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A TEST BENCH FOR CHARACTERIZING ELECTRON COOLER COMPONENTS AT UP TO −80 kVDC

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Abstract

During the upcoming Long Shutdown 3 (LS3), the electron cooler of CERN's Antiproton Decelerator (AD) will be replaced by a new electron cooler. Present electron cooler is operating at the maximum energy of about 27 keV. However, the new electron cooler will have electron collector and electron gun with the possibility of operating at up to 68 keV electron energy. To characterize the gun and the collector at this higher energy, a test bench has been built and put in operation. The test bench is equipped with a drift solenoid of 1.5 m length operating at 600 Gauss, a Faraday cage with high voltage platform that can be biased up to −80 kVDC. First element of the new AD electron cooler, the electron collector, is presently being tested at the test bench. In this poster we describe in detail the main elements of the test stand, give some highlights of the ongoing tests with the new collector and future plans.

INTRODUCTION

Electron cooling of charged particle beams, originally proposed by G. Budker in 1966 [1], allows to improve quality of the beam by reducing it's 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]. Parts of the cooler are more than 40 years old and lack spares. Therefore decision was made to build a new electron cooler to replace the existing one [5].

Scope of this work is to develop, test and characterize electron gun and collector for the new cooler that can work at least at 2.4 Amp / 27 keV and possibly at higher power. For this purpose a dedicated test bench was put in place. In the section following, a detailed description of the test bench is given. And then some preliminary results of the new collector/gun tests are presented.

TEST BENCH

Figure 1 shows main elements and layout of the test bench. It is a linear test bench, having no bending magnets but only a straight solenoid between the electron gun and the collector. As shown in Fig. 2, the gun is located inside the solenoid at a uniform axial field of 600 Gauss, while the collector is situated at the end of solenoid. At the entrance of the collector a magnetic coil is used to compress the transverse electron beam size, and thus maximising collector efficiency. The high voltage platform consists of a Faraday cage enclosing a 3-phase isolation transformer and two 19" racks on isolation leg posts. The secondary windings of the transformer are floating at the cathode potential provided by an −80 kV power supply that is situated outside the Faraday cage (on ground potential). The high voltage potentials, as illustrated in Fig. 3, are referenced to the cathode by placing the relevant power supplies on the racks inside the Fraday cage. The magnet power supplies are located on the racks at ground potential.

The necessary low vacuum pressure is achieved with the help of turbomolecular pump, titanium-sublimation pump and an ion pump. Due to being more than 20 years old, the achieved vacuum with these pumps is not great. 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 in the drift region is estimated to be between 5×10^{-6} and 5×10^{-7} mbar.

The test bench is equipped with safety interlock system that prevents damage to the equipment and allows safe operation for the users. A LabVIEW and python based hybrid control system allows remote control and monitoring of all the power supplies as well as vacuum pressure readout and have logical dependencies on the safety interlock system.

TESTS OF THE NEW COLLECTOR

The original design of the collector underwent a few iterative refinements to mitigate issues related high voltage sparks (e.g. triple junction) in the vacuum before it was able to hold the 30 kV DC bias. However several challenging issues came up before further tests could be done and are described below. Note that the new collector was tested using existing electron gun from AD that operated at nominal beam of 2.4 A and 27 keV.

Observation of Magnetron Discharge

When the magnetic field of 600 Gauss was switched on along with the high voltage, regular and reproducible spikes in the vacuum pressure readout were seen, see Fig. 4. These were understood as magnetron discharges. A surface at relatively negative electric potential would emit an electron which, under crossed electric and magnetic field, would then take a helical path as it accelerates. By collision with the residual gas in the vacuum, it creates secondary electrons and eventually an avalanche. This process repeats when the residual gas replenish in the location of discharge. As this happens, the vcauum is conditioned (by high voltage) and thus the time interval between two consecutive vacuum spikes increases. The solution for getting rid of these discharges was to do a vacuum chamber bakeout. Due to risk of breaking ceramic insulators in the gun and collector, the

