ISBN: 978-3-95450-247-9 ISSN: 2673-5490 doi: 10.18429/JACoW-IPAC2024-TUPS19

DEVELOPMENT OF HIGH-POWER ELECTRON GUN AND COLLECTOR FOR THE NEW ANTIPROTON DECELERATOR ELECTRON COOLER

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Abstract

The electron cooler of the Antiproton Decelerator (AD) at CERN was initially developed for the Initial Cooling Experiment (ICE) in 1979. It was subsequently adapted for use at Low Energy Antiproton Ring (LEAR) and is currently employed in the AD. However, certain components of the cooler are now more than 40 years old and lack spare parts. To ensure the reliable operation of the AD, a new electron cooler is under development.

This presentation focuses on the development of the new electron gun and collector that will provide the 2.4 A / 27 keV electron beam. The process involves choosing the gun/collector design, informed by electron-beam simulations, which aim to achieve the lowest transverse temperature of the electron beam within the cooling section and the highest collection efficiency of the collector. Subsequently, the gun and collector undergo meticulous testing and characterization on a dedicated test bench. The design undergoes iterative refinement to address issues related to high voltage sparks, vacuum pressure, and electron losses.

Distinguishing features of the new cooler that make it more reliable compared to its predecessor will also be discussed.

INTRODUCTION

Electron cooling, originally proposed by G. Budker in 1966 [1], allows to improve quality of the beam by reducing its emittance. The AD electron cooler was originally built for Initial Cooling Experiment (ICE) at CERN [2] and subsequently modified for use in the Low Energy Antiproton Ring (LEAR) [3] and then in AD [4]. Due to lack of spares and some parts being more than 40 years old, a decision was made to build a new AD electron cooler [5,6]. This paper highlights development, tests and characterization of the electron gun and collector for the new AD electron cooler operating at 2.4 A / 27 keV. The old electron gun and collector in present AD electron cooler are described elsewhere [7,8].

EXPERIMENTAL SETUP

New collector and gun designs are presented in Fig. 1. The distinguishing features of the new collector (compared to the old one) are (1) cooling water circuit is outside the vacuum, (2) collector pot is made of copper for better thermal conduction and (3) addition of a decelerator electrode at the entrance. The new electron gun is designed with high perveance of 2.2–2.5 $\mu A \cdot V^{-3/2}$ and operating at 2400 Gauss uniform field. It uses a 25 mm diameter BaO impregnated tungsten dispenser cathode. The electron beam would be extracted from the gun adiabatically into a lower field region of 600 Gauss, thus expanding beam size by factor of 2.

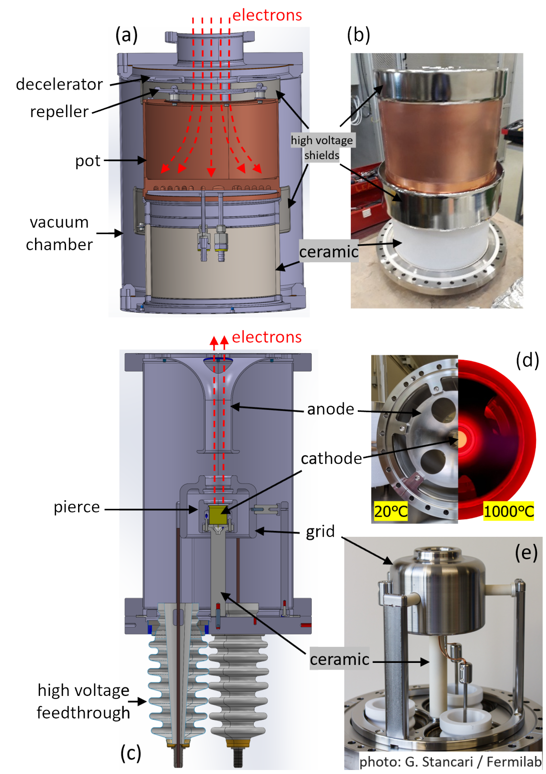

Figure 1: New collector (top row)/gun (bottom row) design: (a),(c) show cutaway 3D model, (b),(e) show photos without the vacuum chamber and (d) with hot/cold cathode.

