Full Energy Injector Upgrade

Reza Kazimi

The Project Charter

PC 2010-01

JLAB ACCELERATOR DIVISION
FULL ENERGY INJECTOR UPGRADE
Scientific/Technical Project Charter

Project Name (and Number)	Full Energy Injector Upgrade (PC 2010-01)
Project Abstract	Providing improved parity quality beam for the 12GeV CEBAF to meet Nuclear Physics experiment requirements. The entire project scope includes: • To install a higher voltage source and a second Wien filter (*installation and commissioning in progress*). • Design and build an improved cryomodule with accelerating capability of up to 10 MeV with elimination of x/y coupling and more adiabatic damping. • Increase the injector final energy from 45 MeV to 123.5 MeV to achieve the 12 GeV injector energy requirements.
Project Sponsor	Andrew Hutton
Funding Sources	Nuclear Physics Accelerator Ops and AIP
Project Management Team	Reza Kazimi, Arne Freyberger, Geoff Krafft
Lead Organization	SRF Institute, Electron Gun Group, CASA
Supporting Organizations	Accelerator Operations and Experimental Nuclear Physics are the primary stakeholders with improved beam quality and ease of accelerator operation. Engineering and FEL will be called upon for their expertise to provide design and planning guidance.

Scientific/Technical Background	The current injector system was designed for lower final beam energy. The upgrade from 45 to 123.5 MeV is necessary to match the injector energy to the 12 GeV CEBAF. This is achieved by replacing one of the two injector region C25 cryomodules with a refurbished unit capable of reaching 100 MeV. This added to existing C25 cryomodule will attain the final 12 GeV design energy of 123.5 MeV The electron gun voltage increase will produce a more relativistic beam from the start. This will lower the space charge effect for high current beams resulting in better beam quality with lower transverse and longitudinal emittances. The redesigned capture and Cryo-unit will reduce the x/y coupling, achieve better adiabatic damping across the Cryo-unit, and produce a beam up to 10 MeV as opposed to present 5 MeV. The redesign may include changing the cavity sizes to better match the beam velocity, establishing new distances between the elements, and finding different phase and gradient for the cavities.
Project Scope	Within the project scope: • Install a higher voltage source and a second Wien filter (installation and commissioning in progress). • Redesign the ¼ cryomodule for adiabatic acceleration. • Eliminate x/y coupling in ¼ cryomodule. • Find optimum operational gun high voltage, by considering the bunching process, capabilities of the chopper system, and final beam parameters. • Replace a C25 cryomodule with a higher gradient cryomodule. Outside the project scope: • Other considerations such as calculating the change to the helicity properties of the beam or designing higher energy Wien filters and so on will be outside the scope of this work. • Upgrades to diagnostics hardware and software.

February 8, 2010

Objectives	Match injector energy to 12GeV CEBAF, and improve beam quality to meet Nuclear Physics experimental demands for clean parity quality beams.
Deliverables **Do we need to state a 10 MeV requirement for cryounit?**	• Provide robust full-energy injector for 12 GeV era with digital LLRF and RF power for up to 200µA. • Installation and commissioning of higher voltage source and a second Wien filter • New quarter cryounit to eliminate transverse coupling for improved parity quality beam. • Replace C25 cryomodule with a higher gradient cryomodule (R100). • Optimum operational gun voltage specified. • Measure and document realized beam quality improvements in first year of post-installation operation.
Constraints	Competition for engineering and simulation expertise, demands on the SRF Cryomodule production staff, and the 12 GeV Project installation schedule are potential constraints outside the immediate control of the project managers. Achieving the goals of the Full Energy Injector projects before the first 12 GeV operational experiments will rely on the schedule and priorities of the Lab. The replacement of the existing C25 cryomodule with the R100 cryomodule must take place during the May 2012 to April 2013 Scheduled Accelerator Down. The warm RF cavities, controls, and RF power supplies devices, including choppers, pre-buncher, and buncher, will be reused. The capture section may be redesigned as internal to the cryounit; if not, the capture will remain unchanged. New components: • The cryounit will be redesigned and remanufactured. • All cold RF controls will convert to digital.

Assumptions	Use of R100 cryomodule; engineering support for design and construction of cavities and 10MeV quarter cryomodule; integration of cryomodule in SRF production schedule. Engineering and Operations support available for installation and commissioning phase.
Special JLab Commitments	None identified.
Budget	$5 million (not including overhead or escalation for inflation)
Schedule	FY09-FY10 200kV gun and Two-Wien filter (Parity improvements phase) FY10-FY12 R100 cryomodule (Rebuild CM phase) FY10-FY12 New quarter cryounit section (Intermediate Energy Phase)
Controls/Reporting	Combined use of JLab internal annual work planning system and budget reporting should provide adequate oversight of financial progress. Internal review by Project Sponsor and Other Participants will be used to monitor project progress.

