STATUS OF THE FERMILAB ELECTRON COOLING PROJECT

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Abstract

Fermilab is constructing 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 will test all of the electron beam properties, needed for cooling. However, it will fall short of demonstrating the actual electron cooling of antiprotons as it is being constructed outside of the Recycler tunnel. To date, the Fermilab electron cooling R&D project has achieved several important milestones, which allow for detailed planning of an electron cooling system in the Recycler tunnel. This paper describes the experimental results obtained with the prototype cooler system, as well as overall status of the project.

1 INTRODUCTION

Electron cooling in the Recycler ring requires a high-power DC beam. The beam generation scheme employs an electrostatic accelerator (Pelletron [2]) in a so-called recirculation regime: the beam is accelerated down one tube of the Pelletron, passes through the beam line at ground, and returns to the high voltage terminal through the 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. To prepare a beam generation device for a future full-scale electron cooling system, an experimental set-up with a simplified beam line has been manufactured, installed, and commissioned at Fermilab [3]. The main goal of the experiment was to demonstrate the stable operation of an electron beam with parameters listed in Table 1. This paper describes how these parameters were achieved and what is expected in the near future.

Table 1: Electron beam parameters

Parameter	Design	Achieved
Electron kinetic energy, MeV	4.36	3.5
Electron Beam Current, A	0.5	0.5
Terminal Voltage Ripple, V	500	500
Cathode Radius, mm	2.5	2.5
Magnetic Field at Cathode, G	600	600

2 RECIRCULATION EXPERIMENT

Figure 1 shows the schematic layout of the beamline. The detailed description of the mechanical setup can be found in Ref. [3].

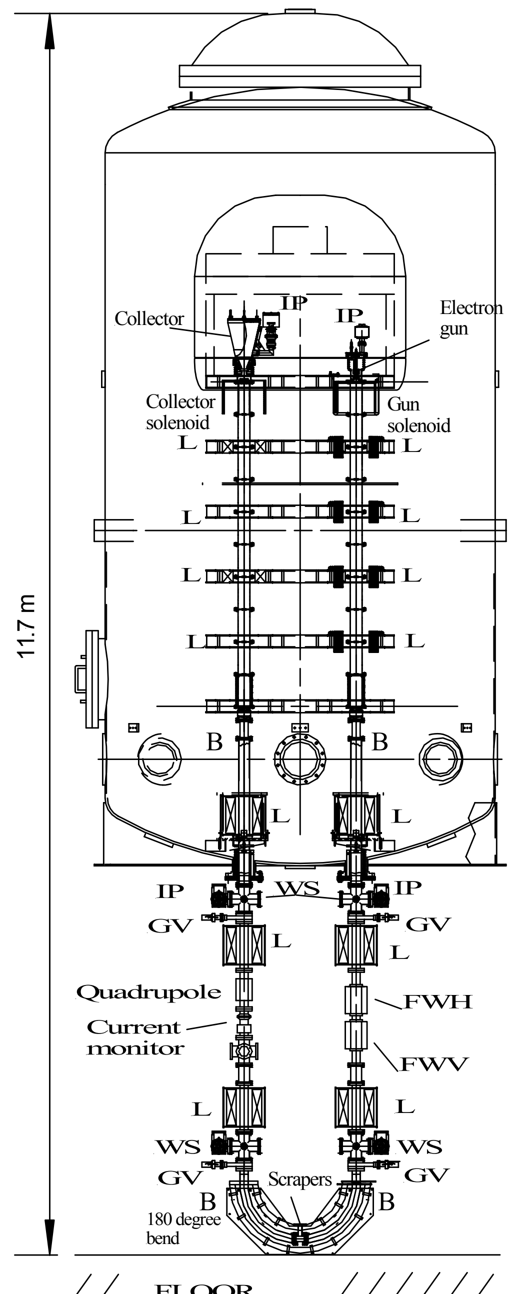

Figure 1: Mechanical schematic of the U-bend test stand. Symbols denote: IP- ion pump, L- lens, GV- gate valve, WS- wire scanners, FWH and FWV- flying wires, B – beam-position pick-up electrodes

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After commissioning of the Pelletron high-voltage system and passing the first µA-range current to the collector in the spring of 2001, work began on increasing the beam current to achieve 500 mA. The initial progress was significantly hindered by several problems, which we will discuss in more detail.

