COMMISSIONING OF THE 123 MeV INJECTOR FOR 12 GeV CEBAF*

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Abstract

The upgrade of CEBAF to 12GeV included modifications to the injector portion of the accelerator. These changes included the doubling of the injection energy and relocation of the final transport elements to accommodate changes in the CEBAF recirculation arcs. This paper will describe the design changes and the modelling of the new 12GeV CEBAF injector. Stray magnetic fields have been a known issue for 6 GeV CEBAF injector, the results of modelling the new 12GeV injector and the resulting changes implemented to mitigate this issue are describe in this paper. The results of beam commissioning of the injector are also presented.

BRIEF HISTORY

The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab was originally designed in the mid-1980s to provide 4 GeV of continuous electron beam. In 2009 the beam energy was successfully raised to 6 GeV after refurbishment of ten 25 MeV capable (C25) cryomodules, and the injector energy was raised from 45 MeV to 67.5 MeV. The injector and other sections of the beamline had the capacity to support 6 GeV operations; therefore, no hardware upgrades were needed for the injector.

As the CEBAF scientific program progressed, in the late-1990s the laboratory and the user community developed a scientific case that demanded a higher energy – the 12 GeV upgrade of CEBAF [1]. Upgrading CEBAF to 12 GeV will enable the generation and study of exotic meson states, contributing to a better understanding of the confinement and the forces within the nuclei. An extended period of 12 GeV installation started in May 2012, and the beam-based commissioning started in October 2013.

HARDWARE CHANGES [2]

There are two major changes in the injector (shown in Fig.1and Fig. 2). The first change is to replace the second full C25 cryomodule just upstream of the injection chicane with a 100 MeV capable one (C100). To meet the energy requirement of the 12 GeV CEBAF and maintain the 0.11284 energy ratio between the injector and the linacs, the injector energy was increased from 67.5 MeV to 123 MeV. In the 6 GeV injector, the beam energy started at 130 keV at the gun increasing to ~500 keV after the capture RF element and ~6 MeV at the exit of the 2-cavity SRF booster. The final injector beam energy (up to 67.5 MeV) was reached after transport through two full C25 type cryomodules. The energy required for the 12 GeV injector is 123 MeV, well beyond the capability of two C25 crymodules. Changing the second cryomodule to C100 provided the extra needed energy gain [3]. C100's maximum achieved energy gain during cryomodule commissioning was 115 MeV satisfying 12 GeV operations with sufficient headroom.

The second change stems from the interference with the new high energy beam recirculation transport arc for the 12 GeV upgrade (at the same elevation). Several injector elements were moved to provide enough physical clearance. The injector full energy spectrometer dipole and diagnostic dump line were shifted upstream by 4.57 m. The bending angle of the spectrometer line was changed for a better physical fit between beamline elements. The start of the injector chicane was moved upstream by 20.51 m. The spacing between the 5-quad matching section in the dispersion free line is shortened due to this change.

With the increased energy, several beam transport and corrector magnets were improved or added. The number of trim magnet girders in the chicane region was increased from 7 to 9 to provide good flexibility for alternative optics that can vary the M_{56} compression in the chicane. Each girder has a beam position monitor (BPM), a horizontal corrector, a vertical corrector, and a quad. Both the spectrometer dipole magnet and the power supply remained unchanged but operate at a higher current, but the power supplies for the four chicane dipoles were upgraded from 10 A to 12 A to match the increased beam momentum. Four of the five matching quads were upgraded from QD type to QB type to provide stronger focusing power. Ten correctors were upgraded from AT type to DB and DJ type to have more steering strength (shown in Table 1).

Table 1: Magnet types and their strength

Type	Quad Strength (Gauss)	Dipole Strength (G-cm)
QD	3250	
QB	14143	
AT		328
DB		926
DJ		981
BT		2826

Beam diagnostics were added. Two viewers and two beam wire scanners were added to the matching section to speed up the optics matching process. A BPM was, also, added to have two BPMs to establish the proper trajectory

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before the spectrometer. The spectrometer is designed to measure absolute momentum to better than 0.1% accuracy.

The existing synchrotron light monitor was upgraded. The analog camera was replaced with a digital camera, and the optics system was replaced. These improvements increased the dynamic range of the imaging system and allow for real-time and post-mortem digital image processing.

The initial goal of the 12 GeV CEBAF was to deliver beam to any three of the four halls simultaneously. Recently the injector laser systems were modified so that all four halls can receive beam simultaneously [4].

MAGNETIC CROSS TALK

As mentioned before, the injector chicane region is in close proximity to the recirculating beamline. Stray fields introduced from magnets and their cables were large enough to steer the lower energy beam in the injector line. The drift portion of the beamline was shielded with Mu-metal. Additionally, the supply and return lines of the cabling were paired and twisted together to further cancel/diminish the stray fields.

PRE-BEAM HOT CHECKOUT

After all the installation work was complete, the beamline components in the tunnel, the design master sheet, the songsheet [5], and the CEBAF Element Database [6] were checked against each other to make sure they agree. Each and all of the beamline components, the radiation shielding, LCW cooling system were checked and verified that they worked. All the RF systems and magnets were powered up. The hot checkout also included the software control system. Some issues were found and corrected in a timely manner.

The SRF group commissioned the C100 cryomodule. The highest average gradient achieved in the new cryomodule is 20.5 MV/m. The electron beam could gain up to 115 MeV from the C100. The average Q_0 is 8E+9.

