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DESIGN OF A 6 MeV ELECTRON COOLING SYSTEM FOR THE SSC MEDIUM ENERGY BOOSTER

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A 6 MeV-2 A electron cooling system is being designed for the SSC Medium Energy Booster (MEB). This system has the potential of decreasing the beam emittance by a factor of 2 in less than 20 s, consequently increasing the initial SSC luminosity by the same factor. Alternately, the required number of particles per bunch (and therefore synchrotron radiation and required cryogenic cooling power) can be reduced while keeping the luminosity constant; or this system can compensate for unexpected emittance-increasing effects while relaxing the closed orbit error and dynamic aperture requirements in the following machines. This report summarizes the system design, and the status of the proof-of-principle electron beam recirculation tests to be carried out at the National Electrostatics Corp.

The lower limit for the beam emittance in the SSC is determined by the space charge tune shift, $\Delta Q_{sc} \approx 0.33$, in the Low Energy Booster (LEB) at injection (1.46 GeV/c). After acceleration to 12 GeV/c, however, ΔQ_{sc} is reduced to 0.02 in the LEB before extraction and is 0.065 at injection in the MEB. We estimate that the beam emittance can be reduced by greater than a factor of 3 in the MEB at injection using an electron cooling system.[1] The specifications for this system are summarized in Table I.

The cooling rate (emittance e-folding time), using values from Table I, is estimated[2] to be less than 30 s, increasing the SSC fill (fill + ramp) time by less than 50% (30%). Proton beam emittances, or electron beam temperatures a factor of three higher than estimated will still allow cooling times less than 60 s. Enhancements in the cooling rate due to magnetized cooling effects are not expected. Intrabeam scattering[3] does affect the equilibrium longitudinal emittance, but has no effect on the transverse beam emittance. The projected proton beam emittance as a function of time is shown in Fig. 1.

TABLE I

Parameter	Symbol	Value	Units
Electron Beam Current	I_e	2	A
Cathode Radius	r_c	3.2	mm
Electron Beam Radius	r_b	4.5	mm
Cooling Region Length	L	40	m
Coulomb Logarithm	Λ	10	
Cool Reg. Beta Functions	β_I	100	m
Cathode Temperature	$T_{e\perp}$	0.12	eV/k
Proton rms normalized emittance	ϵ_N	0.7	π μm
Emittance (e^{-1}) Damping Time	τ_ϵ	25	s

