PROGRESS REPORT ON CONSTRUCTION AND TESTING OF A 3 MEV, DC, AMPERE INTENSITY ELECTRON BEAM RECIRCULATION SYSTEM*

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ABSTRACT

Construction is underway on a 3 MV electrostatic accelerator designed to recirculate D.C. electron beams with intensities up to 4 amperes. The test facility includes a 3 MV, SF_6 insulated vertical accelerator with parallel accelerator and decelerator tubes, diagnostic equipment, and vacuum and beam line components to bend the beam 180° and return it to the terminal. Special consideration has been given to cathode, electron gun, electron collector, and optical design to allow beam recovery efficiency of better than 99.99% at currents up to 4 amperes.

Goals

Numerous applications would benefit from the availability of a D.C. electron beam of an intensity on the order of a few Amperes with an energy in the MeV range. For the large class of applications which do not actually extract the megawatts of power that such a beam would carry, it is clearly advantageous to recirculate the beam while adding only the power required to replace the transmission losses and the losses in the application of the beam.

To allow for recirculation, the 3 MV vertical Pelletron accelerator available for testing at National Electrostatics Corporation (NEC) has been modified to include (See Figure 1) two parallel accelerating tubes, one for acceleration and one for deceleration of the electron beam. Both the electron gun and collector reside in the terminal, and two 90° magnetic dipoles located outside the accelerator turn the beam around and return it to the terminal. Since the maximum charging current available on this accelerator is about 0.2 mA it is clear that our losses may not exceed that amount. Thus a 4 Ampere beam requires 99.995% recirculation for D.C. operation.

Optics calculations based on data taken during earlier pulsed mode operation indicate that the facility under construction should allow operation at 2.5 - 3.0 MeV and 3-4 Amperes. Higher currents may produce beams whose diameters approach the 25 mm aperture diameter of the accelerating tube. This is likely to produce current losses which would be intolerable.

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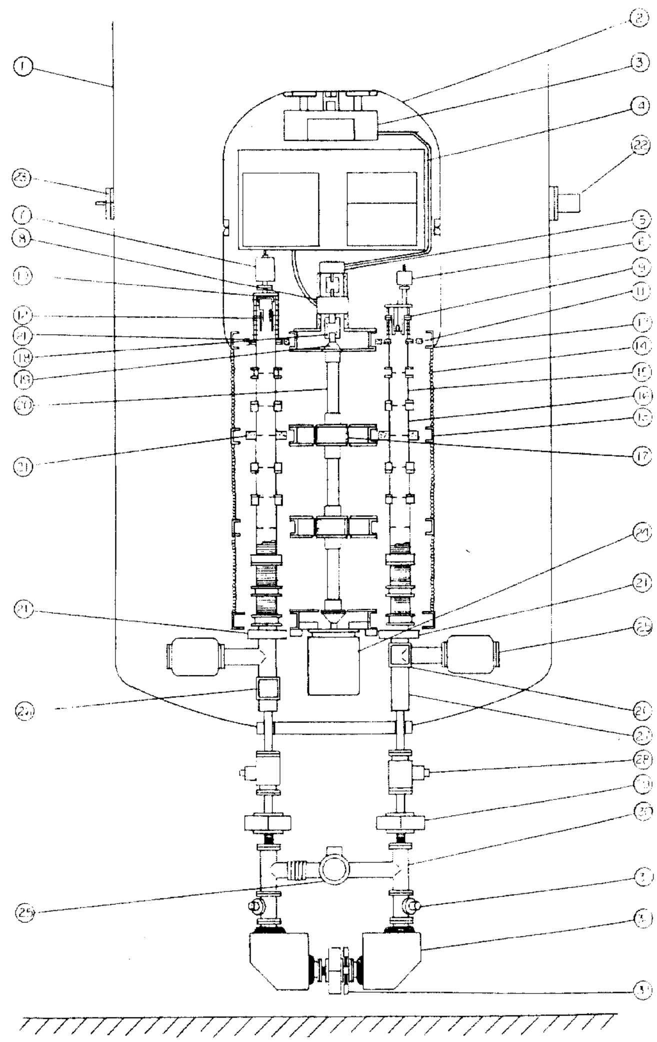

Figure 1. Beam Line Layout: (1) Tank, (2) Terminal, (3) Terminal potential (-3MV) electronics, (4) Cathode potential (-3.05 MV) electronics, (5, 8, 17) 400 Hz generators, (9, 6) Electron gun with ion pump, (11, 21) Solenoid lenses, (26) Magnetic steerers, (15, 16) Accelerating tubes, (20, 24) Rotating shaft and motor, (25) Ion pumps, (31) Beam Profile Monitor, (29) Quadrupole Singlets, (32) Bending magnets, (28) Faraday cups, (10, 12, 7) Collector with ion pump, (22) Generating voltmeter, (23) Capacitive pick-up.

