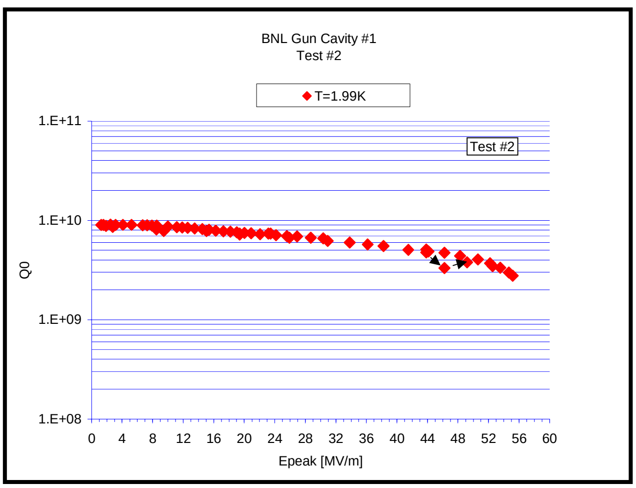

Figure 3, Test Results from Cavity #1 with Nb Coupling Probes.

Initial testing of the first cavity resulted in measured Q_0 values that were somewhat lower that expected. Subsequently new Nb coupling probes were fabricated which were much smaller that the original probes. Following these changes and additional cleaning much better results were achieved. These improved results with cavity #1 are shown in figure 3.

The maximum observed Q_0 of $9\text{x}10^9$ actually exceeds the value calculated by SUPERFISH by almost 30% and corresponds to a residual resistivity of closer to 4 nΩ. In addition, the achieved 55MV/m E_{peak} is well in excess of the "maximum" E_{peak} we had considered in the SUPERFISH design. The cavity was designed to operate best with an E_{peak} of closer to 45 MV/m.

Tests of cavity #2

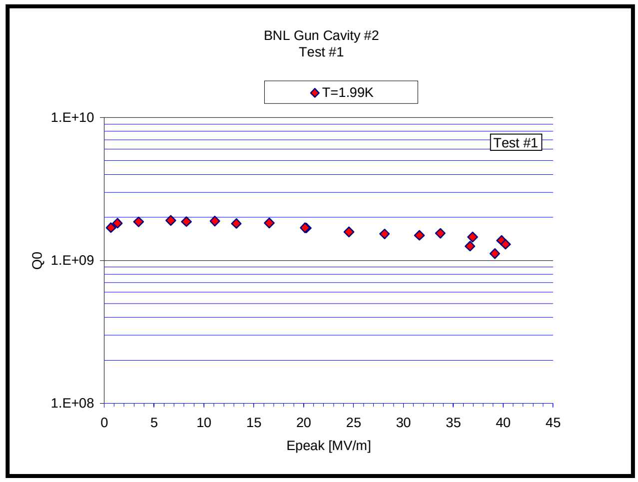

Figure 4, Test Results from Cavity #2 with Aluminum Coupling Probes

The second cavity was tested only with the original aluminum probes, although the output coupling probe was shortened. The results are shown in figure 4. These results are not as good as those achieved with the first cavity. We attribute that to the large aluminum input coupling probe which was retained for this cavity.

4K TEST RESULTS IN OPERATIONAL CRYOSTAT

Following completion of cavity cleaning and VTA testing at JLAB, the cavities were sent back to BNL for installation in the operational cryostat. During integration it was discovered that cavity #1 had developed a 2K leak. It was then decided to use cavity #2 for testing with beam.

Initial Test Results

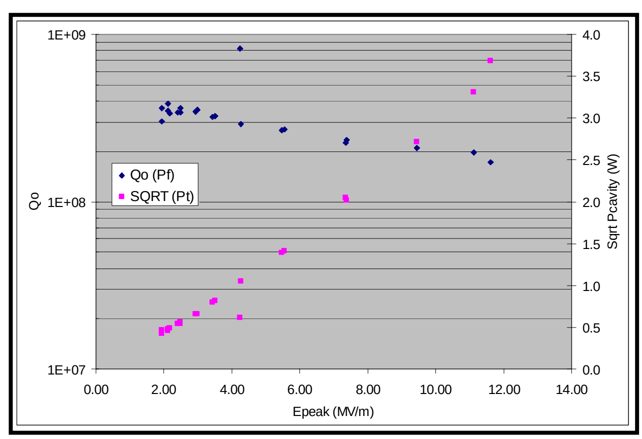

Figure 5, Initial 4K Test Results in Operational Cryostat showing Q_0 and the Square Root of the Power Transmitted to the Cavity

