The Development of a Prototype Multi-MeV Electron Cooling System*

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Abstract

Next generation electron cooling systems require a multi-MeV, 2 A DC electron beam source. Such electron cooling systems can reduce the emittances of proton and heavy ion beams leading to corresponding increases in luminosity. The technology needed to produce the necessary DC electron beams is being developed by the MEBEC group and tested at the National Electrostatics Corporation (NEC). This paper will outline the design considerations behind the system, improvements made over previous systems and the current status of the project.

I. INTRODUCTION

Although electron cooling has now become a routine tool in many laboratories, its use has been restricted to lower energy accelerators (<500 MeV). This is unfortunate, as it could prove to be very effective in higher energy accelerators as well. For example, the emittance of fully-stripped 7 GeV/nucleon gold beams in the proposed PS collider (KEK lab, Japan) could be reduced by an order of magnitude resulting in a factor of 10 increase in the machine luminosity. Other examples have been described in a previous paper [1]. Above electron energies of about 500 keV the traditional approach of using a Cockcroft-Walton power supply and magnetically-confined electron beams becomes impractical. A Pelletron electrostatic accelerator is well-suited to such an application requiring the acceleration of electron beams without subsequent emittance blow-up. NEC has made their 3 MV test Pelletron available for the construction and testing of a prototype 2 MeV, 2 A DC electron recirculation system. An increase in energy above 2 MeV should not pose a problem since it would involve no fundamental changes in technology. The goal of this project is to develop the technology to the point where such a system could be purchased commercially and used as a tool to significantly enhance accelerator performance.

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II. BEAMLINE DESIGN AND OPTICS

A. Design Principles

Figure 1 shows the beamline layout for the electron recirculation system tests [2]. The beamline joins a pair of Pelletron acceleration/deceleration tubes (not shown). Both the electron gun and collector are located inside the high voltage terminal of the Pelletron accelerator.

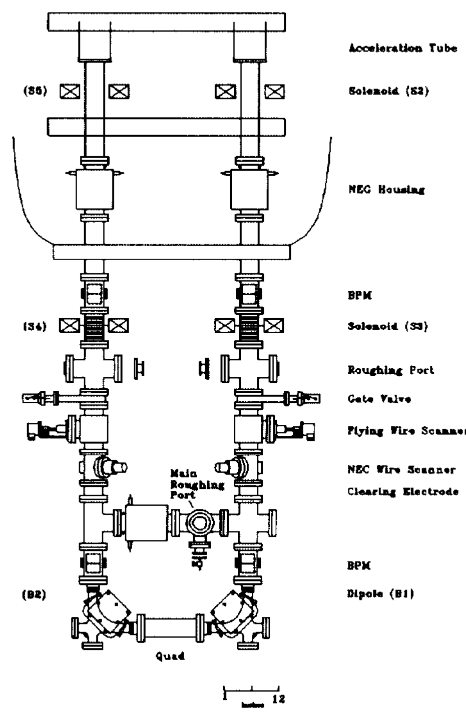

Figure 1. Recirculation test system beamline.

The beamline is symmetric about the center of the quadrupole. The quadrupole strength is adjusted to make the entire 180° bend achromatic, thus relaxing the stability requirements for the dipole magnet power supplies. The dipole magnets have a field index $n = ½$ to provide equal focussing in both the horizontal and vertical planes. There are six beamline solenoids in the recirculation test apparatus; one in the acceleration tube, four more in the external beamline, and the last one in the deceleration tube. Solenoidal focussing was chosen over quadrupole doublets or triplets due to the beam cylindrical symmetry at the exit of the Pelletron acceleration tube.

