OPERATIONAL EXPERIENCE WITH THE HESR ELECTRON COOLER TEST SET-UP

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Abstract

The electron cooler test set-up built at Helmholtz-Institut Mainz as a feasibility study for the electron cooling device at the High Energy Storage Ring (HESR) at FAIR has been set in operation. One of the main goals of the test set-up is to evaluate the gun design proposed by TSL (Uppsala) with respect to vacuum handling, EM fields and the resulting beam parameters. Another purpose of the set-up is to achieve a maximum relative collection loss of 10^{-5}. To measure this quantity, a Wien filter will be employed, which will also prove capable of mitigating collection losses. Recent developments and operational experiences with the test set-up are presented.

INTRODUCTION

At the proposed High Energy Storage Ring (HESR) at FAIR in Darmstadt, it is planned to store antiproton beams at energies up to 15 GeV. Since the internal experiment PANDA [1] increases the emittance of the stored beam, beam cooling mechanisms have to be employed. One possible way of reducing the emittance of the stored beam is to employ an electron cooling device as depicted in Fig. 1.

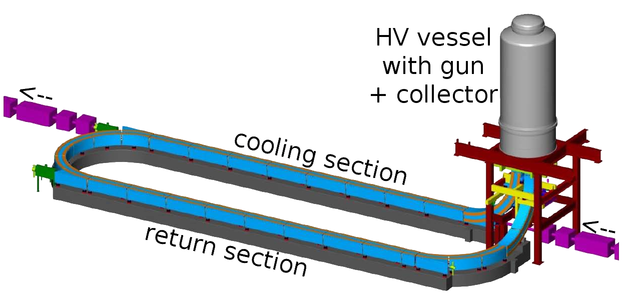

Figure 1: Proposed design of the HESR electron cooler [2].

In this device, a high-intensity electron beam moves coincidentally along the axis of the hadron beam, allowing for unwanted momentum components to be shifted into the phase space of the electrons, which are subsequently extracted and dumped in a collector. In order for the electron plasma to appear at rest from the perspective of the hadron beam, one has to ensure that the beams meet the requirement

$$v_e = v_{\overline{p}} \quad \Rightarrow \quad E_e = \frac{m_e}{m_{\overline{p}}} E_{\overline{p}}. \tag{1}$$

Therefore, an electron beam with an energy of up to 8 MeV is needed. Calculations done by FZJ [3] show that the current should be of the order of 3 A for maximum cooling rate. Additionally, the demand for magnetized cooling requires the beam to be constrained within a solenoidal magnetic field.

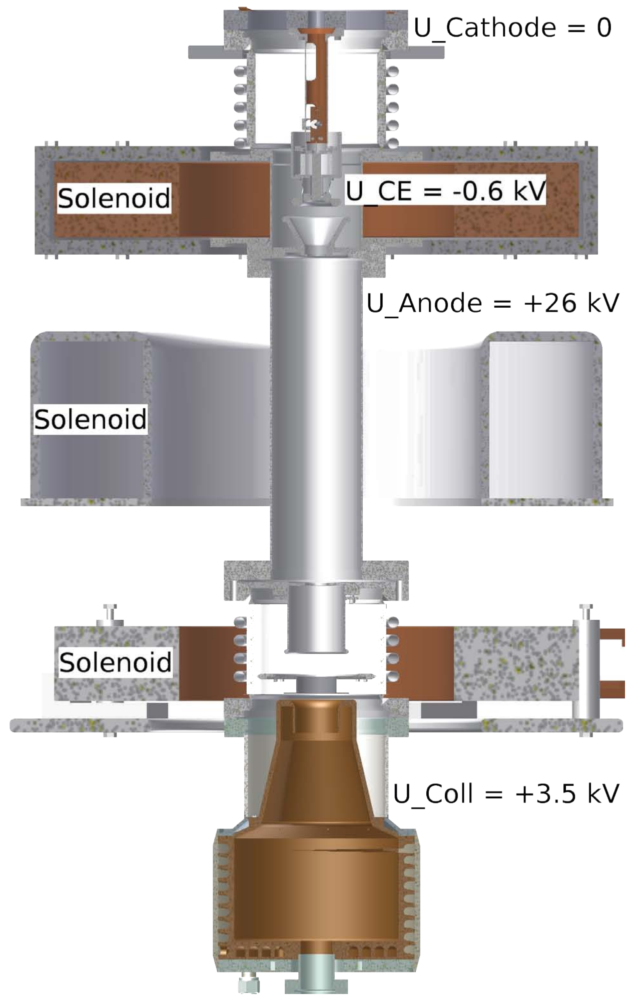

Figure 2: Schematic view of the complete test bench.

