UPGRADING THE CEBAF INJECTOR WITH A NEW BOOSTER, HIGHER VOLTAGE GUN, AND HIGHER FINAL ENERGY*

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Abstract

The Continuous Electron Beam Accelerator Facility (CEBAF) accelerator at Jefferson Lab will be upgraded from 6 GeV to 12 GeV in the next few years. To meet the requirement of the new machine and to take the opportunity to improve the beam quality, the CEBAF injector will be upgraded with a higher voltage gun, a new booster, and a new accelerating RF module. The CEBAF injector creates and accelerates three beams at different currents simultaneously. The beams are interleaved, each at one third of the RF frequency, traveling through the same beam line. The higher voltage gun will lower the space charge effects. The new booster with optimized beam dynamics will complete the bunching process and provide initial acceleration matched to the new gun voltage. Using our latest SRF design, the new booster has significantly lower x/y coupling effects that should improve our beam setup and operation for the highly sensitive parity experiments scheduled for the CEBAF's future. Finally, the new accelerating RF module will roughly double the injector final energy to match the rest of the 12 GeV accelerator. In this paper we will provide more detail about this upgrade.

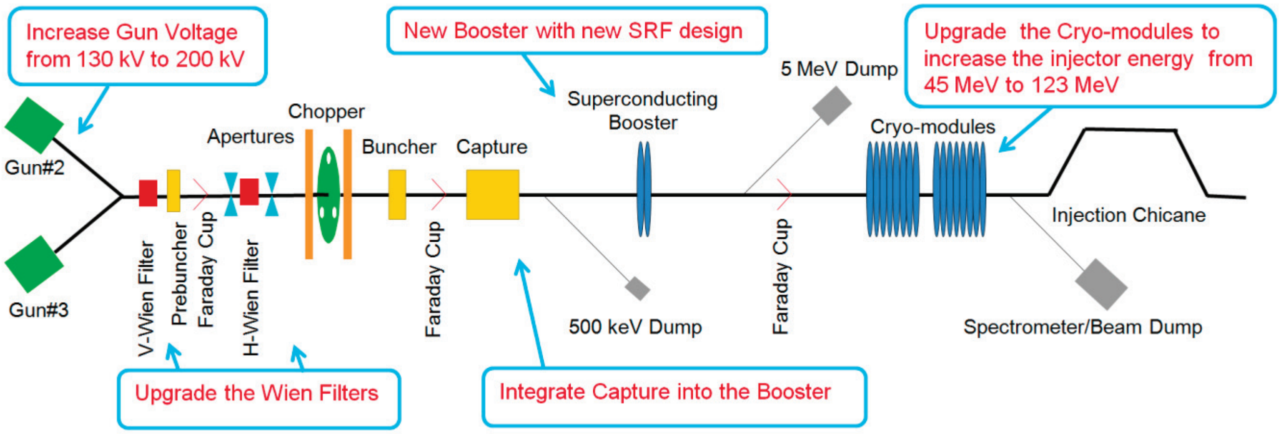
INTRODUCTION

The Jefferson Lab has just finished 6 GeV operations and has started the 12 GeV CEBAF upgrade. In addition to energy upgrade, CEBAF will add a new experimental hall to the existing three experimental halls. The upgraded CEBAF main accelerator will still be a five-pass machine consisting of two parallel accelerating linacs connected by arcs at both ends. The increase in energy is achieved by adding five new accelerating modules in each linac. In addition, the accelerator will still run with three interleaved beams each at one third harmonics supplying beam to three out of four experimental halls. These beams may have different currents, from a few pico-amps to up to 200 μA, and can be directed to the halls at different passes. The three beams are created in the injector part of the machine from a single photocathode gun and traverse a common beam line for bunching, acceleration, and final matching to the CEBAF main accelerator.

In the following sections of this paper we outline the different upgrades planned for the injector. Some of the modeling and simulation results in support of these changes are also presented.

INJECTOR UPGRADES

Different areas of the injector are to be upgraded for the 12GeV CEBAF. Figure 1 depicts these areas on a schematic of the CEBAF injector. First is the gun voltage which will increase from the present 130 kV to 200 kV. The first ten meters after the photocathode gun are used for manipulation of the electron beam spin, for setting up very low beam currents, and for providing the initial bunching to the beam. In this low energy region, the space charge forces can cause the high current beam (200 μA at 499 MHz or 0.4 pC/bunch) to behave quite differently from a low current beam and make running three different beams in the same beam line a more difficult task. In order to lower the space charge effects, the gun operating voltage was previously increased from 100 kV to 130 kV with positive results. The plan is to increase the gun high voltage further to 200 kV.



Increase Gun Voltage from 130 kV to 200 kV

New Booster with new SRF design

Upgrade the Cryo-modules to increase the injector energy from 45 MeV to 123 MeV

Upgrade the Wien Filters

Integrate Capture into the Booster

Figure 1: Schematics of the CEBAF injector showing different areas for upgrade (not drawn to scale).

