Design of a 6 MeV Electron Cooling System for the SSC Medium Energy Booster[a]

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Abstract

A 6 MeV 2 A electron cooling system is being designed for the SSC Medium Energy Booster (MEB). This system will decrease the beam emittance by at least a factor of two in 25 to 60 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 of the following machines. This paper summarized the system design, and the status of the proof-of-principle electron beam recirculation tests to be carried out at the National Electrostatics Corp.

1. INTRODUCTION

The lower limit for the beam emittance in the SSC is determined by the space charge tune shift, $\Delta Q_{sc} = 0.33$ 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, 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.

Table I. Summary of the parameters for the proposed electron cooling system for the SSC MEB.

Parameter	Symbol	Value	Units
Electron Beam Current	I	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_f	100	m
Electron 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

2. LAYOUT

2.1. Overview

Figure 1 is an overall view of the 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 6 MV terminal of a Pelletron accelerator. Two solenoids following the first 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. Following the cooling straight, the beam is then transported back to the 6 MV terminal and collected.

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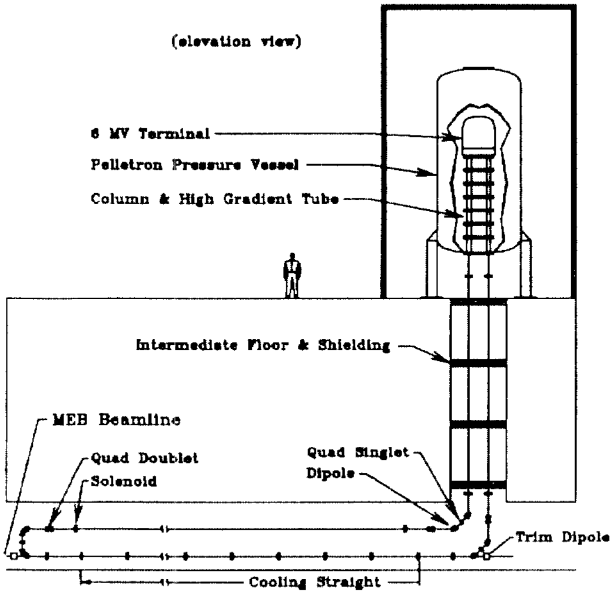

Figure 1. Electron cooling system layout in the MEB.

2.2 Cooling Region Electron Optics

We require the electron and proton beams to be aligned with a tolerance of less than 20 μrad to preclude "effective" temperatures in excess of the cathode temperature; the electron beam divergence must also be less than this value. Figure 2 shows a layout of the electron beam optics, alignment, vacuum and diagnostic systems in the electron

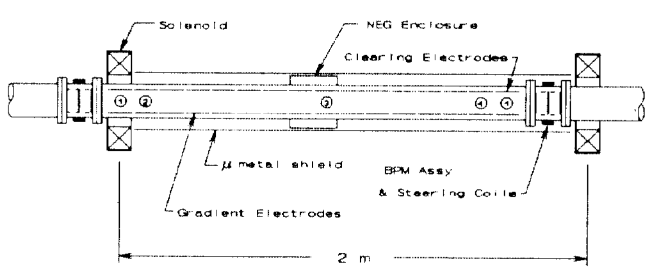

Figure 2. Electron confinement, alignment, vacuum, and clearing system.

cooling region. The electron confinement system[5] consists of weak solenoids spaced by 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 easily 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 $1 \cdot 10^{-09}$ Torr, providing 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.

3. MEB Modifications

3.1 Long straight section optics

An alternate scheme for the MEB long straight section proton beam optics design has been designed[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 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 towards the inside of the tunnel by 0.87 m in the insertion, and decrease the ring circumference by 6 cm.

3.2. Reduction in average ring pressure

A ring pressure of $1 \cdot 10^{-8}$ Torr is needed to prevent multiple scattering from competing with the electron cooling process[3,7]. At this pressure, the equilibrium emittance would be 0.045 and 0.11 $\pi\mu$m for 25 and 60 s cooling times, respectively. The present MEB vacuum pressure specification is $5 \cdot 10^{-8}$ 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.

3.3. Possible implementation of transition crossing scheme

Although the space charge tune shift at injection allows for 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 plans, space has been reserved the ring for such a system.

3.4. Partial de-bunching

Since the optical properties of the electron cooling beam line depend solely on beam space charge[5], the maximum current variation that the system can tolerate is about 10%. Proton beam peak current at injection is 800 mA (the longitudinal emittance is 0.038 eV $\cdot$ s)[9]. To decrease this value by a factor of 4 the RF voltage must be decreased from 170 kV at injection to $\approx$ 660 V to stretch the bunch length. The bucket area for this voltage is 21.6 eV $\cdot$ s, which is still much larger than bunch area.

4. 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 the 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 Figure 3. 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 both give 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 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. The beamline pressure of less than $1 \cdot 10^{-8}$ Torr will be maintained using a combination of non-evaporable getters and ion pumping.

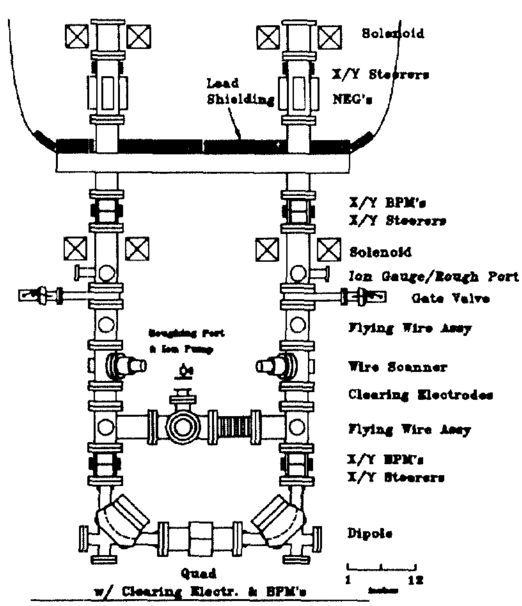

Figure 3. Recirculation test system transfer beamline.

5. Summary and Schedule

A design report for this cooling system is currently under preparation, 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 will be assembled during the first part of 1993, and tests will then be carried out during the following year.

6. Acknowledgements

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