COMMISSIONING OF THE FERMILAB ELECTRON COOLER PROTOTYPE BEAM LINE

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Abstract

A prototype of a 4.3-MeV electron cooling system is being assembled at Fermilab as part of the ongoing R&D program in high energy electron cooling. This electron cooler prototype will not demonstrate the actual cooling but it will allow determining if the electron beam properties are suitable for antiproton beam cooling. An electron beam is accelerated by a 5-MV Pelletron (Van de Graaff type) accelerator and transported to a prototype cooling section. The cooling will take place in a 20-m long solenoid flanked on both sides by a delivery and return beam-line – a total of 60 meters of transport channel. This paper describes the first results of commissioning this novel beam line as well as the status of the electron cooling R&D program.

INTRODUCTION

The application of electron cooling to 8.9 GeV/c antiprotons in the Recycler ring is a part of the program aimed to increase the collider luminosity. The Recycler Electron Cooling system (REC) is expected to counteract various beam heating mechanisms and to aid beam stacking in the Recycler [1]. The technical parameters of the REC system are summarised in Table 1.

Table 1: Electron Cooling System Parameters

Parameter	Design value	Achieved or installed	Units
Electrostatic Accelerator			
Terminal Voltage	4.34	4.34/3.5	MV
Electron Beam Current	0.5	0.5/1.0	A
Terminal Voltage Ripple	500	500	V
Cathode Radius	2.5	2.5	mm
Gun Solenoid Field	≤ 600	600	G
Cooling Section			
Length	20	18	m
Solenoid Field	≤ 150	150	G
Vacuum Pressure	0.1	wip (work in progress)	nTorr
Electron Beam Radius	6	wip	mm
Electron Beam Divergence	≤ 80	wip	µrad

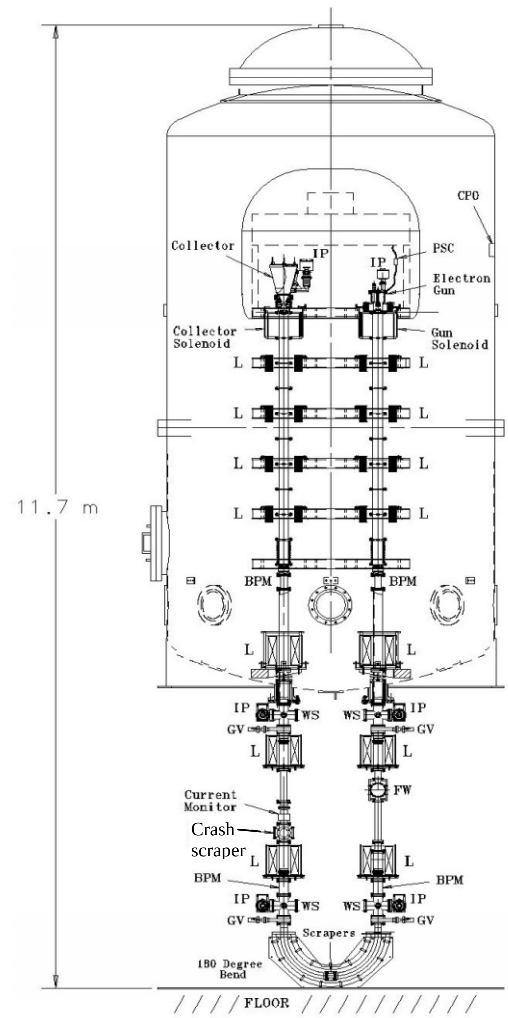

Figure 1: Mechanical schematic of the U-bend test stand. Symbols denote: IP- ion pump, L- lens, GV- gate valve, WS- wire scanners, FW - flying wire, BPM – beam-position monitor.

At present, the test of beam recirculation in the short beam line (Figure 1) has been completed. The magnetic field measurements of the cooling section solenoid have been carried out. The full-scale prototype beam line assembly and installation is nearing completion. Beam is expected to be tested though a complete cooling line in June, 2003.

BEAM RECIRCULATION EXPERIMENT

The recirculation experiment at Fermilab was performed in 2001 – 2002 within the framework of the REC project with a system, which included (see Fig. 1) an electrostatic accelerator, Pelletron, and a short beam line (U-bend). After attainment of a 0.5-A, DC electron beam at the kinetic energy of 3.5 MeV in December, 2001 [2], the main efforts on the final stage of the experiment, in May-November, 2002 were devoted to improving of the beam operational stability.