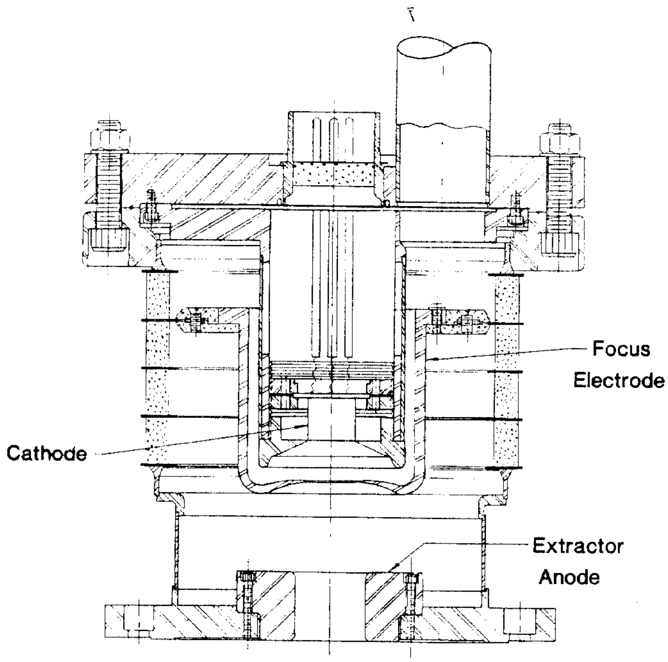

Figure 2. Electron Gun with Ion Pump Port.

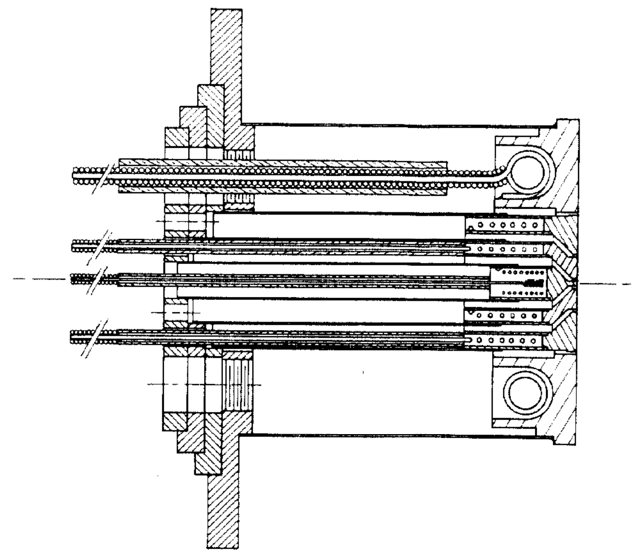

Figure 3. Cathode with Concentric Elements

Electron Gun

The electron gun geometry is based on the design used by Elias and Ramian [1], but the mechanical design has been altered to conform to NEC standard manufacturing practice. The emittance of this design was previously measured by the authors to be 1.25 $\pm$ 0.3 mm-mR at 2.5 MeV [2]. The new design incorporates the following features (see Figure 2):

1. Three element (cathode, control electrode, anode) geometry.
2. Disassembly to replace electrodes or cathode elements requires no welding; reassembly requires no alignment tools.
3. Entire construction is all metal and ceramic, bakeable to 450°C.
4. Cathode flange has a shielded multipin heater feedthru and an ion pump port.
5. All insulators are shielded from sputtering or beam induced charging.
6. The dispenser cathode has four independently heated concentric emitting surfaces (see fig. 3). These allow operation with space charge limited gun optics over a wide range of beam currents, and make D.C. operation possible by slowly ramping the current while adjusting the various optics parameters to achieve the necessary recirculation efficiency. The four cathode surface areas and their current ranges are shown in figure 4.

Beam Line

The beam line (Fig. 1) consists largely of standard NEC components [4]. In order from the electron gun at the upper right: nine NEC High Gradient Accelerating Tube sections, rated at 3 MV, pumping tee with 120 l/sec ion pump, NEC High Power Faraday Cup, magnetic quadrupole singlet lens, pumping tee with shared 220 l/sec ion pump, NEC Beam Profile Monitor, 90 degree double focusing dipole magnet, and single slit assembly. All components then repeat in reverse order to the collector at the upper left to produce a symmetrical beamline.

In addition, there are solenoid lenses one third of the way down, and at the bottom of, each accelerating tube, and there are three small magnetic steerers: at the electron gun exit, and in the drift tube beneath each accelerating tube.

The beam tube is 4 inches in diameter wherever possible, but due to tank restrictions, the portion of the tube passing thru the tank bottom is 3 inch and the magnetic quadrupole chamber is 2 1/2 inch. At no point does the beam size approach the effective aperture of the beam line; moreover, due to distributed pumping, the localized small diameters should have minimal affect on the vacuum quality.