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An increase in gun voltage would of course require changes to the operating points of other elements in this area. Correctors and solenoids have enough range but the spin manipulators (Wien filters) hardware needs to be upgraded. The RF cavities in the 200 keV beam path are the choppers, the prebuncher, and the buncher, and they have sufficient power to accommodate 200 keV beam. Choppers are single cell deflecting cavities, and the prebuncher and buncher are single cell re-entrant cavities running close to zero phase.

The next RF cavities in line are the capture cavity and the superconducting booster module (also referred to as cryo-unit in other literature). The capture is a beta graded five-cell cavity and is not matched to a 200 keV input beam. The existing booster is based on an older SRF design with significant transverse x/y coupling and deflecting field on the beam axis. The x/y coupling causes emittance growth and degrades the high beam quality needed for the very sensitive parity experiments conducted at CEBAF. In the present injector, skew quadrupoles near the booster are used to correct the x/y coupling. For ease of operation and accommodation for a 200 keV beam, the plan is to eliminate the capture cavity and instead use a new booster to provide the first acceleration of the 200 keV beam.

The last upgrade needed is to increase the final energy of the injector to match the higher energy main CEBAF accelerator. This will be achieved by replacing one of the injector's main accelerating modules with a high power module.

SIMULATIONS

A model of the injector has been developed using ASTRA [1]. It includes the area from the gun to the end of the accelerating cryomodules located about 50 meters from the cathode. The important beam parameters such as bunch length, emittance, energy spread, etc. are all determined in this region. An evolutionary genetic algorithm was implemented to find optimum solution satisfying our beam requirements for various injector hardware configurations [2]. First, we found that the beam brightness is reduced at the higher gun voltage due to the beta mismatch at the start of the capture. With the capture removed from the line, we experimented with different booster designs. In the existing booster, there are two five-cell cavities (5+5). We tried 1+7, one cell cavity followed by a standard CEBAF seven-cell cavity. We also tried 1+1+7, 2+5, and 2+7. Based on the beam bunch length and transverse emittance, the best results were achieved with 2+7 where the two-cell cavity had shorter cells (6.35 cm) and the seven-cell cavity had cells at the standard λ/2 length, about 10 cm (Figure 2). For this case, the energy at the exit of the booster is 6 MeV with a bunch length of 0.13 mm (rms) and normalized transverse emittance of 0.94 μm mrad (rms) [2]. This was chosen as the nominal operation case.

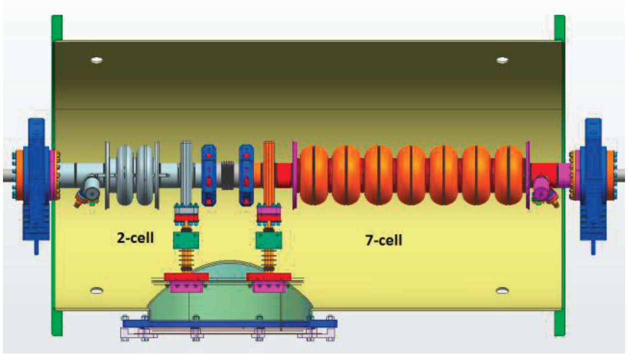

Figure 2: New booster with 2 cell + 7 cell cavities.

The final optimized ASTRA design was successfully tested at different currents to ensure that the design is good for different beams. Figure 3a shows the bunch length from the gun to the start of the accelerating cryomodules. In this figure the prebuncher is located at about z=4 m, the buncher is at z=9 m, and the new booster is at z=12.5 m. It shows that the bunch length of higher current beam increases initially, but eventually all currents have similar bunch lengths at the exit of the booster.

For the next step, the beam parameters obtained from ASTRA simulations were cross-checked with General Particle Tracer (GPT) [3]. The GPT results were almost identical to ASTRA's. Figure 3b is the same as Figure 3a except that it is created using GPT. The slight difference in the final bunch length is due to the fact that we could not precisely match the phases of the RF cavities between ASTRA and GPT. Other beam parameters such as energy spread and emittance were also compared showing good agreement between results of the two codes.

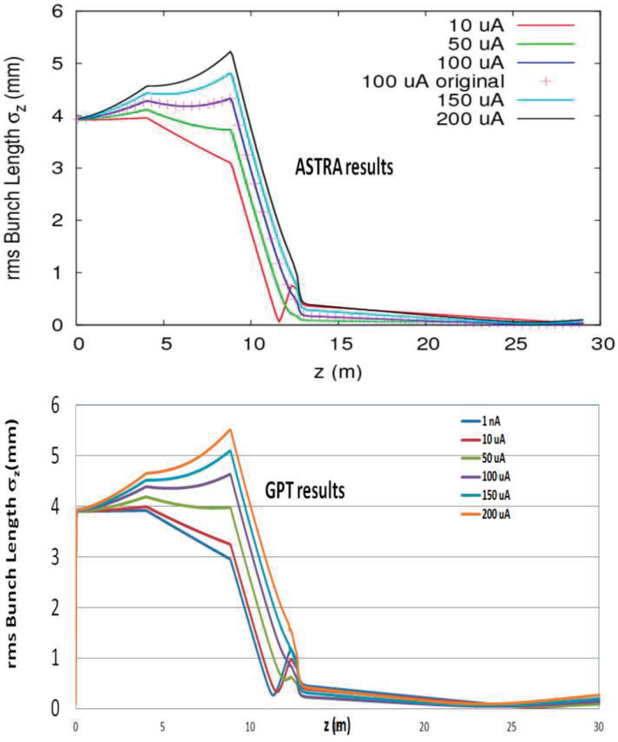

Figure 3a (above) ASTRA results for rms Bunch length along the injector; 3b (below) GPT results for same.