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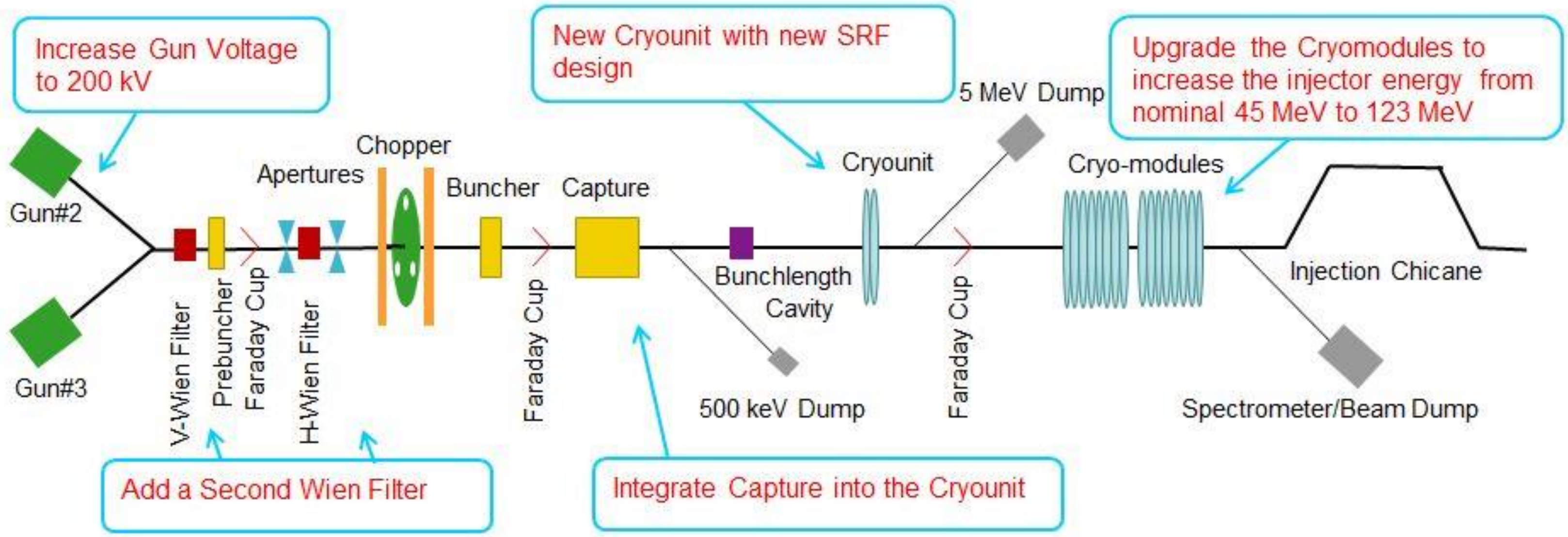
Charter in Graphics

