

FIRST DEGRADED BEAMS IN THE CEBAF INJECTOR*

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Abstract

The electron beam degrader in the Continuous Electron Beam Accelerator Facility (CEBAF) injector at Jefferson Lab serves to generate electron beams with transverse emittance over 10x the nominal values, with the ultimate goal of using degraded electron beams to measure machine acceptance. Electron beams are degraded through multiple scattering in thin carbon foils, and maximum transverse emittance is defined through two collimating apertures. The degrader device was installed in late 2024, with commissioning and first beams on degrader targets during the 2025 physics run. We report on first operation of the degrader device.

INTRODUCTION

The transport of large emittance beams in CEBAF is of interest for optimizing beam properties near the limits of the machine acceptance. This is especially important for the Ce^+ BAF positron project [1]; the polarized positron source generates beam emittances that are 1-2 orders of magnitude larger than nominal electron beam emittances in CEBAF, and understanding large emittance beam transport will help to establish limits on positron beam intensity available for the Ce^+ BAF physics program.

The electron beam degrader [2, 3] generates large emittance beams through multiple scattering in thin targets. The targets are sufficiently thin, a fraction of the material radiation length, yielding transverse emittance degradation with immaterial effects on the longitudinal emittance. This allows for independent characterization of transport of large emittance transverse and longitudinal beams.

The degrader device was designed, fabricated, and installed under a Jefferson Lab Laboratory Directed Research and Development (LDRD) project. The device was installed in the CEBAF injector in late 2024 and is shown in Fig. 1. Degrader commissioning began in March 2025, and first degraded beams were generated in June 2025.

DEGRADER COMMISSIONING

Degrader commissioning focused on exercising the various components to demonstrate functionality while ensuring that degrader operation would not be detrimental to normal CEBAF operations. During the commissioning period, vacuum and radiation signals were monitored for degrader operations with beam on target. Radiation monitors in the area are sensitive to gamma and neutron radiation. Vacuum signals were monitored both upstream and downstream of

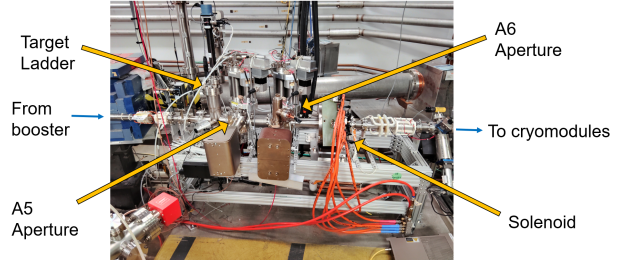


Figure 1: The degrader device as installed in the CEBAF injector.

the degrader device. Beam loss monitors for machine protection also exist upstream and downstream of the degrader. Figure 2 shows radiation signals nearest to the degrader device over a 12 hour period during which beam was first incident on each of the three degrader targets (carbon foils with thicknesses of 1, 5, and 10 μm). Degrader operation is administratively limited to 160 nA of average current; most tests were performed with 8 μA of low duty factor, “tune mode” beam, where beam current is pulsed on for 150 μs at 60 Hz. In the commissioning test, electron beams were incident on degrader targets for about 48 total minutes, and the activity generated during this period is within the range of normal activity during routine physics operation for both vacuum and radiation signals. We note that beam loss monitors nearest to the degrader did not register increased activity during the commissioning tests.

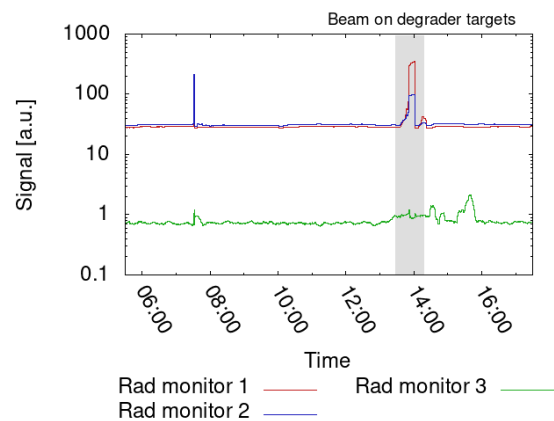


Figure 2: Signals from radiation monitors near the degrader during degrader commissioning. The shaded region indicates time for which beams were incident on degrader targets.

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DEGRADED BEAMS AT 6.7 MeV/c

Figures 3, 4, and 5 show undegraded and degraded beams from 1 μm and 10 μm thick degrader targets on the first viewer downstream of the degrader device, respectively. The degrader solenoid MPT0L02 was unpowered and the two collimating apertures, denoted A5 and A6, were not inserted. The degraded beams are clearly larger in size than the nominal, undegraded beam, with lower overall beam brightness due to the induced angular spread from multiple scattering. We also note that the electron beam current was increased for the image of the degraded beam from the 10 μm thick target for ease of viewing.