BOOSTER'S RF DESIGN

The existing booster is an early CEBAF design and suffers from two problems: transverse deflecting field and x/y coupling. The transverse fields come from the input couplers. The stub tuner design does not create a symmetric field around the beam axis and has a nonzero field on axis. In addition, the couplers are too close to the cavities making it possible for some of the fields to leak in to the cavities. These problems have been fixed in later CEBAF designs. The x/y coupling is due to the way HOM (higher order mode) dampers couple to the cavities. Their geometry and orientation with respect to the cavity are not optimal. Subsequent HOM geometry designs use coaxial couplers coming in at different angles, and that significantly reduces the x/y coupling. The new booster will incorporate the latest CEBAF design that includes long established solutions to these problems.

The cavities in the new booster were also studied for the possibility of beam breakup, BBU. A 2-dimensional time-domain code called TDBBU, developed in-house, was used for this purpose. The stability was confirmed for the new booster [4].

There is a separate paper in this conference addressing the RF properties of the new booster [5].

INJECTOR ENERGY INCREASE

As mentioned before, in CEBAF the electron beam circulates through the two linacs before ending in the experimental halls. The injector beam starts the first pass through the main CEBAF machine. For proper operation of the CEBAF, the injector energy should maintain certain proportionality to the energy of both linacs; that energy for the 12 GeV CEBAF injector is 123 MeV. The original design for the injector energy was 45 MeV with 5 MeV from the booster and 20 MeV from each cryomodule. Over the years, the injector energy has been pushed higher, up to about 63 MeV, as CEBAF has run at higher energies. However, the present accelerating cryomodules in the injector cannot make 123 MeV required for the 12 GeV upgrade. We have considered re-circulating the beam through two cryomodules [6] but at the end concluded the operational difficulties outweighed the option's cost effectiveness. The second option is to replace one of the cryomodules with a new high gradient cryomodule capable of 100 MeV. The new cryomodule, just like the new booster, would also have very low x/y coupling due to better geometry of its HOM couplers. The next question to answer is the relative order of the new high gradient and old low gradient cryomodules in the beam line. A simulation using ASTRA showed that if the high gradient cavities are placed first where the beam energy is still low, the RF focusing forces are too large for good beam optics. One could lower the gradient on the first few cavities in the new module but that would lower the maximum deliverable injector energy. Therefore, the old lower gradient module will be first in the beam line followed by the new high gradient module. Figure 4 shows the horizontal beam size and energy vs. z through the two accelerating modules centered at about z=33 m and z=42 m..

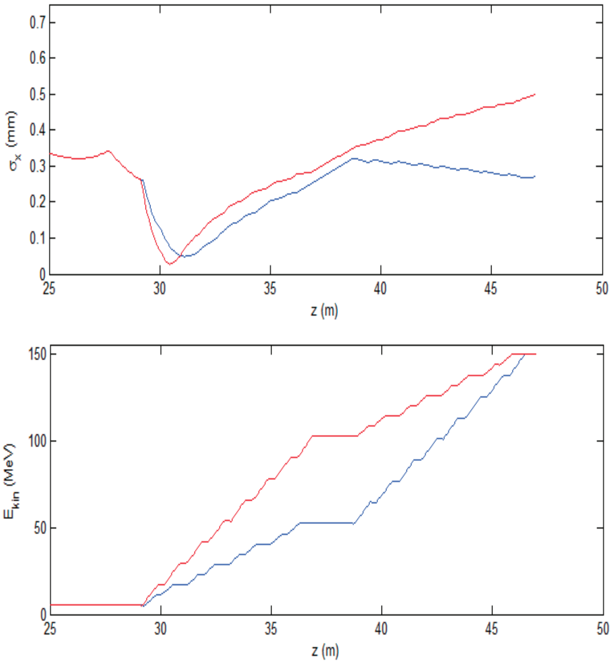

Figure 4: Horizontal rms beam size (above) and beam energy (below) along the two modules. Red curve is high gradient module first. Blue curve is low gradient first.

OUTLOOK

The injector upgrades are scheduled to be completed by 2015 in time for the 12 GeV operations. The plan is to test the new booster with beam in our test facility before installing in the CEBAF injector tunnel. This summer, while we are waiting for construction of cavities and other work, we will have a chance to examine our designs in more detail. One area in need of deeper study is the upgrade of the spin manipulators. We will continue to study our past operational problems and explore new possibilities for improving the injector design.

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