SECONDARY ELECTRON MEASUREMENTS AT THE HIM ELECTRON COOLER TEST SET-UP

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Abstract

The planned advances in electron cooling technology aimed at improving the operation of future hadron storage rings include an increase in electron beam current and acceleration voltage. A test set-up has been built at Helmholtz-Insitut Mainz (HIM) to optimize the recuperation efficiency of such high-current beams in energy recovery operation, requiring a thorough understanding of their interaction with external electric and magnetic fields, such as those found in a Wien velocity filter. Beam diagnostics are carried out using a BPM and current-sensing scraper electrodes. At present, the set-up can be successfully operated at $U = 17\,\mathrm{kV}$, $I = 600\,\mathrm{mA}$, showing a relative secondary electron current of $\approx 2 \times 10^{-4}$. We present the current state of the project and its objectives for the foreseeable future.

INTRODUCTION

Electron coolers are designed for energy recuperation so that the total deposited energy is independent of the acceleration voltage. 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. Recent progress made by BINP [1] suggests that this effect can be eliminated using a Wien filter, at the same time allowing for measurement of the secondary electron current. Consequently, such a filter has been designed and successfully implemented in our cooler test set-up with the different properties of the components in mind [2].

A schematic view of the set-up is shown in Fig. 1. Using an isolating transformer, it is possible to use the same negative high-voltage power supply for the cathode and the collector, with an additional 6.5 kV, 1.5 A power supply providing the potential difference between cathode and collector to account for the finite perveance. This way, the beam pipe is at ground potential, greatly facilitating beam diagnostics. After the Wien filter, the set-up includes a moveable fluorescent screen, a beam position monitor obtained from BINP [3], and a mutually isolated double aperture to distinguish between secondary and primary current hitting the plates.

GAS DISCHARGES IN THE ELECTRON SOURCE

When operation of our test set-up started, it quickly turned out that the electron source obtained from TSL [4] could not be operated with the desired parameters ($U = 26\,\mathrm{kV}$, $B_z = 200\,\mathrm{mT}$) because of gas discharges between the electrodes [5]. In an attempt to identify the reason, CST simulations of

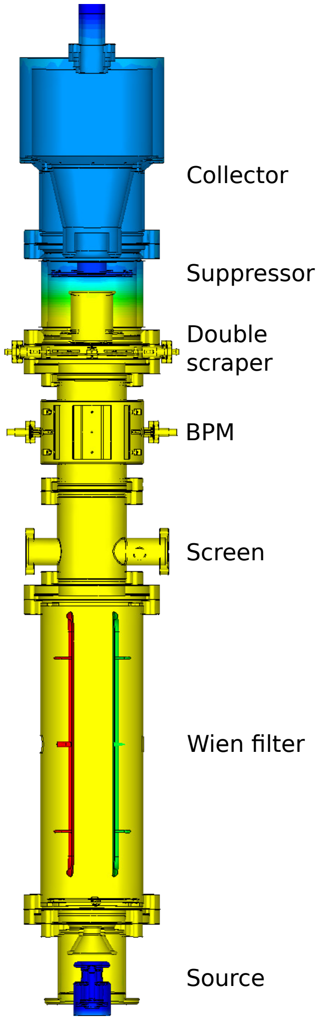

Figure 1: Schematic view of the vacuum chamber. Blue: $U < 0$. Yellow: $U = 0$.

electric fields and particle trajectories were carried out. The result of a particle simulation with the whole outer surface of the Pierce electrode emitting electrons is shown in Fig. 2. It can be seen that due to the electric field components caused by the varying distance between the outer Pierce electrode and the surrounding pipe, there are two local maximums of electric potential (indicated by arrows) along the symmetry axis of the source (vertical direction in the picture). Given a longitudinal magnetic field sufficiently high to confine the radial movement of electrons to a narrow space, all particles starting at one of the surfaces with a kinetic energy close to zero will oscillate between the potential minimums, greatly increasing the ionization probability of the residual gas. This constitutes a variety of the cylindrical magnetron where the

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threshold voltage for electrical breakdown depends strongly on the magnetic field [6]. It is expected that the problem can be solved by redesigning the Pierce electrode and its mechanical support so that a monotonous behaviour of the electric potential is obtained in the high-field region.

