STATUS OF THE FERMILAB ELECTRON COOLING PROJECT

J. Leibfritz, D. Broemmelsiek, A. Burov, K. Carlson, B. Kramper, T. Kroc, M. McGee, S. Nagaitsev, L. Nobrega, G. Saewert, C.W. Schmidt, A. Shemyakin, M. Sutherland, V. Tupikov, A. Warner, FNAL, Batavia, IL 60510, USA; S. Seletsky, University of Rochester, Rochester, USA; G. Kazakevich, Budker INP, Novosibirsk, Russia

Abstract

Fermilab* has constructed and commissioned a full-scale prototype of a multi-MV electron cooling system to be installed in the 8.9 GeV/c Fermilab Recycler ring [1]. This prototype has been used to test all of the electron beam properties needed for cooling. However, the actual cooling of antiprotons could not be demonstrated because the prototype was located outside the Recycler tunnel. The Fermilab electron cooling R&D effort was completed in May 2004 and the prototype system is currently being disassembled and relocated to a newly constructed facility, where it will be tied into the Recycler ring. This paper describes the experimental results obtained with the prototype cooling system, gives an overview of the new electron cooling facility, and discusses the overall status of the project.

INTRODUCTION

Electron cooling in the Recycler ring requires a high-power DC beam. The beam generation scheme employs an electrostatic accelerator (Pelletron [2]) operating in a so-called "recirculation" regime; the electron beam is accelerated down one tube of the Pelletron, passes through the beam line at ground, and returns to the high voltage terminal through a second (deceleration) tube. The great advantage of this scheme is a low dissipated power (several kW) while achieving a beam power of more than 2 MW. Table 1 lists the electron cooling system parameters.

Table 1: Electron Cooling System Parameters

Parameter	Design Value	Achieved (max)	Units
Electrostatic Accelerator			
Terminal Voltage	4.34	3.5 (4.34)	MV
Beam Current	0.5	0.5 (0.7)	A
Terminal Voltage Ripple, rms	500	500	V
Cathode Radius	2.5	2.5; 3.8	mm
Cathode Field	≤ 600	280 (670)	G
Cooling Section			
Length	20	18	m
Solenoid Field	≤ 150	150	G
Vacuum	0.1	0.7	nTorr
Beam Radius	6	6	mm
Electron Angular Spread, rms	≤0.08	≤0.3	mrad

*Fermilab is operated by Universities Research Association, Inc., under Contract No. DE-AC02-76CH03000 with the U.S. Department of Energy

ELECTRON COOLING R&D FACILITY

A large, vacant, fixed-target experimental hall at Fermilab was selected as the location for an experimental R&D facility (Fig. 1). This location was selected because of its availability and size. The purpose of this facility was to establish an area where the Pelletron and related beam lines could be installed and tested for feasibility of a final electron cooling system. Assembly of the Pelletron began in 1999 and the first phase of commissioning began in 2001.

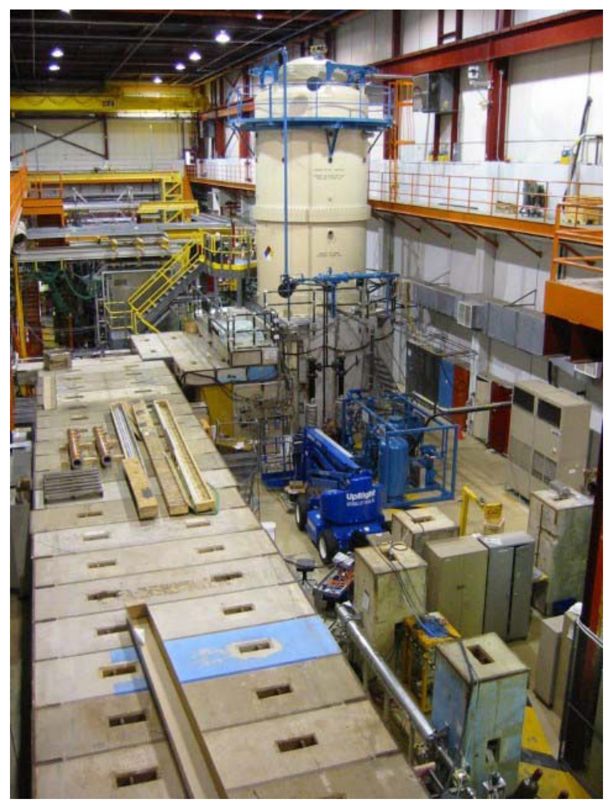

Figure 1: Electron Cooling R&D Facility

Recirculation Experiment

The first stage of commissioning was the recirculation experiment (2001–2002) [3]. This experiment involved operating the Pelletron with a short "U"-shaped beam line (Fig. 2). The principle goal was to achieve the required operating parameters of the Pelletron listed in Table 1. The most noteworthy result of this phase of commissioning was that a stable operation of 0.5 A at 3.5 MeV, with a 99% duty factor, was achieved. In addition, a maximum DC current of 1.7 A at 3.5 MeV was attained, resulting in a total power of 6 MW. A significant finding of this experiment was that the Pelletron acceleration tubes could not operate reliably with a high beam current at 4.3 MeV. As a result, an additional section was ordered for the Pelletron to increase the stable operating voltage from 3.5 MeV to 4.3 MeV. However, because of height restrictions of the R&D facility, the new section cannot be installed until the Pelletron is moved to the new building.