B. Electron Optics

The optics for this beamline have been modelled using both a version of TRANSPORT [3] which includes the effects of space charge and SCAT [4], a code that integrates the Twiss parameters and includes the effects of finite emittance, space charge and acceleration. The transfer line produces a beam waist at the middle of the 180° bend, and the beam envelope shape is consequently symmetric about that point. Figure 2 shows a typical optics plot obtained from SCAT. Additional waists occur prior to the first dipole, B1, and after the second dipole, B2. The position of these foci depend somewhat on beam current, moving slightly away from the dipoles with increasing current. A set of clearing electrodes has been placed at these focal points to sweep away any ions produced.

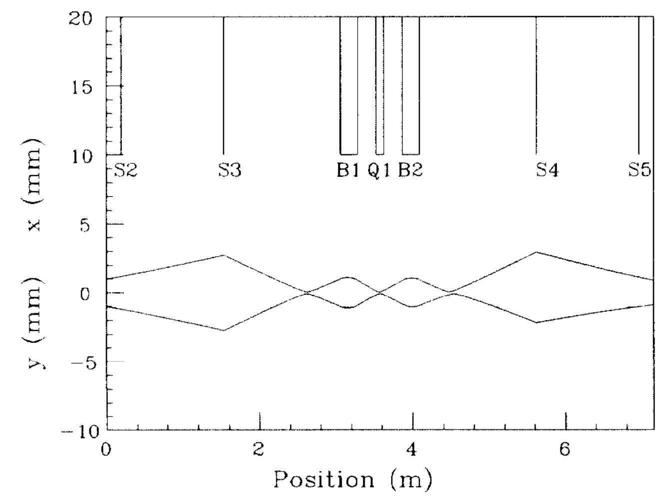

Figure 2. Horizontal and vertical beam envelopes. The slight asymmetry is due to the quadrupole.

As the beam current increases, space charge effects require that the solenoid field strengths change to compensate for the resulting defocussing. Changes in focussing must occur smoothly, to allow them to follow the increasing beam current without passing through a point where the beam can be lost. The optics are also constrained by the maximum solenoid field strengths and periodic 1 inch apertures within the transfer line.

A solution was found that utilized S3 and S4 together (with S2 and S5 off), for the full range of expected beam currents. The search for the calculated solenoid settings was automated, and carried out for over twenty different beam currents. The results are shown in Figure 3, where the solenoid currents, as a fraction of the maximum solenoid current, are plotted versus the electron beam current. This is a solution which changes relatively slowly with increasing beam current, and satisfies all the applicable constraints. This is also a rather elegant solution, considering that the total number of beam waists changes from 5 to 3 as the electron beam current varies from 0 to 2 A. These settings will be tabulated for automatic computer control.

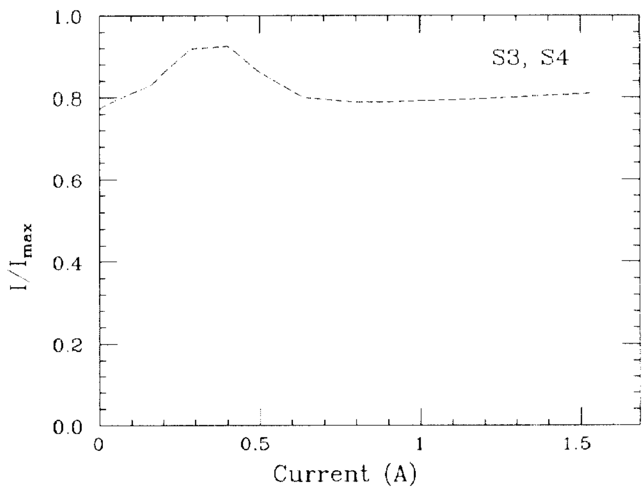

Figure 3. Calculated solenoid currents as a function of electron beam current.

