TEST OF A FULL-SCALE PROTOTYPE OF THE FERMILAB ELECTRON COOLER

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Abstract

The Fermilab's Recycler ring will employ an electron cooler to store and cool 8.9 GeV antiprotons [1]. The cooler is based on an electrostatic accelerator, Pelletron, working in an energy-recovery, or "recirculation", regime. A full-scale prototype of the cooler has been assembled and commissioned in a separate building. The main goal of the experiments with the prototype is to demonstrate a stable operation with a 3.5 MeV, 0.5 A DC electron beam while preserving a high beam quality in the cooling section. The paper describes the current status of the work and preliminary experimental results.

INTRODUCTION

After successful demonstration of feasibility of a MeV, Ampere-range DC beam generation in a recirculation test with a short beam line [2], the Fermilab Electron Cooling project entered its next stage, commissioning of a full-scale prototype. The prototype has all major features of the cooler's final design but differs by physical dimensions. Because of limitations by the size of an existing building, where the experiment takes place, the prototype's beam lines are shorter; the cooling section consists of 9 identical modules instead of 10; and the number of acceleration sections in the Pelletron is five instead of six in the final version. So far the activity has concentrated primarily on achieving stable beam recirculation and commissioning of the beam diagnostics. The main achieved parameters are compared with the design in Table 1.

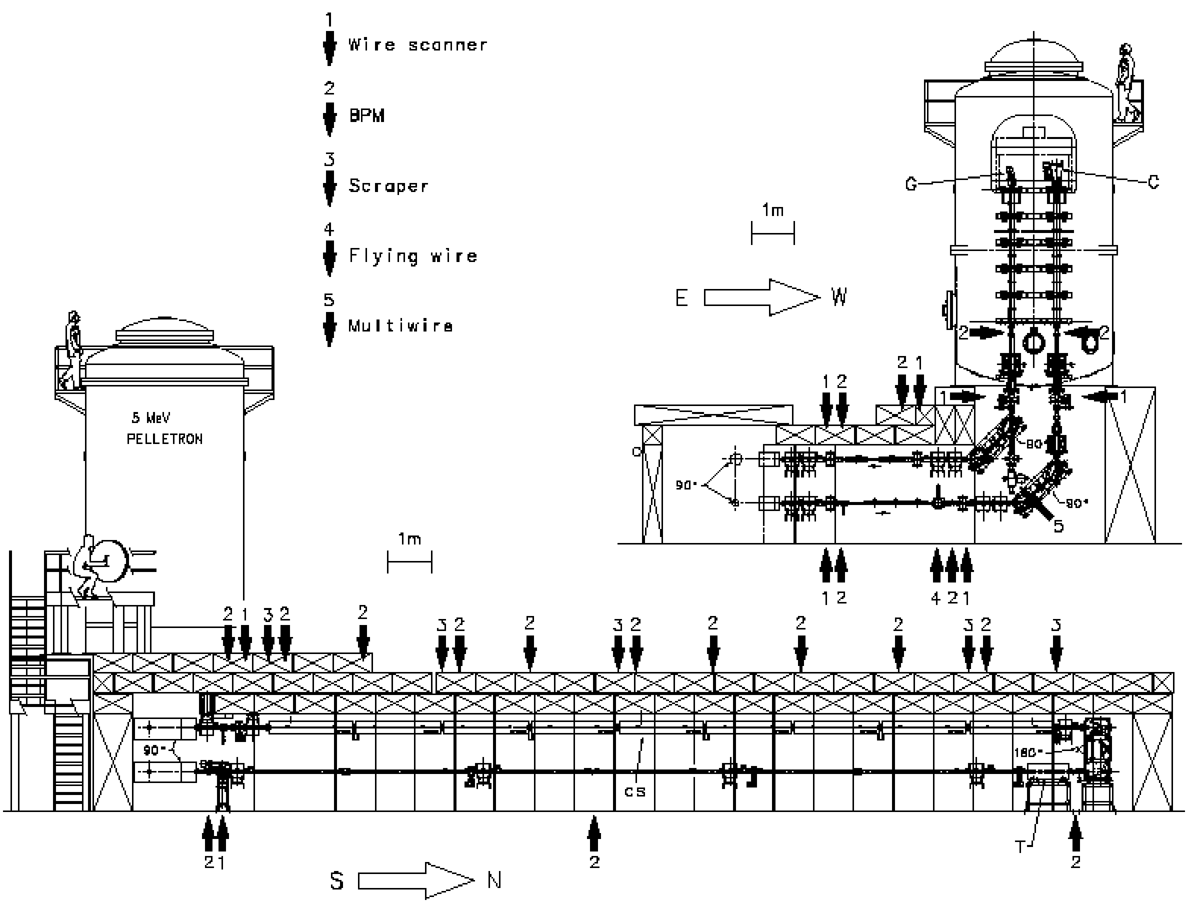

Figure 1: Mechanical schematic of the setup. Arrows shows positions of various types of diagnostics. 90° and 180° label the corresponding bends. Letters indicate: G-gun, C-collector, CS- cooling section, T – quadrupole triplet.