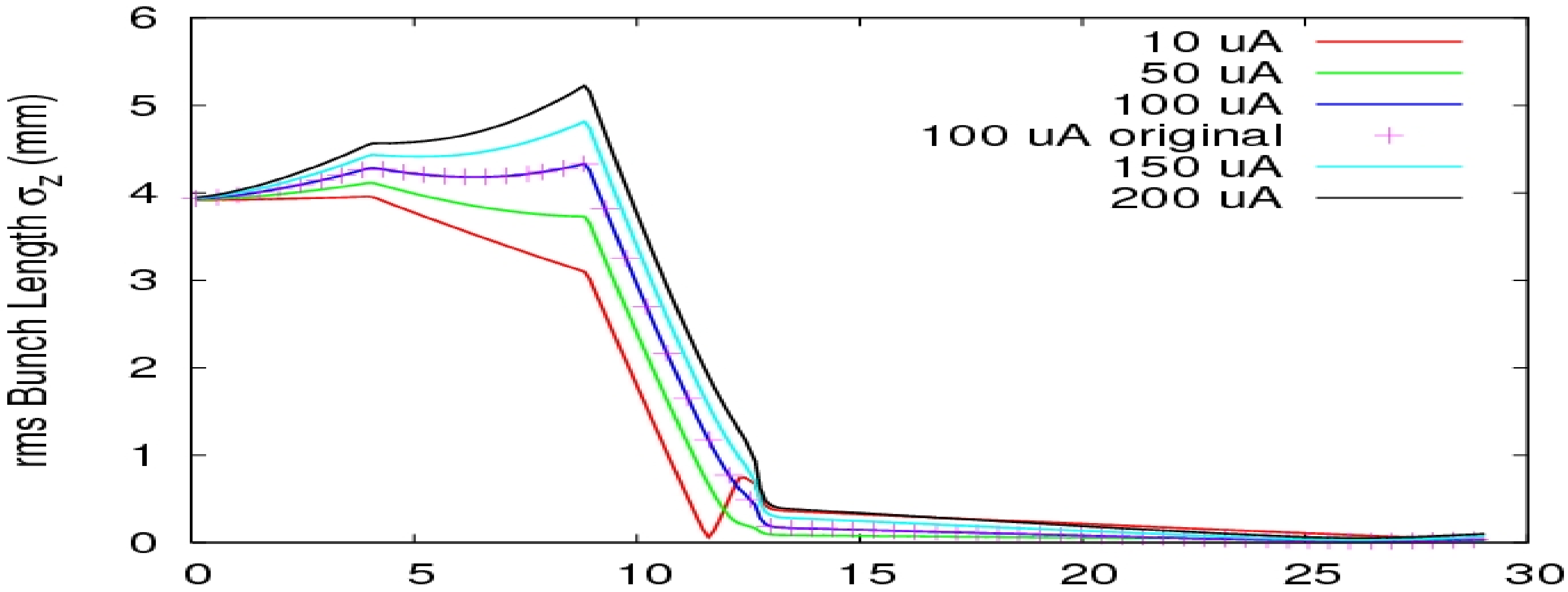


What Has Been Done

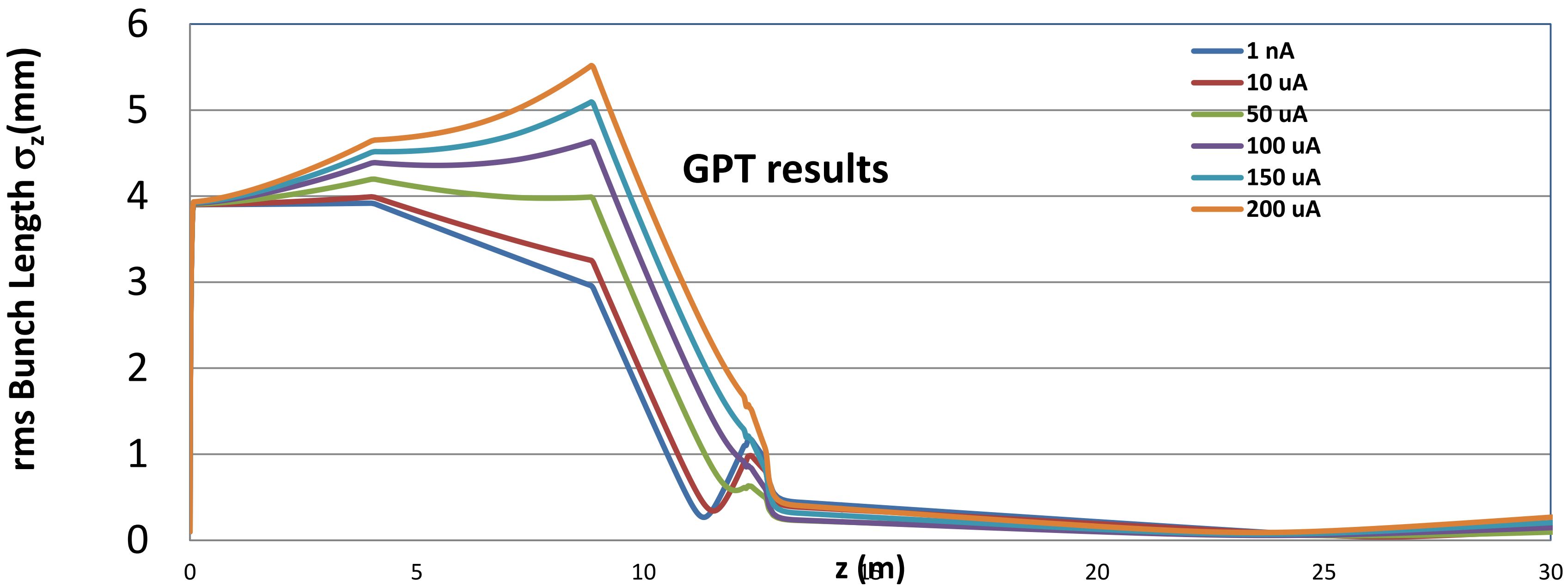
- R100 was installed
- Beam dynamics with 130 keV initial energy was simulated.
- Gun voltage was increased to 130 kV
- The beamline with an initial energy of 130 keV has been setup and a final energy of 125 MeV was demonstrated in the new chicane.
- Beam dynamics calculations and optimization was done for 200 a kV gun. It includes the new quarter cryo-module.
- The RF design of the new quarter was studied extensively FPC issues, HOM, microphonic, and BBU.
- The mechanical design and manufacturing of the new quarter is ongoing.
- All injector RF cavities, with exception of capture, quarter, and zone 3 cavities, are already converted to digital.

The Simulations

- Simulations and optimizations for 200kV gun and the new unit were done using ASTRA and checked by GPT.
- We are struggling with some of the problems that other labs also have. For example what is the distribution of the initial beam, what space charge algorithm should we use.... We will continue to study these issues.
- Some sensitivity studies were done, we plan to do more.



rms Bunch Length σz (mm)
10 uA
50 uA
100 uA
100 uA original
150 uA
200 uA



rms Bunch Length σz(mm)
GPT results
1 nA
10 uA
50 uA
100 uA
150 uA
200 uA
z (m)

Sensitivity

Limits:

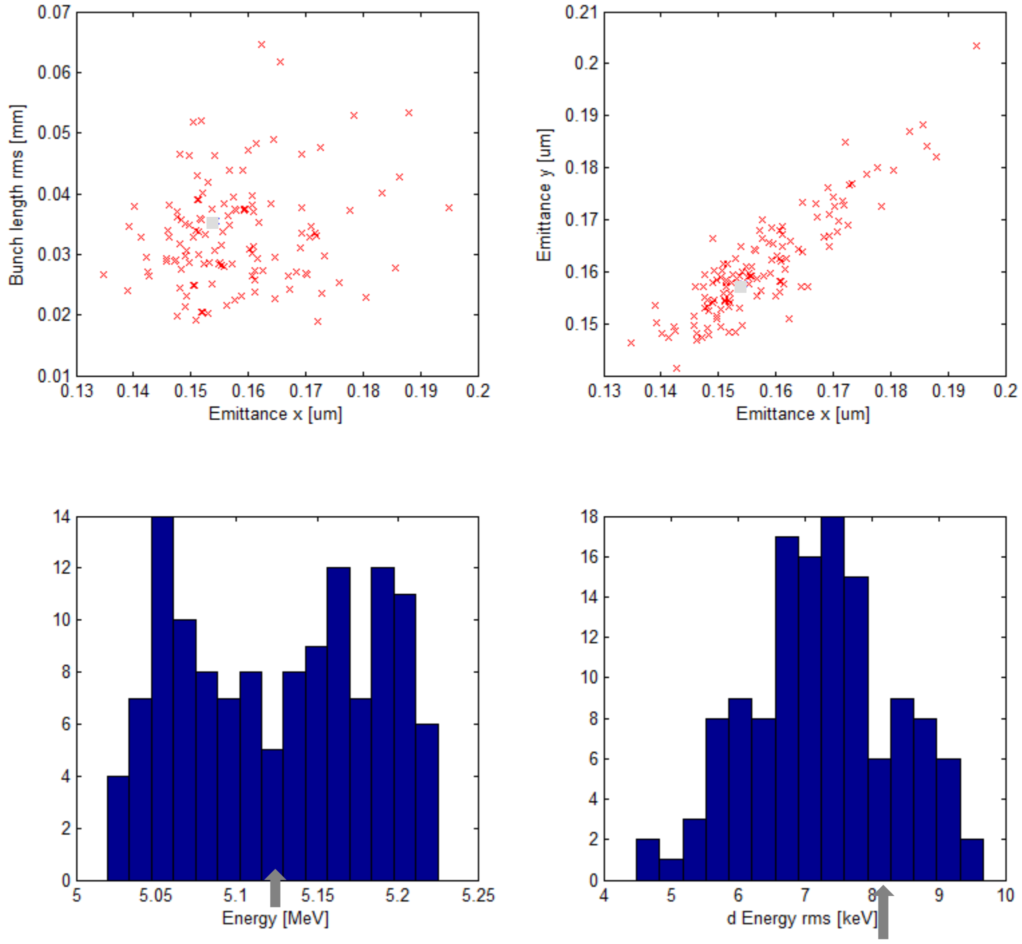
Set points chosen randomly +/-2% around the nominal condition.

