BERLINPRO BOOSTER CAVITY DESIGN, FABRICATION AND TEST PLANS

A. Burrill#, W. Anders, A. Frahm, F. Göbel, J. Knobloch, A. Neumann, Helmholtz-Zentrum Berlin, Berlin Germany

G. Ciovati, P. Kneisel, L. Turlington, Jefferson Laboratory, Newport News, VA, USA

Abstract

The bERLinPro project, a 100 mA, 50 MeV superconducting RF (SRF) Energy Recovery Linac (ERL) is under construction at Helmholtz-Zentrum Berlin for the purpose of studying the technical challenges and physics of operating a high current, c.w., 1.3 GHz ERL. This machine will utilize three unique SRF cryomodules for the injector, booster and linac module respectively. The booster cryomodule will contain three 2-cell SRF cavities, based on the original design by Cornell University, and will be equipped with twin 115 kW RF power couplers in order to provide the appropriate acceleration to the high current electron beam. This paper will review the status of the fabrication of the 4 booster cavities that have been built for this project by Jefferson Laboratory and look at the challenges presented by the incorporation of fundamental power couplers capable of delivering 115 kW. The test plan for the cavities and couplers will be given along with a brief overview of the cryomodule design.

INTRODUCTION

Helmholtz-Zentrum Berlin (HZB) is in the process of building a high average current Energy Recovery Linac (ERL) at the site in Adlershof, Berlin Germany.[1, 2] The ERL will utilize all superconducting RF cavities for the generation and acceleration of an electron beam of up to 100 mA average current with a beam energy of 50 MeV in continuous wave (c.w.) operation. Figure 1 shows the layout of the ERL, which is made up of a 1.4 cell SRF photoinjector with normal conducting photocathode, a 3 cavity booster cryomodule to increase the low energy beam from 2 MeV to 6 MeV, and a 3 cavity linac cryomodule which will be used to accelerate and decelerate the 6 MeV beam to 50 MeV and then back to 6 MeV again. This ERL is designed to study the operation of a high current, low emittance electron beam from an SRF photoinjector, and is being built in order to explore the operation of such a machine and the challenges that come from recirculation of a 5 MW beam. The ERL will be operated in several different modes which include operation with bunch charges ranging from a few pC to 77 pC and repetition rates that range from low repetition rate burst modes up to c.w. operation at 1.3 GHz, the fundamental mode of the cavities. This wide range of operating conditions will place great demands on many of the components of the ERL, and will test the limits of the SRF cavities, in particular the photoinjector and the booster cavities, due to the high beam loading condition and the greater than 200 kW that needs to be delivered to each cavity.[3-5]

