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TESTS OF THE GUN PROTOTYPE FOR THE ELECTRON COOLING SYSTEM OF THE NICA COLLIDER

A.P. Denisov, M.I. Bryzgunov, A. Bubley, V. Chekavinskiy, A.D. Goncharov, A. Ivanov, V.V. Parkhomchuk, A. Petrozhitskii, V.B. Reva, E.R. Urazov[1], BINP SB RAS, Novosibirsk, Russia
[1]also at Novosibirsk State University, Novosibirsk, Russia

Abstract

The efficiency of the electron cooling depends on the electron beam quality produced be the electron gun. The characteristics of the electron gun were tested on the test bench with the linear transport channel. For the beam diagnostics, we used beam position monitors alongside with the W-Re wire sensor for 1-D quantitative profile measurements. We also used a high-definition CCD camera with high sensitivity for qualitative 2-D measurements of the electron density distribution via the wire thermal radiation.

INTRODUCTION

This work is related to the new electron cooling system, developed for the NICA collider facility, located in Dubna.

Unlike the previous electron cooling systems manufactured in the Budker Institute [1], the NICA collider requires the electron beam with higher current density for the effective cooling. Meanwhile, the size of the electron beam is not required to be as large as in the previous systems. Therefore, we decided to develop a new electron gun.

ELECTRON GUN

The electron gun we developed and tested is based on the Pierce optics with the shield electrode placed near a flat BaO cathode and with an additional four-sector control electrode [2] (Fig. 1).

The anode controls the overall emission, whereas the control electrode controls the emission from the edges of the cathode. This allows us to change the electron current density distribution of the beam. Also an auxiliary electrode is introduced, which controls the output energy of the electron beam on the desired distance from the anode.

To prevent the beam from expanding due to the space charge the gun is emerged into the longitudinal magnetic field.

The geometry, position and voltages of the electron gun electrodes were calculated in an iterative manner using the SAM software developed at BINP [3] in order to minimize the amplitude of Larmour oscillations. The parameters of the electron gun are in Table 1.

Table 1: Parameters of the Electron Gun

Parameter	Value
Anode voltage, kV	0-20
Control electrode voltage, kV	-3..+3
Electrons output energy, keV	1-30
Cathode / Electron beam diameter, cm	1
Electron current density, A/cm^2	0..1.5
Magnetic field, G	900-1000

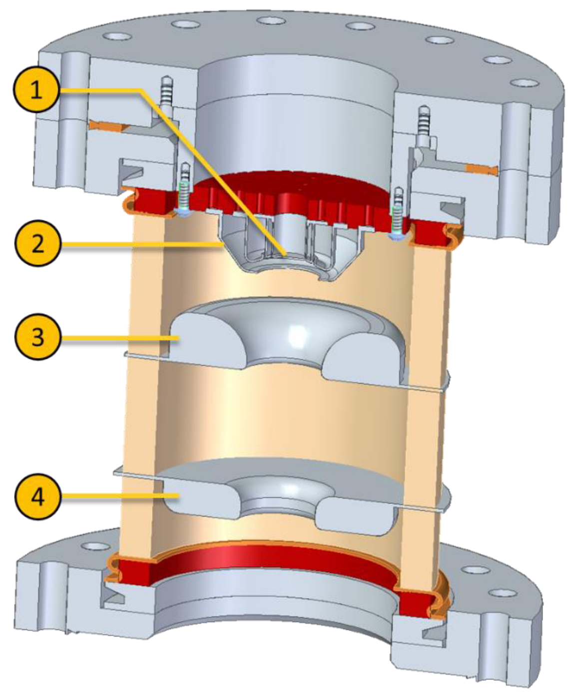

Figure 1: A design of the electron gun based on the Pierce optics. The gun includes a cathode (1), a control electrode (2), an anode (3) and an auxiliary electrode (4) for setting the electrons output energy.

TEST STAND

For testing the electron gun and developing the beam diagnostics techniques the test stand with a linear structure was assembled (Fig. 2 and Fig 3). It bases on the test stand used for testing the electron gun for the EC-300 electron cooling system. It includes the magnetic coils for providing a longitudinal magnetic field about 900-1000 Gauss along the beam transport channel.

The modified version of the test stand has a longer transport channel for the electron beam. Additional coils create the longitudinal magnetic field for the gun and collector. Magnetic coil correctors allow shifting the electron beam in the transverse direction. Additional magnetic coils placed in the centre of the transport channel change the longitudinal magnetic field locally in order to control the Larmour oscillation phase.

