EXPERIMENTAL RESULTS OF BEAM BRIGHTNESS IMPROVEMENTS AT THE ADVANCED TEST ACCELERATOR (ATA)*

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Abstract

We have experimental data showing improved brightness of Lawrence Livermore National Laboratory's Advanced Test Accelerator both at the injector and at the high-energy output. The effects of matching onto a laser-produced ion channel have been demonstrated, and an improved matching technique is now being used.

Introduction

During 1986 we have continued to improve the brightness of Lawrence Livermore National Laboratory's Advanced Test Accelerator (ATA) and have now produced 2000 A at 43 MeV ($\gamma = 85$) and at a normalized brightness of at least 1.3×10^5 A/(cm-rad)^2. The improvements in brightness at the high-energy end of the accelerator are due to improved injector performance and an improved transport technique through the accelerator.

Beam Transport

In June of 1986 we measured the brightness of the ATA beam at high energy (43 MeV) using a long, narrow pipe to sample the phase space of the beam. The beam was in free expansion in the pipe with no focusing from magnetic fields or ion guiding. The emittance selecting pipe was 0.4 cm in radius and 360 cm in length. We define the normalized brightness as

$$J_n = \frac{\pi^2 I}{(\gamma\beta)^2 \ V_4} \quad , \qquad (1)$$

where I is the current contained in the phase space four-volume, V_4. For a circular pipe

$$V_4 = \frac{\pi^2 \ R^4}{L^2} \quad . \qquad (2)$$

For a $\gamma = 85$, we were able to pass 15 A through the emittance selector, which is a normalized brightness of 1.0×10^4 A/(cm-rad)^2. This value was a factor of about 4 to 5 lower than our best measured values of beam brightness at the injector.[1] It was clear that the brightness of the beam was being degraded during the transport of the beam through the accelerator.

Late in 1985 we had noticed an instability at the location in the accelerator where we changed from magnetic to laser guiding.[2] This matching onto the ion channel was done by ramping up the benzene pressure and lowering the B_z field over the length of one or two cell blocks (3 to 6 m). This matching was done typically between accelerator cells 20 to 30 where the beam energy was about 5.5 MeV. An analytical model for the matching of the electron beam onto the ion channel showed that an instability produced by an angular mismatch between the magnetic axis and the laser-produced ion axis could lead to an increase in beam emmittance and a degradation of brightness.[3]

The solution to the mismatch problem was to do the matching within the 1-cm-radius collimator that is placed just after the injector. The collimator acts as a conductance-limiting device so the benzene profile is naturally tapered. The magnets over the collimator are varied to adjust the B_z field for the correct match. In the collimator the size of the laser channel, the electron beam, and the wall of the collimator are all characterized by the same radius. Any portion of the beam that is improperly matched to the channel is eliminated by the collimator wall before it can mix with the beam and degrade the brightness.

Using the new matching technique, we again measured the brightness with the high-energy emittance selector. This time the current through the pipe was 80 A. This calculates to a normalized brightness of 5.6×10^4 A/(cm-rad)^2.

Injector Improvements

During July, we ran experiments to explore improvements to the brightness of the injector. By trying new cathode/anode geometries and variations on the magnetic tune used in the injector, we maximized the brightness of the beam coming through the collimator. The data indicated a brightness at the injector between 1.3 and 2.6×10^5 A/(cm-rad)^2. This brightness has been adjusted to correct for the space-charge effect that adds a degree of complication in making brightness measurements at low energy.[4]

After maximizing the brightness at the injector, we repeated the brightness measurements at high energy using the emittance selector.

In this mode of operation, the maximum current was 175 A, which corresponds to a normalized brightness of 1.2×10^5 A/(cm-rad)^2. This is in very good agreement with the measurements made at the injector. The only remaining question was whether this brightness represented the entire 2-kA beam or that we were selecting a local maximum in brightness. (Was the phase space uniformly filled?) To answer this question, we changed the geometry of the emittance selector.

New Emittance Selector

We replaced the narrow pipe with the device shown in Fig. 1. The holes were 1.5 cm in diameter and were spaced at 388-cm intervals. (The four-volume of this device is calculated using Eqs. (1) and (2).)

At a $\gamma = 85$, the brightness of the device is given by

$$J_n = 66 \ I \ \text{A/(cm-rad)}^2 \quad , \qquad (3)$$

where I is the current through both slits. Our initial measurements using this new emittance selector showed 2000 A through the device. This corresponds to a brightness of 1.3×10^5

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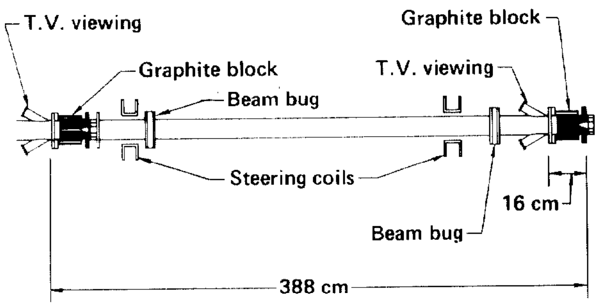

Figure 1. Emittance selector.

A/(cm-rad)^2, which is in good agreement with the measurements made at the injector using the smaller emittance selector.

One possible source of error in the measurements made with the large-diameter emittance selector is the presence of benzene, which can cause a residual guiding channel. (The brightness calculation is based on free expansion.) The laser is on-axis and residual benzene would be ionized, giving a focusing effect to the beam. We investigated this issue by employing a deflection coil (dipole magnetic field) downstream of the first graphite block and measuring the motion of the beam centroid with a current monitor before the second graphite block.

The motion of the beam depends on the strength of the dipole field and the residual focusing (if any). We found the motion of the beam to be only that caused by the dipole field. We thus concluded that residual ion guiding was not a factor.

Conclusions

We have succeeded in producing 2000 A of current at $\gamma = 85$ and $J_n = 1.3 \times 10^5$ A/(cm-rad)^2. Work is continuing on the injector and the transport technique to drive this value even higher.

References

[1] J. T. Weir, G. J. Caporaso, F. W. Chambers, R. Kalibjian, J. Kallman, A. C. Paul, IEEE Trans. Nuc. Sci., Vol. NS-32, p. 1812, Oct. 85.

[2] J. T. Weir, ATA Operations, Lawrence Livermore National Laboratory, Livermore, Calif., UCRL-94759, (June 20, 1986).

[3] G. J. Caporaso, Kiloamp High-Brightness Beams, Lawrence Livermore National Laboratory, Livermore, Calif., UCRL-95319 (March 1987).

[4] J. K. Boyd, G. J. Caporaso, A. G. Cole, and J. T. Weir, Beam Quality of the ATA Injector, Lawrence Livermore National Laboratory, Livermore, Calif., UCRL-95304 (March 1987).