ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-THYBA1

STATUS OF THE CBETA CORNELL-BNL ERL PROTOTYPE

K.E. Deitrick*, N. Banerjee, A.C. Bartnik, J.A. Crittenden, L. Cultrera, J. Dobbins, C.M. Gulliford, G. H. Hoffstaetter, W. Lou, P. Quigley, D. Sagan, K.W. Smolenski, D. Widger, CLASSE, Ithaca, NY, USA
J.S. Berg, S. J. Brooks, R.L. Hulsart, R.J. Michnoff, S. Peggs, D. Trbojevic, Brookhaven National Laboratory, Upton, NY, USA

Abstract

CBETA, the Cornell-BNL ERL Test Accelerator, is an SRF multi-turn ERL which has been commissioned in the one-turn configuration from March to July 2019. During this time, the project has demonstrated an energy acceptance of 1.5 in the FFA arc, high-transmission energy recovery performance, and increased the CBETA energy-recovered maximum average current.

INTRODUCTION

CBETA, the Cornell-BNL Energy recovery linac Test Accelerator, is a superconducting radiofrequency (SRF) multi-turn ERL using a Fixed Field Alternating-gradient (FFA) arc, with the four-turn configuration seen in Fig. 1. CBETA consists of an injector, diagnostic line, main linac cyromodule (MLC), splitter section (SX), FFA arc (FA, TA, ZX, TB, FB), recombination section (RX), and beam stop (DU).

CBETA is designed to have a top energy of 42 to 150 MeV, dependent on the number of turns configured. The electron beam is injected at 6 MeV, before being accelerated up to 150 MeV in four passes; the top energies of the one, two, and three turn configurations are 42, 78, and 114 MeV, respectively.

The FFA arc is made of permanent Halbach magnets and can be divided into five sections. The FA and FB sections consist of repeating FFA cells, while the remaining sections are either transitions (TA and TB) or the straight (ZX). The FFA has a wide energy acceptance - all beams travel through a common pipe. In the SX and RX sections, beams of different energies pass through different lines; SX consists of S1, S2, S3, and S4 lines, with increasing number corresponding to higher beam energy (RX is similarly labeled). The chicanes which make up each SX and RX line have sliding joints between the two center dipoles, which allows for independent path length control at each beam energy [1].

Commissioning of the one-turn configuration, shown in Fig. 2 began in March 2019, with first beam sent through the FFA arc in May 2019. Since then, a significant amount of progress has been achieved, including an energy scan and demonstration of high transmission energy recovery. Figure 3 shows the accelerator enclosure before and after construction, while Fig. 4 shows a top-down view of the straight section of the FFA [2].

* kd324@cornell.edu

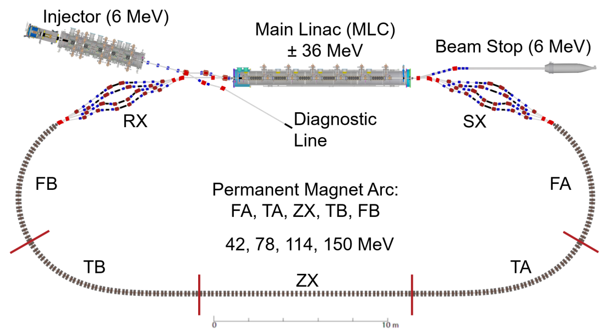

Figure 1: Layout of CBETA in the four-turn configuration; descriptions of the labels can be found in the text.

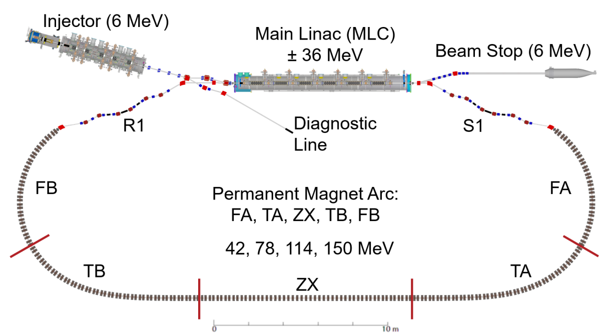

Figure 2: Layout of CBETA in the one-turn configuration; description of the labels can be found in the text.