Phase in unit +/- 5%

Range:

Bunch length and transverse emittance still within budget

Energy spread and mean energy also reasonable



Next for Simulations

- We need to understand the initial beam distribution. We will continue to study this.
- We intend to repeat the simulations and optimization using the latest GPT genetic algorithm.

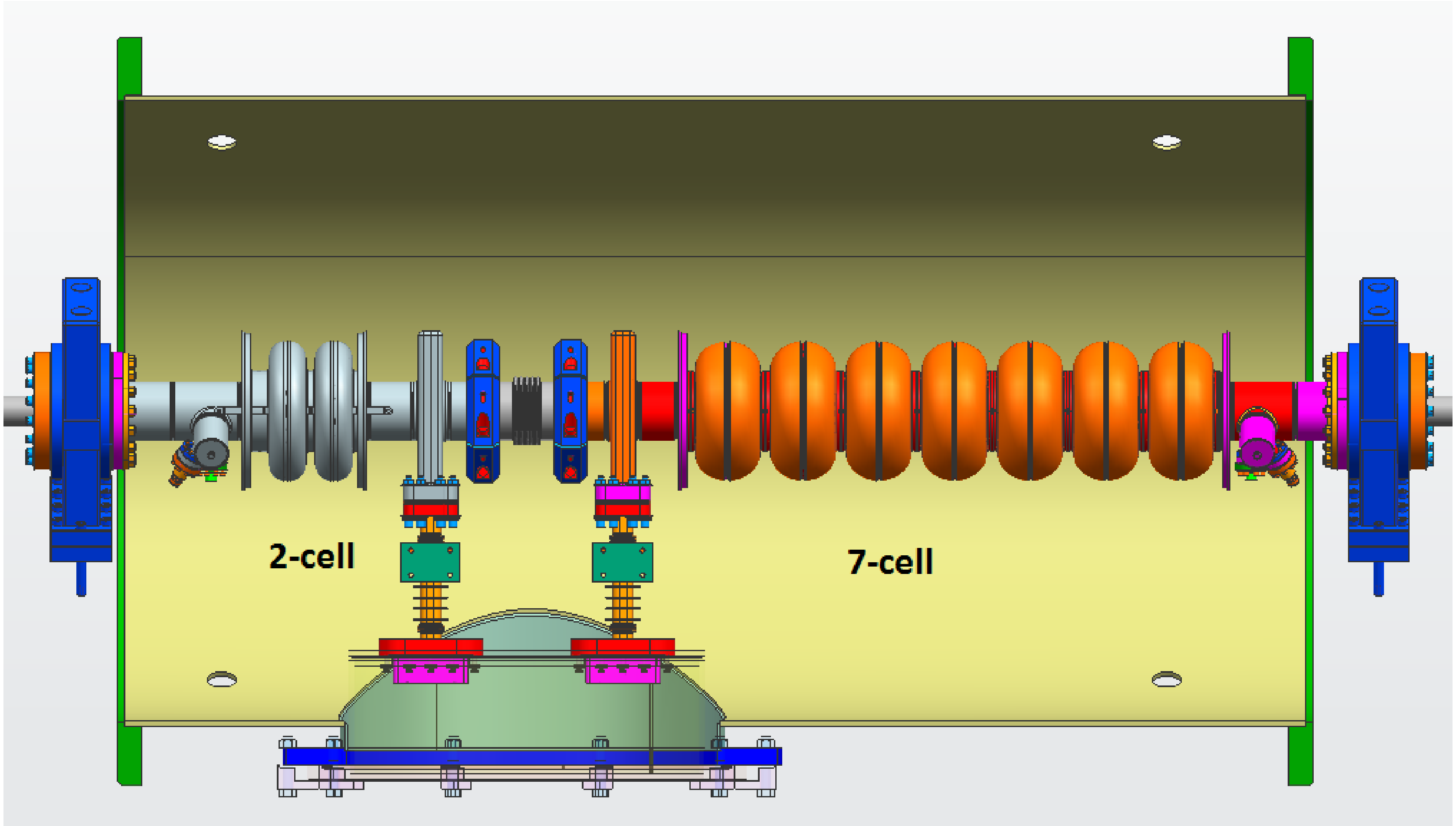
The New Quarter requirements

Parameter	Nominal value (and range)	Verification tech-nique	Stability	Settability	Justification
Beam Energy (end of 2 cell and end of 7 cell)	0.553 MeV and 4.812 MeV	S: Harp in 5MeV spect. M: BPM @ same	within s_E limit	< 0.1%	
s_E	< 5.0 keV **50 keV for 12GeV CEBAF?**	S: Harp in 5MeV spect. M: BPM @ same	< 10%	< 10%	Measurement for all of injector at this point
Bunch length (s_f) at entrance of full modules	< 0.27 degrees	Bunch length cavity	within the 0.27 degree limit	with in the limit	Energy spread req.
Field amplitude in the 2-cell cavity (peak)	4.6 MV/m (2-8 MV/m)		$< 7.8 \cdot 10^{-4}$	$< 7.8 \cdot 10^{-4}$	phase jitter <0.1 degree
Q_0 for 2-cell cavity	8e9				
Q_{ext} for 2-cell cavity	4.8e6				Design for 1 mA
Q_{HOM} for 2-cell cavity	< 1e8				
Phase w.r.t. M. O. the 2-cell cavity	Setup value (-17 deg.)		0.25 degree	0.5 degree	phase jitter <0.1 degree
Rf kick due to 2-cell cavity FPC	< 1e-3 radian				To avoid spherical aberration, the beam should be < 0.5 mm away from the axis at the entrance of the 7-cell cavity.