III. DESIGN IMPROVEMENTS

A. General

Many changes have been made to the design of the recirculation test system as it first appeared during the UW/NEC/FNAL collaboration [5]. A much greater emphasis has been placed on magnet alignment. The magnets themselves have been designed specifically for this project, unlike those from various sources for the previous experiment. They have all been carefully field-mapped and have known focussing properties. Hall probes located inside the dipoles will ensure reproducible fields. Clearing electrodes will be placed at the positions of the three beam waists for ion sweeping to prevent space charge neutralization of the beam, which would greatly affect the electron optics. There will be greatly increased pumping capabilities available from a combination of non-evaporable getter (NEG) and ion pumps. The previous system had no ion clearing, and much less pumping. Other improvements include better radiation shielding of the Pelletron itself (to reduce SF_6 ionization leading to premature breakdown and voltage instability) and corona needles replaced by resistors.

B. Diagnostics

There are a total of eleven diagnostic stations (5 horizontal and vertical nonintercepting Beam Position Monitors (BPMs), 2 NEC wire scanners, 2 single-pass flying wire scanners and 2 residual gas beam profile monitors) included in the present design. The previous system had only two wire scanners which were limited to operation with beam currents below 100 μA due to high beam power and excessive beam loss. The BPM's are designed to operate over the full range of beam currents ($<$ 20 μA to 2 A), while the flying wire scanners have a current limit of 200 mA. For higher currents, a residual gas beam profile monitor is being developed. Use of these monitors will enable the operators to verify correct electron optics throughout the transfer beamline.

C. Enhanced Collection Efficiency

High collection efficiency is important for three reasons. First of all, the Pelletron can only source approximately 400 μA (limited by charging chain current), any further losses lead to a droop in terminal voltage and subsequent loss of beam. Secondly, since the secondary (backscattered) beam will have a much larger emittance than the primary (incident) beam, it can lead to voltage discharges in the deceleration tubes and gas desorption. Finally, any beam loss will produce x-rays which can ionize the SF_6 insulating gas and lead to premature breakdown and voltage instabilities.

The collector design incorporates two systems which prevent nearly all the backscattered electrons from the collector from re-entering the deceleration tubes. The first is a standard Faraday-cup type collector with electron suppression which limits the backscattered electron current to a few parts in 10^4 of the incident beam current. This collector is preceded by a 90° dipole magnet which will deflect the remaining backscattered current in the opposite direction of the primary current. The insulated vacuum chamber for this magnet will then serve as a secondary collector, collecting virtually all the remaining electrons.

IV. CURRENT STATUS

A. Pelletron Accelerator

The Pelletron accelerator has been raised to allow for semi-permanent alignment apparatus to be installed beneath the beamline. A two foot thick concrete vault was then poured around the beamline for radiation shielding. The electrical service and ground end feedthroughs have been reconnected, as well as the main SF_6 gas transfer line. The closed-loop charging system electronics have been reinstalled, and the refurbished light link fiber control cable has been connected to the terminal electronics. Once the control system was tested, the Pelletron column was conditioned (without tubes) to 2.3 MV in approximately 1 hour.

B. Magnets and Alignment Structure

The dipole magnets have been assembled and field-mapped, and their vacuum chambers have been welded and leak-checked. Two of the four external beamline solenoids have been assembled and field-mapped. The acceleration tube lenses (from the previous project) have also been field-mapped. Power supplies for the above magnets have been procured and installed. A beamline support and alignment structure has been designed utilizing standard off-the-shelf components. The dipoles and quadrupole will be mounted on a single frame and have the capability to be pre-aligned.

C. Diagnostics

Components for the Beam Position Monitor (BPM) electrode assembly have been designed and partially procured. The BPM pre-amp and synchronous detection electronics have been prototyped. The pre-amp electronics for the residual gas beam profile monitor have also been built and tested. The single-pass flying wire beam profile monitor design has been simplified and components have been procured and tested. The computer control software has also been modified and simplified.

D. Vacuum Hardware

The majority of the off-the-shelf beamline vacuum components have been procured. The NEG pump housing components have been fabricated and await welding. The associated NEG power supplies have been built and tested.

V. REFERENCES

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