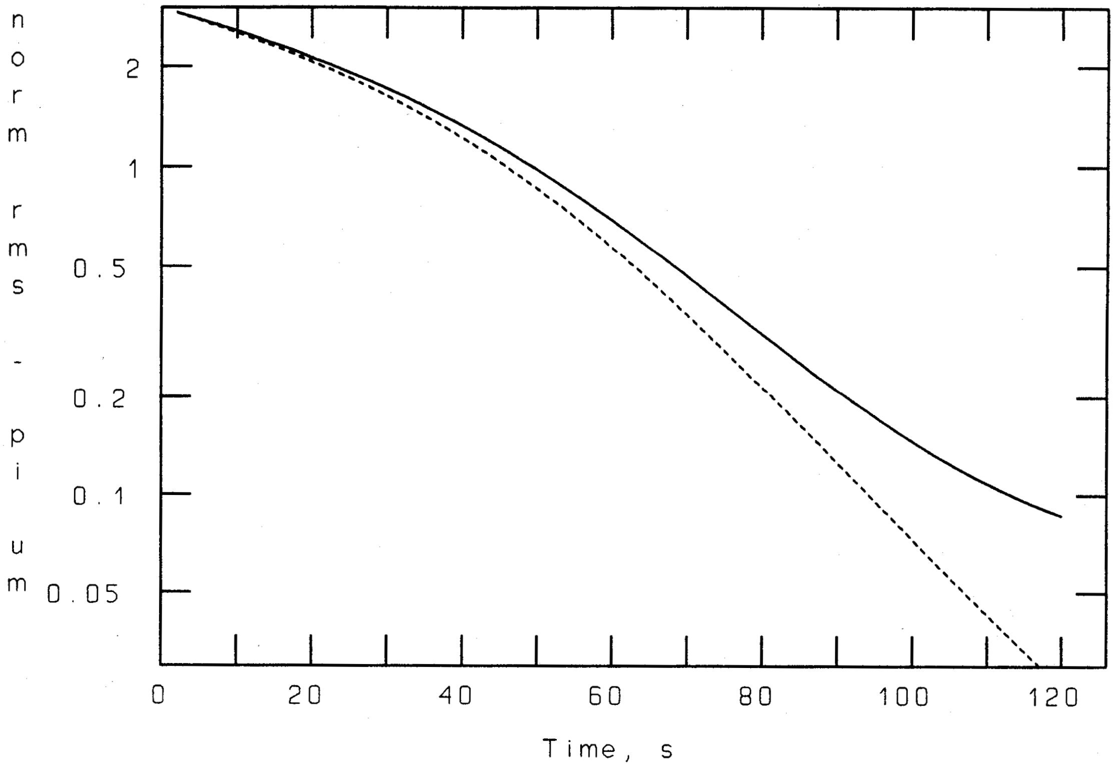

Figure 1. The solid (dashed) line shows the projected proton beam emittance in the MEB as a function of time for a ring pressure of 1×10^{-8} (1×10^{-9}) Torr N_2-equivalent.

Layout

Figure 2 is an overall view of the proposed electron cooling system in the MEB.[4] This configuration was chosen because it provides the shortest possible path (and thus highest beam quality) from the cathode to the cooling section. The electron beam is generated by a dispenser cathode located in the terminal of a 6 MV Pelletron accelerator. Two solenoids following the first 90° bend produce the required beam size (an increase from $r = 3.2$ mm at the cathode to $r = 4.5$ mm in the cooling region) and convergence (20 μrad) at the beginning of the cooling straight section. Following this straight section, the beam is then transported back to the 6 MV terminal and collected.