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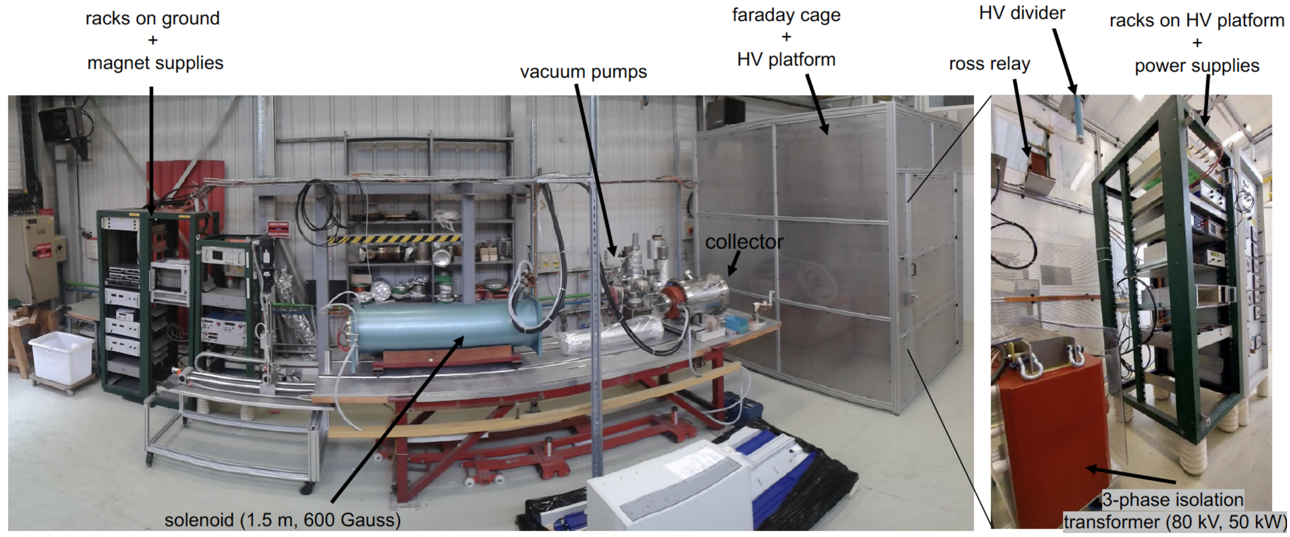

Figure 1: Test bench layout and main elements.

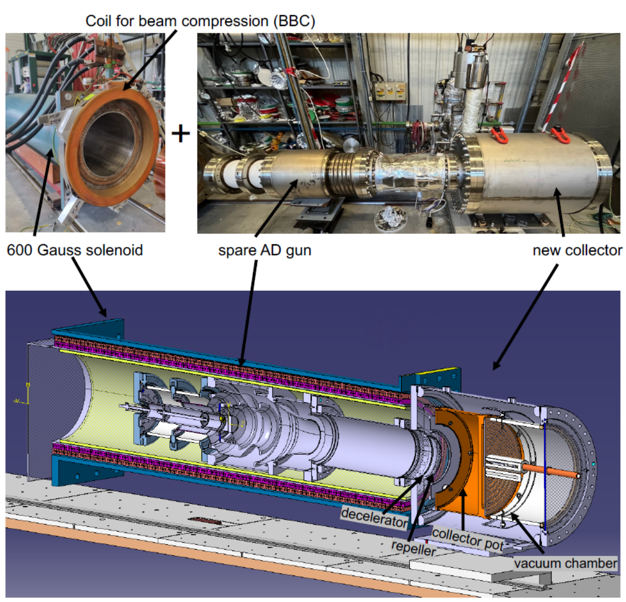

Figure 2: Experimental setup: top of the figure shows photos of the magnets, gun and collector whereas the bottom shows cut-view of the setup drawing.

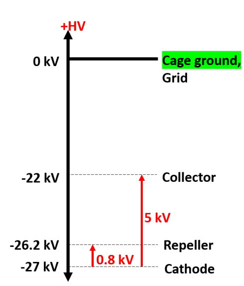

Figure 3: High voltage biasing scheme.

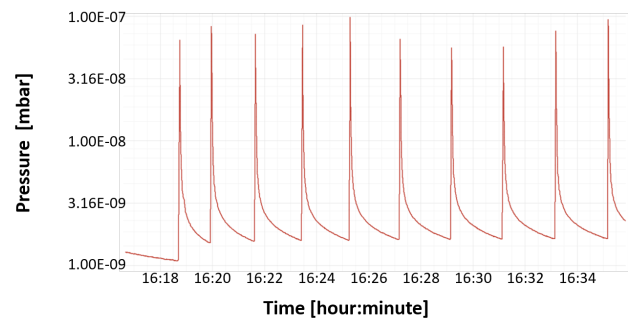

Figure 4: Vacuum gauge readout. The spikes seen are due to magnetron discharge - the time interval between two consecutive peaks is getting longer as more spikes occur.

bakeout was limited to 150 °C. The bakeout helped suppress the magnetron discharges. This allowed to shoot electron beam into the collector.

Beam Compression at the Collector Entrance

Above 100 mA DC electron beam, the electron losses were seen going up with the increase in the beam current. At the point, the collector was placed right against the end of the drift solenoid. Simulation shown that the electron beam was expanding partially hit the entrance electrode in the collector. An additional magnetic coil (“compression coil”) was placed between the drift solenoid and the collector that allowed beam compression and thus reduction in the electron losses. Figure 5 shows simulation of the electron beam transport from the gun to the collector with and without this compression coil.

