STATUS OF THE HESR ELECTRON COOLER TEST SET-UP

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Abstract

For the proposed High Energy Storage Ring (HESR) at FAIR, it is foreseen to install an electron cooling device with a beam current of 3 A and a beam energy of 8 MeV. A test set-up was built at Helmholtz-Insitut Mainz (HIM) to conduct a feasibility study. 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 an energy recuperation efficiency of $1 - 10^{-5}$. To measure this quantity, a Wien filter has to be employed, which will also prove capable of mitigating collection losses.

INTRODUCTION

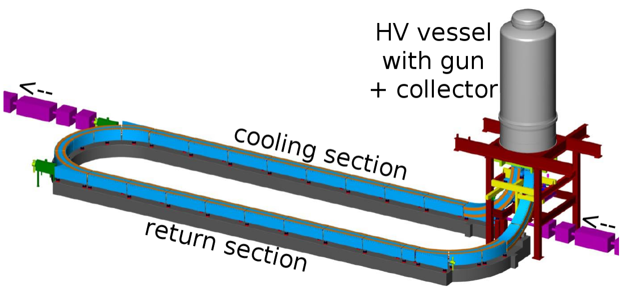

Figure 1: Proposed design of the HESR electron cooler [1].

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 [2] 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. 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 BINP [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.

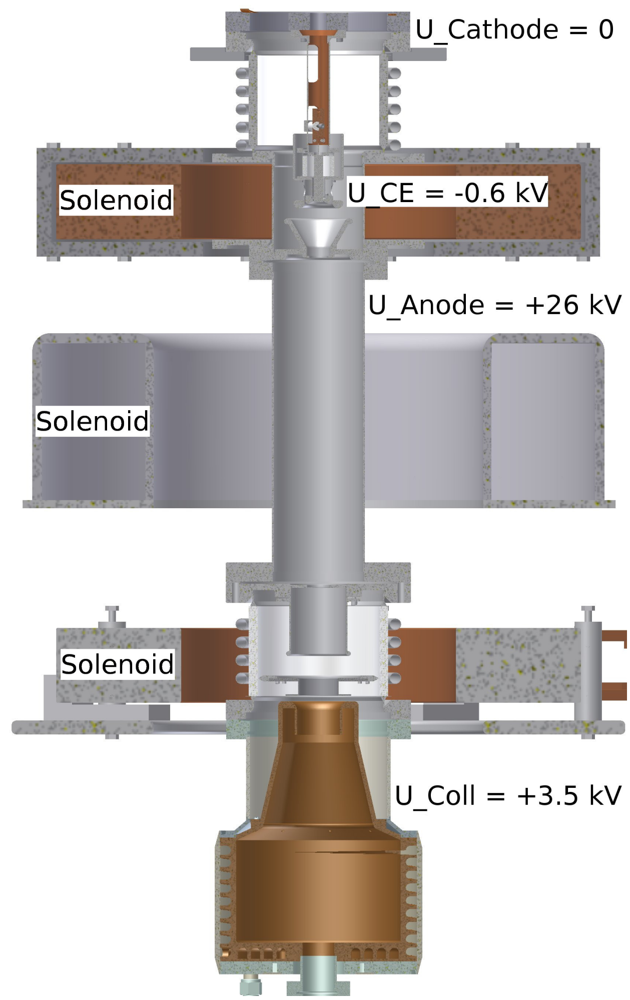

Figure 2: Schematic view of the complete test bench.

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

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sufficient to completely suppress this effect.

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 ≈ 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 to not 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.

The source has been successfully set in operation without any magnetic field. As expected, it exhibits a perveance of 0.35 μA $V^{-3/2}$ with the control electrode voltage set to zero. With the magnetic field set to the design value of 200 mT, full gas discharges occur at voltages above 10 kV at a base pressure of 1.5×10^{-9} mbar. We aim to improve the vacuum conditions to raise the breakdown voltage above the limit necessary for stable operation. 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 that will break the symmetry between the primary and the secondary beam (Fig. 4). 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

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

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.

SIMULATION RESULTS

Correctly predicting the effects of secondary electron generation in a collector is difficult because beam-induced

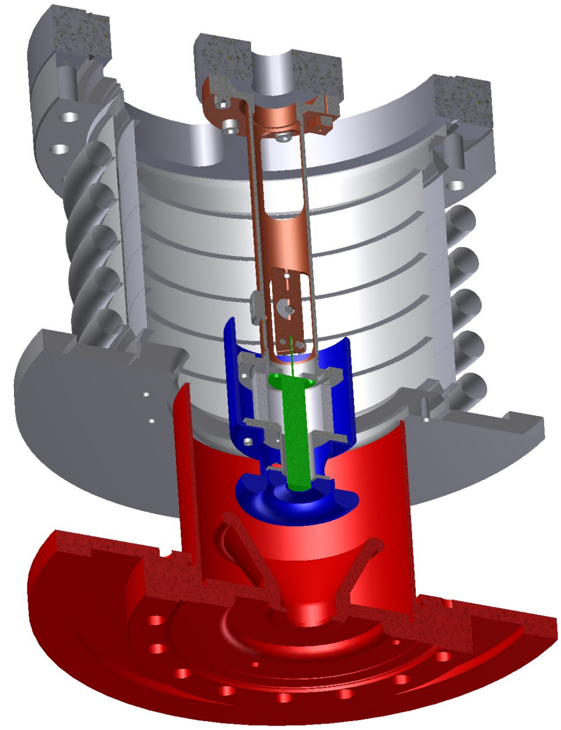

Figure 3: Schematic view of the electron source. Green: cathode, red: anode, blue: control electrode.

