STATUS OF THE FERMILAB ELECTRON COOLING PROJECT

A.Shemyakin, A.Burov, A.C.Crawford, V.Dudnikov, V.Kashikhin, T.Kroc, J.Leibfritz, J.MacLachlan, A.Makarov, M.McGee, S.Nagaitsev, G. Saewert, C.W.Schmidt, J.Volk, A.Warner FNAL, Batavia, IL60510, USA; V.Vostrikov, BINP, Novosibirsk, 630090 Russia

Abstract

Since 1995 Fermilab has engaged in an R&D program in electron cooling that has two principal goals: (1) to determine the feasibility of electron cooling the 8.9 GeV/c momentum antiprotons; and (2) to develop and demonstrate the necessary technology. A full-scale prototype of the electron cooler is planned to be manufactured and tested in 2001. Theoretical modelling of the cooling process and the electron beam transport as well as extensive experimental tests of various components of the device are being made. The paper presents the status of the project and plans for the nearest future.

1 INTRODUCTION

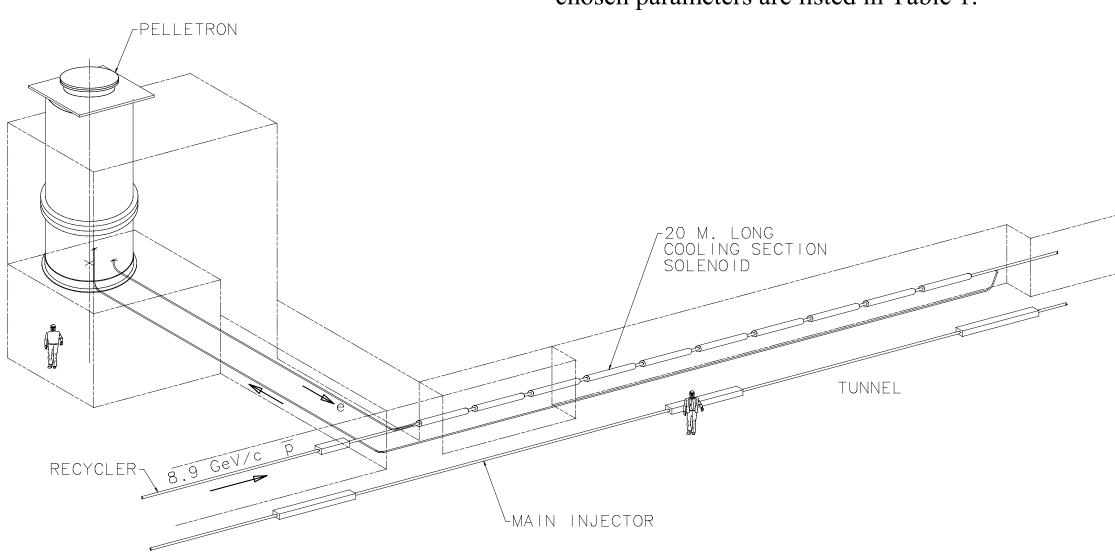
The goal of achieving of the Tevatron luminosity of 10^{33} $cm^{-2}s^{-1}$ supposes usage of electron cooling in the Recycler ring to provide an increased flux of antiprotons [1]. In the framework of the Fermilab's Electron Cooling project, a scheme of the electron beam transport has been proposed, elements for a full-energy recirculation experiment have been designed and manufactured, and tests of various components of the full-size transport line have begun. Also, a set-up for the first stage of the experimental work with a nominal energy beam is under assembly.

2 BEAM TRANSPORT

Electron cooling in Recycler will use a DC, 4.3 MeV, 0.3 A electron beam. The beam is generated in an electrostatic Pelletron[1] accelerator, then transported to the cooling section, and returned back to the high voltage terminal (Fig.1). Such a scheme of an energy recovery, or recirculation, is standard for all existing electron cooling devices. In contrast, the chosen transport scheme is non-standard. Only the gun, low-energy sections of acceleration and deceleration tubes, and the cooling section are immersed in a longitudinal magnetic field, while a lumped focusing system is used in between [2]. Such a system can be employed if an effective beam emittance

$$\varepsilon_{eff} = \frac{e}{2\pi \cdot pc}\Phi \tag{1}$$

is low enough [3]. Here e is the electron charge, c is the velocity of light, p is the momentum, and Φ is the magnetic flux at the cathode. In our case, the maximum affordable value of ε_{eff} is dictated by a typical distance between focusing elements and an aperture of the acceleration column in the Pelletron. Hence, the stronger the magnetic field at the cathode, the higher should be the electron energy where the magnetic field ends. The chosen parameters are listed in Table 1.



