Successful DC Recirculation of a 2 MeV Electron Beam at Currents More Than 0.1 Ampere*

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ABSTRACT

We describe the operation of a DC recirculation electron beam system. This system is a prototype for intermediate energy electron coolers, capable of cooling particle beams in the energy range between γ = 2 and γ = 20. In addition, this system may be altered to provide DC FEL radiation in the submillimeter wavelength region with average power output of 10 kW or greater. Ampere intensity beams with minimal losses now appear attainable as the present system has been run at currents greater than 100 mA with losses of about 10 μA. This corresponds to a combined beam transmission and collection efficiency better than 99.99%.

Background

This system was developed to demonstrate the feasibility of recirculating ampere current electron beams in the MeV energy range for potential applications such as antiproton cooling [1], positron cooling [2], and the DC FEL [3].

We believe this DC system is unique in that the electron beam has no guiding solenoidal field; it is non-magnetized. Other electron recirculation systems for electron cooling operate with magnetized beams in the energy range up to several hundred keV.

System Description

A practical recirculation system for MeV energy electrons requires a source (gun), a beam path including means for accelerating and decelerating the beam, and a sink (collector) at nearly the same potential as the source. Current from the collector must be carried back to the gun through a power supply, whose voltage depends on the energy spread in the beam and the collector design. The collector must capture electrons on an electrode which is more positive than the cathode in order to allow for FEL or cooling-induced energy spread in the electron beam. The collector bias power supply is the one supply which returns the beam current to the gun; therefore, for the sake of efficiency it is desirable to design the collector for as small a collector bias as possible.

Several recirculation configurations are possible, including straight-through designs with gun and collector at ground (Fig. 1A), with gun and collector in the HV terminal (Fig. 1B), or with the "folded" configuration originally used by Elias, et. al. [4] (Fig. 2).

The availability of a suitable vertical test Pelletron® accelerator at the National Electrostatics Corporation led us to use the folded configuration for this system (Fig. 2). The design of the electron gun, collector, beam line, and optics, and the initial testing have been described elsewhere [5,6]. The electron beam originates in the Pierce geometry gun (item 10 in Fig. 2) at 33 kV below the minus 2 MV terminal potential, gains energy to 2 MeV as it passes through the high-gradient accelerator tube (item 12), drifts through the

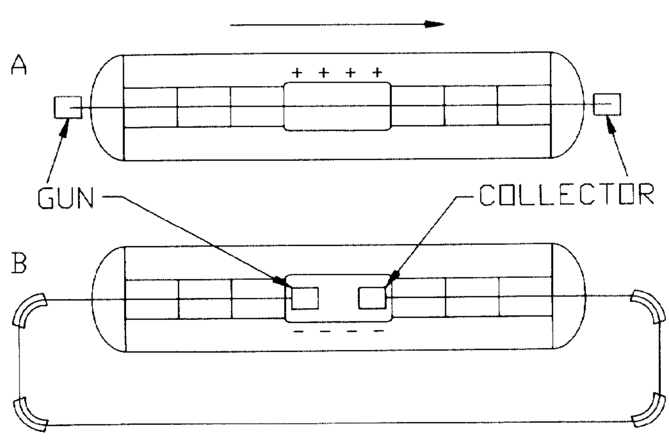

Figure 1

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beam line, including diagnostic beam profile monitors (BPM) (item 25), Faraday cups (item 22), solenoid and quadrupole focusing elements (item 18, 23) and the two 90° dipoles (item 26). Maintaining beam envelope symmetry around the midpoint of the beam line, the beam decelerates until it enters the collector focus electrode at about 7 keV. In the collector (item 14) it slows to about 1 keV, then re-accelerates to be collected at several keV. There are steerers at the exit of the gun (item 11) and at various locations along the beam line (item 20).

Beam losses can not exceed the current capacities of the various acceleration voltage sources. Within the terminal up to 5 mA is available, but between the 2 MV terminal and ground, the test accelerator can provide only about 250 μA of charging current. Although newer accelerators of the same type have delivered over 1 mA charging, it is important to note that at no time during this project was the available charging current a limitation. In practice x-ray production, vacuum outgassing and related difficulties in maintaining stable operation occurred whenever losses approached 50 μA.