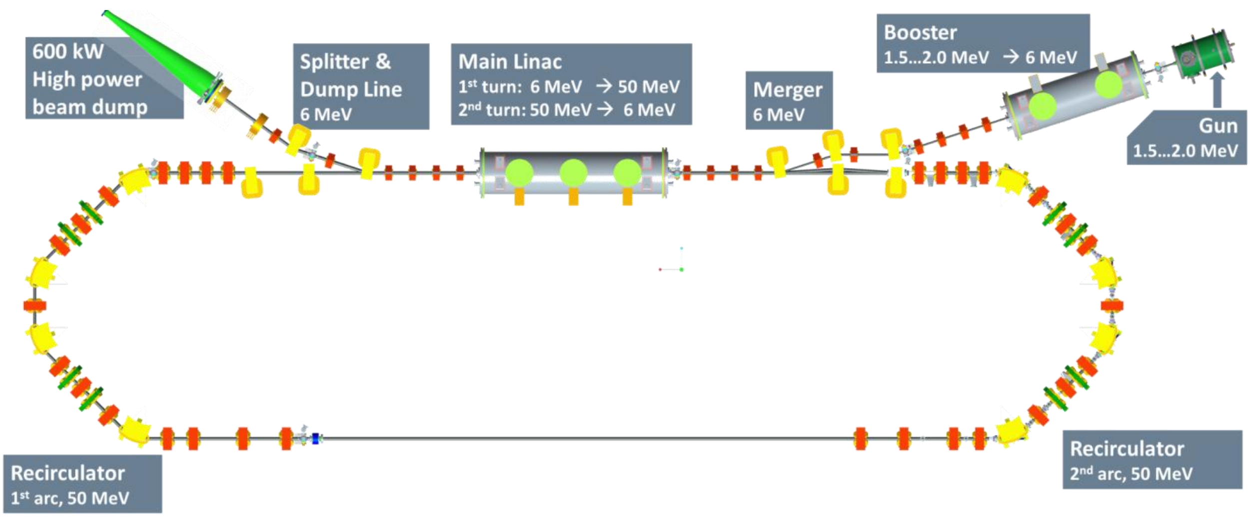

Figure 1: The bERLinPro Energy Recovery Linac machine layout.

#aburrill@helmholtz-berlin.de

BOOSTER CAVITY DESIGN AND FABRICATION

The booster cavities that will be used in the bERLinPro project are two cell elliptical cavities operating at 1.3 GHz.[4] 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. All three cavities will be fitted with two high power RF couplers capable of delivering a total of 230 kW of RF power to each cavity.[6] The coupler design is based on the coupler for the KEK cERL and has been modified for this project.[7]

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
E_{peak}/E_{acc}	2.0
B_{peak}/E_{acc}	4.4 mT/(MV/m)
Q_L at nominal coupler position	1.05x10^5
$P_{forward}$ (100 mA operation)	230 kW

The cavity design is based on the Cornell ERL injector cavity[8], and has been adapted to meet the needs of the project. A model of the cavity is shown in figure 2, along with the first of four cavities that will be produced at Jefferson Lab.

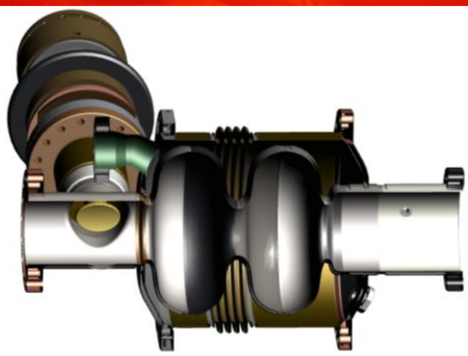

Figure 2: The bERLinPro booster cavity model as well as the first production cavity which was fabricated and JLab.

Three significant changes were made to the cavity design so that it could be used for the bERLinPro ERL Project. These changes were 1) the enlargement of the beampipe where the couplers are mounted, and the subsequent addition of a taper to the FPC port; 2) The addition of a "nose" transition from the cell to this enlarged beampipe; and 3) the use of niobium sheet material to make this beampipe section, instead of manufacturing it from a solid piece of niobium as was done at Cornell. The changes to the geometry of this region were necessary in order to delivery 230 kW of power to the cavity at a loaded Q of 10^5, while minimizing the penetration of the coupler into the beampipe. By adding a "golf-tee" tip to the end of the RF coupler it was possible to obtain a design where the coupler penetration into the beampipe is only 3 mm, thus minimizing the potential for undesirable beam-coupler interactions.

The proximity of the coupler to the cavity, and the larger diameter FPC port required to obtain the desired impedance of the coupler itself resulted in a FPC port flange that appears to be quite far from the cavity, as seen in figure 2. This is a result of the space needed to install the helium vessel head, and blade tuner which will be mounted on each cavity. Additionally it was decided to use standard Conflat® (CF) flange seals on the FPC ports instead of diamond shaped AlMg seals. This was done in order to try and mitigate any anomalous heating issues in the seal area, a subject that can be quite challenging to model, and in the case of the AlMg seal can be very difficult to mitigate after the problem is discovered. By using a CF flange, custom copper gaskets will be fabricated that will produce a smooth, uniform surface on the inside of the coupler, and this should help avoid any unwanted flange heating due to RF losses.