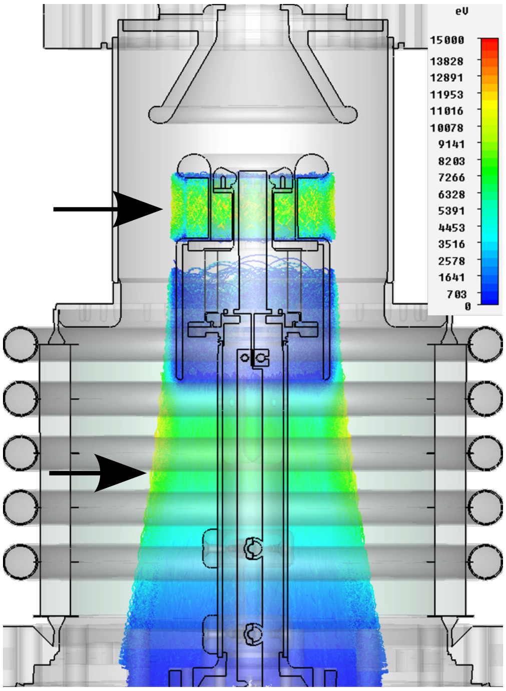

Figure 2: CST simulation of electron trajectories originating from the surface of the Pierce electrode. $t = 400\,\text{ns}$, all crashed trajectories are hidden. $U_{\text{Pierce}} = U_{\text{Cathode}} = -30\,\text{kV}$.

COLLECTION EFFICIENCY MEASUREMENT USING A WIEN FILTER

In order to measure the current of secondary electrons not captured by the aperture plates, a Wien velocity filter is used that breaks the symmetry between the primary and the secondary beam (Fig. 3) [2]. 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

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) = 0 \qquad (1)$$

in the case of the primary beam. However, any secondary particles are deflected because they have a different velocity vector. Given a certain energy distribution of the secondary electrons depending on the collector voltage, the total field strength can be chosen accordingly so all particles are captured by a plate that is insulated from the beam pipe to allow for independent current measurement.

Since the dipole coils have a different geometry than the electrostatic plates and the use of iron for arbitrary field forming is problematic due to the additional longitudinal field, equation 1 generally does not hold everywhere, which causes an undesired spatial displacement of the primary beam. While the exact value of this displacement (in our case ≈ 3 mm) is not critical because the Wien filter is usually placed directly in front of the collector aperture, it is too large to be able to fit a 20 mm beam through a 25 mm hole, which is why the beam reacts extremely sensitively to the value of the longitudinal field. To solve this problem, a correction coil was introduced to flatten the magnetic field profile in the vicinity of the peak. According to CST tracking simulations, the beam offset should be reduced to less than 1 mm. The geometry of the coils and the field errors are shown in Figs. 4 and 5, respectively.

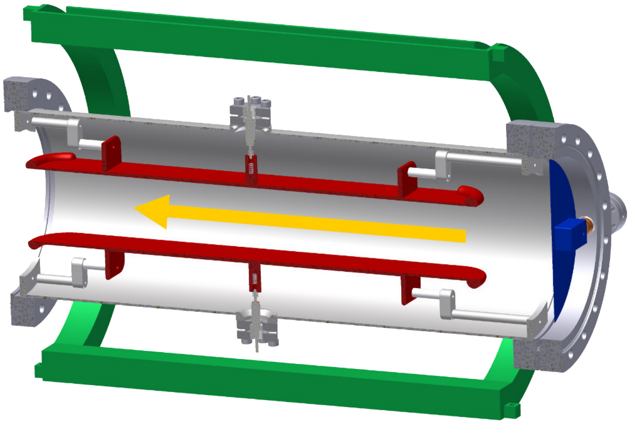

Figure 3: Schematic view of the Wien filter [2]. Red: electrostatic plates. Green: dipole coils. Blue: collecting plate.

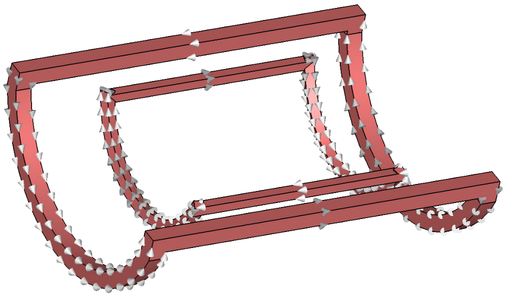

Figure 4: Wien filter dipole coils with added correction coils.