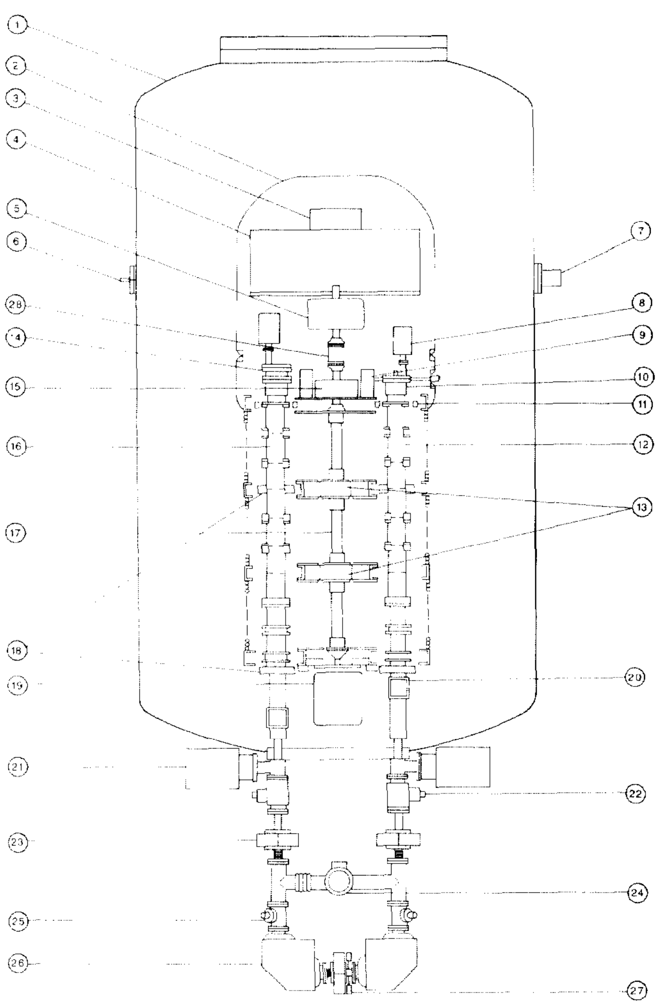

Figure 2: Overall system schematic: 1) tank, 2) high voltage terminal, 4) gun and collector electronics box, 5) 10 kVA generator, 10) gun, 11) steerer coils, 12) acceleration tube, 14) collector, 17) rotating shaft, 18) solenoid lenses -4, 22) Faraday cups -2, 23) quadrupole singlet -3, 25) beam profile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

Three collector configurations were tested in this project. The most successful was the solenoid-electrostatic well configuration developed at Fermilab and described elsewhere [5,6] (Fig. 3). In addition, two purely electrostatic configurations were tried, the first in order to run temporarily in spite of a damaged power supply and the second as an attempt to improve the collector geometrical acceptance by eliminating the long narrow collector solenoid (Fig. 4).

Operation

The first beams were seriously deflected by the 60 Hz field of the rotating shaft motor and its power leads (item 19 in Fig. 2). After considerable effort with mu-metal shielding at the motor and beam lines between the acceleration and deceleration tubes and the tank base, beam motion at the BPM's was reduced from ±4 mm to about ±0.5 mm. The first electrostatic collector configuration rapidly reached the current limit of its temporary power supply, recirculating 788 μA with 30 μA beam induced loss (96.2%). A second run yielded 520 μA with only 12 μA lost (97.69%). All runs reported here took place at 2 MeV.

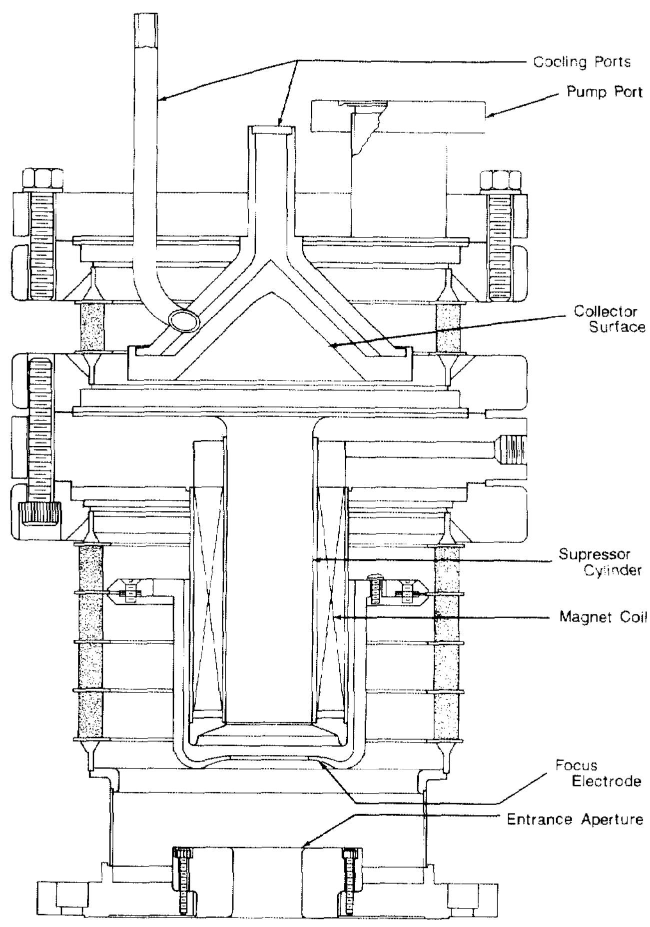

Figure 3: Solenoid/Electrostatic well collector: Entrance aperture typically at 33 kV with respect to gun cathode, focus electrode at 6.5 keV, suppressor at 1.2 kV - 1.4 kV, and collector surface at 5 kV.