Estimations made for the future electron cooler has shown that infrequent short-duration processes in the Pelletron, like beam interruptions or discharges, would not deteriorate the performance of the Recycler ring. A weak interaction (i.e. cooling) between the electron and antiproton beams makes heating of the antiproton beam during electron current interruptions negligible. Long beam lines between the Pelletron and the cooling section preserves the high vacuum in the Recycler ring in cases of pressure bursts in the accelerating tubes. Therefore, the figure of merit for electron beam stability is the average duty factor of the electron beam operation.

Several processes affected the duty factor in the recirculation experiment. First, a stable recirculation of a DC beam can be interrupted by sudden jumps in current losses, which forces the protection system to shut the electron gun off. Second, full acceleration tube discharges can result in large changes of the residual gas pressure and tube's high voltage stability. Third, the full discharges sometimes result in a cold emission from the gun control electrode, which has to be conditioned away before restoring the beam recirculation. These issues are described in detail in Ref. [3]. The cold gun emission was nearly completely eliminated by a proper choice of the gun electrode materials.

As for the beam interruptions and tube discharges, the system behaved differently at a Pelletron voltage of 3.5 MV and 4.34 MV. We found that without any beam the accelerating gradient can be as high as 16 kV/cm (corresponding to 5 MV), with the dc electron beam in excess of 10 mA the stable operating gradient drops to 12 kV/cm. This prompted us to plan an upgrade for the Pelletron from 5 to 6-MV maximum rating by extending the acceleration tube length by 20%. This upgrade will be implemented when the Pelletron is moved to its final location. With this upgrade the accelerating gradient at the design voltage of 4.34 MV will be very close to that of the present machine at 3.5 MV. Table 1 shows the achieved results for two voltages – 4.34 and 3.5 MV. While at 4.34 MV we were able to demonstrate the design current of 0.5 A, the stable beam operation was frequently interrupted by beam-induced tube discharges (every 4 minutes or so) with eventual high-voltage de-conditioning such that the Pelletron was no longer capable of holding 4.34 MV. At a lower 3.5-MV voltage and the best beam line settings we did not see any full-tube discharges, while the beam interruptions occurred on average every 20 minutes (with a 0.5-A beam) and did not cause any de-conditioning to the accelerating tube. Figure 2 shows a 4-hour run with a 0.5 A beam at 3.5 MV.

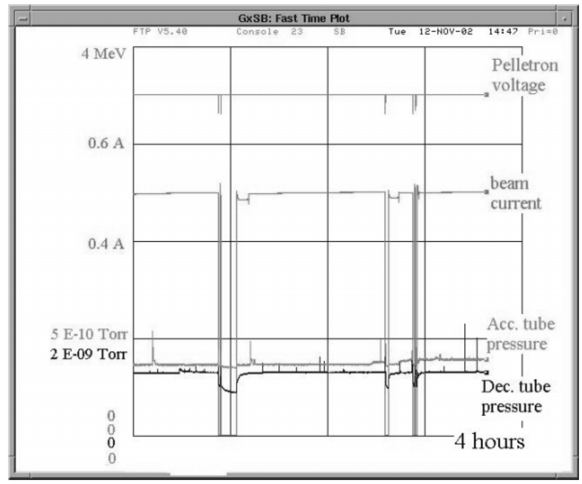

Figure 2: Pelletron voltage, ion gauge readings, and the beam current recorded over 4 hours of running at 3.5 MV, 0.5 A. An interruption in the first hour was caused by a computer glitch.

In all beam interruptions the Pelletron voltage drops by no more than 200 kV. This prompts the computer control system to shut the electron gun off. The Pelletron voltage then returns to its nominal value in several seconds and the recirculation at the nominal current is restored in 20 seconds by the control system without any operator interference. Figure 3 shows the beam recovery process on a shorter time scale.

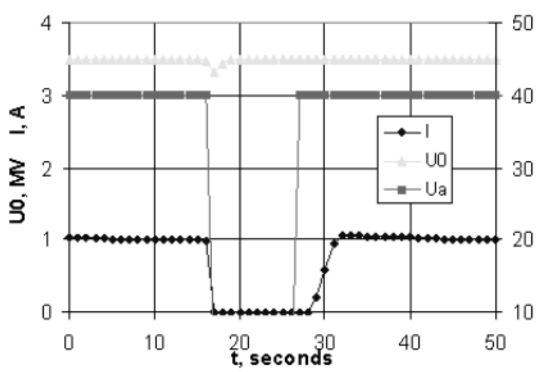

Figure 3: Beam recovery after an interruption of a 1-A beam recirculation. The electron gun was operated with a 40-kV anode voltage (Ua curve).