The test bench is described in detail elsewhere [9]. It is a linear test bench with a 1.5 m long, 600 Gauss, drift solenoid with the electron gun inside it and the collector at the end of it, see Fig. 2. At the entrance of the collector a magnetic “squeeze” coil is used to compress the transverse electron beam size. The high voltage platform consists of a Faraday cage that can be biased up to −80 kV DC (cathode power supply situated outside the cage). The repeller and collector power supplies are placed on the platform, inside the cage, such that they are always referenced to the cathode potential. Typical collector bias values are between +3 and +5 kV and repeller between –1.5 and 0.8 kV. For simplifying the tests, the decelerator was shorted to the collector. The magnet power supplies are located outside the cage at the ground potential.

Following initial tests, that resulted in undesired magnetron discharges, the vacuum system was upgraded by

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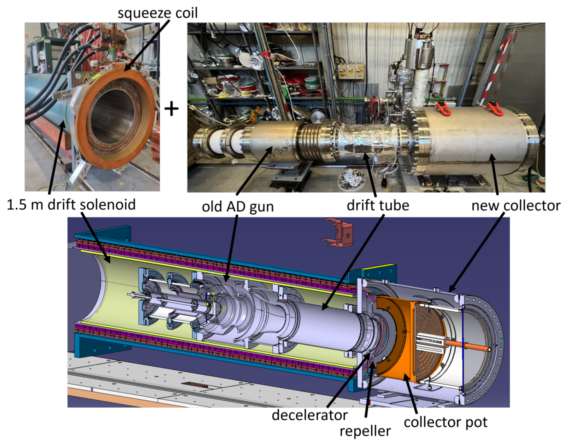

Figure 2: Experimental setup: top of the figure shows photos of the magnets, gun and collector whereas the bottom shows cut-view of the setup drawing.

adding a turbomolecular pump on the vacuum chamber and a NexTORR® (a combined NEG+ion pump). In addition a vacuum bakeout at 150°C helped remove water and improved overall vacuum and thus electron beam transport. The pressure between the gun and collector is estimated to be between $1\text{x}10^{-8}$ and $1\text{x}10^{-7}$ mbar with cathode at 1000°C.

COLLECTOR TESTS

The new collector was tested with the known electron beam parameters (~2.2 A / 27 keV), produced from the old electron gun of the AD electron cooler [8]. The new collector underwent a few iterative refinements to mitigate issues related to high voltage sparks (e.g. triple junction) and poor vacuum (e.g. magnetron discharges) [9]. After systematic and rigorous testing, a beam of ~2.2 A at 27 keV was transported to the collector with very low losses (~99 % collection efficiency). The collector very well handled 10 kW power (equivalent of ~2.2 A at 4.5 kV collector voltage). At this power, the cooling water temperature raised by ~20°C and collector back plane reached ~40°C (thermal imaging). By pushing cathode-to-grid voltage above 27 kV, a beam of 2.4 A was demonstrated. Below are some test results.

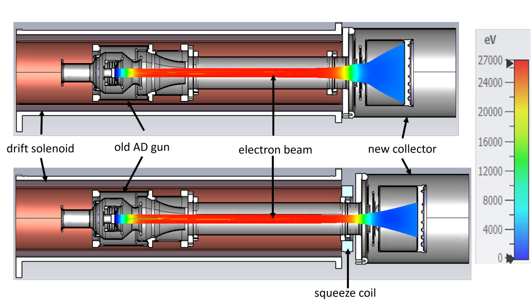

Figure 3: Electron beam transport from gun to collector simulated in CST Particle Studio®. Top image shows the case without the squeeze coil and bottom with the coil.

