ELECTRON GUN AND COLLECTOR FOR 2 MEV ELECTRON COOLER FOR COSY*

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Abstract

COSY storage ring is planed to be upgraded in 2011 by installation of a new electron cooler [1]. Electron cooling will reduce energy spread of protons and so improve the precision of internal target experiments. Some of the most important parts of this new electron cooler are the electron gun and the collector, and they must satisfy several rigid requirements. Electron gun must provide high perveance electron beam with low transversal temperature and variable beam profile. The gun control electrode assembled of four separate sections will provide measurements of beam envelope along the transport section of the cooler. Displacement of corresponding part of the beam may be observed if alternating voltage is applied to each section. Collector should have high perveance, low secondary emission coefficient, and small dimensions. Wien filter is supposed to be installed before the collector to satisfy these requirements. In this case we can use high perveance small-scale collector with axially-symmetric magnetic field; secondary electrons will be absorbed in Wien filter. An additional vacuum pumping must be provided in the collector design.

ELECTRON GUN

The electron gun for COSY cooler is very similar to the guns for other BINP coolers, installed on CSR and LEIR rings [2]. This gun provides high-perveance electron beam with low transversal temperature. The gun design is shown in Fig. 1. The convex cathode 1 immersed into longitudinal magnetic field is used. To form the electron beam together with anode 4 control electrode 3 is used. This electrode is placed near the cathode edge and influences the emission from this area. By applying different potential on this electrode the beam with radial current density distribution from parabolic to hollow can be obtained.

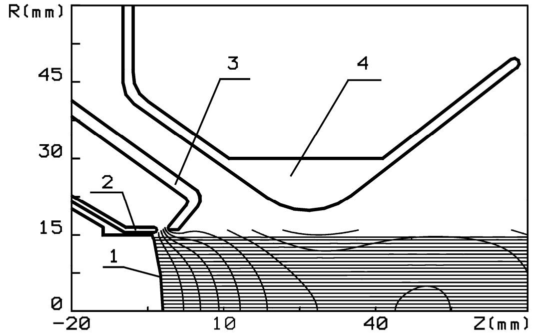

Figure 1: Electron gun for COSY cooler.

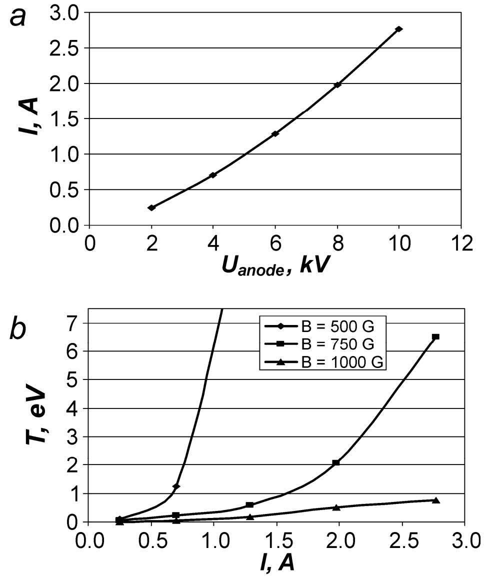

Figure 2: Current (a) and transversal temperature (b) of homogeneous electron beam.

To provide high efficiency of electron cooling at high energies one need to increase beam current density. The calculations of the homogeneous beam current as a function of anode potential (Fig. 2a) were made with UltraSAM code [3]. With the current increase the transversal temperature grows also (Fig. 2b). These calculations show that value of magnetic field should be at least 600 Gs to provide acceptable (< 2 eV) temperature of 1 A uniform beam.

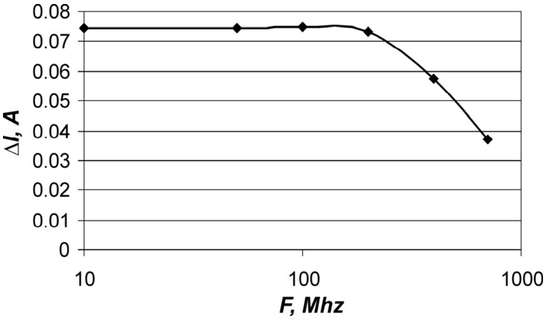

Figure 3: Electron beam current modulation at oscillation of the control electrode potential (*ΔU*= 50 V, *U*=600 V).

For beam diagnostic purposes the suggestion was made to reject axial symmetry and to divide control electrode into 4 segments. By applying small potential variation on one of these segments not only position of beam center but also beam sizes can be measured. Beam current modulation decreases at high frequencies of potential oscillation, thereby to realize this technique the cutoff

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frequency must be found. The calculation results shown in Fig. 3 give 200 Mhz cutoff frequency for this gun. With help of 3D simulation it was found that modulation of emission current density at cathode opposite side from acting segment is less than 2% of the maximal current density modulation, thus this technique looks realizable.

