OPERATION OF A 3 MEV AMPERE INTENSITY DC ELECTRON RECIRCULATION SYSTEM*

M. L. Sundquist, J. A. Adney and S. J. Dehais
National Electrostatics Corporation
7540 Graber Road
Middleton, WI 53562

D. B. Cline, D. J. Larson and D. R. Anderson
Department of Physics
University of Wisconsin
Madison, WI 53706

F. E. Mills
Fermi National Accelerator Laboratory
Batavia, IL 60510

Abstract

We report our observations on the initial operation at 2.2 MeV of the Pelletron electron recirculation system originally designed as a source for electron cooling of GeV-energy antiproton beams, along with final data from test bench operation at energies up to 40 keV. Test bench results indicate that the collector efficiency is better than 99.99%, and that the multi-element cathode in the electron gun produces negligible halo.

Background

Following successful demonstrations of high efficiency electron beam collection in magnetized systems operating in the 100 keV energy range at Fermilab [1] and emission measurements on an unmagnetized electron gun operating at 2 MeV [2], we began work on a 3 MeV DC electron beam recirculation system. The design made use of an existing 3 MV electrostatic accelerator having space for parallel acceleration and deceleration tubes and complicated terminal equipment. We added an electron gun, electron collector, power supplies and cooling system, as well as diagnostic, vacuum and beamline equipment to transport the beam from the exit of the acceleration tube to the entrance of the deceleration tube.

The system was designed [3, 4] to recirculate DC beam currents of several amperes with losses maintained below 200μA. Based on results of test bench operation of the electron gun and collector reported here, along with results of initial operation at 2.2 MeV, the goal of ampere intensities at 3 MeV should be possible after passing the new-system start-up problems.

System Description

The overall accelerator configuration is similar to the pulsed electron recirculation system design of Elias and Ramian [5], but incorporates changes required for the DC beam and a new collector based on the Fermilab work [2]. The system has been discussed thoroughly in [3] and [4].

The basic difficulty with DC recirculation is that the beam must pass from gun to collector with losses less than several hundred microamps, from start-up to full current. To allow a variation in beam current from microamperes to amperes while maintaining high optical quality, there are four concentric cathode surfaces, independently heated, with emission areas of 0.0078 cm^2, 0.071 cm^2, 0.50 cm^2 and 2.83 cm^2. In practice, optimum transmission will be achieved with the smallest cathode in a thermally limited emission mode, then power gradually increased, adjusting optical parameters as necessary, until space-charge limited emission is reached. At that point the larger cathode surfaces can be turned up one at a time while maintaining transmission in the same manner as for the smallest cathode.

In addition to this special four-element cathode, manufactured by the Spectromat Corp., the Pierce geometry, three-element gun can be disassembled and assembled without special tools; it is self aligning, bakeable to 450°C, has insulators shielded from beam, and an electrical feedthrough shielded from spark induced RF (Fig.1).

The beamline includes Faraday cups and rotating-wire

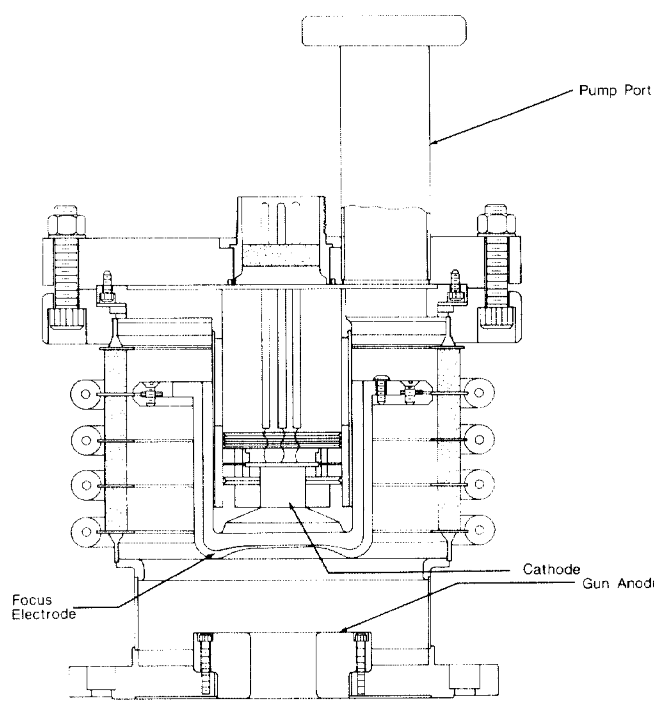

Figure 1. Electron Gun

*Work supported by the U.S. Department of Energy.