[1] Pelletron is a trademark of National Electrostatic Corporation (NEC), Middlton, WI

Table 1: Electron Cooling System Parameters

Parameter	Value	Units
Electrostatic Accelerator		
Terminal Voltage	4.3	MV
Electron Beam Current	0.5	A
Terminal Voltage Ripple	500	V (FWHM)
Cathode Radius	2.5	mm
Magnetic Field at Cathode	≤ 600	G
Cooling Section		
Length	20	m
Solenoid Field	≤ 150	G
Vacuum Pressure	0.1	nTorr
Electron Beam Radius	6	mm
Electron Beam Divergence	≤ 80	µrad

To form a round and cold electron beam in the cooling section, the transport line has to satisfy the following requirements [3]:

1. The magnetic flux inside the beam in the cooling section is equal to the magnetic flux at the cathode.
2. The transportation map between the cathode and the cooling section is rotationally invariant.
3. Aberrations in all elements of the transport line do not increase the beam emittance significantly above its thermal value.
4. To provide the stability of the Pelletron operation, a zero dispersion is desirable in most parts of the transport line.

Because of the condition (2) of the rotational invariance, the transport line consists of the axially symmetric elements (round electrodes of acceleration tubes and solenoidal lenses) and bends with a special matrix fulfilling conditions (2) and (4). Each 90° bend is formed by two 45° dipoles and 5 quadrupoles. The preliminary transport line design [3] was simulated by the beam transport code OptiM 2.1 [4].

3 ELECTRON BEAM RECIRCULATION TEST

An important step in the project will be a stable recirculation of 4.3 MeV, 0.5A DC beam in a dedicated U-bend set-up (Fig.2) , which is conceptually close to that used in the previous 1 MeV range test [5]. We plan also to test all diagnostics proposed for the full version of the cooler. Manufacturing of all parts is scheduled to be finished in the beginning of July, 2000.

4 TRANSPORT LINE COMPONENTS

The most important transport line components are being designed: the cooling section solenoid, bends, vacuum chamber, and various types of diagnostics.