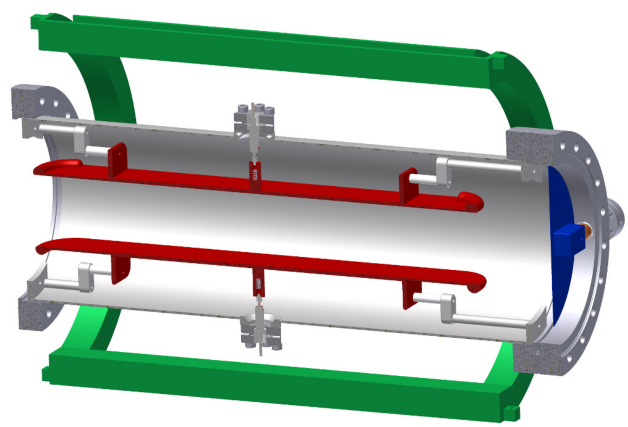

Figure 4: Schematic view of the Wien filter design. Red: electrostatic plates, green: coil for transverse magnetic field, blue: dump for deflected electrons.

ionization of residual gas molecules inside the suppressor electrode results in an additional electric field that effectively raises the potential barrier for secondary electrons [4]. However, in order to show the feasibility of the Wien filter approach, we have conducted a simulation study using CST Particle Studio [5]. An examplary simulation result of the whole test bench including the Wien filter is shown in Fig. 5 (simulation parameters in Table 1). The simulation shows that the test bench can be operated with the given parameter set without any unwanted beam loss or increase of the beam width. Furthermore, it can be seen that while the primary beam passes through the Wien filter unimpeded, the unwanted secondary particles are deflected and dumped on a plate. Numerical evaluation of the simulation results is in progress, especially with respect to the suppressor electrode.

Table 1: Parameters for CST Simulation of the Test Bench

Number of particles	40 000
Number of mesh cells	15 million
Anode voltage	26.0 kV
Control electrode voltage	0 kV
Suppressor electrode voltage	3.5 kV
Collector voltage	3.5 kV
Wien filter voltage	± 8.0 kV
Wien filter B_y	3.2 mT
Wien filter B_z	52 mT
Beam current	1.05 A

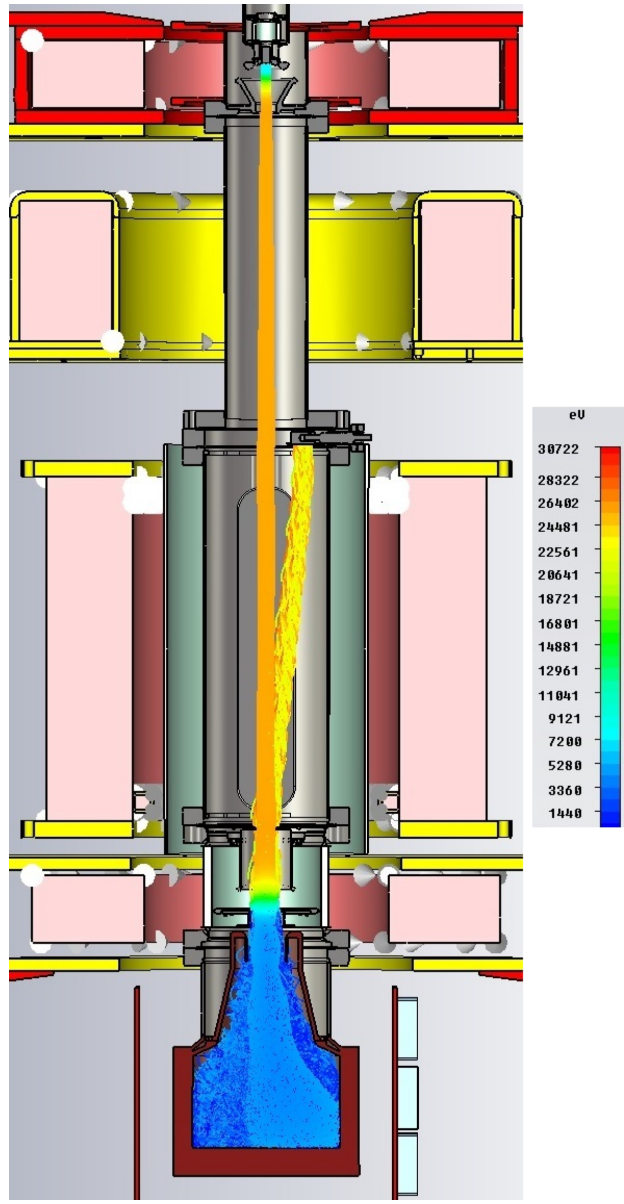

Figure 5: Simulation of beam trajectories inside the test bench including Wien filter. Top: source, bottom: collector.

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 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 (shown in Fig. 2 and Fig. 5), 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}.

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