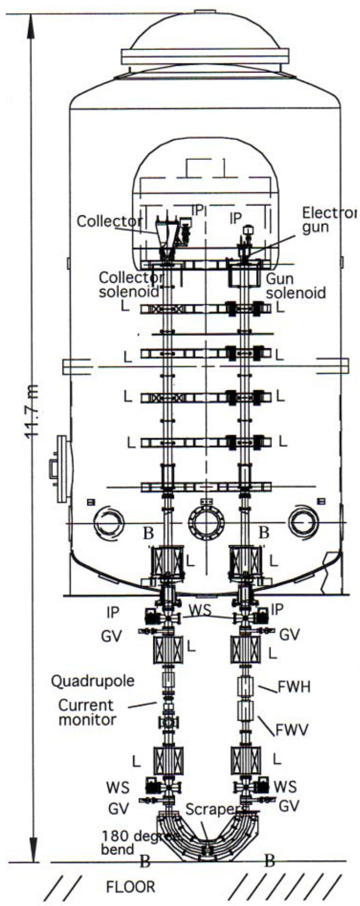

Figure 2: Recirculation Experiment

Full Scale Prototype

After successfully demonstrating the feasibility of generating an adequate electron beam in the recirculation experiment, the next stage of commissioning began: the full-scale prototype (2003–2004) [4]. This phase involved installing a system of beam lines at the R&D facility to replicate the final cooling system (Fig. 3). The beam lines were not quite full-scale (9 cooling solenoids instead of 10, and a shorter transfer line) because of limitations imposed by the size of the existing building. In all other aspects, the beam line system was identical to that planned for the final electron cooling system

This experimental phase had two principle goals: 1) to effectively transport the electron beam at full current through the full beam line and 2) to achieve the required beam properties needed for electron cooling. Efforts towards the first goal resulted in successful recirculation of a beam of 0.7 A at 3.5 MeV. In addition, 12-hour continuous automated operation was achieved at a current of 0.35 A, with recirculation interruptions occurring several times per hour with an average recovery time of 15 seconds. As for the second goal, several constituents of the effective electron temperature in the cooling section were identified and measured. These components include: distortion of the central trajectory, envelope scalloping, and trajectory oscillations. The r.m.s angles associated with each of these individual components were minimized to a level below 0.2 mrad. Methods to lower the total effective angle to the same level in the final cooling section were also determined.

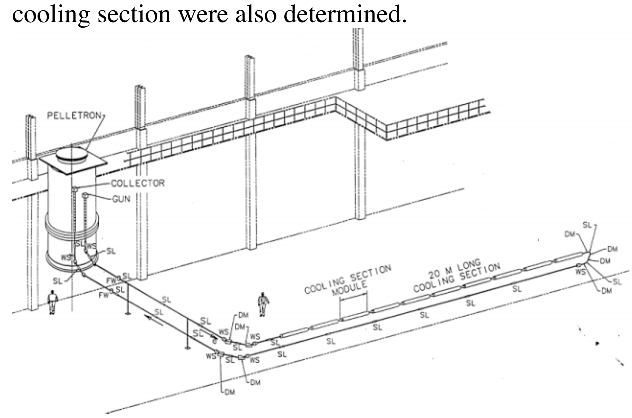

Figure 3: Full Scale Prototype System

Further results of this stage of commissioning included the development of an effective protection system to avoid damage to the electronics in the Pelletron due to discharges as well as the possibility of burning a hole in the vacuum system due to failures. Also, several diagnostic tools for measuring the beam trajectory, envelope, and current density were developed and tested. Most of these will be used in the final cooling system with only minor changes. These tools include a system of BPM's (capacitive pickups) with digital processing, YAG crystals, optical transition radiation (OTR) monitors, multi-wire harps, and removable apertures. Software to take optics analysis data and to measure the beam size was also developed and tested. Data taken during this phase of commissioning is currently in the process of being further analyzed.

MI-31 FACILITY

MI-31 Building Design

After achieving the commissioning milestones associated with the recirculation experiment (thus proving the feasibility of the electron cooling system), the design of a new building (MI-31) to house the final electron cooling system and tie it in to the Recycler ring was initiated. This building is located tangent to the Main Injector accelerator tunnel (which houses the Recycler ring). The design and construction of this building was planned to coincide with the remaining R&D efforts as well as with planned Lab-wide shutdowns of operation. The construction of MI-31 began in November 2003 and was completed in May 2004. The completion date coincided precisely with the planned conclusion of the R&D activities. Figures 4 and 5 show the MI-31 building and electron cooling system in the Recycler ring.