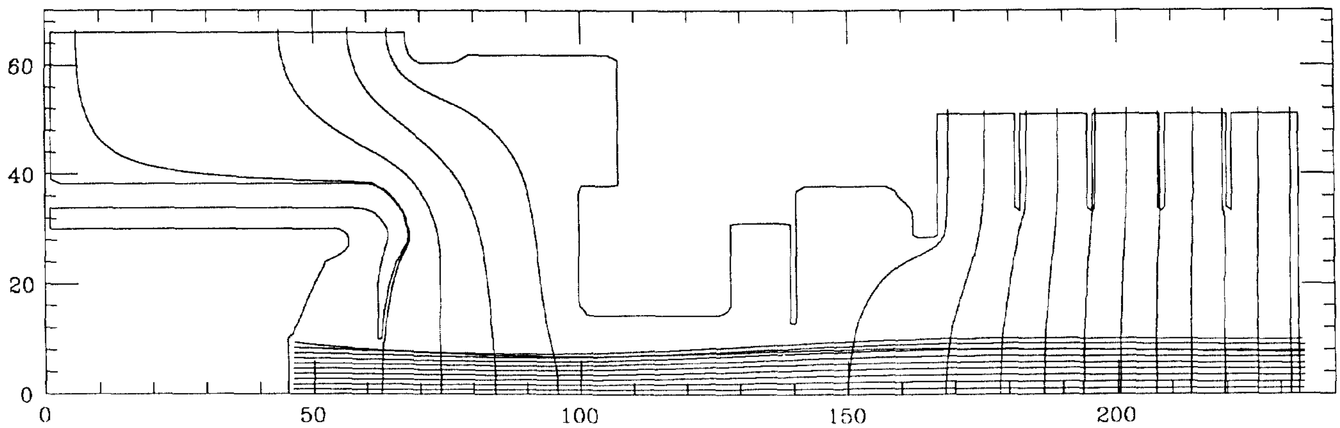

Figure 3. EGUN plot for electron gun: anode, 50 kV, focus 10 kV, beam current 2.2A. (Dimensions in mm.)

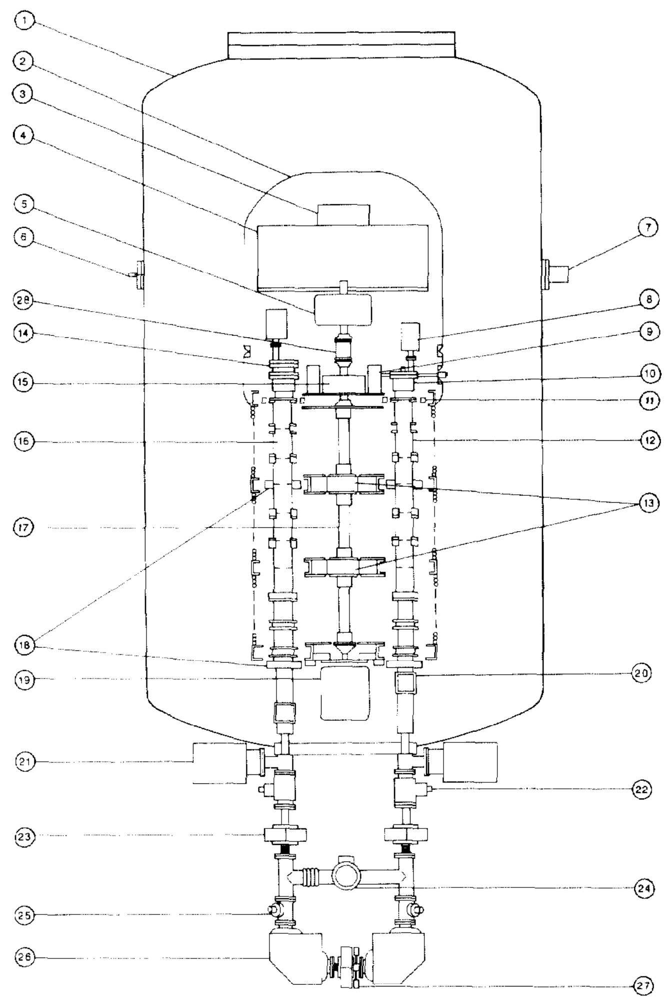

Figure 2. Overall system schematic: 1) tank, 2) high voltage teminal, 4) gun and collector electronics box, 5) 10 kVA generator, 10) gun, 11) steerer coils, 12) acceleration tube, 14) collector, 15) 1 kVA generator, 18) deceleration tube, 17) rotating shaft, 18) solenoid lenses (4), 22) Faraday cups (2), 23) quadrupole singlet (3), 25) beam profile monitor (2), 26) dipole (2).