2.1 High-voltage conditioning

During the initial commissioning, we determined that without any beam the highest stable voltage on the Pelletron was limited to 4.2-4.3 MV [3]. Even though it was possible to transport the beam through the beam line at voltages close to the upper limit, the multiple full-tube, beam-induced sparks reduced the operation duty cycle to less than 50%. The remainder of the time had to be spent on high-voltage conditioning and waiting for the vacuum to recover, typically from a 10^{-6}-Torr range immediately after the spark to below 10^{-8} Torr, which is the level needed for stable beam operation. The decision was then made to reduce the beam energy to 3.5 MeV in order to allow more time for beam studies. At 3.5 MV, the Pelletron operation was stable enough to continue the experiment. As of today, the high-voltage acceleration tubes have been replaced with new improved tubes and tests are being conducted to determine their quality. In the final installation, we are planning to increase the length of the tube stack by one 1-MV module.

2.2 Protection of electronics against sparks

A potential danger of the electronics' vulnerability to sparks was obvious to us from the initial design stage of the Pelletron because of our previous experience [4]. The primary concerns were both a direct coupling of the Pelletron energy (3 kJ) to an output of some electronic device and an rf interference. All of the numerous electronic components were designed and manufactured following strict guidelines for grounding, filtering, clamping and rf-shielding. After the initial installation and operation with beam, which induced multiple full-tube sparks, the protection of certain devices was improved and the problem was finally eliminated by July, 2001.

2.3 Spark prevention

While conditioning the Pelletron, we found that there were two types of break-downs: (1) a full-tube spark, when the Pelletron voltage almost fully discharges instantaneously and (2) a fast partial discharge, which did not lead to a full-tube spark. Since the amount of energy released in both of these break-downs is significantly different, the consequence of the former was a tube de-conditioning and a pressure burst (see section 2.1), while the latter only resulted in a short regulation interruption with no other effects. However, in the presence of a beam, the latter would almost always result in a beam-induced full-tube spark because of the beam flashing the tubes. To reduce the number of such beam-induced full-tube sparks, the following steps were taken:

- A beam scraper was installed in a high-dispersion region to intercept the beam if its energy starts to drop. This prevented the beam from flashing the deceleration tubes and inducing a spark.
- The beam optics was changed to make focusing more rigid in the accelerating tubes.
- A fast circuit that would shut the beam off in the event of the Pelletron voltage dropping by 50 kV or more was installed.
- A slow software loop that would turn certain devices off in the case of a Pelletron voltage decrease was installed. This forced an operator to follow an established procedure for the trip recovery.

Figure 2 shows a typical 4-hour operation period after the above improvements were made. One can see many voltage trips of 500 kV or so in magnitude, but no full-tube sparks, as can also be evidenced by a pressure increase being solely due to the beam-induced gas load in the collector.

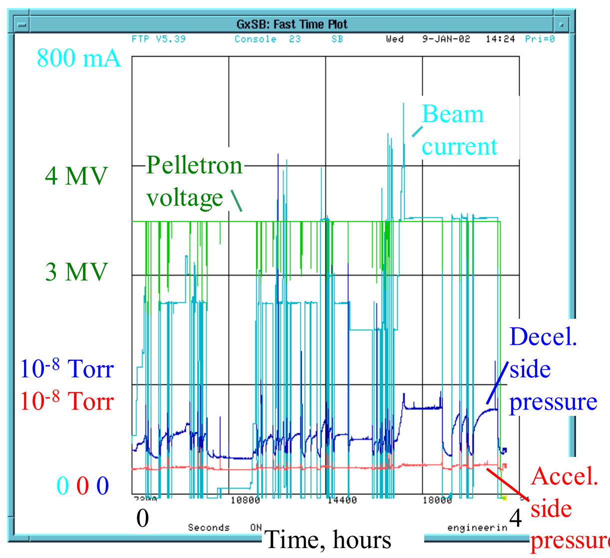

Figure 2: Beam current, Pelletron voltage and vacuum pressures during 4 hours of operation.

Multiple partial Pelletron trips (mostly resulting from beam tuning and steering), as seen in Fig. 2, interrupt the beam recirculation. After such a trip, it takes about 1 minute to restore the beam recirculation. Below we will summarize our experience with reducing the frequency of such trips and improving the beam stability.

