FIRST TEST RESULTS OF THE BERLINPRO 2-CELL BOOSTER CAVITIES

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Abstract

The bERLinPro Energy Recovery Linac (ERL) is currently being built at Helmholtz-Zentrum Berlin in order to study the physics of operating a high current, 100 mA, 50 MeV ERL utilizing all SRF cavity technology. This machine will utilize three unique SRF cryomodules for the photoinjector, booster and linac cryomodules respectively. The focus of this paper will be on the cavities contained within the booster cryomodule. Here there will be three 2-cell SRF cavities, based on the original design by Cornell University, but optimized to meet the needs of the project. All of the cavity fabrication, processing and testing was carried out at Jefferson Laboratory where 4 cavities were produced and the 3 cavities with the best RF performance will be fitted with helium vessels for installation in the cryomodule. This paper will report on the test results of the cavities as measured in the vertical testing dewar at JLab after fabrication and again after outfitting with the helium vessels.

INTRODUCTION

Helmholtz-Zentrum Berlin (HZB) is building a high average current, 100 mA, Energy Recovery Linac (ERL) at the site in Adlershof, Berlin Germany. The machine is designed using all superconducting RF accelerating cavities in order to demonstrate that the operation of such a machine is possible and to allow for a study of the physics of its operation.[1, 2] The 100 mA average current will be recirculated in a single pass at an energy of 50 MeV in continuous wave (c.w.) operation as shown in figure 1. The ERL is made up of a 1.4 cell SRF photoinjector cryomodule, fitted with a normal conducting multi-alkali (CsK_2Sb) photocathode, a 3 cavity booster cryomodule, the focus of this paper, and a 3 cavity linac cryomodule. More information on the photoinjector can be found in references 3 & 4.[3, 4] The booster cryomodule is designed to accelerate the 2 MeV beam from the photoinjector to 6 MeV for insertion into the recirculation arc and the linac cryomodule. Here the beam will be further accelerated to 50 MeV to make a single pass around the machine and then decelerated to 6 MeV and sent to the beam dump.

The ERL is designed to operate in a number of different modes to fully explore the operational parameter space associated with the recirculation of a high current, low emittance 5 MW beam. In many of these operating modes there is very strong beam loading for the photoinjector and booster cavities which places stringent demands on the fundamental power couplers, a topic which has been expanded upon in other publications and will not be covered here. In short, for the 100 mA operation the photoinjector and the accelerating booster

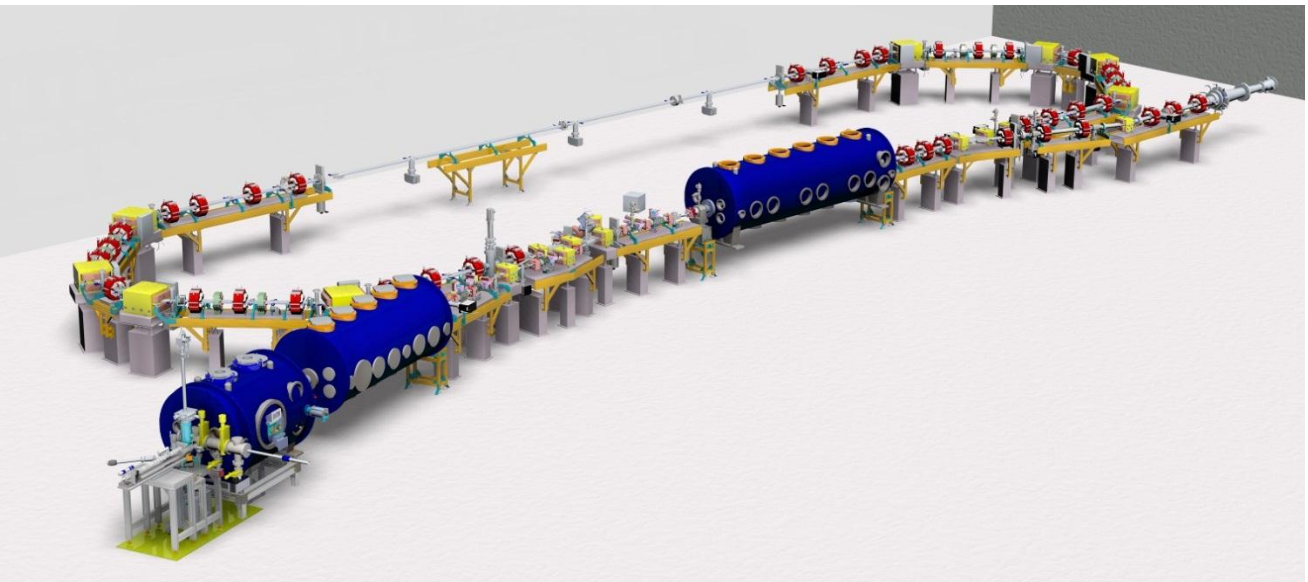

Figure 1: The bERLinPro Energy Recovery Linac machine layout.