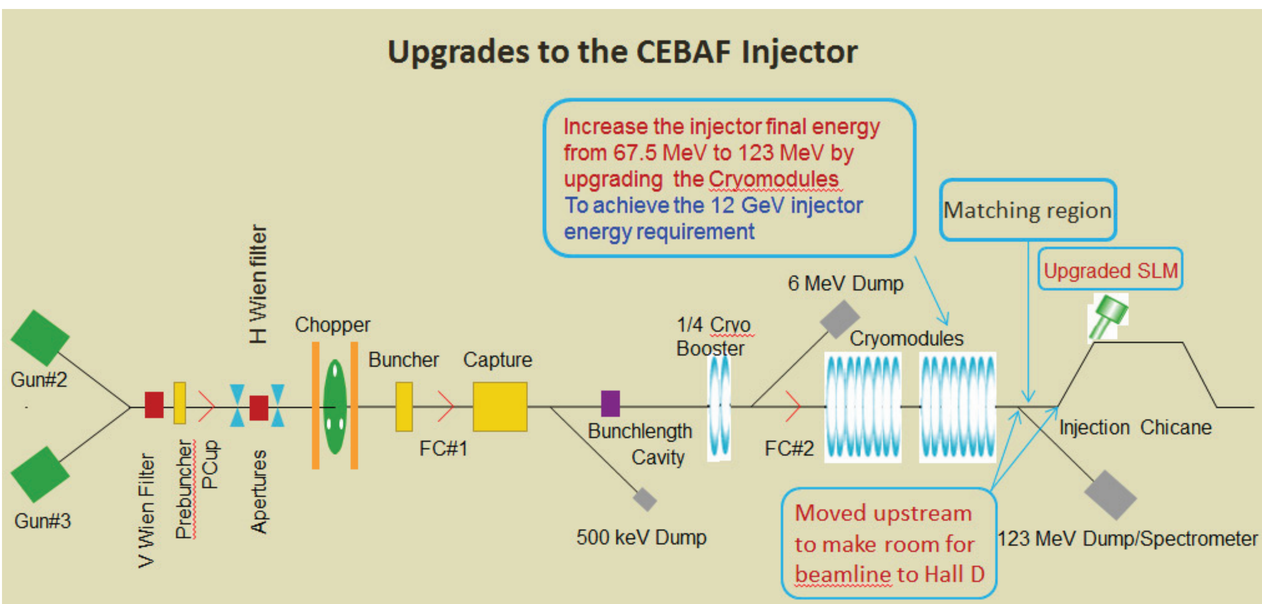

Figure 1: Upgrades make the injector compatible with the 12 GeV CEBAF (not to scale).

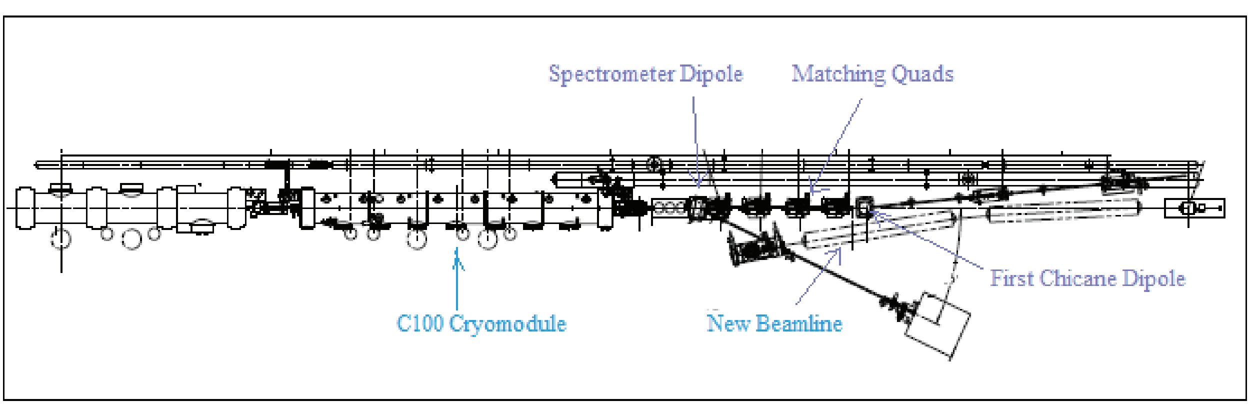

Figure 2: Changes Made in the Injector.

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BEAM-BASED CHECKOUT

A commissioning plan which divided the injector into four beam-termination sections was developed. These sections are 100/500 keV dump, insertable Faraday cup (6 MeV), 0L06 spectrometer dump (123 MeV), and insertable inline dump (123 MeV) segments. For each segment tune beam was established first and then CW beam. At each stage the beam characteristics were measured and adjusted to match the expectation. When cross-checking the General Particle Tracer (GPT) [7] model and a difference orbit measurement tool, two mis-wired BPMs and three solenoids in the early injector section that had wrong polarities were identified and corrected. During the optics check four matching quads were identified to have the wrong polarities; two corrector magnets, an x/y pair, were found to be installed improperly. These errors were corrected. Using the beam the alignment errors were identified and corrected.

The BPMs indicated that the recirculating beam transport magnets still induced beam steering in the chicane segment. Replacing an air-core corrector with a stronger iron-core corrector gave enough strength to counter the effect of the stray fields.

CONCLUSION

The CEBAF injector upgrade has been commissioned to the full design energy, 123 MeV. The identification and correction of issues during this commissioning period were greatly aided by comparison of beam behaviour with model predictions. Modelling and analysis of the stray fields from nearby beamlines led to partial mitigation of the issue. The remaining steering effect of the stray fields was easily compensated by a single point correction.

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