EXPERIMENTAL RESULTS

Without the aforementioned improvements, our set-up can be successfully operated at $U = 17\,\text{kV}$, $B_{z,\text{max}} = 80\,\text{mT}$. Depending on the voltage applied to the Pierce electrode, collector currents in the range of 600 mA can be obtained without any signs of instability. The relative loss current at anode potential is 2×10^{-4} in total, about half of which flows through the beam pipe in a way that is yet experimentally undetermined. According to CST simulations, secondary current flowing into the positive deceleration electrode is the most likely cause. This assumption is strongly supported by

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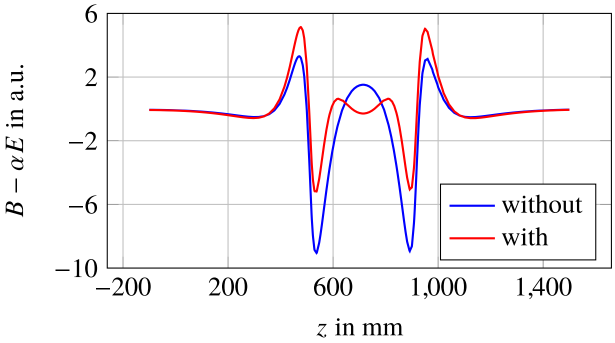

Figure 5: Lorentz force imposed on primary particles by the Wien filter field geometry before and after optimization. Vertical scale depends on operating parameters.

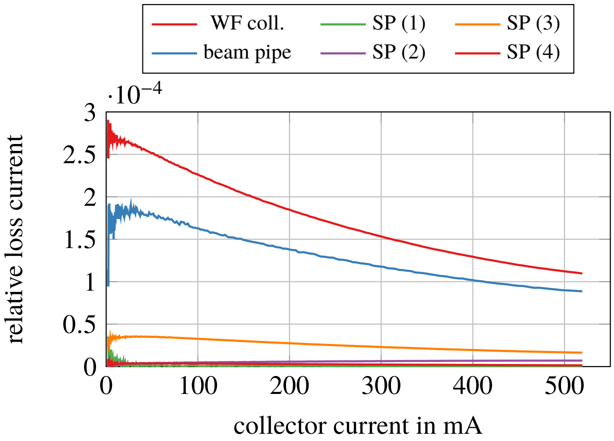

Figure 6: Electron current lost at anode potential. WF: Wien filter collector plate, SP: scraper plates.

the fact that the beam pipe current shows the same primary current dependence as the Wien filter current.

IMPROVED DECELERATION OPTICS

CST simulations have shown that given the original positive electrode in the deceleration system, the original high-voltage insulator, and the BINP collector, the space left for the suppressor electrode is not enough to be able to obtain a reasonably low potential minimum. Therefore, both electrodes have been redesigned, at the same time changing the mechanical support of the positive one in such a way that the current flowing into it can be measured independently. This way, we hope to show that all secondary particles behave in accordance with our simulations. The potential distribution of the new system is shown in Fig. 7.

OUTLOOK

It is likely that the optimization steps described above regarding the Wien filter and the deceleration optics will be completed in November 2015, after which we hope to operate the set-up without any unknown sources of loss current. The complete control of secondary emission by the Wien filter will strongly suppress any undesired electron flow, thereby facilitating diagnostics and high-voltage operation in a real cooler. We believe the relative number of resulting secondaries to be $\ll 10^{-5}$.

The test device can then be used to conduct further studies on suppression of optical background, which is a challenge to be overcome in order to advance development of the Thomson Laser Scanning technique in coolers [7]. Additionally, it is planned to further increase the electron current to look for possible limitations that might present themselves.

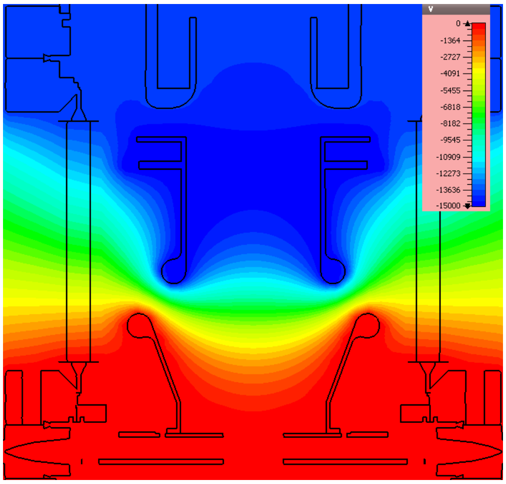

Figure 7: Distribution of electric potential with new deceleration electrodes. Cutplane at $x = 0$.

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