WIEN FILTER

In order to increase efficiency of absorption of electron beam it is proposed to suppress secondary electron flux from the collector with Wien filter installed before the collector. The filter can significantly improve efficiency of recuperation (I_{loss}/I_{total}) of electron cooler. The idea of Wien filter is to suppress secondary electrons with crossed electric and magnetic fields. For main electron beam, electric and magnetic (Lorenz) forces are compensated and the beam goes to collector:

$$F_{\perp} = \frac{e}{c} V_{\|} B_{\perp} - eE_{\perp} = 0\,,$$

where $V_{\|}$ is longitudinal velocity of electron, $B_{\perp}$ and $E_{\perp}$ is transverse magnetic and electric fields. For secondary beam, which is reflected from collector, the forces are not compensated and the beam drifts to wall of vacuum chamber:

$$F'_{\perp} = \frac{e}{c} V_{\|} B_{\perp} + eE_{\perp} = 2\frac{e}{c} V_{\|} B_{\perp}\,.$$

Transverse electrostatic field is produced with special plates. During entrance to the filter, electron can be accelerated or decelerated by edge fields of the plates, that depends on coordinate of an electron. It means that in the filter electrons, flying closer to positive plate, have higher velocity than in center of the beam. As a result, for homogeneous distributions of transverse fields, beam shape will be changed (Fig. 4) and it can decrease perveance of collector.

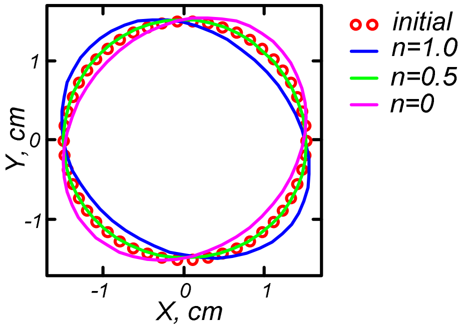

Figure 4: Change of main beam shape in homogeneous transverse fields.

In order to avoid this problem transverse magnetic field should have gradient:

$$B_x = B_{\perp} \frac{n}{R} y\,, \quad B_y = B_{\perp}\left(1 + \frac{n}{R} x\right),$$

where $R = \frac{pc}{eB_{\perp}}$, $n = \frac{1}{2\gamma^2}$, x and y – coordinates in transverse direction, γ – Lorentz factor.

Two methods of production of transverse magnetic field were investigated: with magnetic coils and with permanent magnets. Calculations show that to produce magnetic field 35-40 G the thickness of coils is about 4 cm. That is too much in order to insert it in our system without significant changes. Decreasing of size of the coil leads to increasing of its power and it becomes necessary to cool it.

System based on permanent magnets was chosen. Permanent magnets provide required value of magnetic field and their size is small enough in order to insert them in the system without significant changes in construction. Varying properties and position of the magnets one can produce required values of field and gradient. Disadvantage of such system is that it is impossible to adjust magnetic field without disassembling of the filter.

Fields in Wien filter were calculated with the help of Mermaid program. Length of electrostatic plates is 39 cm, integral of transverse magnetic field in center 1400 G·cm, voltage on electrostatic plates ±8 kV relative to vacuum chamber. Potential of vacuum chamber of the filter is 20 kV relative to cathode. Special shim is added to the plates to make homogeneous distribution of electric field.

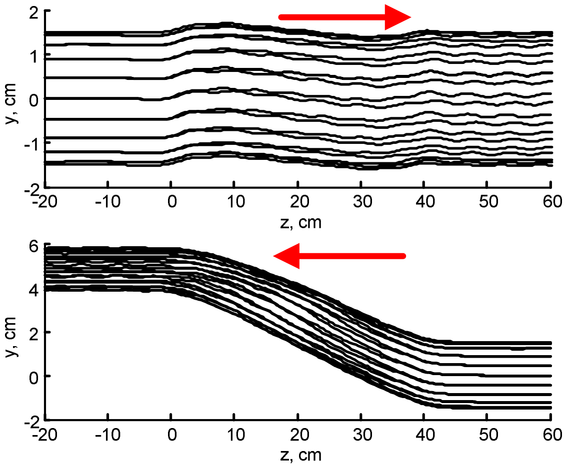

Figure 5: Electron beam motion in the filter: upper – primary beam, lower – secondary beam.

Using results of field calculations beam motion in the filter was calculated (Fig. 5). Beam radius 1.5 cm, electron energy 20 keV, longitudinal magnetic field 500 G. In the figure one can see that primary beam flies along the system with small deviation from axis which are result of mismatch between electric and magnetic fields in entrance end exit of the filter. Secondary beam is deviated from the axis to about 5 cm. Since diaphragm for secondary beam collection has inner radius 2.5 cm such deviation is enough.