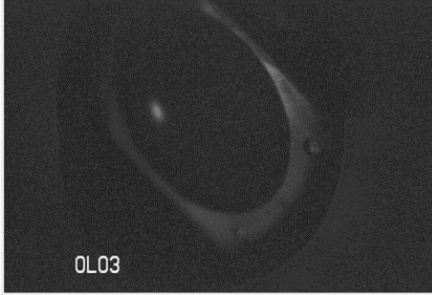


Figure 3: Nominal electron beam on viewer ITV0L03.

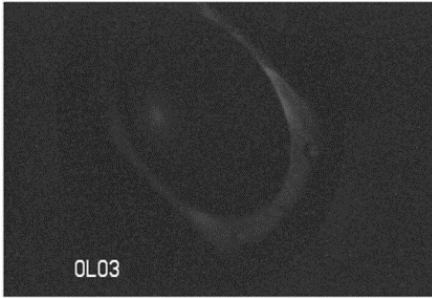


Figure 4: Degraded electron beam from 1 μm thick target.

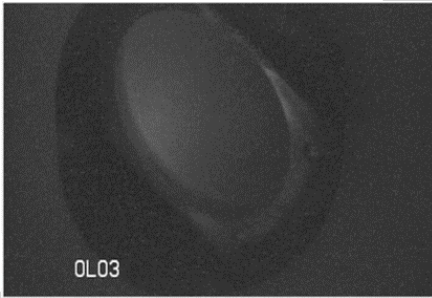


Figure 5: Degraded electron beam from 10 μm thick target.

Degraded beam emittance characterization at 6.7 MeV/c was challenging for several reasons. The only diagnostic “harp” wire-scanner device for beam size measurement in this region of the CEBAF injector was not operational during the run. Attempts were made to use viewers for beam size measurements needed for conventional quadrupole scans, but this proved to be difficult due to insufficient resolution of the viewer and camera system and latency in the view screen material. An additional complication for this method was

in the response of the degrader solenoid MPT0L02, which could not focus the degraded beam to a waist at the first downstream viewer after the degrader, and did not produce an obvious degraded beam waist on a second downstream viewer. Despite best efforts at image analysis, the transverse emittance could only be estimated for one degraded beam configuration.

Beam loss monitors at the entrance to the first full cryomodule 0L03 showed no additional activity during degraded beam tests with both collimating apertures A5 and A6 inserted. This gave confidence that degraded beams could be accelerated through the two full cryomodules with no issue for characterization with operational harps available further downstream in the injector.

DEGRADED BEAMS AT 119 MeV/c

Degraded beams generated using 1 and 5 μm thick targets were accelerated to 119 MeV/c through the two full cryomodules 0L03 and 0L04 and transported to the inline beam dump SDL0R08 near the end of the injector. Degraded beam transport was facilitated by simulating the degraded beam distributions in GEANT4 [4] and optimizing transmission to the inline dump using Elegant [5]. The nominal electron beam size and optical parameters were estimated using view screens and design values in this region of the injector; the nominal electron beam on target was simulated as a round, uncoupled beam with $\sigma_{x,y} = 750 \mu\text{m}$. Example beam envelopes comparing design optics with degraded beam optics are shown in Figs. 6 and 7. Simulated transmission of degraded beams beyond the degrader device was over 95% for all degrader combinations (target, A5 aperture, A6 aperture) explored; this does not take into account electrons lost in the degrader device itself.

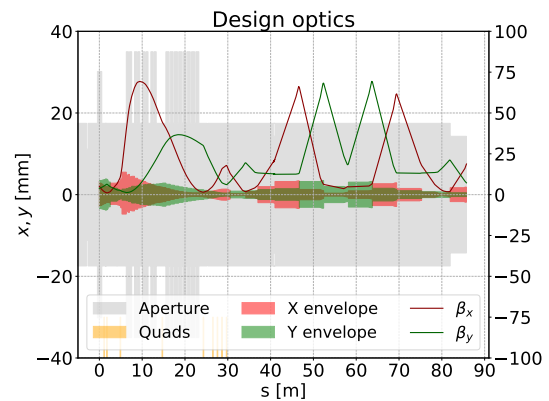


Figure 6: Design optics and beam envelopes in the 119 MeV/c region of the CEBAF injector.

Quadrupole scans at two different diagnostic harps were simulated in Elegant for the degrader configuration using the 1 μm thick target, A5 aperture radius of 1 mm, and A6 aperture radius of 4 mm. Figs. 8 and 9 show simulated and measured beam sizes as a function of the scanning quadrupole integrated field strength for the two different diagnostic harps.