The bulk of the RF testing was performed at 4K since we have a pool boiling LHe system that must be pumped for 2K operation. Figure 5 shows results from our initial test run including measured Q_0 and $\sqrt{P_{cav}}$. Low field Q_0 values are close to the SUPERFISH predicted values. They drop rapidly as the cavity field is turned up, most likely due to the limit on cleanliness imposed by the inability to keep the cavity under vacuum during installation in the cryostat. During this initial test we only reached about an E_{peak} of about 11MV/m.

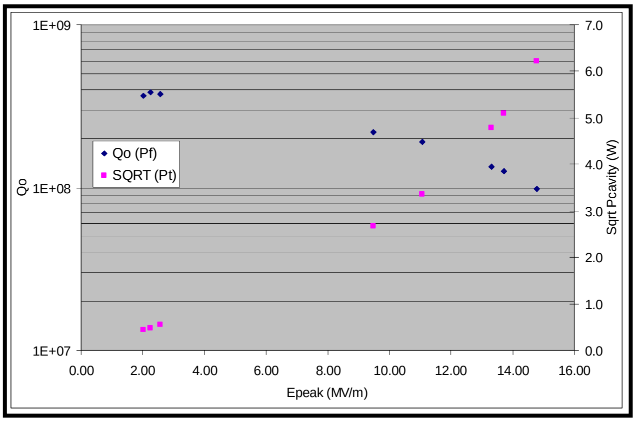

Figure 6, Subsequent 4K Test Results in Operational Cryostat showing Q_0 and the Square Root of the Power Transmitted to the Cavity

Results of Subsequent Testing

During our second test run we pushed the cavity fields slightly higher. Measured Q_0 values were again close to those observed during the first test run. Results from this test are shown in figure 6.

SUB 4K TESTING IN OPERATIONAL CRYOSTAT

Following completion of testing at 4K we began testing at sub 4K by pumping down on the LHe to produce sub-atmospheric LHe. The primary focus was to perform beam tests to measure the quantum efficiency of the Nb. The focus on the primary effort of QE testing and the complications of pumping on the LHe and maintaining temperature limited our ability to collect RF data. Table 2 shows data collected for a series of LHe temperatures.

Table 2, Results from Various Measurement Points showing Temperature, Q_0, and E_{peak}

Temperature (K)	Q_0	E_{peak} (MV/m)
3.5	1.28E+08	13.968
3.4	7.12E+07	14.322
2.8	7.20E+08	4.273
2.7	4.76E+08	7.749
2.7	1.02E+08	14.204
2.2	3.75E+07	11.783
2.1	3.19E+07	11.429
2	2.06E+08	12.079

FUTURE TEST PLANS

Testing of this SRF gun in the current configuration is complete. We are currently undertaking a program to retrofit a removable cathode to this cavity. When this is complete a new series of tests will begin with various advanced cathode materials and configurations.

CONCLUSION

In parallel with experiments to measure the quantum efficiency of a bare Nb cathode in an SRF cavity a series of RF measurements were performed in an operational cryostat. Prior to testing with beam a more detailed characterization of the cavities SRF properties took place in a VTA. Results of the detail characterizations in the VTA compared favorably with expected results. Since this was a proof of principle device, the operation installation was not optimized for SRF cavity use. Results obtained in the operational cryostat were impacted by limitations imposed by the operational configuration and were not as good. We expect that if this cavity were installed in a redesigned cryostat optimized for SRF cavity use, results similar to that achieved in the VTA could be realized.

REFERENCES

[1] Photoemission Studies on BNL/AES All Niobium, Superconducting RF Injector, T. Rao, these proceedings.

[2] The Analysis of Cross Talk in a RF Gun Superconducting cavity, Y Zhao, PAC 2003, Portland Oregon