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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 (0.66)	A
Terminal Voltage ripple, rms	500	500	V
Cathode Radius	2.5	2.5	mm
Cathode Field	≤ 600	280 (670)	G
Cooling Section			
Length	20	18	m
Solenoid Field	≤ 150	100 (200)	G
Vacuum	0.1	0.7	nTorr
Beam Radius	6	4.5	mm
Electron Angles, rms	≤0.08	≤0.6	mrad

SETUP AND DIAGNOSTICS

The mechanical schematic of the setup is shown in Fig.1. The electron beam is generated by an electrostatic accelerator, Pelletron [3], passes through a beam line, is decelerated in the second Pelletron tube, and is absorbed in a collector at the kinetic energy of 3-5 keV. A detailed description of the prototype optics can be found in [4].

The setup is equipped with several types of beam diagnostics. The beam trajectory is measured by 19 pairs of capacitive pickups, referred further as BPMs. The BPMs can work in either of four modes: pulsed (1-8 μsec pulses at 1 Hz); negative pulsing, when a DC beam is interrupted for the same 1-8 μsec; a sinusoidal modulation of a DC beam current at frequency of 20 – 90 kHz; and a mode that will be used for measurements of the position of the antiproton beam circulating in the Recycler ring with the revolution frequency of 89 kHz.

Five scrapers installed in the gaps between the modules of the cooling section are used to measure the beam dimensions (see Part 4). Each scraper is a retractable copper plate with a 15 mm round orifice. Also, the beam size can be measured by a multi-wire harp (50 tungsten, 25 μm wires in each of two planes separated by 0.5 mm) in a pulsed mode and by a carbon, 25 μm wire flying through the beam at a speed of 5 m/s in a DC mode.

RECIRCULATION

The maximum achieved current, 0.66 A, is equal to the space-charge limit of the gun at the gun voltage of 25 kV. Recirculation at high currents was possible only with +300 V applied to both plates of BPMs under the acceleration and deceleration tubes to prevent ions from entering the tubes, and with -200 V at one of the plates of each of the other BPMs to clear ions in the beam line.

Two attempts to run a 0.5 A beam for hours in an automated mode have been made. In both cases, at the beginning the beam recirculation was interrupted in average once per hour with 15 s of the recovery time, similar to what has been observed in the recirculation test [2]. However, after 4-5 hours of operation the trajectory drift resulted in a decrease of the maximum recirculated current below 0.5 A. Currently attempts are being made both to understand the reasons for the drift and to implement a feedback loop to stabilize the trajectory.

The current losses (Fig. 2) were found to be by an order of magnitude higher than in the recirculation test. Also, the losses rapidly increased with decreasing of the collector voltage from its maximum value of 4.6 kV, while in the recirculation test the optimum collector voltage was 2 – 2.5 kV.

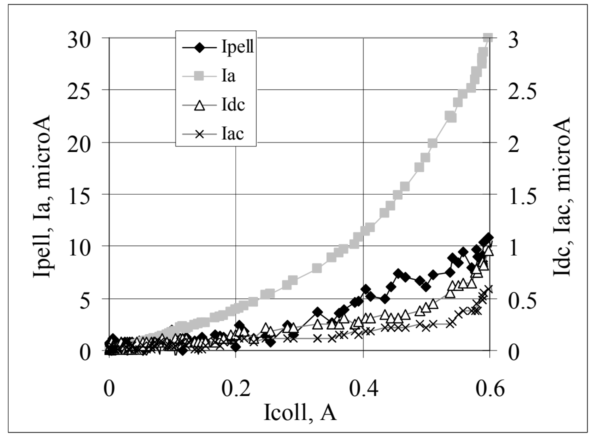

Figure 2: Losses as functions of the beam current. Changes in currents of the Pelletron, anode power supply, deceleration and acceleration tube resistive dividers are labeled, correspondingly, as Ipell, Ia, Idc and Iac.. The collector voltage was 4.6 kV, and the Pelletron voltage was 3.5 MV.

The losses practically did not depend on the residual pressure and most likely were caused by the worsen collector efficiency. Two possible reasons for the efficiency degradation are considered: widening of the electron energy distribution resulted from the intrabeam scattering and a transverse oscillation of the beam near the collector entrance.