The decision to use sheet niobium for the coupler region instead of ingot material necessitated very careful engineering design work in order to fabricate this section. This, along with the tapered FPC port, took a great deal of effort to design the tooling and fixtures to obtain the correct geometry, and to fabricate these parts. In the Cornell design this coupler section was machined from a solid piece of niobium to provide precise alignment of the couplers to the cavity. However, the overall size of the section was much smaller as the beampipe radius was 70 mm vs 88 mm in our design, and the couplers which were attached to the cavity were designed to deliver 50 kW each, not the 130 kW that the project requires. In our case this necessitates a coupler that is larger, thus requiring more space. The tapered section of the FPC port was needed in order to position the coupler as close to the cavity as possible in order to achieve the desired loaded Q of 10^5, while minimizing the penetration of the coupler into the beampipe.

BOOSTER CAVITY TESTING PLAN

At the time of submission of this paper the cavity fabrication was underway at Jefferson Lab with the second cavity fabrication being completed. The plan for the four cavities following fabrication is to carry out the buffered chemical processing and vertical RF testing at JLab. After successful RF tests, the three best performing cavities will be fitted with helium vessels for use in the booster cryomodule and the fourth cavity will be reserved for further testing. After the helium vessels are attached the cavities will be shipped to HZB for further testing in HoBiCaT, our 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 actual 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. This should all be possible with minimal impact on the overall bERLinPro schedule. The high power couplers should be delivered in the 4th Quarter of 2015 and the testing in HoBiCaT should begin in early 2016 with the module assembly taking place in the summer of 2016.

BOOSTER CRYOMODULE DESIGN

The booster cryomodule for bERLinPro will consist of the 3 aforementioned SRF cavities along with 4 beamline higher order mode absorbers, based on the Cornell design, made from a solid piece of SiC mounted inside of an 80K thermal anchor.[9] Each cavity will be fitted with two layers of magnetic shielding along with a blade tuner. The entire cold mass will be suspended from a 300mm helium gas return pipe. The cryomodule design philosophy, which was adopted from the Cornell Injector cryomodule, is the same as was used for the photoinjector module and will also be used for the linac module. Figure 3 shows a view of the booster cryomodule. By utilizing the same architecture for all of the bERLinPro cryomodules a significant time and cost savings can be realized by allowing for small modifications to fit different style cavities in a general cryomodule configuration. Additionally much of the assembly tooling can be reused.

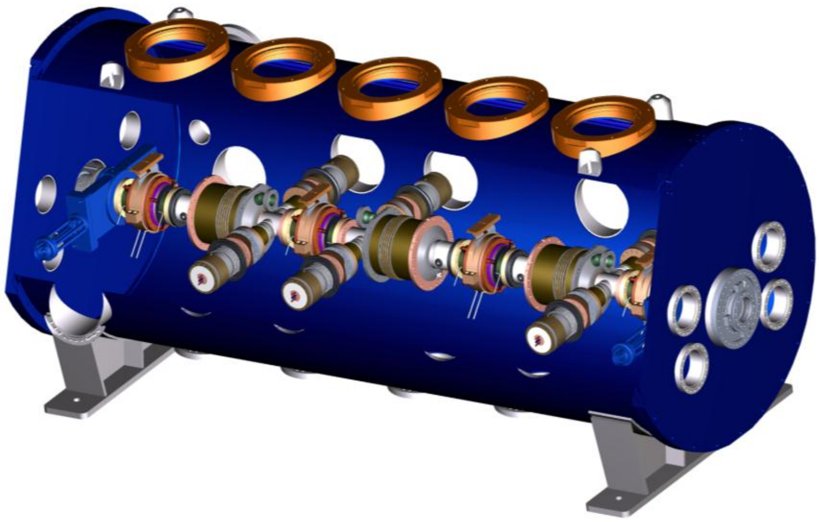

Figure 3: The booster cryomodule for the bERLinPro project.

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