Putting aside mechanical and electronics failures, at 3.5 MeV, 0.5 A, and the best conditions, only short beam interruptions were present, and the duty factor was better than 99%. While a current of 0.5 A has been achieved at the energy of 4.34 MeV, multiple interruptions led to full discharges and loss of tube conditioning. The necessity to recondition the tubes makes such a regime intolerable. The level of the beam current at 4.34 MeV, at which the duty factor is above 95%, is 0.1 A or less.

FIELD QUALITY IN THE COOLING SECTION SOLENOID

The cooling section solenoid consists of ten solenoid modules, gaps between the modules and magnetic field correctors [4]. The transverse field in the cooling section is measured by a dedicated compass-based magnetic sensor, while the longitudinal field is measured by a Hall probe.

For successful cooling it is necessary to keep the electron beam angles (with respect to the anti-proton beam) below 0.1 mrad inside the cooling section (see Table 1). This requirement in turn sets several restrictions on the magnetic field quality: the longitudinal field at any point in the cooling section shouldn't differ too much from the field averaged over the whole cooling section and the absolute value of a running integral of the transverse field should be below 1G·cm at any point inside the cooling section [4].

The measured transverse field of an un-corrected solenoid does not satisfy these requirements. Indeed, the simulation of the electron motion in this field showed that the acquired angles are as large as 5 mrad.

To improve the field quality an algorithm of compensation was suggested [5]. Initially, it was tested in a 4-meter prototype of the cooling section. It was found that the algorithm works reliably and gives a field of the proper quality.

The field of the full-scale 18-m long cooling section was measured and served as an input for the algorithm. The calculated currents of the transverse correctors were used to predict the compensated field. Figure 4 gives the electron trajectory in this expected field. It shows that the angle of an electron beam is below the threshold value in 95% of the cooling section, which is more than enough for successful cooling.

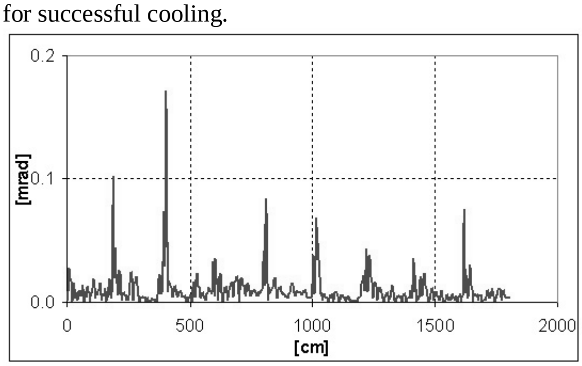

Figure 4: Simulation of electrons motion (electrons angle) in the predicted magnetic field (electron enters the solenoid at 5mm off axis).

A more careful analysis of the compensated field showed it to be unsatisfactory although it was approximately 10 times better than the initial field (see Figure 5).

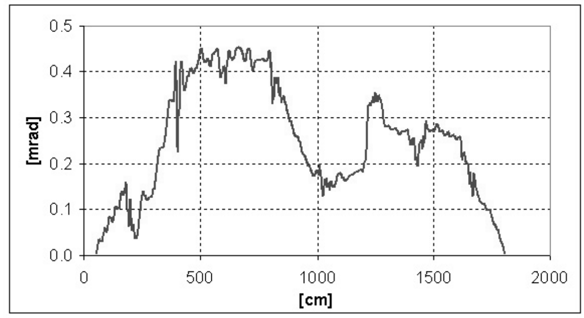

Figure 5: The total electron angle simulated in the fields obtained after the adjustments of field correctors (electron enters the solenoid at 5mm off axis).

Such a situation is related to a problem with the long-term stability of the measurement. At the present time significant work is being done to improve the measurement stability. Repeated adjustments and measurements are planed for this summer.

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REFERENCES

[1] S. Nagaitsev et al, NIM A441(2000), 241.
[2] J. Leibfritz et al, “Status of the Fermilab Electron Cooling project”, Proc. of EPAC’02, Paris, 3-7 June, 2002.
[3] A. Shemyakin, “Attainment of an MeV-range, dc electron beam for the Fermilab cooler”, to be published in COOL 03 workshop proceedings.
[4] S. Nagsitsev et al, “Fermilab Electron Cooling Project: Estimates for the Cooling Section Solenoid”, FERMILAB-FN-689, March 2000.
[5] S. Nagaitsev et al, “Field measurements in the cooling section solenoid for the Recycler cooler”, Proc. of EPAC’02, Paris, 3-7 June, 2002.