The New Quarter requirements (2)

Parameter	Nominal value (and range)	Verification technique	Stability	Settability	Justification
Field amplitude 7-cell cavity (peak)	13.2 MV/m (8-26 MV/m)		$< 10^{-3}$	$<10^{-3}$	phase jitter <0.1 degree
Phase w.r.t. M. O. the 7-cell cavity	Setup value (-15 deg.)		0.625 degree	0.625 Degree	phase jitter <0.1 degree
Q_0 for 7-cell cavity	8e9				
Q_{ext} for 7-cell cavity	8e6				Design for 1 mA, add stub tuners for 380mA
Q_{HOM} for 7-cell cavity	< 1e8				
Rf kick due to 7-cell cavity FPC	< 2e-3 radian				Displacement < 1 mm at first 0L corrector/BPM.

The New Booster



Position of the Elements

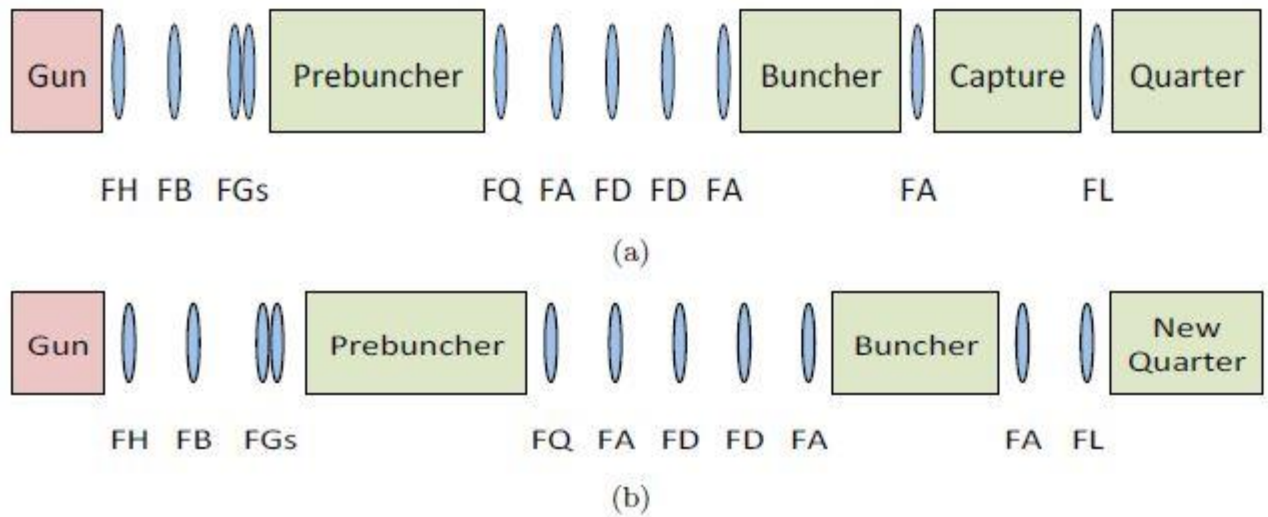


Figure 1: (a) 130 kV injector with "5-5" quarter cryomodule (093) and (b) 200 kV injector with "2-7" quarter cryomodule (078). The 078 model additionally includes quadrupoles downstream of the new quarter (not shown). Neither figure is to scale.

Position of the Elements (2)

Element	Zero location (m)
gun	0
FH (MFH2I01)	0.81509
FB (MFB1I02)	2.20239
first FG center (MFG1I04A)	3.39159
prebuncher	4.03699
FQ (MFQ0I01)	4.72649
FA (MFA0I03)	6.808153
FD (MFD0I04)	7.509828
FD (MFD0I04A)	7.681278
FA (MFA0I05)	8.382953
buncher	8.875078
FA (MFA0I06)	9.14019
FL (MFL0I07)	10.69145

Element	093 zero location (m)		078 zero location (m)
capture	9.805353		not included
quarter cavity 1 (0L02-07)	12.42		12.3177
quarter cavity 2 (0L02-08)	13.16637		13.0643

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.

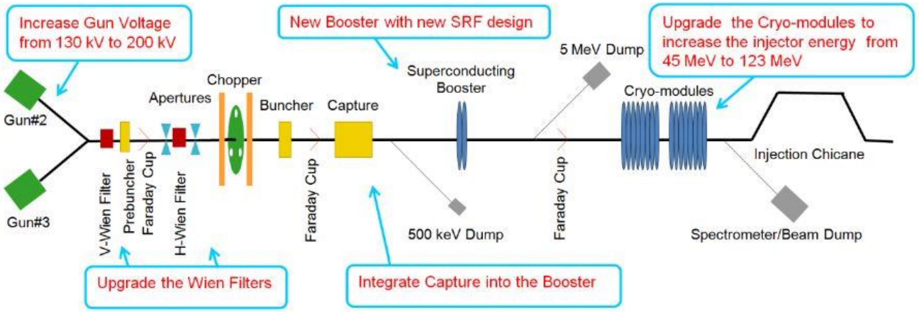

Figure 1: Schematics of the CEBAF injector showing different areas for upgrade (not drawn to scale).

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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 $\lambda/2$ 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.

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.

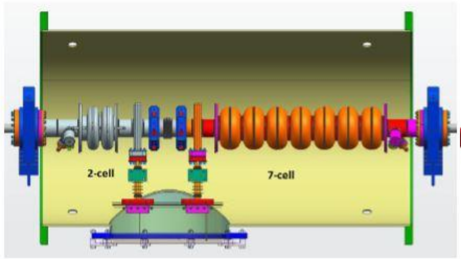

Figure 2: New booster with 2 cell + 7 cell cavities.

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.