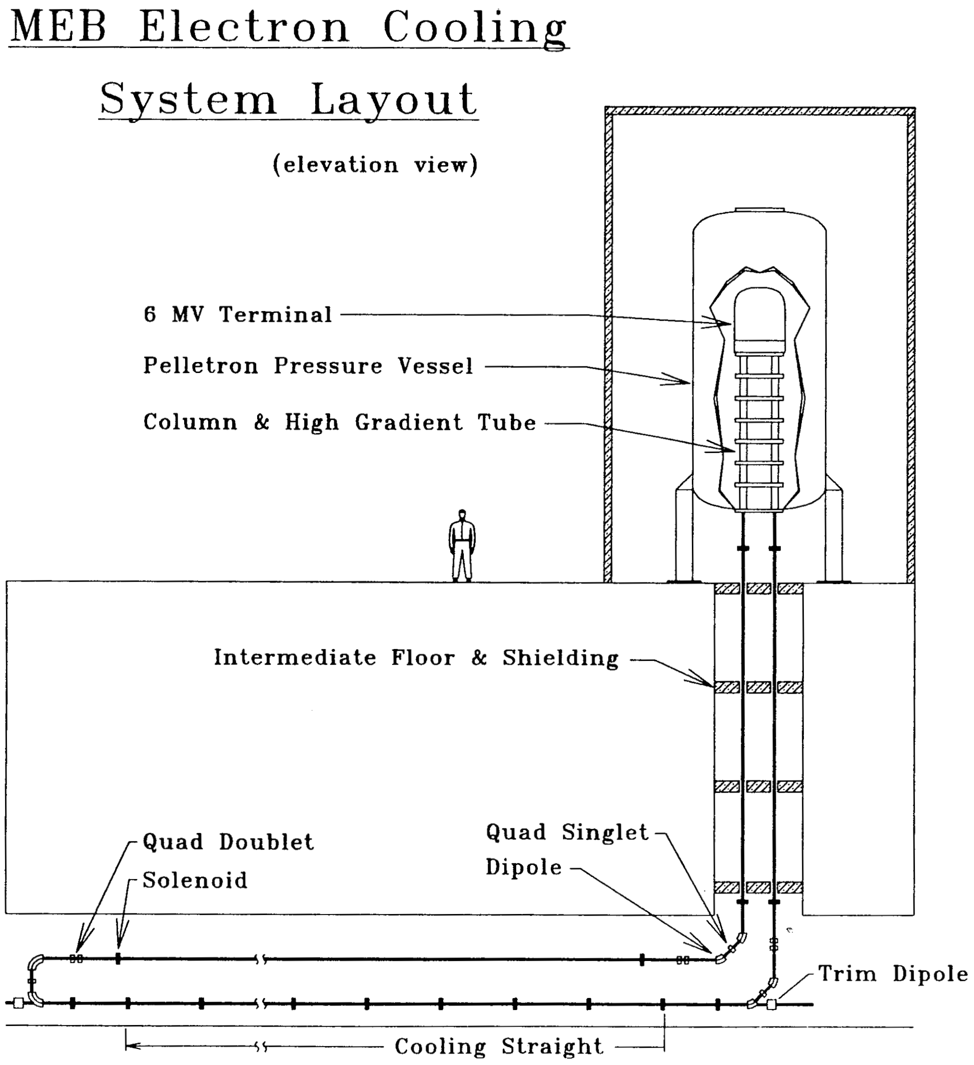

Figure 2. Electron cooling system layout in the MEB.

The electron and proton beams must be aligned with a tolerance of less than 40 μrad to preclude "effective" temperatures in excess of the cathode temperature; the electron beam divergence must also be less than this value. Figure 3 shows a layout of the electron beam optics, alignment, vacuum and diagnostic systems in the electron cooling region. The electron confinement system[5] consists of weak solenoids (focal length of 95 m) located every 2 m. Each solenoid provides just enough focussing to compensate the electron beam expansion due to its space charge. An error in the beam size or divergence causes the beam envelope to modulate about the equilibrium size with a wavelength of 65 m (the plasma wavelength). Such a modulation can be detected using single-pass flying wires. The electron and proton beams are aligned using nonintercepting beam position monitors with a resolution of 10 μm. The μ-metal shielding attenuates the magnetic fields from the earth and other stray sources. The degree of space charge neutralization must be kept below 0.06% to prevent "pinching." This is accomplished by a design pressure of 1×10^{-9} Torr, provided by nonevaporable getter pumps, and ion clearing electrodes located every 2 m. The gradient electrodes are used to accelerate ions to the clearing electrode system. We plan on assessing the effect of this beamline on the MEB impedance budget in the future using the Hewlett-Packard program *High Frequency Structure Simulator.*

MEB Modifications

An alternate scheme for the MEB long straight section proton beam optics design has been created.[6] This scheme leaves the basic ring FODO structure unaltered and preserves the dispersion suppression while reducing the number of quadrupoles in the insertion by 2, increasing the magnet free length from 20 to 45 m, and increasing the beta functions from