The device is designed for energy recuperation such that the total deposited energy is independent of the beam power. However, the electrostatic symmetry induced by this approach leads to the problem that secondary electrons reflected from the collector surface can traverse the beam pipe in the wrong direction. This effect can be reduced by using a suppressor electrode in front of the collector aperture so the low-energy tail of the secondary electron spectrum is reflected back into the collector. However, as high-energy secondaries cannot be reflected in this geometry, we are planning to investigate whether a Wien filter is sufficient to completely suppress this effect.

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In 2011, the essential components under investigation were transferred from TSL (Uppsala) to HIM (Mainz). Since then, we have been constructing a test bench to measure the basic properties of these components (Fig. 2).

OPERATION OF THE ELECTRON SOURCE

The electron source that was built by TSL (Fig. 3) consists of a thermionic cathode (green) that is operated at a temperature of $\approx 1000\,°C$ and a high-voltage acceleration field (red) of 26 kV for a current of 1 A. The diameter of the cathode is 10 mm. In order for the beam not to get heated when it enters the magnetic field, the electron source itself has to be immersed in a magnetic field that has its maximum at the cathode surface. The design value of the field maximum is 200 mT. A Pierce-type electrode (blue) surrounds the cathode to parallelize the electric field lines in the presence of high space charge.

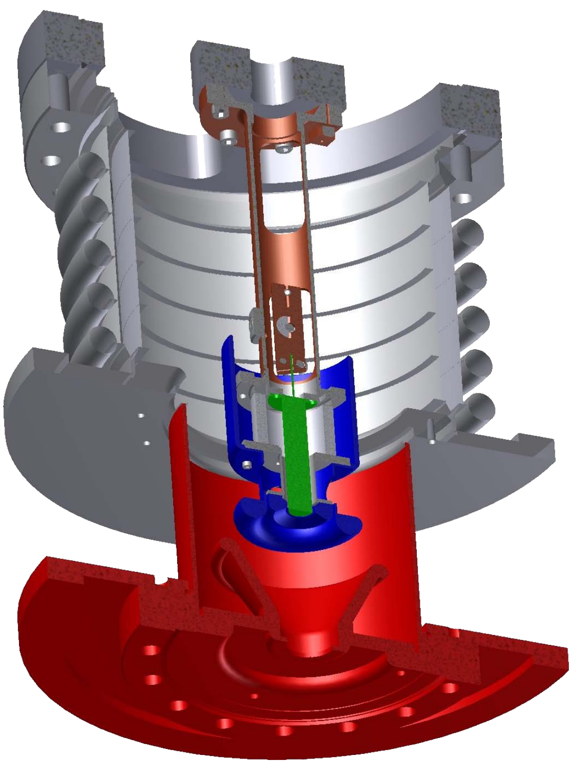

Figure 3: Schematic view of the electron source. Green: cathode, red: anode, blue: control electrode.

The source has been successfully set in operation without any magnetic field. As expected, it exhibits a perveance of $0.35\,\mu A\,V^{-3/2}$ with the control electrode voltage set to zero. With the magnetic field set to the design value of 200 mT and the control electrode at −0.6 kV, full gas discharges occur at anode voltages above 10 kV at a base pressure of 1.5×10^{-9} mbar. With the anode voltage set to the design value of 26 kV, the magnetic field can be set to 80 mT at most without any influence on the pressure; any higher value immediately causes a full discharge.

To develop an understanding of the problem, measurements of the dependence between anode voltage and pressure were carried out under different conditions. Fig. 4 shows the change in behaviour when varying the control electrode voltage U_{CE}. It is apparent that high negative values of the control electrode voltage tend to shift the anode breakdown voltage to higher values. This observation is not consistent with our initial expectation as negative values of the control electrode voltage increase the transverse electric field strength at all points inside the chamber except for the space between the cathode and the inner part of the control electrode. If the problem cannot be solved by improving the vacuum conditions, further experiments will be necessary for a consistent interpretation of this phenomenon.

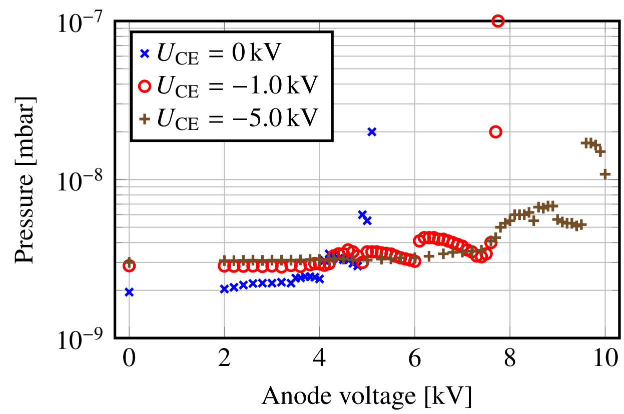

Figure 4: Control electrode voltage dependence of gas discharge effects at $B_{\|} = 200$ mT.