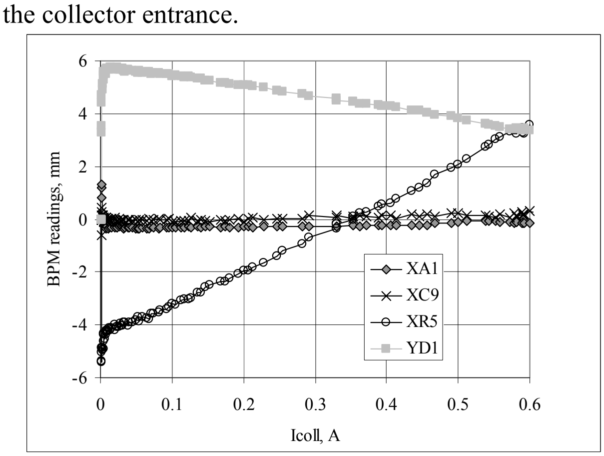

Figure 3: Changes of beam position in several BPMs with the DC beam current. The BPM A1 is immediately under the acceleration tube; C9 is the last BPM in the cooling section; R5 is a BPM upstream of the last vertical bend; and D1 is under the deceleration tube.

One of the difficulties in optimizing the recirculation was a dependence of the beam positions on the beam current in a DC mode (Fig. 3). At low currents the positions were identical to those measured in a pulse mode, where such effect was not found. The shift appeared in the second part of the cooling section and increased downstream. The current hypothesis is an interaction of the beam with its image charges [5], which is suppressed by γ^2 times in a pulsed mode due to interaction with image currents.

BEAM IN THE COOLING SECTION

The angles of electron trajectories in the cooling section can be split into several constituents: distortion of the central trajectory, envelope scalloping, and oscillations of the beam.

If the entrance beam parameters are optimum, the straightness of the central trajectory is determined by the transverse components of the magnetic field in the cooling section. The components have been compensated by dipole correctors (10 pairs per each 2 m module) according to magnetic measurements [6]. However, at best the trajectory deviated in BPMs up to 0.6 mm from a straight line. The value is in a reasonable agreement with reproducibility of the magnetic measurements. A simulated electron trajectory that fits the measured BPM positions assuming reasonable scenarios of possible errors in the field maps gave an rms angle of about 0.3 mrad.

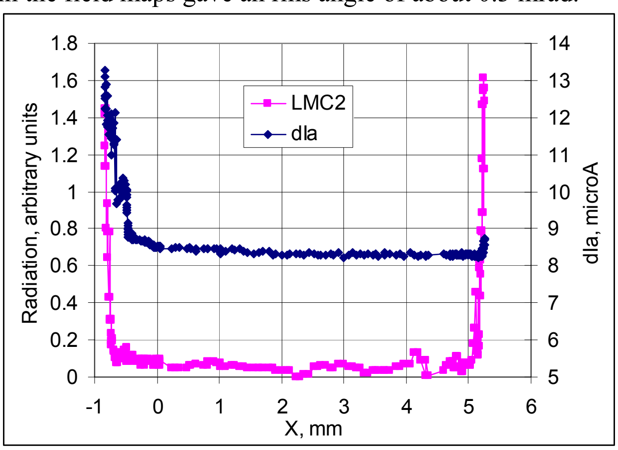

Figure 4: Changes in the anode power supply current (dIa) and in radiation (LMC2) when a DC beam is moved inside a 15 mm orifice. The beam current is 0.22 A. Only one of the orifices is at the beam pass at a time.

To measure scalloping of the beam envelope, the beam was shifted inside each of orifices until it scraped (Fig. 4). The motion is made with simultaneous changes in currents of several correctors to displace the beam parallel to the axis in the cooling section. The procedure allows using of a neighboring BPM to determine a beam shift in the orifice. The beam boundary is determined by a sharp rise of radiation the scraper. The beam dimension in a given direction is determined as a result of subtraction of the beam shift between two positions with an increased radiation from 15 mm. The measurements are made in 4 directions every 45° to identify all linear perturbations of the beam shape. Tests showed the resolution and reproducibility of the procedure at the level of 0.1 mm.

The first attempt to measure the angles associated with the envelope scalloping was made using three orifices at the magnetic field of 100 G. Due to non-optimum phase advance between orifices, the result gave only a rough estimation for the upper limit of the rms angle, 0.6 mrad. Currently we are preparing a set of measurements at 70 G with all 5 orifices. Note that the quality of the longitudinal field distribution was tested with a parallel beam shift in the cooling section and was found to be satisfactory. Hence, scalloping may be caused only by the beam entrance parameters.

The temporal behavior of the beam position was analyzed at frequencies up to 300 Hz. The largest component, up to 0.5 mm in the cooling section and 2 mm in the transfer line, is a slow (many hours) drift. The next component is 29.6 Hz, which amplitude reaches 0.2 mm at the end of the cooling section, corresponds to rms angle of 0.06 mrad. Most likely, the component is associated with one of the Pelletron motors, which affect the beam either through a mechanical motion of the column or by fringe fields. Toward the end of the transfer line a 60 Hz line became dominant, which may be explained by absence of any shielding in the return line.

CONCLUSION

A full-scale prototype of the cooler has been commissioned, and no effects that would prevent an effective electron cooling have been found. Tested diagnostics tools are capable of providing necessary precision but need optimization and improved software. Presently, the major difficulty is a slow drift of the beam trajectory.

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