beam profile monitors on both the accelerating and decelerating legs, solenoid and quadrupole singlet lenses, magnetic steerers and dipoles, plus ion pumps and gauges (Fig. 2). The beamline is symmetric about a slit assembly between the two 90° dipoles; the beam profile is nearly symmetric (Fig. 3 shows the gun optics alone, and Fig. 4 shows overall beam envelope).

The electron collector entrance geometry mirrors the gun, except that the diameter of the focus electrode is larger than that of the gun (Fig. 5). Once past the focus electrode and the "reverse" Pierce geometry leading to the suppressor cylinder, the beam arrives at its minimum potential within a solenoid field produced by a water-cooled coil within the suppressor cylinder housing. It is then accelerated to the collector. There is evidence for some space charge neutralization due to residual gas ions trapped in this electrostatic potential well. This may help explain the very high trapping efficiency of this collector.

Cathode Temperature Measurements

Before installing the gun in the test bench we mounted the gun in a vacuum housing equipped with a window through which we could measure the cathode temperatures using an optical pyrometer (Pyrometer Instrument Co., Inc., Model 95). The temperatures of each cathode

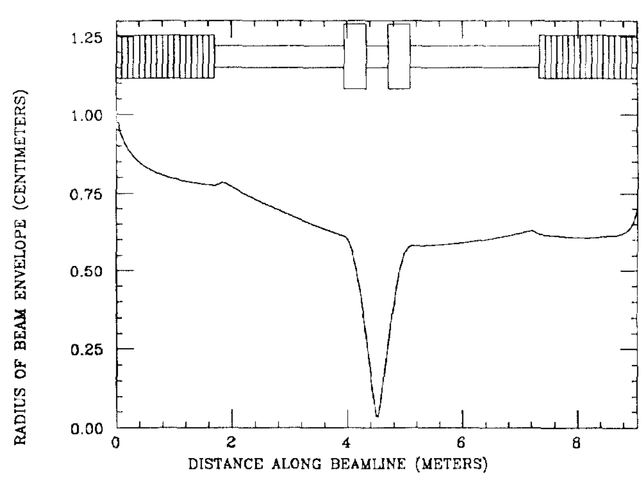

Figure 4. Optics plot from gun to collector. schematic shows accel tube, dipoles and decel tube.

surface as a function of heating current and adjacent cathode temperatures must be known in order to ultimately operate all four elements at the same temperature. Our data enable us to operate the first (inner) cathode surface from 850C to 1150C (spectral degrees), then maintain its temperature as the second surface is heated over the same range, then to maintain the first and second surfaces at constant temperature as the third surface is heated and similarly as the fourth and final surface is heated. During accelerator operation pyrometry is virtually impossible.

Bench Test

To test the gun and collector for performance under the simplest conditions, we attached the exit of the gun anode to the entrance of the collector and mounted the gun and collector 20 l/sec ion pumps. This bench test configuration was connected to the large ion pumps on the beamline assembly by a metal hose having a conductance similar to the 3 MV length of acceleration tube. The gun and collector, powered by the same power supplies and 400 Hz generator now installed in the accelerator terminal, initially recirculated 250 mA with 60μA lost (0.025%) and later 390 - 400 mA with about 120μA lost (0.03%). At higher currents the anode power supply exceeded its 5 mA limit and recirculation collapsed. At this point we realized that the test bench configuration had optics quite different from the final arrangement due principally to the lack of the strong entrance lens of the high gradient acceleration tube. We recalculated the optics, again using the EGUN program of W. B. Herrmannsfeldt. The calculations model the performance closely; without a lens between gun and collector, the beam will hit the anode aperture at a current of about 350 mA.