4.1 Main solenoid

The main solenoid [6] consists of 10 identical 1.92 m

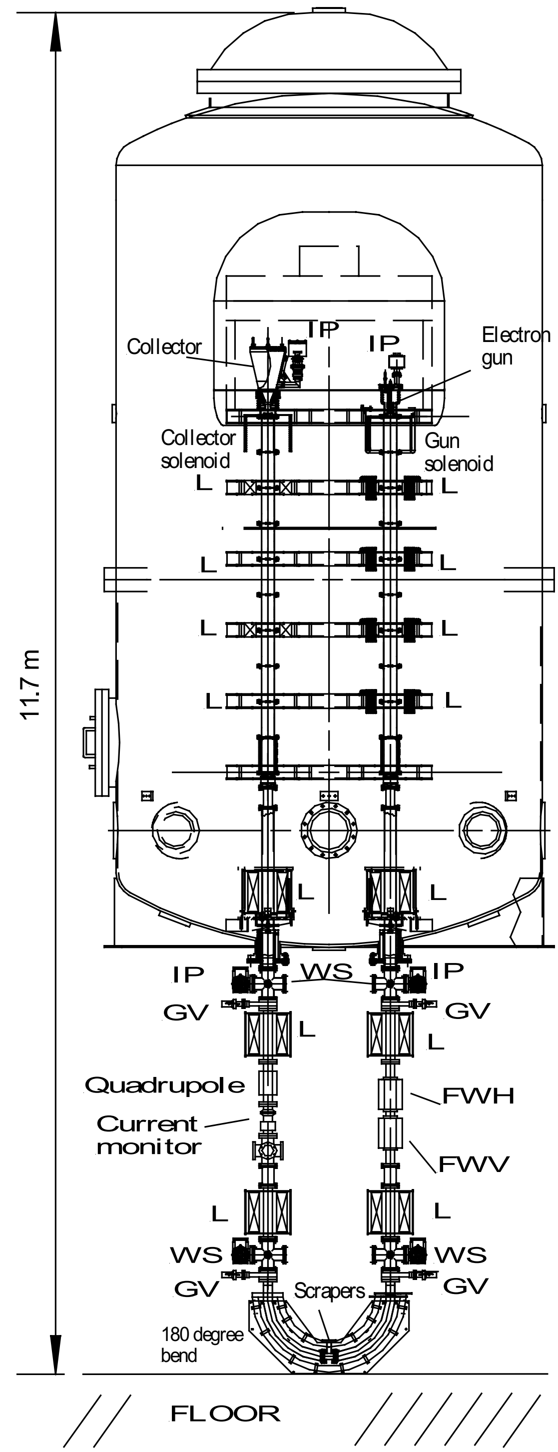


Figure 2: Mechanical schematic of the U-bend test stand. Symbols denote, correspondingly: IP- ion pump, L- lens, GV- gate valve, WS- wire scanners, FWH and FWV- flying wires.

modules, separated by 8 cm instrumentation gaps. Each module is a long solenoid wound around an aluminium tube by a 1.8 mm square copper wire, equipped with two short coils on the module ends for correction of the gap influence. Eight pairs of dipole correctors placed around each section are intended to correct the transverse magnetic field components. Two layers of a high-permeability alloy cover the entire section to attenuate external magnetic fields by a factor of about 5000. The measurement of the magnetic field quality in the 20 m solenoid will be performed with a compass-based sensor [7]. The first full-size prototype of the section has been manufactured, and measurements with the sensor have begun.

4.2 Bends

To preserve a low transverse velocity in the cooling section, the bending angle has to be stable within 0.05 mrad. Another possible problem is hysteresis in the dipole magnets because the bending field is only about 300 G. Since the Recycler ring is a permanent magnet fixed energy ring, the use of permanent magnet dipoles in the electron beam transport line is considered. The first prototype of a 45° magnet equipped with samarium-cobalt bricks was manufactured. The magnetic field deviation with temperature was compensated down to $2\cdot10^{-5}$/K analogously to that done for the Recycler [8].

To measure optical properties of a bend, a special test bench with a pencil proton and H^- beam was developed. Ions with energy of 12.5 keV, which can be precisely measured and stabilised, have its momentum equal to the momentum of the 4.3 MeV electrons, and, therefore, follow to the same trajectories in a magnetic field. By changing the input position and angle of the pencil beam and measuring its output parameters, one can make a full map of an element including non-linearity. The stand is presently used for measuring properties of a single 45° magnet. We plan later to trace the whole bend and, in the future, the entire transport line.

4.3 Vacuum chamber

The base pressure in the cooling section seems to be easily reachable at the level of the Recycler vacuum (about 10^{-10} Torr) if pumps are installed in each instrumentation gap between solenoids and a cleaned stainless steel vacuum chamber is baked at 120°C. The pressure can dramatically rise with the beam on. Even 1 μA of the current loss increases pressure in the tube above 10^{-9} Torr if the desorption coefficient is about 0.1 molecules/electron (typical value for a fresh baked surface). On the other hand, the system is very convenient for transporting a low-energy electron beam, which can effectively clean the vacuum tube [9]. We tested such a procedure at a dedicated stand, where a 3” OD, 5 m length stainless steel tube was cleaned by a 1.5keV, 0.15A beam focused by a 50 G longitudinal magnetic field. The desorption coefficient dropped below 10^{-3} after irradiation by a dose of 0.1 mA·hour/cm^2; hence, such a treatment can solve the problem with the electron-stimulated desorption in the cooling section.

4.4. Diagnostics

Several types of diagnostics [10] will be installed and tested at the U-bend test stand: continuously rotating wire scanners for initial positioning of a microampere-region beam; beam scrapers necessary for precise beam positioning and tuning in the cooling section; BPMs (capacitive pickups); and flying wires for full-current beam profile measurements.

5 PLANS

The first full-energy beam plans to be generated in the U-bend stand in September, 2000. Our intention is to finish the test in the summer of 2001 by demonstrating a stable, uninterrupted recirculation of 0.5 A beam during 8 hours. In parallel, tests of transport line elements and the main solenoid will be continued. The final goal of this part of the project is to develop, produce, and assemble a transport line, replicated that will be used in the Recycler, with a full-length cooling section. Most of the system will probably traced by an H^- beam. The optimistic scenario is to switch the electron beam from U-bend stand to the full-size transport line in fall of 2001. In this case, all preliminary tests with the system can be done during the next 1-1.5 year, and the electron cooling device can be installed into the Main Injector/Recycler tunnel in 2003.

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