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cavities required that 230 kW be delivered to each cavity via a pair of high power coaxial RF couplers.[4-6] The coupler design is based on the coupler for the KEK cERL and has been modified for this project. [7]

The booster cavities are two cell elliptical cavities operating at 1.3 GHz that are based on the Cornell injector design.[6, 8] Three cavities will be installed into the cryomodule where two cavities will be used to accelerate the electron beam from 2 MeV to 6 MeV, while the third cavity will be operated at zero-crossing for bunch compression of the beam prior to injection into the recirculation loop.

The cavity design has been modified to provide the necessary strong coupling to the cavities, loaded Q of 10^5, while minimizing the penetration of the coupler into the beampipe. This was accomplished by tapering the fundamental power coupler port to get the coupler as close to the cavity as possible, while also utilizing a golf tee antenna tip on the coupler. Figure 2 provides a view of the first production cavity while table 1 summarizes the relevant RF parameters for the three cavities.

Table 1: The RF parameters of the booster cavity with two high power RF couplers.

Operating Frequency	1300 MHz
Number of cells	2
E_0–peak field on axis	7, 19, 19 MV/m
Energy gain per cavity	0, 2.1, 2.1 MeV
R/Q	219 Ω
G	261 Ω
E_{peak}/E_{acc}	2.0
B_{peak}/E_{acc}	4.4 mT/(MV/m)
Q_L at nominal coupler position	$1.05\text{x}10^5$
$P_{forward}$ (100 mA operation)	230 kW

CAVITY FABRICATION AND TESTING

Jefferson Laboratory produced 4 booster cavities for the bERLinPro project from 3.125 mm Nb sheet material (RRR>300) and NbTi flanges. The beamline and coupler flanges have a 6” Conflat design while the two field-probe flanges are of the XFEL design. The helium vessel heads were made from Titanium, so a short NbTi transition piece was added to each beampipe to avoid possible contamination of the Nb sheet material with Titanium during welding. The entire cavity was electron beam welded at Jefferson Lab. The four cavities were all fabricated successfully and the overall frequency spread between the four cavities was excellent at less than 30 kHz.

Following the fabrication the cavities were all chemically etched using the 1:1:2 buffered chemical polishing in the JLab closed chemistry cabinet. Following the bulk, 120 μm, chemistry the cavities were heat treated at 600 °C for 10 hours and subsequently given a light 25 μm BCP and high pressure rinse before testing. It should be noted that all cavities except BB002 where HF rinsed after the bulk BCP, and before heat treatment. Each cavity was cooled to 2K and then 1.8K for qualification testing in the VTA at JLab. The

Figure 2: The first bERLinPro booster cavity fabricated at Jefferson Lab.

qualification, Q vs E curves are shown in figure 3 for all four cavities. It should be noted that all cavities far exceeded the design specification during the first vertical test. In addition to the outstanding performance, the pressure sensitivity of the cavities was also measured and compared to simulations of the bare cavity. The simulated df/dp for a 3 mm thick cavity wall is -180 Hz/mbar, in good agreement with the measured average value for the four cavities of -205 Hz/mbar.[9] One cavity, BB001, had a much larger df/dp value than the other three, -240 Hz/mbar vs -194 Hz/mbar (avg of 3), and it was the only cavity fabricated with half cells formed by both Cornell and Jefferson Laboratory, suggesting that the differences in the forming or trimming of the ½ cells may have influenced the material properties and thus the frequency sensitivity. The df/dp of the cavity installed in the helium vessel with the tuner