	Cathode O.D.	Cathode Area	I Minimum (0.1 A/cm^2)	I Maximum (1.0 A/cm^2)	% Minimum (for 0.2 mA lost)	% Maximum (for 0.2 mA lost)
Inner Spot	1 mm	.0078 cm^2	.7 mA	7.8 mA	71.0%	97.4%
+First Ring	3 mm	.071 cm^2	7 mA	70 mA	97.1%	99.7%
+Second Ring	8 mm	.501 cm^2	50 mA	500 mA	99.93%	99.96%
+Third Ring	19 mm	2.83 cm^2	280 mA	2.8 A	99.93%	99.993%
				4.5 A*		99.996%

*At slightly increased cathode loading of 1.6 A/cm^2.

Figure 4. Cathode areas and current loading with recirculation efficiencies required for D.C. operation.

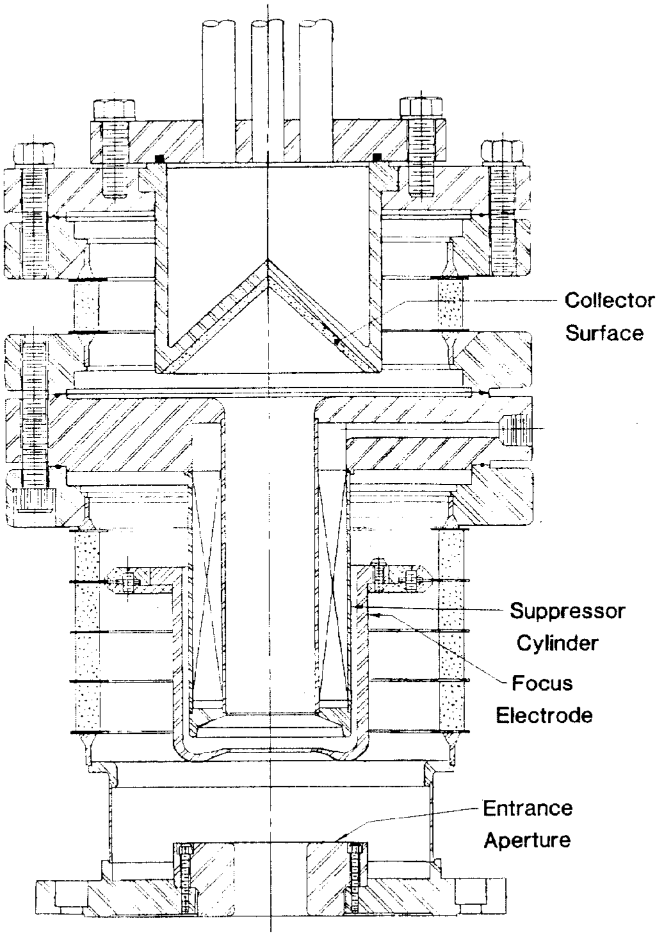

Figure 5. Electron Collector

Electron Collector

The collector design (Fig. 5) is patterned after the collector developed and tested at Fermilab by Mills, et al. at 120 keV[3]. It incorporates entrance electrodes that mirror the electron gun geometry (some parts are common to both) and combines electrostatic secondary electron trapping with space charge neutralization by ions confined in the ion potential well which is located within the collector solenoid. Electrons are slowed down to about 1 keV within the collector solenoid, then accelerated to about 3 keV at the collector. The Fermilab experiments with this design suggest that an ion plasma is trapped within the collector solenoid which prevents space change blow-up of the low energy electron beam.

One of our major design problems centered on power dissipation in the collector itself. While the collector power supply is a 3 kV, 5A supply, the 400 Hz generator for this part of the terminal is only a 10 kVA unit. Thus we do not plan to draw both maximum voltage and maximum current from the supply at the same time. Nevertheless, it is still necessary to allow for 10 kW of power dissipation in the collector. This requires water cooling through plastic tubing to carry the water across the 3 kV potential difference to the cathode potential electronics box. Here there will be a water/SF_6 heat exchanger and a recirculation pump.

Bench Test

Following completion of the necessary power supplies we intend to bolt the electron gun and collector directly to one another to run a bench test. Such a test will allow us to test not only the proper functioning of the power supplies and their control systems, but also the adequacy of the collector cooling system. As a bonus, it will be possible to calibrate the output of each cathode element as a function of its heater input pwer.

In the course of the bench test phase we may also insert a short (1-2 cm) tube section between the gun and collector. Such a test section would have a feedthru to an internal probe which could be used to determine beam diameter at different total beam currents.

These tests will take place in air at an accelerating/decelerating potential of 30 to 50 kV using the same power supplies that will eventually be used in the terminal. Since these power supplies are specifically designed for use at 400 Hz, the bench test power will be taken from the terminal generator while the terminal is grounded. All the parts for this test are complete or nearly complete, so that we expect to perform the bench test during the summer of 1985.

References

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

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, (June 83).

3. 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.

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