We also added a beam diagnostics chamber for measuring the beam position and beam current density profile. The electrons energy is up to 30 keV.

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Figure 2: A photo of the test stand for the electron gun.

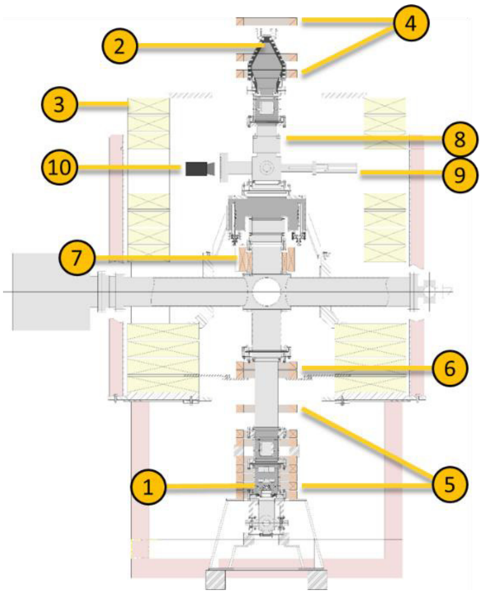

Figure 3: The schematic layout of the test stand. The layout includes the electron gun (1), the collector (2), the coils creating the magnetic field in the transport channels (3), coils for adjusting the magnetic field around the collector (4), coils for adjusting the magnetic field around the electron gun (5), coils for adjusting the Larmour oscillation phase (6), coils for shifting the beam in the transverse direction (7), beam diagnostics chamber (8), a vacuum feedthrough (9), a CCD camera (10).

The diagnostics chamber (Fig. 4) includes the electrostatic Beam Position Monitor (BPM), a channel for the wire-based beam profile sensor placed on a movable holder and a channel with a vacuum feedthrough.

The BPM measures the position of the beam, necessary for performing the profile scanning. It also allows us to measure the shape of the beam.

The window is necessary for the measurements of the thermal radiation of the wire. Such measurements can be used to restore the 2D profile, while the current measurements alone can provide only 1D profiles.

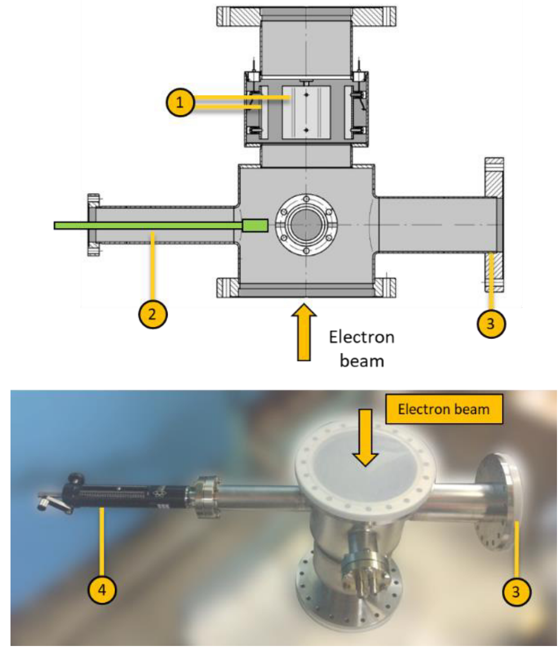

Figure 4: The beam diagnostics chamber. It includes an electrostatic BPM (1), the wire sensor attached to the movable holder (2), a viewport (3), the vacuum feedthrough (4).

For measuring the electron beam profile, we use a wire-based profile sensor (Fig. 5). The wire is 25 μm in diameter and made of W-Re alloy (85%/15%).

The wire sensor is placed on the movable holder. The vacuum feedthrough changes the position of the wire sensor roughly. The beam profile scanning is performed by changing the position of the electron beam using the magnetic coils correctors.

When the wire is heated, its length increases. To prevent the wire from sagging the flexible bronze plate is used, which pulls the wire.

The current is measured through the shunt connected through wires to the rigid plate and the U-shaped part of the holder.

This design allow us to let the current from the external power supply through the wire in order to heat it. By letting the known amount of current through the wire sensor, we can establish the dependency between the power emitted from the wire and the CCD camera signal. In other word, it is necessary for calibrating the camera. It also allows us to preliminary clean the wire sensor from any organic materials.