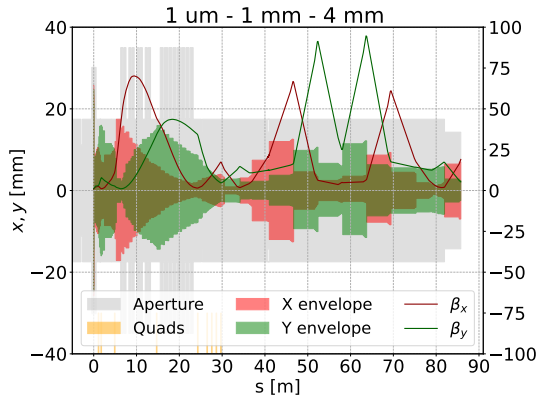


Figure 7: Degraded beam optics and beam envelopes optimized for transmission. Degraded target thickness of $1\ \mu\text{m}$, A5 aperture radius of 1 mm, A6 aperture radius of 4 mm.

The simulation and measurement generally agree, with discrepancies possibly attributable to coupling that is known to be imparted by the cryomodules and that is not fully compensated by the existing skew quadrupoles in the region.

Beam sigma matrix elements were estimated using the least squares minimization method to fit quadratic functions to the beam size experimental data obtained from fitting Gaussian curves to the harp scans. The extracted Twiss parameters and emittances are listed in Table 1. The simulated transverse emittances are approximately 10x larger than nominal beam emittance in this region, and the measurements reflect this increased emittance.

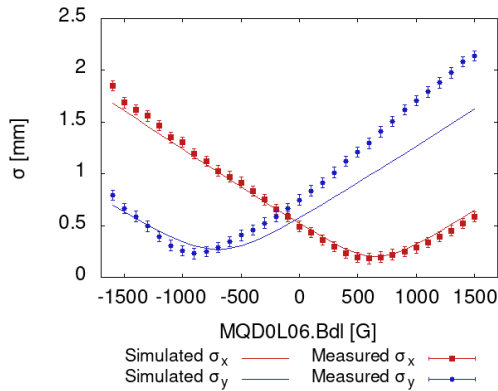


Figure 8: Simulated and measured RMS beam sizes at diagnostic harp IHA0L08.

DISCUSSION AND OUTLOOK

The increased beam emittance due to multiple scattering in the degrader device has been confirmed by measurement, though we note that quantifying the true performance of the degrader is complicated by the difference in the two harp measurements. Two skew quadrupoles were adjusted between the harp measurements and may account for the discrepancies, but more measurements are needed for thorough investigation.

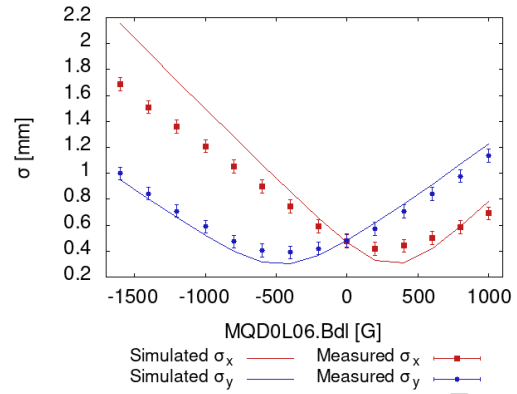


Figure 9: Simulated and measured RMS beam sizes at diagnostic harp IHA0L09.

Table 1: Simulated and measured phase space parameters upstream of MQD0L06 using harps IHA0L08 and IHA0L09 for target-A5-A6 configuration of $1\ \mu\text{m}$ -1 mm-4 mm. Geometric emittances are listed.

	Model	IHA0L08	IHA0L09
β_x [m]	14.96	22.9 ± 2.25	8.49 ± 0.31
α_x [-]	1.67	2.53 ± 0.26	1.01 ± 0.06
ε_x [nm rad]	56	41 ± 3.8	63 ± 1.7
β_y [m]	11.04	16.97 ± 0.86	8.46 ± 0.38
α_y [-]	1.36	1.71 ± 0.1	1.21 ± 0.06
ε_y [nm rad]	56	62 ± 2.8	68 ± 1.9

Degraded beam experiments during the CEBAF FY26 physics run have commenced. The diagnostic harp just downstream of the degrader device has been repaired and is operational, allowing for characterization of both nominal beams incident on the degrader targets and degraded beams at 6.7 MeV/c. Following characterization at 6.7 MeV/c and repeat characterization at 119 MeV/c, degraded beams will be transported beyond the injector for acceleration in the North Linac, terminating at the end of Arc 1, for first measurements of machine acceptance in CEBAF using large emittance electron beams.

ACKNOWLEDGMENTS

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