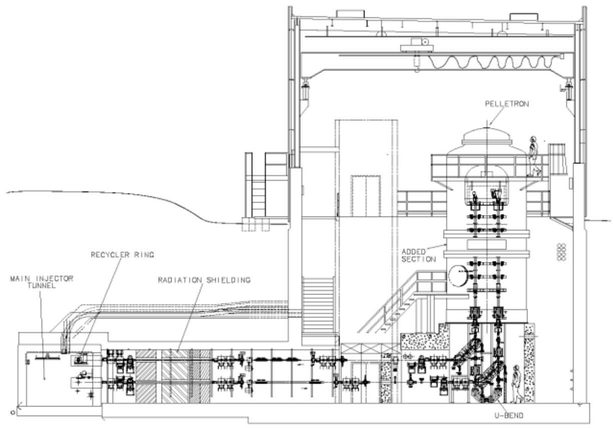

Figure 4: Elevation view of MI-31 building showing Pelletron, acceleration and deceleration beam lines, transfer lines passing through connecting enclosure from MI-31 to Recycler ring, and cross-section of Main Injector tunnel which houses the Recycler ring.

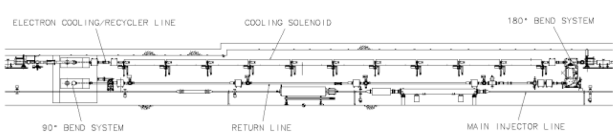

Figure 5: Elevation view of Main Injector tunnel showing the 90°-bend system which injects the electron beam from the transfer line into the Recycler ring, cooling section of Recycler, 180°-bend system which extracts the electron beam from the Recycler, and the return line.

Changes Implemented at MI-31

Several improvements are being made to the electron cooling system when it is moved to MI-31:

1. A sixth acceleration section is being added to the Pelletron (see Fig. 4).
2. In order to improve the ultimate vacuum level of the acceleration/deceleration tubes, a "dead" section is being added to the Pelletron extension to accommodate an additional ion pump.
3. The beam line configuration under the Pelletron is being altered to accommodate both the "U"-shaped beam line used for commissioning in the recirculation experiment, and the vertical bend magnets used to transport the beam to the cooling section (see Fig. 4). This will greatly accelerate the final commissioning process by allowing an easy switch over from one mode to the other.
4. A vacuum protection system is being implemented using a series of fast-acting gate valves, ion gauges, and burst-discs. This system is designed to protect the Recycler ring vacuum system in the event of a catastrophic failure of the vacuum system inside the Pelletron, which could potentially introduce pressurized sulfur hexafluoride gas into the vacuum system.
5. A significant increase in the number of diagnostics is being implemented in the final design. This includes the addition of YAG crystals and OTR monitors throughout the beam lines, as well as the addition of a BPM and removable aperture between each of the ten cooling solenoids.
6. The electron cooling beam lines located in the Main Injector tunnel (Fig. 5) are being magnetically shielded to protect the electron beam from the fields imposed by the ramping of the Main Injector magnetic bus located in near proximity of the electron cooling system.

SCHEDULE AND STATUS

The R&D phase of Fermilab's Electron Cooling project was concluded on May 28th, 2004. On June 1st, 2004 a massive effort was set into motion to disassemble the R&D facility (Pelletron, beam lines, controls, utilities, etc.) and relocate it to the new MI-31 building.

The relocation of the entire electron cooling system is expected to be complete by February 2005. The installation of the associated beam lines, and necessary modifications to the Recycler ring, are planned to be completed during a Lab-wide shutdown scheduled for late summer.

Once relocated, the process of commissioning the electron cooling system for integration into Fermilab's scientific program will begin. It is anticipated to have an electron beam circulated through the full system in April 2005, and perform the first cooling of antiprotons in the Recycler in Fall 2005.

ACKNOWLEDGEMENTS

Authors acknowledge useful discussions with V. Lebedev and C. Gattuso and are thankful to S. Oplt and S. Wesseln for participation in the mechanical design and to technical specialists A. Germain, R. Kellett, and J. Nelson for all their efforts.

REFERENCES

[1] J.A. MacLachlan et al., "Prospectus for an Electron Cooling System for the Recycler," MEEC'98, edited by I Meshkov, Dubna, 1999, pp. 25-113.

[2] Pelletrons are manufactured by the National Electrostatics Corporation, www.pelletron.com

[3] A. Shemyakin et al., "Attainment of an MeV-range, DC Electron Beam for the Fermilab Cooler," COOL'03, Japan, May 2003.

[4] A. Shemyakin et al., "Test of a Full-Scale Prototype of the Fermilab Electron Cooler," to be published in proc. of APAC'04, Seoul, S. Korea, March 2004.