The dependence between the discharge induced increase in pressure and the base pressure at the start of the measurement is shown in Fig. 5. The breakdown voltage clearly depends on the base pressure, which leads to the assumption that it might be possible to raise the breakdown voltage above the limit necessary for stable operation by further reducing the base pressure. Since operation of the heated cathode introduces additional gas load, special care has to be taken to include pumps with sufficient pumping speed.

COLLECTION EFFICIENCY MEASUREMENT USING A WIEN FILTER

In order to measure and improve the efficiency of the electron collector, we have designed a Wien velocity filter based on the design done for the 2 MeV COSY electron cooler by BINP [4]. The purpose of the Wien filter is to break the symmetry between the primary and the secondary beam (Fig. 6). This filter consists of two electrostatic plates that impose a transverse electric field on the beams. On the other hand, a magnetic field perpendicular to both the longitudinal magnetic field and the transverse electric field is created such that the corresponding Lorentz force

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \tag{2}$$

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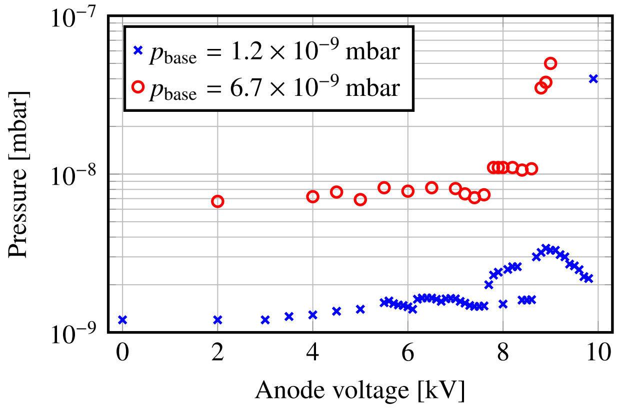

Figure 5: Base pressure dependence of gas discharge effects at $U_{CE} = -0.6\,\mathrm{kV}$, $B_{\parallel} = 200\,\mathrm{mT}$.

results to zero in the case of the primary beam. However, any secondary particles are deflected because they have a different velocity vector. By measuring the current that flows through a third plate which defines the aperture of the Wien filter, we will be able to determine the efficiency of the collector.

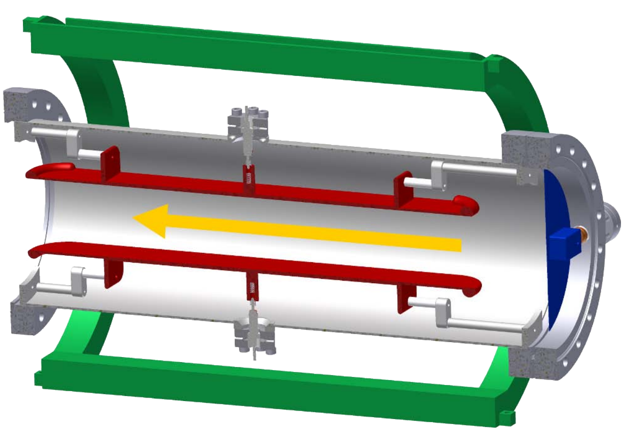

Figure 6: Schematic view of the Wien filter design. Red: electrostatic plates, green: coil for transverse magnetic field, blue: dump for deflected electrons, yellow: primary beam.

OUTLOOK

Since the electron source presently cannot be set in operation with the parameter set it was designed for, further improvements of the vacuum conditions will be carried out. Residual gas pressures on the order of 1×10^{-10} mbar or better will be reached by using a $2000\,\mathrm{L\,s^{-1}}$ NEG pump and by improving the bakeout conditions, minimizing the risk of gas discharges.

We have recently received a new collector to be tested from BINP similar to the one used in the 2 MeV COSY cooler (shown in Fig. 2), so changes to the existing test bench will be made accordingly to include this collector in the set-up.

The Wien filter is currently under construction and will be tested independently along with the respective solenoid that will have to be added to the test bench to compensate for the additional length of the beam pipe. After these tests, the Wien filter will be incorporated into the test bench, making an efficiency measurement with full beam power possible. The relative secondary current after the Wien filter is expected to be less than 10^{-5}.

REFERENCES

[1] “FAIR Baseline Technical Report”, GSI, Darmstadt, 2006.

[2] “HESR Electron Cooler Design Study”, The Svedberg Laboratory, Uppsala, 2009.

[3] A. Lehrach, “The ENC@FAIR Accelerator Project”, Workshop on Electron-Ion Colliders, 2009.

[4] J. Dietrich, V. Kamerdzhiev, M. Bryzgunov et al., “Status of the 2 MeV Electron Cooler for COSY Juelich”, Proceedings of IPAC’10, 2010.

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