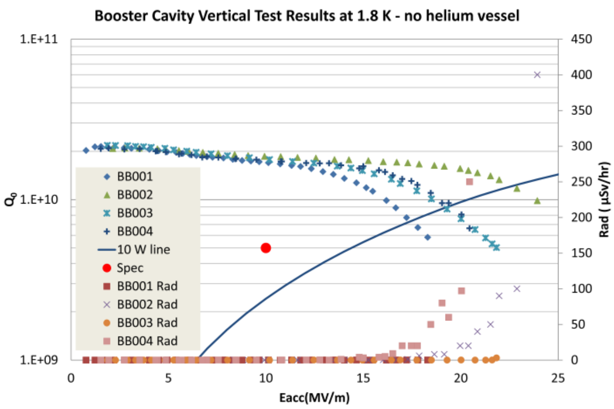

Figure 3: The Q_0 vs Eacc curves for the four booster cavities for the bERLinPro project as measured at 1.8K in the JLab VTA. The design specification for the accelerating cavities is shown by the orange circle and the 10 W dissipated power line is shown by the solid blue line.

attached has been calculated to be ~ 5 Hz/mbar, a value that will be measured soon.

The Lorentz force detuning for the 4 cavities has been measured in the VTA and the average detuning for the 4 cavities was -6.4 Hz/[MV/m]^2. Again, cavity BB001 had a much higher detuning coefficient than the other 3 cavities, -9.2 vs -5.45 Hz/[MV/m]^2 (avg of 3).

Following the vertical testing, the best 3 performing cavities were outfitted with helium vessels, as shown in figure 4a.

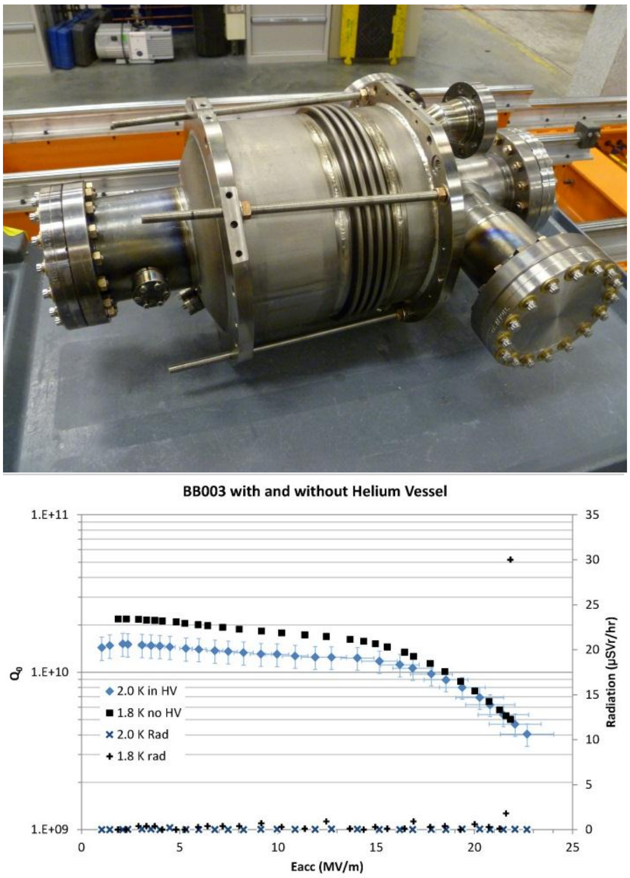

Figure 4A & 4B: The first booster cavity welded into the helium vessel, and the RF test of the cavity in the helium vessel as measured at 2K compared to the bare cavity at 1.8K.

The first cavity test in the helium vessel has been completed, and the performance is nearly identical to the bare cavity test, as shown in figure 4b. It should be noted that the cavity in the HV had a superfluid leak that appeared when pumping to 1.8K. Unfortunately after several attempts to isolate the leak the cavity has still not been tested successfully at 1.8K. Even with these testing challenges, the cavity performance still far exceeds the required operating gradient of 10 MV/m and Q_0 of 5e+9.

BOOSTER CAVITY FUTURE PLANS

After the helium vessels are attached and the cavity tests completed at JLab the cavities will be shipped to HZB for further testing in HoBiCaT, the horizontal test cryostat. The purpose of this set of tests is to equip the cavities with the two high power RF couplers that will be used in bERLinPro and measure the cavity/coupler performance in a configuration that most closely matches the cryomodule. This will allow us to measure the coupling to the cavity as well as perform a set of detailed RF and thermal measurements of the cavity/coupler arrangement. This should provide us with the best understanding of this system prior to building the cryomodule for bERLinPro, and should allow us identify and remedy any issues which are noted before the module is built. The high power couplers should be delivered in the 3rd Quarter of 2016 and the testing in HoBiCaT should begin in early 2017 with the module assembly taking place in the summer of 2017.

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