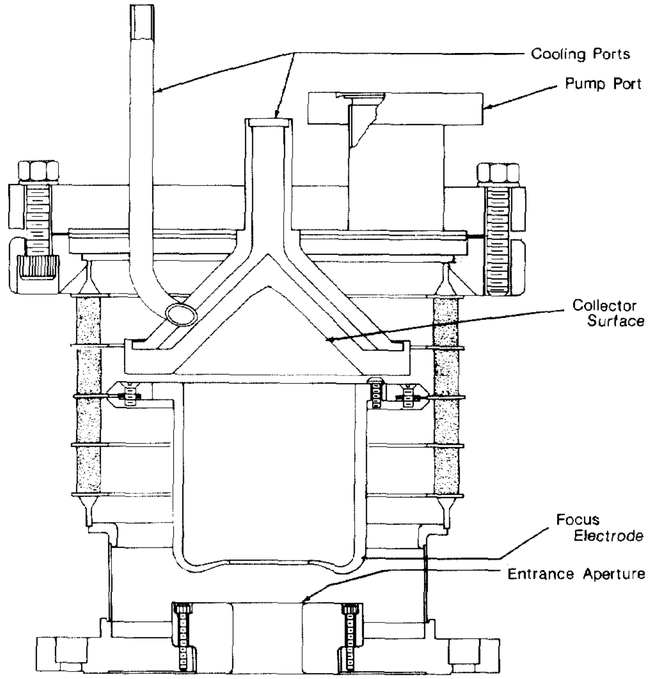

Figure 4: Electrostatic collector: Entrance aperture typically at 33 kV, with respect to gun cathode, focus electrode at 0 kV and collector surface at 5 kV.

Installation of the solenoid/electrostatic well collector (Fig. 3) yielded a large improvement in the first run, reaching 6 mA with 60 μA lost (99.0%). At this point it was necessary to concentrate on beam line focusing, which then resulted in 8 mA with 30 μA lost (99.6%). Clearly, the solenoid/electrostatic well collector was a vast improvement over the temporary electrostatic configuration. However, further improvement seemed possible, since the best results occurred at the maximum voltage of the collector power supply. Therefore, the supply capability was increased from 3.5 kV to 5 kV.

With this higher collector voltage some improvement in recirculation efficiency was observed, along with higher current, 15 mA with 47 μA lost (99.7%). By now a pattern of operation had developed: beam current during a particular run appeared to be limited by outgassing of the collector with each day's run reaching a new maximum beam current until system pressure rose, collection efficiency deteriorated, and the recirculation ended. Recirculation currents significantly below that day's maximum appeared to be sustainable indefinitely while currents in the higher ranges could be recirculated for periods of one to ten minutes. In general, recirculation could be restarted by simply switching off the electron gun focus voltage, allowing the accelerator to stabilize, and switching the beam back on.

The next improvement was to reroute the rotating shaft motor leads at the tank feedthroughs to further reduce 60 Hz deflection. This sizeable job resulted in deflections too small to be seen in the BPM's. Beam currents increased to about 30 mA, with improvement in losses: 19 mA with 29 μA lost (99.85%).

Finally, a third BPM was installed between the two dipoles. Painstaking optimization of alignment and steering over the next two months brought down overall losses more than a factor of 10, yielding 105 mA with 11 μA lost (99.99%).

At this point the extreme sensitivity of the beam to any steering suggested that it would help to open up the collector solenoid and thus improve collector acceptance. This was done by changing to the second electrostatic collector configuration (Fig. 4). Various modifications over the next 5 months and about 25 runs yielded currents as high as 42 mA with 25 μA lost (99.94%) with efficiencies limited to 99.96%.

Conclusions:

1. Based on this research we believe it is now commercially feasible to build a DC recirculating electron beam system, non-magnetized, to produce a few tenths of amperes in the 2 to 20 MeV range, with a reasonable likelihood of reaching currents over 1 ampere,

2. The relatively low charging currents available in chain driven electrostatic accelerators (up to 1 mA) do not limit the attainable recirculating current, and

3. The solenoid/electrostatic well collector can operate with losses lower than 1 part in 10,000, and represents the best configuration we have tried.

References

[1] D.J. Larson, PhD Thesis, University of Wisconsin- Madison (1986).

[2] D.J. Larson, Phys. Rev. Lett., 60, 13, 1988, pp. 1274- 1277.

[3] D.J. Larson, D.B. Cline, D.R. Anderson, J.B. Rosenweig, F.E. Mills, M.L. Sundquist, J.R. Adney, an S.J. Dehais, Proc. 1987 IEEE Particle Accel. Conf., March, 1987, pp. 215-217.

[4] L. Elias, J. Hu, and G. Ramian, Proc. 1984 Free Electron Laser Conference in Castelgandolfo, Italy, North-Holland, 1984, p. 203.

[5] J.R. Adney, M.L. Sundquist, F.E. Mills, D.J. Larson, and D.B. Cline, IEEE Trans. Nucl. Sci., NS-32, 5, Oct, 1985, pp. 1841-1843.

[6] M.L. Sundquist, J.R. Adney, S.J. Dehais, D.B. Cline, D.J. Larson, D.R. Anderson, and F.E. Mills, Proc. 1987 IEEE Particle Accel. Conf., March, 1987, pp. 316-318.

[7] 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.