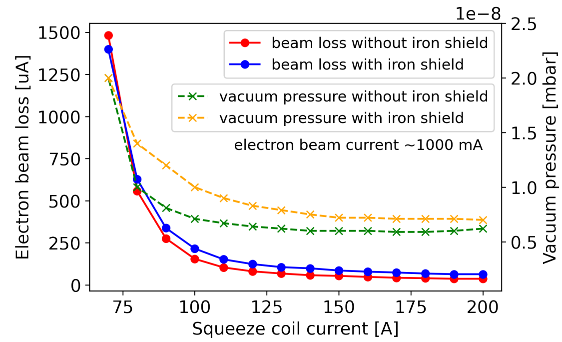

Figure 4: Electron losses and vacuum pressure dependence on the squeeze coil current. Measurements were done with and without an 4 mm iron shield on the collector.

Squeeze Coil at the Collector Entrance

Low magnetic field at the edge of the drift solenoid causes electron beam to expand as it enters the collector causing beam losses. This can be seen in the CST simulation in Fig. 3. By adding a beam squeeze coil at the entrance of the collector, the beam losses are reduced and the beam expands inside the collector. This also forms a magnetic bottle for secondary electrons escaping the collector. Figure 4 shows beam losses as a function of the squeeze coil current. Resulting combination of the electric and magnetic field inside the collector causes the beam to rotate around its axis. This determines angle of impact for the primary electrons at the back of collector and therefore controls generation of the true secondary and back reflected electrons [10].

Iron Shield on the Collector Vacuum Chamber

An iron shield of 4 mm thickness on the exterior of the collector vacuum chamber was added. The shield reduces magnetic field inside the collector which results in further expansion of the beam. This serves two purposes (1) enhances magnetic bottle effect to trap secondary electrons and (2) electrons are dumped on the collector on a larger area aiming for a more uniform heat deposition.

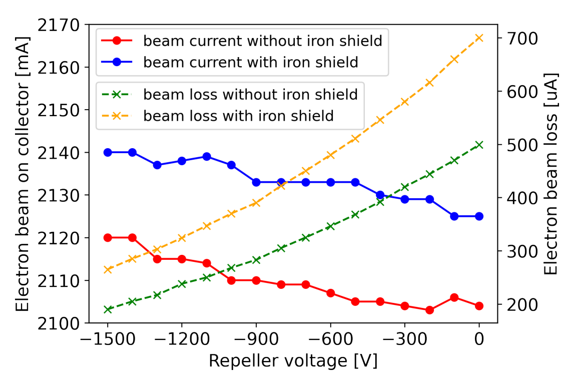

Figure 5: Electron beam current and beam losses as function of repeller voltage. Measurements were done with and without a 4 mm iron shield on the collector.

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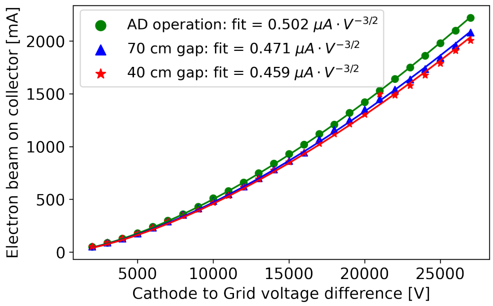

Figure 6: Beam current on the collector as a function of the cathode to grid potential difference for (a) 40 cm gap (red) and (b) 70 cm gap (blue) between the gun and collector. Data from AD operation are presented as well (green) for a comparison where the gap is of several meters.

Repeller Biased with Negative Potential

Figure 4 shows that the beam losses are slightly higher with the iron shield. However, by adjusting the repeller voltage, see Fig. 5, one can reduce the losses and increase the collector intensity (hence efficiency). Similar behaviour was observed with squeeze coil current variation. Further tests are ongoing to fine tune the setup.