MOTIVATION

An electron-ion collider (EIC) is one of the highest priorities for nuclear physics; by necessity, this spurs accelerator research and development. There are currently two potential EIC designs - eRHIC at Brookhaven National Laboratory (BNL) and Jefferson Lab EIC (JLEIC) at Thomas Jefferson National Accelerator Facility (TJNAF). In both designs, a high-power, high-average current ERL serves as an electron cooler for the ion beam, thus producing the desired high luminosity [3]. CBETA was originally intended to serve as a prototype demonstration for eRHIC; however, it has similarities to both cooler designs.

Additionally, the design parameters of CBETA push the bounds of state-of-the-art accelerator physics and technologies, particularly for ERLs. Some of the more challenging critical phenomena related to next-generation ERLs and the EIC effort include Beam-Breakup (BBU) instability, halo development and mitigation, and Coherent Synchrotron Radiation (CSR) microbunching and energy spread growth [1].

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-THYBA1

Figure 3: CBETA accelerator enclosure before (top) and after (below) construction for one-turn configuration was finished.

Figure 4: Top-down view of the straight section of the permanent magnet arc.

ENERGY SCAN

In early June, an energy scan was performed by transporting a beam of various energies through the FFA arc; the energy of this beam ranged from 39 to 59 MeV. The betatron phase advance per cell (i.e., the tune per cell) was measured in three sections of the machine and compared to the model at these energies, as shown in Fig. 5. The horizontal and vertical tune per cell was measured in the FA, FB, and ZX sections. In all sections and energies, the measurements demonstrated good agreement with the model. This test reproduced the demonstration of the CBETA FFA acceptance for this energy range first shown during the CBETA Fractional Arc Test [4] for a single arc cell.

ENERGY RECOVERY

In mid-June, the beam was recirculated for the first time; the recirculated beam on the first viewscreen in the beam stop line is shown in Fig. 6, after having passed through the FFA arc. Energy recovery transmission was measured through beam loading in the MLC cavities. Beam loading was determined by measuring the field, forward power, and reflected power of each cavity as a function of average beam current in both non-energy recovery and energy recovery modes.

We began by demonstrating beam loading on the six MLC cavities, sending a beam of up to 1 μA through the MLC and directly into the beam stop, bypassing the FFA arc completely. This was done by accelerating the beam up to 24 MeV with the first 3 cavities and decelerating back down to the injected energy with the last three. A typical example of load deviation, or RF load due to the beam, for both an accelerating and decelerating cavity is shown in Fig. 7. As the cavities were

On Monday June 24, 2019, energy recovery demonstrated through beam loading with a transmission of 87.0% ± 0.6%. Two days later, this was improved to 99.3% ± 0.2%, in part by reducing the bunch charge; the beam loading of each individual cavity is shown in Fig. 8, compared with the load deviation for a non-energy-recovered beam. The load deviation for each cavity while in energy recovery mode is very close to zero for all average beam currents; a load deviation exactly equal to zero would demonstrate perfect energy recovery. On July 1, the transmission had improved to 99.6% ± 0.1%, with a top average current of 8 μA.

HIGHER CURRENT

During early commissioning operations in CBETA, the average beam current in the FFA arc was typically restricted to 5 nA; this was typically achieved by a pulsed beam of 5 pC bunches. After achieving 8 μA, it was decided to spend a week pushing the maximum average current energy recovered. An average beam current of 70 μA with a pulsed beam of 2.5 pC bunches was achieved, seen in Fig. 9, before being stopped due to a cavity trip. Based on this experience, it is anticipated that higher currents of up to 1 mA will not be precluded by radiation after additional shielding is added to the beam stop area. Previously, this injector has demonstrated an average current of 4 mA in this location and 75 mA in a different location with more shielding [5].