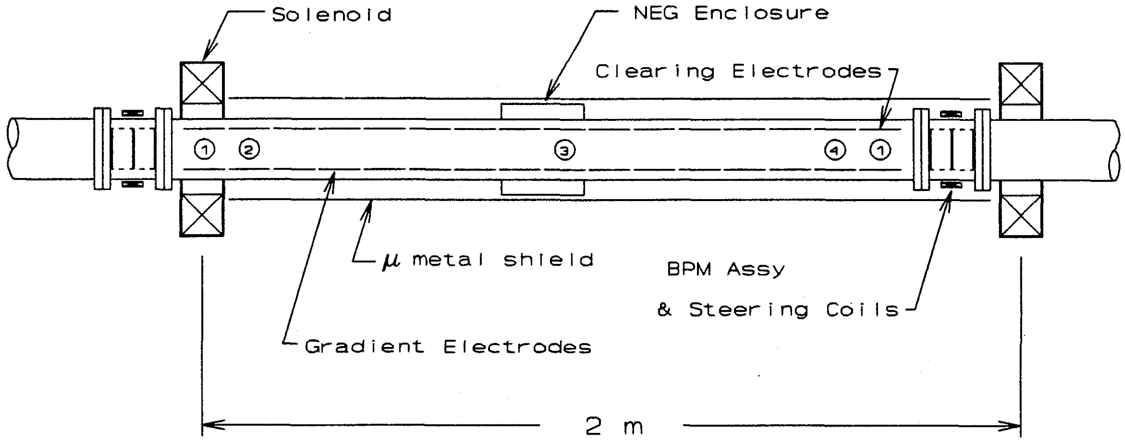

Figure 3. Electron confinement, alignment, vacuum, and clearing system.

about 25 m to 100 m. This modification significantly increases the cooling rate, which scales approximately as the product of the cooling region length and the square root of the beta functions. These modifications, however, move the ring 0.87 m closer to the center of the tunnel in the insertion region, and decrease the ring circumference by 6 cm.

A ring pressure of 1×10^{-8} Torr N_2-equivalent is needed to prevent multiple scattering from competing with the electron cooling process.[3,7] At this pressure, the equilibrium emittance would be $< 0.09\ \pi\mu$m for a 25-s cooling time. The present MEB vacuum pressure specification is 5×10^{-8} Torr. The reduced pressure requirement could be met by a combination of lower outgassing rate (using improved surface preparation techniques) and inexpensive nonevaporable getter pumping. In-situ baking should not be necessary to achieve this value.

Although the space charge tune shift at injection allows the beam emittance to be reduced by at least a factor of 3, the tune shift would exceed 0.3 at transition, necessitating a transition gamma jumping system.[8] Although such a system is not presently included in the SSC design, space has been reserved in the ring for such a system.

Since space charge plays such an important role in the electron beam optics,[5] it was initially thought that the proton beam would need to be nearly completely debunched. Further work, however, has shown that although the proton beam space charge leads to "non-ideal" electron optics, these distortions do not necessarily significantly affect the cooling process. Solutions for the electron beam optics design have been found for the cases of no debunching, partial debunching, and complete debunching. Consequently, the system can be easily adapted to any conceivable MEB operating mode without altering the electron beam confinement system hardware.

Recirculation Tests

To date, there have been two electron recirculation systems built that are similar to the one we propose to use at the SSC MEB. The UCSB FEL driver[10] has recirculated currents up to 3 A with collection efficiencies as high as 99.7% while operating in a pulsed mode; the NEC/FNAL/Univ. of Wisc.[11] system, which operated with DC current, demonstrated collection efficiencies as high as 99.99%, though current was limited to 0.12 A. A recirculation test system will be built at the National Electrostatics Corp. using an existing 2 MV Pelletron. The increase in energy from 2 to 6 MeV should not pose a problem since it involves no fundamental changes in technology.

The beamline[12] that joins the pair of Pelletron acceleration tubes to be used in the test system is shown in Fig. 4. The electron optics for this beamline have been modelled using a version of TRANSPORT which includes the effects of space charge. The transfer line produces a beam waist at the middle of the 180° bend, and is consequently symmetric about that point. Two solenoids provide enough flexibility to give both the required focal point position as well as a choice of beam size at the symmetry point. A quadrupole will be inserted between the two 90° dipoles to make the entire bend achromatic. Beam diagnostic systems will include non-intercepting beam position monitors,[13] single-pass flying wire scanners, and rotating wire beam profile monitors. The first two systems can be used to monitor the beam with beam currents up to the full design limit of 2 A. A beamline pressure of less than 1×10^{-8} Torr will be maintained using a combination of non-evaporable getters and ion pumping.