TESTS OF THE NEW GUN

A prototype electron gun for the new electron cooler was recently built, having purpose of only testing and validating the geometry, it was made with low-cost and low-precision,

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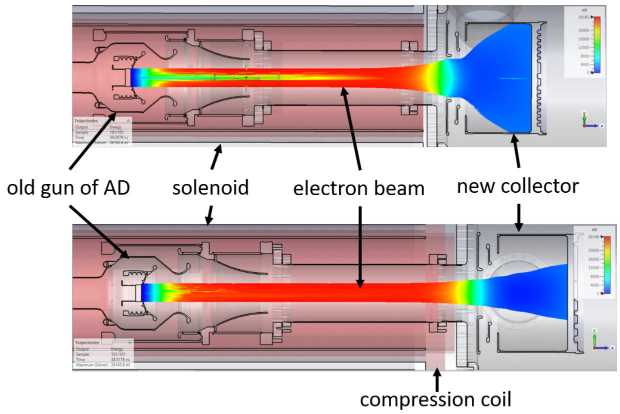

Figure 5: Electron beam transport from gun to collector simulated in CST Particle studio. Top image shows the case without the compression coil and bottom with the coil.

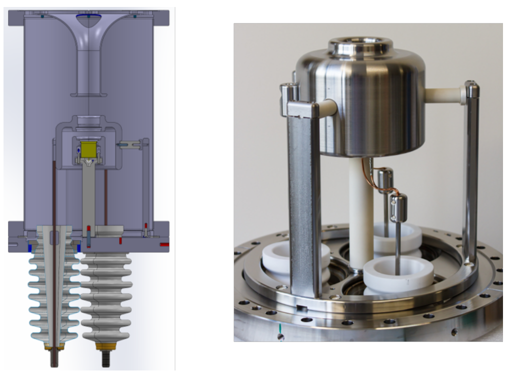

Figure 6: The new electron gun: left image shows a CAD model and right image shows gun assembly without the vacuum chamber.

see Fig. 6. The gun design was originally proposed by [6], 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.

RESULTS

A 1.75 A DC electron beam transport from the old gun to the new collector was demonstrated for 72 hours. During this test, collector cooling water had a 15 °C temperature increase. The objective is to reach the minimum of 2.4 A but due to aging of the cathode in the old gun, it was not possible. Tests will resume with a new cathode early 2024. Figure 7 shows important results from the collector tests - basically minimising the electron losses (in other word maximizing collector efficiency).

As discussed above, one of these is the compression coil need at the entrance of the collector helps greatly in the reduction of the electron losses. Second is the effect of vacuum quality on the electron beam. Higher the beam intensity, the

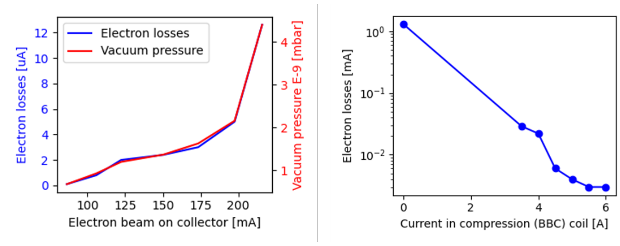

Figure 7: Electron losses and their relation with (a) ESD (left plot) and (b) compression coil current (right plot).

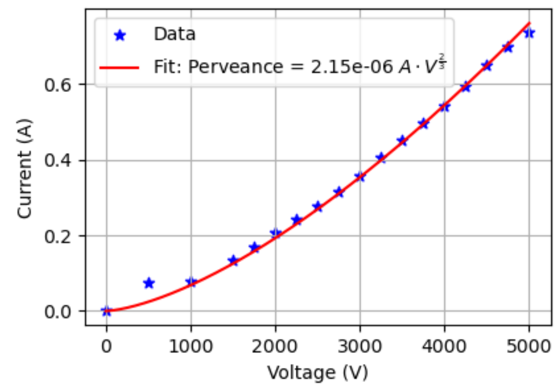

Figure 8: Preliminary results of measured perveance with the new electron gun.

more out-gassing in the collector due to Electron Stimulated Desorption (ESD). The electron beam interacts with the residual gas and causes electron losses.

Electron beam was extracted from the prototype gun, the preliminary results are shown in Fig. 8. The purveance measured here agrees with the simulated design values of 2.2×10^{-6} A · $V^{2/3}$ and hence the gun geometry is validated.

CONCLUSION

A fully operational test bench dedicated for testing high power electron gun and collectors is presented. Further improvements and upgrades of the test bench, in terms of computer control system and vacuum setup, are underway.

The collector tests so far show optimistic results and not far from full validation at nominal beam of 2.4 A / 27 keV. If time permits, one can optimise the collector operational settings by separating the deceleration electrode from the main cup and biasing them separately. Plan is to add a stronger magnetic compression coil to compress the beam at the entrance of the collector which will help trap secondary electrons and reduce back reflected electrons. And finally do a vacuum bake-out of the collector to at least 250 °C to check that it will not break the copper-ceramic brazing during operation.

Preliminary results of the new electron gun shows agreement with the design value of the perveance. However fur-

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ther tests are necessary, mainly with the expansion solenoid at 2.4 A / 27 keV and possibly at higher power.

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