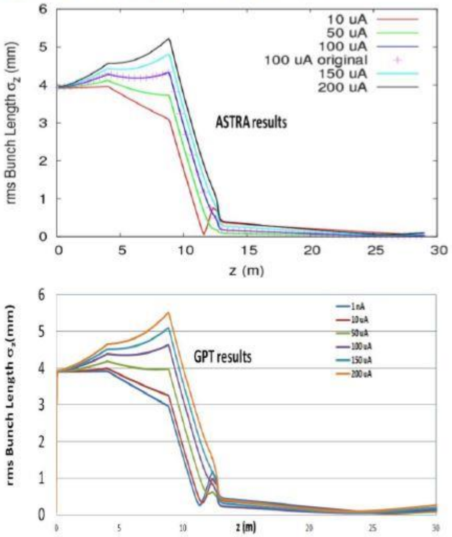

Figure 3a (above) ASTRA results for rms Bunch length along the injector; 3b (below) GPT results for same.

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..

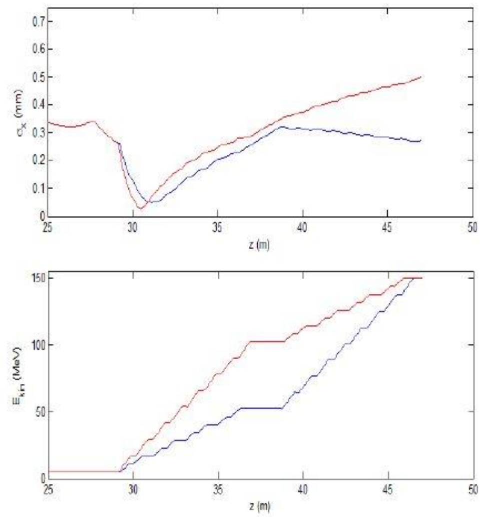

Figure 4: Horizontal rms beam size (above) and beam energy (below) along the two modules. Red curve is high gradient module first. Blue curve is low gradient first.

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.

REFERENCES

[1] K. Floettmann, ASTRA – A space charge Tracking Algorithm, http://www.desy.de/~mpyflo/Astra_dokumentation/
[2] F.E. Hannon et al., "Optimizing the CEBAF Injector for Beam Operation with a Higher Voltage Electron Gun," PAC11, New York, NY.
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[6] R. Kazimi et al., "Injector Options for 12 GeV CEBAF Upgrade," PAC05, Knoxville, TN.

MECHANICAL DESIGN OF A NEW INJECTOR CRYOMODULE 2-CELL CAVITY AT CEBAF*

G. Cheng#, J. Henry, J. Mammosser, R. A. Rimmer, H. Wang, M. Wiseman, S. Yang, JLAB, Newport News, VA 23606, USA

Abstract

As a part of Jefferson Lab's 12 GeV upgrade, a new injector superconducting RF cryomodule is required. This unit consists of a 2-cell and 7-cell cavity, with the latter being refurbished from an existing cavity. The new 2-cell cavity requires electromagnetic design and optimization followed by mechanical design analyses. The electromagnetic design is reported elsewhere. This paper aims to present the procedures and conclusions of the analyses on cavity tuning sensitivity, pressure sensitivity, upset condition pressure induced stresses, and structural vibration frequencies. The purposes of such analyses include: 1) provide reference data for cavity tuner design; 2) examine the structural integrity of the cavity; and 3) evaluate the 2-cell cavity's resistance to microphonics. Design issues such as the location of stiffening rings, effect of tuner stiffness on cavity stress, choice of cavity wall thickness, etc. are investigated by conducting extensive finite element analyses. Progress in fabrication of the 2-cell cavity is also reported.

CEBAF NEW INJECTOR CRYOMODULE CAVITIES

Presently in the injector section of CEBAF there is a "Quarter Cryomodule", which has two 5-cell cavities. With the upgrade of operating energy from 6 GeV to 12 GeV, a few options for the booster cavity layout have been studied [1] and the 2-cell plus 7-cell cavities layout is deemed desirable. The demanded field amplitude for the 7-cell cavity is around 13 MV/m. An economic decision is made to refurbish a low loss JLAB Renascence cryomodule [2] 7-cell cavity, which is capable to provide 17-21 MV/m accelerating field amplitude, to be used in the new Injector Cryomodule. The 2-cell cavity is a new design based on the low loss cavity shape and is expected to provide approximately 4.6 MV/m accelerating field.

2-CELL CAVITY MECHANICAL DESIGN

The 2-cell cavity is made of high RRR fine grain niobium. Basic mechanical properties used in all design analyses are listed in Table 1. Note that the 2-cell cavity niobium material is the same as SNS cavity material and the cavity will be baked at 600 °C for 10 hours. Although niobium is not a "code material", the ASME Boiler & Pressure Vessel Code (BPVC) rules are referenced during the pressure induced stress analysis for the 2-cell cavity. The allowable stresses are determined per BPVC rules, i.e. the allowable stress is the lesser of 2/3 of yield strength or 1/3.5 of the tensile strength.

Among the major cavity mechanical design considerations, the choice of cavity wall thickness is mainly dictated by the upset condition pressure induced stress. The wall thickness also affects the cavity stiffness, tuning and pressure sensitivities, as well as vibration natural frequency. Similar theory applies to the option of using ring shape stiffeners. All mechanical design analyses are performed in ANSYS®. The tuning and pressure sensitivity calculations involve electromagnetic to structural coupled field analysis technique. Each design topics is addressed in a bit more details in the following sections.