Electrons moving to the diaphragm also produce secondary electrons which can make system efficiency worse. Form of the diaphragm allows decrease this flux. We expect resulting efficiency of the system will be lower then 10^{-5}.

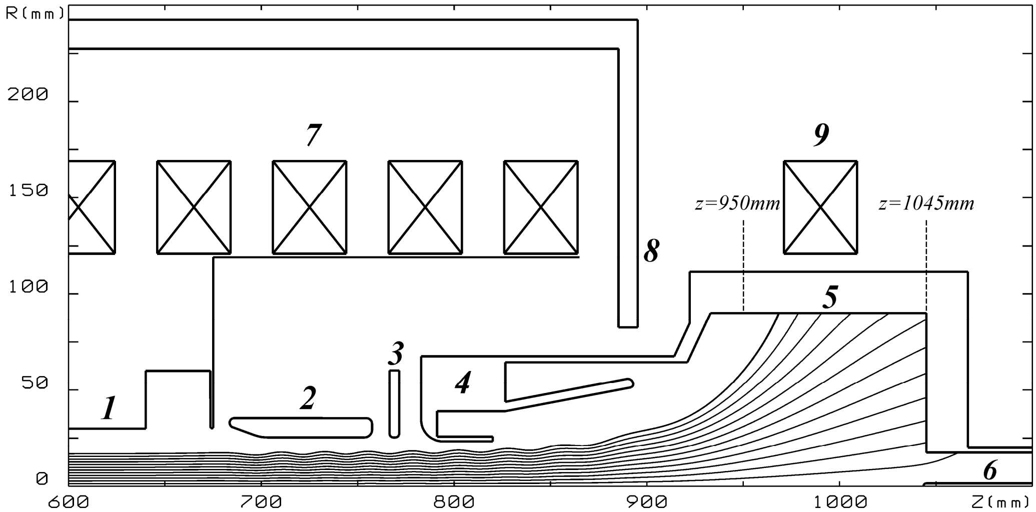

Figure 6: The collector assembly design.

COLLECTOR

The collector for high-voltage electron cooler must be small, simple design installation with high perveance and small secondary emission coefficient. To meet these requirements the suggestion was made to refuse a design with totally shielded collector as in previous BINP coolers. To weaken the magnetic field inside the collector that is needed to expand the electron beam and to form the magnetic mirror for the secondary electrons another technique was proposed – to feed one of the solenoids with opposite current.

The collector assembly design is shown in Fig. 6. The electron beam coming from drift tube 1 passes through collector anode 2 and suppressor 3 and enters inside collector 4. Due to magnetic shield 8 and coil 9 with opposite current the beam expands and deposits on cooled collector surface 5. To implement effective pumping the hole 6 is provided that connects collector with vacuum pump. To avoid electron flux into this hole in its center thin electrode under cathode potential is placed.

To optimize the collector performance current in coil 8 must be adjusted. The calculations show that with proper choice of this current most of the beam current deposits on cooled surface without local overheating (Fig. 6). The perveance of this collector with fully opened suppressor varies from 13 to 15 $\mu A/V^{3/2}$ depending on electron beam profile.

The second method to lock secondary electrons in collector is the electrostatic barrier. This barrier is formed by suppressor if its potential is lower than collector potential. Collector secondary emission coefficient is calculated as a function of suppressor potential, the results are shown in Fig. 7.

CONCLUSION

The electron gun and collector are developed for high-voltage COSY electron cooler that is under construction in BINP.

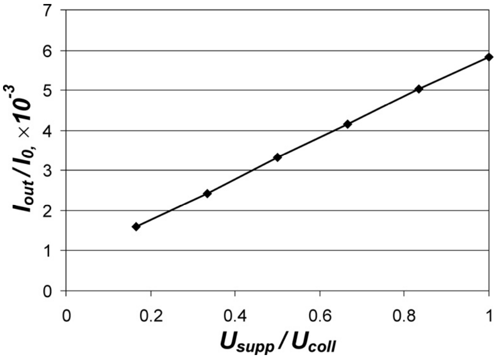

Figure 7: Secondary emission coefficient of the collector. Primary beam current $I_0 = 1$ A.

The gun can provide electron beam with current up to 3 A, low transversal temperature and variable beam profile. The beam current density can be modulated on one of the sides that will help measure the beam sizes. The collector is small and has high perveance that facilitates its placement at the top of electrostatic column. Using both electrostatic and magnetic barriers allows obtaining collector secondary emission coefficient less than 10^{-3}. Additional decrease of reverse electron flux in high-voltage system (less than 10^{-5} of the main beam) can be achieved with help of Wien filter installed before the collector that will help to increase system stability and reduce high voltage source load.

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