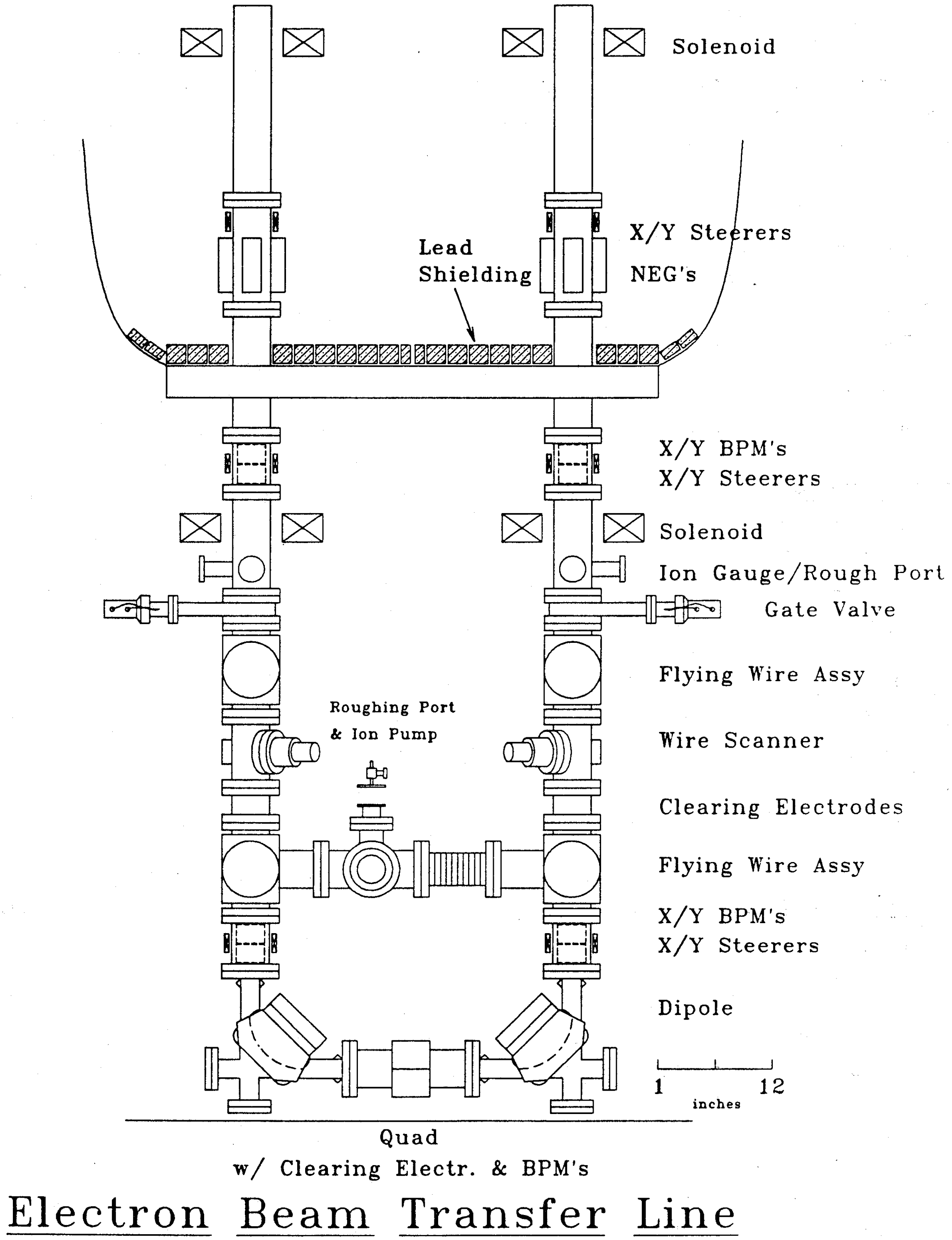

Figure 4. Recirculation test system transfer beamline.

Summary and Schedule

A design report for this cooling system is currently being prepared, and will be finished by the end of the summer 1992. Detailed design and procurement are underway for the test electron recirculation system. The system is scheduled to be assembled during the first part of 1993, and tests will then be carried out during the following year. A design review by outside experts was held in March 1992. The committee report strongly supported the project.

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