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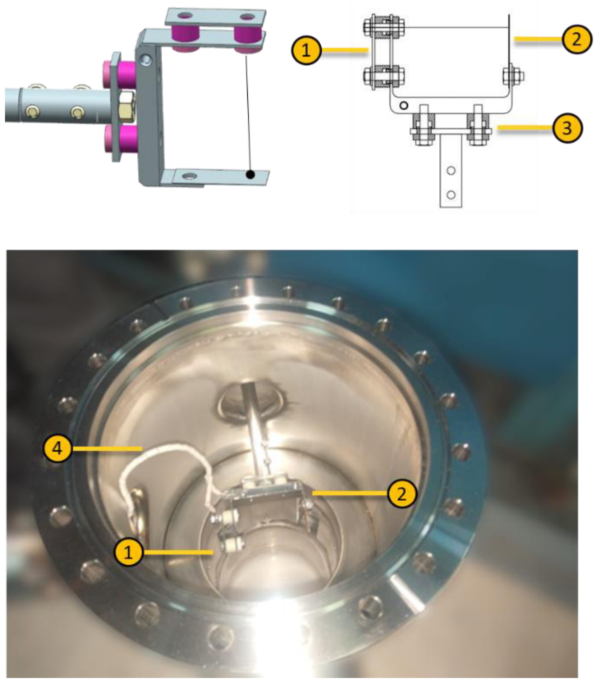

Figure 5: The wire sensor for beam profile measurements. (1) and (2) are rigid and elastic plates for attaching the wire for profile measurements. (3) is insulation for preventing the electrical current flow through the holder and the vacuum feedthrough. (4) Wires for measuring the current absorbed by the wire sensor.

MEASUREMENTS OF THE ELECTRON BEAM PROFILE

In this section, we want to share some results of the experiments conducted with the electron beam on the test stand.

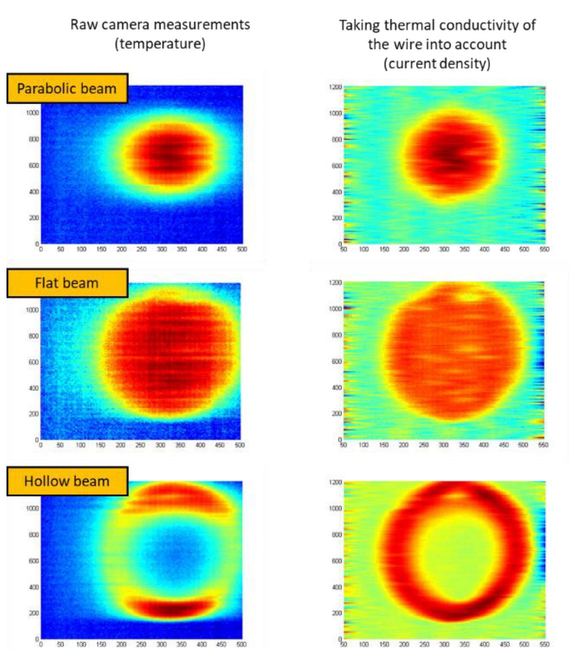

Figure 6: Qualitative beam profiles restored from the CCD camera measurements.

The list of conducted experiments includes the calibration of the wire sensor (analysing the secondary emission, and the CCD camera signal) one-dimensional current profile measurements and two-dimensional profile measurements based on the sensor thermal radiation.

The firs experiment also included the beam shapes measurements using the BPM. The control electrode have four sectors. The potential of each electrode can be slightly modulated in time, resulting in the modulations of the current density on different sides of the beam. BPM can register these modulations and provide us the information about the beam position, its shape and the beam rotation around its axis for different values of the longitudinal magnetic field.

Figure 6 shows the results of the beam profile measurements using the CCD camera. Due to the thermal conductivity, an electron beam heats up not only the part of the wire where it is absorbed, but also its adjacent parts. Therefore, the signal from the camera does not match the actual distribution of the current density.

We can associate the current distribution with the measured temperature using the steady-state form of the heat equation:

$$T''(x) = A \cdot j(x) + B \cdot T^4(x) + C$$

We assume that we do not know the exact values of the coefficients of the heat equations. However, we can estimate them by applying restoration procedure for simple cases, for example for restoring the profile of a small beam, for which the actual size is much smaller than the heated area of the sensor. The examples of the restored beam current distributions is in Fig. 6 (the right column).

CONCLUSION

The further experiments require the upgrades for the gun electronics in order to modulate the electron beam current. The 1 A beam with electron energies 1-10 keV can break the wire sensor. By modulating the beam current, we can effectively decrease the average power absorbing by the wire sensor.

One of the experiments to be conducted is measuring the amplitude of the Larmour oscillations at the edge of the beam, by measuring the oscillations of the outer size of the beam.

We also look forward for improving the method of restoring the beam current density distribution using the CCD camera measurements.

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