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-THYBA1

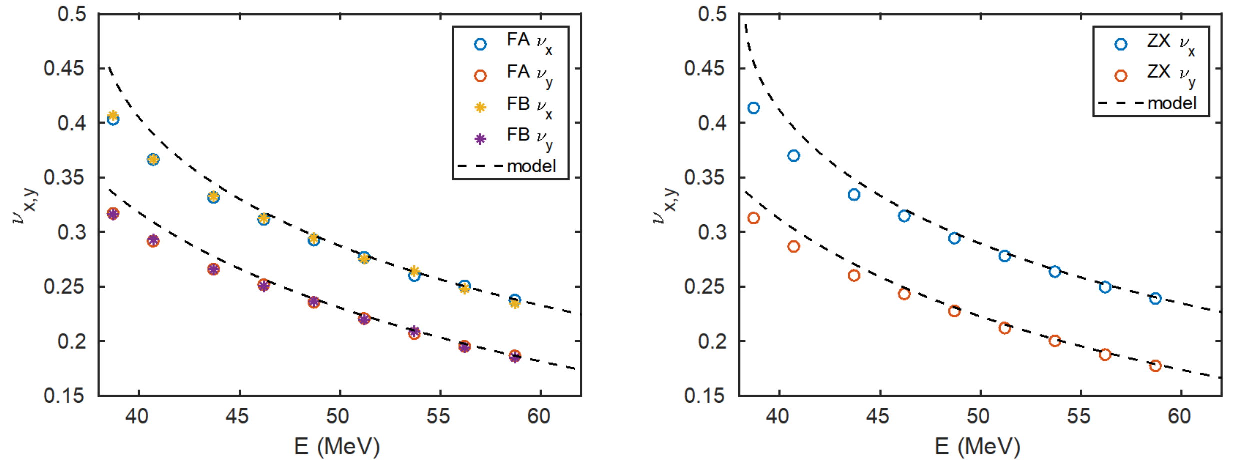

Figure 5: Measured and calculated tunes as a function of beam energy in three different FFA arc sections (FA, FB, ZX).

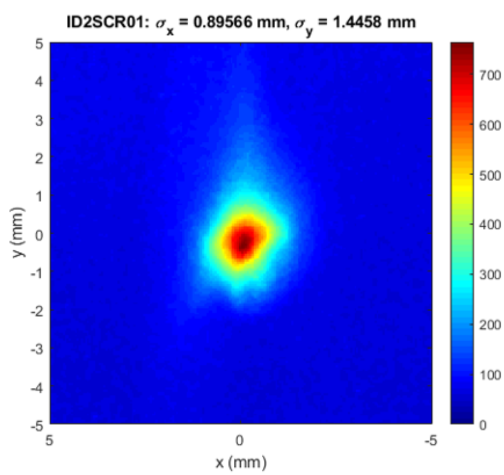

Figure 6: Viewscreen of first recirculated beam on first screen in beam stop line.

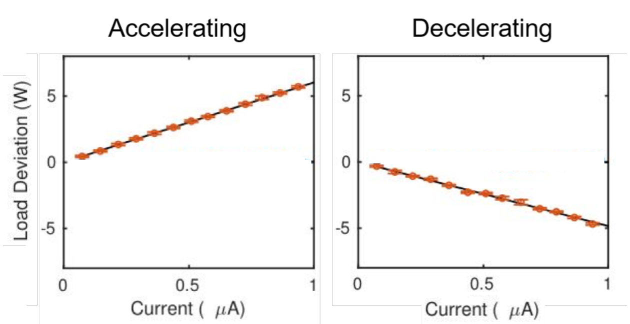

Figure 7: Load deviation (RF load due to beam) for an accelerating and decelerating cavity in non-ER mode as a function of average beam current.

Radiation levels have been a frequent concern, as levels need to be controlled within and without the accelerator enclosure. Inside the enclosure, high levels of radiation can damage the permanent magnets which make the FFA arc. Outside the enclosure, scientists and technicians will be working; personnel protection demands a controlled and minimal amount of radiation in the course of normal operations. However, we believe that the radiation currently observed can be sufficiently minimized by increasing shielding around the beam stop.

CONCLUSION

In less than four months, CBETA went from turning on the gun to achieving high transmission energy recovery in the one-turn configuration. Throughout this commissioning, a number of critical milestones were fulfilled, particularly the energy scan through the entire FFA arc and the high transmission energy recovery. The energy scan demonstrated an energy acceptance of 1.5 through the FFA arc, and energy recovery with greater than 99% transmission was repeatedly demonstrated. As CBETA moves into commissioning the four-turn configuration this fall, we anticipate completion of our remaining milestones and exploration of potential uses for CBETA after commissioning.

ACKNOWLEDGEMENTS

This work was funded by the New York State Energy Research and Development Authority (NYSERDA), National Science Foundation (NSF) award DMR-0807731, and U.S. Department of Energy (U.S. DOE) grant DE-AC02-76SF00515. This project has been supported in part by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy.

ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-THYBA1

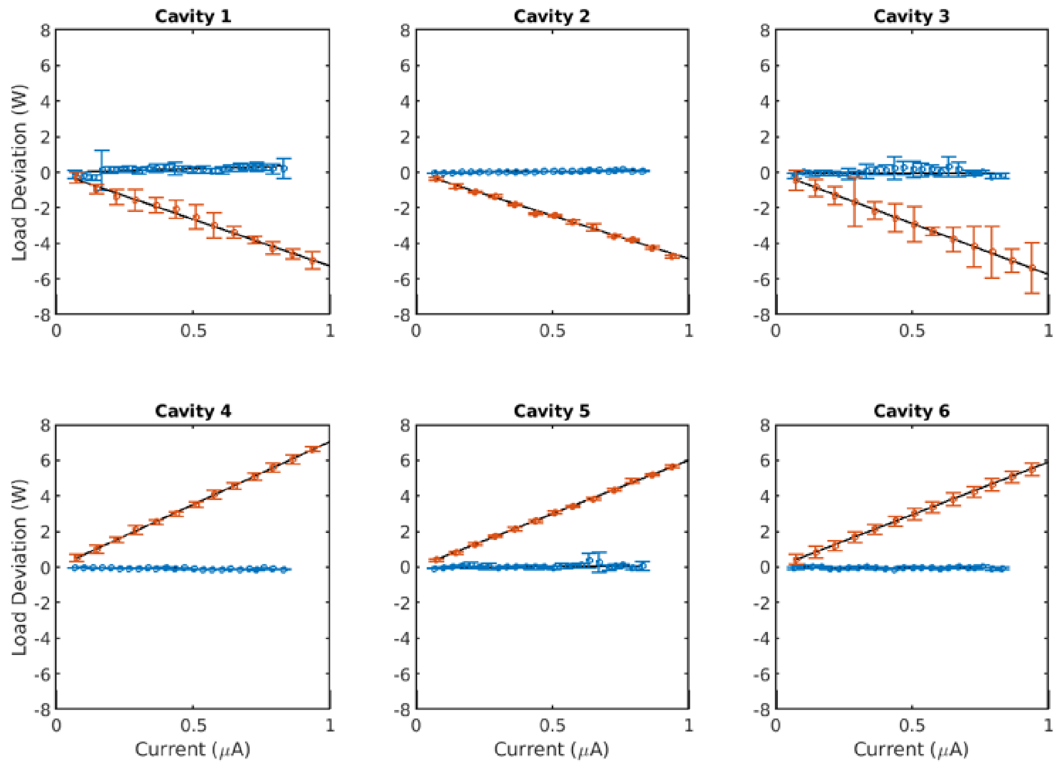

Figure 8: Load deviation (RF load due to beam) on each cavity in the MLC in non-ER mode (orange) and ER mode (blue)as a function of average beam current. The near-zero slope of the blue lines indicates high transmission.

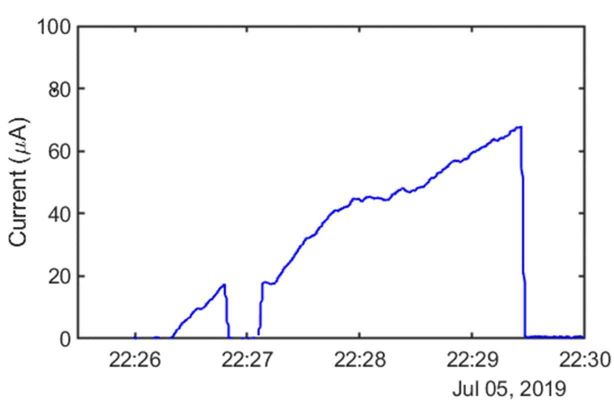

Figure 9: Plot of average beam current in gun during higher current push.

REFERENCES

[1] G. Hoffstaetter *et al.*, “CBETA Design Report, Cornell-BNL ERL Test Accelerator”, BNL, Upton, USA, Rep. BNL-114549-2017-TECH, Jun. 2017.

[2] C.M. Gulliford *et al.*, “CBETA Beam Commissioning Results”, in *Proc. IPAC’19*, Melbourne, Australia, May 2019, pp. 748–750, doi:10.18429/JACoW-IPAC2019-MOPRB076

[3] National Academies of Sciences, Engineering, and Medicine, *An Assessment of U.S. Based Electron-Ion Collider Science*. Washington, DC, USA: The National Academies Press, 2018. doi:10.17226/25171

[4] C. Gulliford *et al.*, “Beam Commissioning Results from the CBETA Fractional Arc Test”, BNL, Upton, USA, Rep. BNL-211713-2019-TECH, Apr. 2019.

[5] B. Dunham *et al.*, “Record high-average current from a high-brightness photoinjector,”*Appl. Phys. Lett.*, vol. 102, no. 3, p. 034105, Jan. 2013. doi:10.1063/1.4789395