Drift Tube Length (Gun to Collector Gap)

The collector electric field was found to be interfering with the gun, as a result the effective measured perveance of the gun was dependant on the collector voltage. This was confirmed by varying collector voltages and seeing the perveance change. By increasing the gap between gun and collector from 40 to 70 cm, small reduction in the interference was demonstrated, see Fig. 6. To give a comparison, the length of the solenoid used in [8] was 2.5 m as to the 1.5 m in this work.

Electron Stimulated Desorption (ESD)

The quality of vacuum affects the beam transport. With the increase in beam intensity, the collector surface outgasses due to ESD. The electron beam interacts with the residual gas and causes electron losses and neutralisation, see Fig. 7. The solution is to either condition the collector surface by bombarding with electron beam over an extended period of time or to increase pumping speed.

GUN TESTS

A prototype electron gun for the new electron cooler was recently built, with the main purpose of testing and validating the geometry, see Fig. 1, hence it was made with low-cost and low-precision. The gun design was originally proposed by [11], and adopted in this work with minor changes in the electrode shape for easier manufacturing. The cathode was heated to nominal temperature of 1000°C and left hot for few weeks: no sign of damage to the ceramic insulators was observed. A preliminary test with electron beam extraction was demonstrated at 900 Gauss (maximum field available at the time of the tests). The results are shown in Fig. 8.

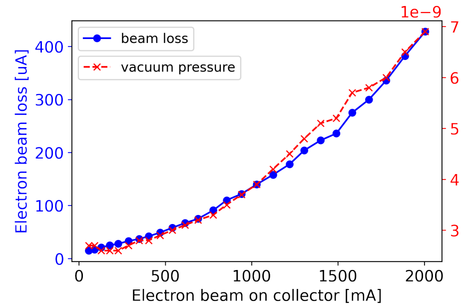

Figure 7: Electron losses and vacuum pressure dependence on the electron beam current on the collector. The vacuum rise is primarily due to ESD at the back plane of the collector.

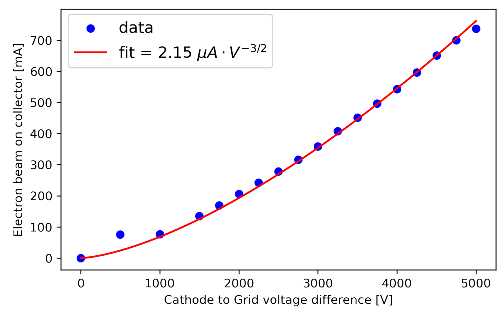

Figure 8: Measured perveance for the new electron gun.

The measured perveance measured is close to the simulated design values of 2.2-2.5 $\mu A \cdot V^{-3/2}$. Further tests are planned at 27 keV and 2400 Gauss field.

CONCLUSION AND OUTLOOK

During operation in AD, the electron beam is pulsed for 16 seconds with 15% duty cycle at 7.2 kW. The new electron collector design has been thoroughly tested and characterized with a DC electron beam, demonstrating a 2.4 A DC beam (nominal requirement for the new AD electron cooler), and a 10 kW beam dump for 24 hours (power test), thus proving its resilience and exceeding safety margins. By designing the cooling water circuit outside the vacuum, weakness of the previous collector has been addressed, thus eliminating the risk of failure as experienced in 2018 during AD operation [12]. The collector has demonstrated a good efficiency of 99%. The performance of the collector can further be improved by separately biasing the decelerator electrode, biasing repeller below −1500 V and by optimising position/thickness of the iron shield.

Preliminary results of the new electron gun tests are encouraging, further tests will be carried out to fully test and validate the design.

ACKNOWLEDGEMENTS

The authors would like to thank A. Pikin and F. Wenander for helpful discussion in understanding the test bench results, D. Steyaert and Y. Coutron for the design of the new collector and CERN AD-CONS project members for their collaboration.

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