Table 1: High RRR Niobium Mechanical Properties [3-5]

Properties	Room Temperature	Cryogenic Temperature
Young's Modulus, psi	1.49e7	1.79e7
Poisson's Ratio	0.38	0.38
Density, lb/in^3	0.31	0.31
Yield Strength, ksi	9.5	83.7
Tensile Strength, ksi	26.3	118.8
Allowable Stress, ksi	6.33	33.9

2-CELL CAVITY STRUCTURAL STRESS

Three loading conditions are examined for the stress state in the 2-cell cavity: 1) 2.2 atm pressure at room temperature (R.T.) simulating pressurization during the cryomodule cool down process, 2) 5 atm pressure at cryogenic temperature (C.T.) simulating pressurization caused by upset conditions [6], and 3) 5 atm pressure with 300 µm tuning displacement. The pressure chamber surrounding the niobium cavity is formed by the interior of a helium vessel and the cavity external surfaces. The helium vessel for this 2-cell cavity is made of stainless steel and has one bellows to mitigate the thermal stress developed during cool down and caused by the mismatch of expansion coefficients between niobium and stainless. The bellows also permits tuning of the cavity without holding up against an otherwise stiff helium vessel. Outside the helium vessel, a scissor-jack tuner is mounted. The helium vessel bellows and tuner are simulated as springs in the cavity stress analysis model. The bellows' longitudinal spring constant is relatively small. The tuner's warm and cold stiffnesses are analysed separately on a preliminary tuner design model.

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#cheng@jlab.org

078 Input File

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- Lmagnetized=F
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- TR_EmitS=F
- PhaseS=T
- T_PhaseS=F
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- RefS=F
- TcheckS=F
- CathodeS=F
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- TRACK_ALL=T
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- ZSTOP=29.02
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- Zphase=10
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- H_min=0.2E-3
- Qbunch=0.2E-3
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- LScan=F
- /

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- Lmirror=T
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- !Nrad=25, Nlong_in=53 !14K
- !Nrad=20, Nlong_in=44
- !Nrad=18, Nlong_in=38 !7K
- !Nrad=13, Nlong_in=28 !4K
- !Nrad=9, Nlong_in=20 !2K
- Nrad=7, Nlong_in=14 !1K
- Cell_var=2.2
- min_grid=0.2E-6
- Max_scale=0.01
- Max_count=1000
- /

- &APERTURE
- LApert=F
- File_Aperture(1)='RAD'
- Ap_Z1(1)=5.37
- Ap_Z2(1)=5.38
- Ap_R(1)=1.2
- File_Aperture(2)='RAD'
- Ap_Z1(2)=6.41
- Ap_Z2(2)=6.42
- Ap_R(2)=1.75
- File_Aperture(3)='RAD'
- Ap_Z1(3)=7.5
- Ap_Z2(3)=7.51
- Ap_R(3)=1
- /
-
- &FEM
- /
- &CAVITY
- LEFieLD=T
- FILE_EFieLD(1)='cebaf-invgun.dat'
- C_smooth(1)=0, C_higher_order(1)=T
- Nue(1)=0
- MaxE(1)=-3.76
- Phi(1)=90
- C_pos(1)=0
-

- FILE_EFieLD(2)='prebuncheronaxis.dat'
- C_smooth(2)=0, C_higher_order(2)=T
- Nue(2)=1.497,
- MaxE(2)=0.02,
- Phi(2)=-87,
- C_pos(2)=4.03699
- FILE_EFieLD(3)='buncheronaxis.dat'
- C_smooth(3)=0, C_higher_order(3)=T
- Nue(3)=1.497,
- MaxE(3)=0.17,
- Phi(3)=-95.5,
- C_pos(3)=8.875078
- FILE_EFieLD(4)='2cell-haipeng.txt'
- C_smooth(4)=0, C_higher_order(4)=F
- Nue(4)=1.497,
- MaxE(4)=5.27,
- Phi(4)=-12.4,
- C_pos(4)=12.3177
-

- FILE_EFieLD(5)='7cell1GHz5.txt'
- C_smooth(5)=0, C_higher_order(5)=T
- Nue(5)=1.497,
- MaxE(5)=13.94,
- Phi(5)=-16.3,
- C_pos(5)=13.0643
- /
- &SOLENOID
- LBFieLd=T
- File_Bfield(1)='fb_profile.txt'
- S_smooth(1)=0, S_higher_order(1)=T
- MaxB(1)=0.0036653
- S_pos(1)=0.81509
- File_Bfield(2)='fb_profile.txt'
- S_smooth(2)=0, S_higher_order(2)=T
- MaxB(2)=0.0124634
- S_pos(2)=2.20239
-

- File_Bfield(3)='fg_profile.txt'
- S_smooth(3)=0, S_higher_order(3)=T
- MaxB(3)=0.0016712
- S_pos(3)=3.39159
- File_Bfield(4)='fq_profile.txt'
- S_smooth(4)=0, S_higher_order(4)=T
- MaxB(4)=0.009912
- S_pos(4)=4.72649
- File_Bfield(5)='fa_profile.txt'
- S_smooth(5)=0, S_higher_order(5)=T
- MaxB(5)=0.0278593
- S_pos(5)=6.808153
- File_Bfield(6)='fa_profile.txt'
- S_smooth(6)=0, S_higher_order(6)=T
- MaxB(6)=0.0208472
- S_pos(6)=7.509828
-

078 Input File

- File_Bfield(7)='fa_profile.txt'
- S_smooth(7)=0, S_higher_order(7)=T
- MaxB(7)=0.0208472
- S_pos(7)=7.681278
- File_Bfield(8)='fa_profile.txt'
- S_smooth(8)=0, S_higher_order(8)=T
- MaxB(8)=0.0258668
- S_pos(8)=8.382953
- File_Bfield(9)='fa_profile.txt'
- S_smooth(9)=0, S_higher_order(9)=T
- MaxB(9)=0.0232715
- S_pos(9)=9.14019
-

- File_Bfield(10)='fa_profile.txt'
- S_smooth(10)=0, S_higher_order(10)=T
- MaxB(10)=0.0232715
- S_pos(10)=10.69145
- /