3 RECIRCULATION STABILITY

We currently associate the Pelletron trips with the following two phenomena: (1) high beam losses, which typically occur during beam steering, can exceed the Pelletron voltage regulation capacity and cause a slow voltage drop followed by a trip; (2) secondary particles (electrons, ions and vacuum UV's) can charge up the surface of the ceramic acceleration tubes and cause a partial surface discharge. Such a partial discharge results in changes of the beam envelope and position, which in turn, can increase losses, decrease the voltage further, and induce a trip.

Secondary particles can be produced by several mechanisms:

- Gun halo
- Collector losses
- Ionization and excitation of the residual gas

A solution was found to reduce the gun halo during initial recirculation tests [4]. It is a combination of a negative potential on the gun control electrode and a diaphragm in the gun anode. Simulations show that the gun halo is small and that it is normally transported into the collector together with the primary beam.

The beam losses from the collector were significantly reduced by the introduction of a transverse magnetic field at the entrance to the collector cavity [5]. On a 50-kV test bench, the measured collector losses were about 6 µA at a beam current of 1.7 A. At 3.5 MV, it is difficult to distinguish one loss mechanism from another. When all beam line elements are optimized, the total Pelletron loss current is about 5 µA for a 500-mA beam. Figure 3 shows beam losses, measured by various circuits, as a function of beam current, in optimum.

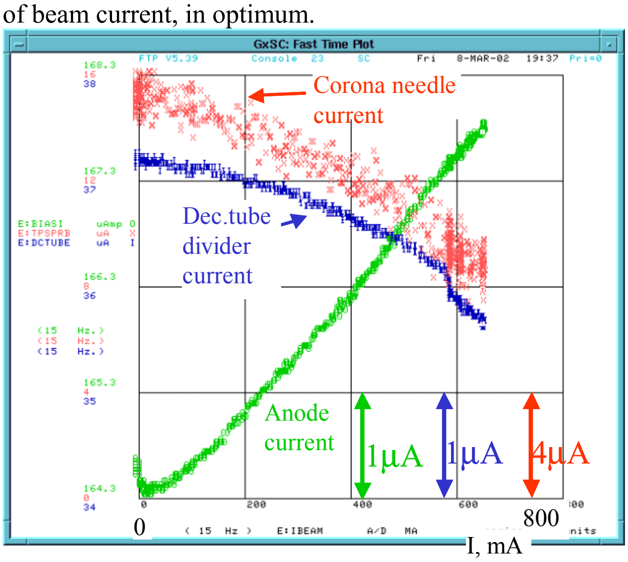

Figure 3: The measured loss currents as a function of beam currents. The anode current is the current between the gun cathode and the gun and collector anodes. The corona needle current is the current needed to keep the Pelletron in regulation; its reduction indicates a current loss from the HV terminal. The Pelletron voltage was 3.5 MV, the anode voltage – 40 kV.

The most dramatic effect on electron beam stability was the application of ion blocking and clearing voltages to the beam-position pick-up electrodes (labeled as B in Figure 1). Ions, originating in the beam channel, can be prevented from traveling into the accelerating tubes by placing a small (20-80 V) voltage on the electrodes, just below the tubes. A significant dependence of the crash frequency on the voltage was found at beam currents above 10 mA. We now speculate that in addition to ions, there might be trapped macro particles (dust) in the electron beam.

In summary, the following improvements allowed us to attain the beam parameters listed in Table 1.

- Ion clearing and blocking
- Vacuum improvement to 1-2x10^{-9} Torr, tubes were baked to 120C
- Beam size optimized, focusing in the tubes was made more rigid.

A typical time between the Pelletron trips (with all settings fixed) at 3.5 MV with a 500-mA beam is about 20 minutes (1 hour max.), with a recovery time of less than one minute. This completes our recirculation tests in a short beam line.

4 OTHER ACTIVITIES

In parallel with the beam recirculation tests, other developments have allowed us to start planning the installation of the electron cooling system in the Recycler tunnel. These developments include the commissioning of beam diagnostic devices, manufacturing of all beamline elements for the full-scale prototype, and development of a reliable measuring technique for the cooling section solenoids [6].

At present, the full-scale 60-m long beam line [1] is being constructed and its commissioning is planned for the end of the summer, 2002.

The civil construction of a new building near the Recycler/MI tunnel is scheduled to begin in November of 2002.

5 ACKNOWLEDGEMENTS

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