The second test bench configuration included a large solenoid lens between the gun and collector, operated by a power supply floating at the anode voltage. Again, EGUN modeling of this solenoid was confirmed when currents of about 500mA with less than 100μA lost (0.02%), and about 150 mA at less than 10μA lost (0.007%). were transmitted. However, within a few minutes of operation the cathode became contaminated enough to stop emitting, probably a result of ion formation in the solenoid field and bombardment of the cathode by those ions accelerated by the anode potential. Recovery of the cathode surface by outgassing allowed the tests to be repeated several times; the results were the same each time.

The third and final test bench configuration replaced the solenoid with a thin 19 mm diameter aperture between the gun and cathode to test for the presence of a beam halo. Results were the same as without aperture, suggesting that if a halo exits, its total current is less than a few μA.

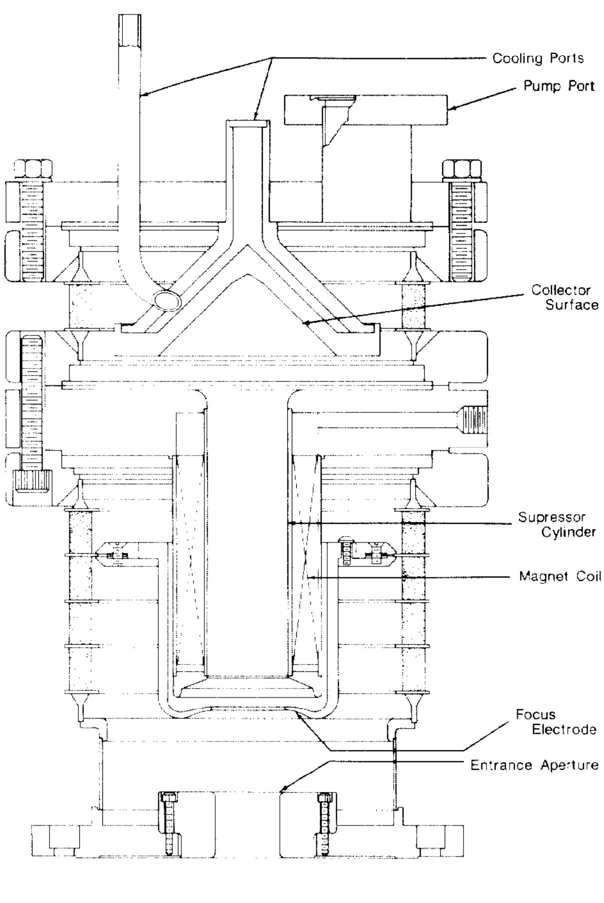

Figure 5. Electron collector.

Initial Operation above 2 MV

As of the end of February 1987, there have been four runs with the system at energies around 2 MV. The first ended with spark damage to several terminal power supplies, a typical first run result with a new design. With refinement of shielding and spark protection there has been no further damage. Operating with the smallest cathode in a thermally-limited emission mode, approximately 25μA have been accelerated and transmitted through the 180° bend into the decelerating tube. The rotating shaft motor (Fig. 1) located between the two drift tubes in the tank bottom needed additional magnetic shielding to eliminate 60 Hz motion of the beam. When this modification and slight realignment of the optical path is complete, tests will continue at energies between 2.0 and 3.0 MeV.

References

1. T. Ellison, W. Kells, V. Kerner, F. Mills, R. Peters, T. Rathbun, D. Young, and P.M. McIntyre, "Electron Cooling and Accumulation of 200 MeV Protons at Fermilab", presented at the APS 1983 Particle Accel. Conf. Santa Fe, NM Mar 21-23, 1983.

2. D.B. Cline, D.J. Larson, W. Kells, F.E. Mills, J. Adney, J. Ferry and M. Sundquist, "Intermediate Energy Electron Cooling for Antiproton Sources Using a Pelletron Accelerator", IEEE Trans. Nucl. Sci., 30, 4 (June 1983) 2370.

3. M. Sundquist and J. Adney, "Design of Components for an Ampere Intensity, MeV Energy, DC Electron Beam System", National Electrostatics Corp. Report No. 182. (Jan, 1984).

4. J.R. Adney, M. L. Sundquist, F.E. Mills, D.J. Larson and D.B. Cline, "Progress Report on Construction and Testing of a 3 MeV, DC, Ampere Intensity Electron Beam Recirculation System", IEEE Trans. Nucl. Sci., NS-32, 5 (Oct 85) 1841.

5. L.R. Elias and G. Ramian, "Design of the UCSB FEL Electron Beam System", Quantum Institute, University of California-Santa Barbara, QIFEL011/81.