- &QUADRUPOLE
- Lquad=T
- Q_length(1)=0.15
- Q_type(1)=' '
- Q_grad(1)=0
- Q_pos(1)=15.09
- Q_length(2)=0.15
- Q_type(2)=' '
- Q_grad(2)=-0.006821
- Q_pos(2)=18.13
- Q_length(3)=0.15
- Q_type(3)=' '
- Q_grad(3)=-0.00336
- Q_pos(3)=18.74
- Q_length(4)=0.15
- Q_type(4)=' '
- Q_grad(4)=-0.011579
- Q_pos(4)=23.92
- Q_length(5)=0.15
- Q_type(5)=' '
- Q_grad(5)=0.0479898
- Q_pos(5)=24.56
- Q_length(6)=0.15
- Q_type(6)=' '
- Q_grad(6)=-0.02375
- Q_pos(6)=27.71
- /

Also See

Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA WEP085

BEAM BREAKUP STUDIES FOR NEW CRYO-UNIT*

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Abstract

In this paper, we report the numerical simulations of cumulative beam breakup studies for a new cryo-unit for injector design at Jefferson lab. The system consists of two 1-cell and one 7-cell superconducting RF cavities. The study has been performed using a 2-dimensional time-domain code TDBBU developed in-house. The stability has been confirmed for the present setup of beamline elements with different initial offsets and currents ranging 1 mA - 100 mA.

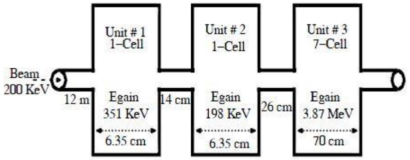

Figure 1: Schematic layout of the system considered in the simulations.

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OPTIMIZING THE CEBAF INJECTOR FOR BEAM OPERATION WITH A HIGHER VOLTAGE ELECTRON GUN

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Abstract

Recent developments in the DC gun technology used at CEBAF have allowed an increase in operational voltage from 100kV to 130kV. In the near future this will be extended further to 200kV with the purchase of a new power supply. The injector components and layout at this time have been designed specifically for 100kV operation. It is anticipated that with an increase in gun voltage and optimization of the layout and components for 200kV operation, that the electron bunch length and beam brightness can be improved upon. This paper explores some upgrade possibilities for a 200kV gun CEBAF injector through beam dynamic simulations.

CEBAF operates in two bunch charge modes simultaneously, one at 0.2pC and the other at 0.004pC. The high and low charge bunches are interleaved and a RF switchyard is used to direct them to the appropriate hall. The beamline setup must therefore work for both cases at the same time. As the setup for the high charge case is more demanding because of the space charge forces involved this was used for the optimization. The setup was then later checked at low charge to ensure beam quality was acceptable.

BENCHMARK EXPERIMENT

The nominal set up of the CEBAF injector with a 130kV gun was modelled using ASTRA [3], which is

RF Design Optimization For New Injector Cryounit at CEBAF*

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Abstract

A new injector superconducting RF (SRF) cryounit with one new 2-cell, β=0.6 cavity plus one refurbished 7-cell, β=0.97, C100 style cavity has been re-designed and optimized for the engineering compatibility of existing module for CEBAF operation. The optimization of 2-cell cavity shape for longitudinal beam dynamic of acceleration from 200keV to 533keV and the minimization of transverse kick due to the waveguide couplers to less than 1 mrad have been considered. Operating at 1497MHz, two cavities has been designed into a same footprint of CEBAF original quarter cryomodule to deliver an injection beam energy of 5MeV in less than 0.27° rms bench length and a maximum energy spread of 5keV.

SPECIFICATION AND LAYOUT

The new SRF booster section of CEBFA injector after the bunching and capture sections have been designed and built recently until the cavity qualifications. This cryounit used to be two 5-cell cavities built within a quarter CEBAF cryomodule. In order to overcome the difficulties during the beam tuning up operation for the CEBAF injection particularly for the new 12GeV machine, this new unit contains a low beta cavity which can handle the low energy electron beam (~200keV) well both in bunching and acceleration processes without blowing emittance up. After electrons reaching nearly relativistic (β≈0.9), acceleration can be taken by new C100 style cavity in high gradient and later β=1 cryomodule. The beam dynamic analysis has been done by using the scheme of Figure 1, i.e. a 2-cell, low β cavity plus a 7-cell, β=0.97 cavity. The RF design including the fundamental power coupler (FPC), HOM damping and frequency tuning has been considered for the engineering compatibility of existing quarter cryomodule and also the beam dynamic requirement. Table 1 lists the design specification derived from the beam dynamic analysis and

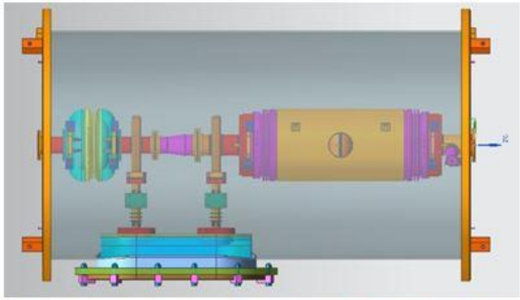

Figure 1: Top view of new injector cryounit, electrons beam runs from the left of 2-cell to the right of 7-cell.

Table 1: Injector Cryounit Design Specification

Cavity type	2-cell	7-cell
End beam energy (MeV)	0.533	5
Peak on axis E field (MV/m) nominal / (range)	4.6 (2-8)	13.2 (8-26)
E_{acc} including TTF (MV/m) nominal / (range)	2.5 (1.1-4.5)	7.0 (4.2-13.8)
Beam voltage V_c (MV) nominal / (range)	0.33 (0.13-0.54)	4.9 (3-10)
Beam current I (mA) nominal/max	0.38/1.0	
Geometry β_g	0.6	0.97
Q_0 at nominal gradient	>8.E9	>8.E9
Off-crest phase setup ϕ_b (deg)	-17	-15
FPC Q_{ext}	6E6	9E6
HOMs Q_{ext}	<1E8	<1E8
FPC RF kick dP_y/P_z (mrad)	<1	<2
Beam energy spread (keV)	-	<5
Beam bunch length (deg)	-	<0.27

The End

- Thanks to all who have contributed to this work.