NEW COLLECTOR FOR THE CELSIUS ELECTRON COOLING SYSTEM

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ABSTRACT
Results of collector efficiency measurements performed on the present CELSIUS collector are given. Pecularities of such measurements in electron cooling systems are discussed. A new collector, which is expected to have a collection efficiency considerably better than the present one, has been produced and tested at the BINP test bench. The results of these measurements are presented.

1. INTRODUCTION

For the CELSIUS storage ring performance the so called "electron heating" effect is an important problem [1]. One of the possible explanations of this phenomenon may be related to secondary electrons escaping from the collector. This work was initiated in order to decrease the flow of these electrons and thus to promote understanding of the "electron heating" mechanism.

The present CELSIUS collector has a good enough efficiency to provide an electron beam energy recovery up to the current of 2 A [2]. It is important to specify the collector efficiency concept. As a rule, the ratio of the high voltage power supply current I_{hvps} to the cathode current I is considered to be a characteristic of the collector efficiency. For the case of a strong magnetic field this value is determined not only by the recuperator, but also by properties of the electron cooling device as a whole system. The current I_{hvps} may be much less than a flow δI of secondary electrons created by the primary beam on the collector surface and escaped from the recuperator. For instance, in straight systems (i.e. in devices without bending magnets), the main fraction of such electrons comes to the gun, is reflected, returns into the collector and is captured with the same efficiency as the primary beam. In this case $I_{hvps} << \delta I$. To characterize the efficiency of a recuperator itself, it is useful to introduce

$$\sigma_{col} = \frac{\delta I}{I} \quad (1),$$

which can be called the collector secondary emission coefficient. The values of σ_{col} and $\frac{\delta I}{I}$ are the same only under definite conditions. In section 2 these conditions are discussed and results of measurements of the CELSIUS collector secondary emission coefficient are presented.

The magnitude of σ_{col} can be considerably decreased if the potential minimum in the recuperator is formed in accordance with the solution for two guns with coinciding cathodes, which was proposed in ref.[3]. A geometry of equipotentials in such a potential barrier is almost planar, therefore we will name this solution a flat electrostatic mirror. At the BINP test bench measurements were performed to compare the efficiency of the recuperators with the tube-shaped suppressor (like that used in CELSIUS) and with diaphragm-shaped one, where the flat electrostatic mirror was formed. On the base of results of these measurements a new collector for CELSIUS electron cooling system is made.

2. MEASUREMENTS OF THE CELSIUS COLLECTOR SECONDARY EMISSION COEFFICIENT.

At the CELSIUS ring a recuperator with a tube-shaped suppressor has been used. To define the coefficient of secondary emission of that, it is necessary that the whole flow of secondary electrons from the collector on its way to the gun should come to an electrode on ground potential. This is possible for a large enough displacement due to centripetal drift in the toroid bends Δ_1:

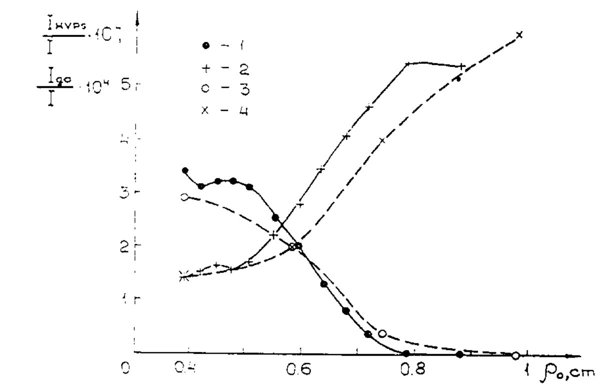

Fig.1. The current of the high voltage power supply (2,4) and the gun anode current (1,3) as functions of ρ_0. I= 1 A, U_{col} = 5 kV, U_s= 0.7 kV. 1,2- B_0= 0.15 T, U_{hvps} changes, 3,4- U_{hvps}= 30 kV, B_0 changes.

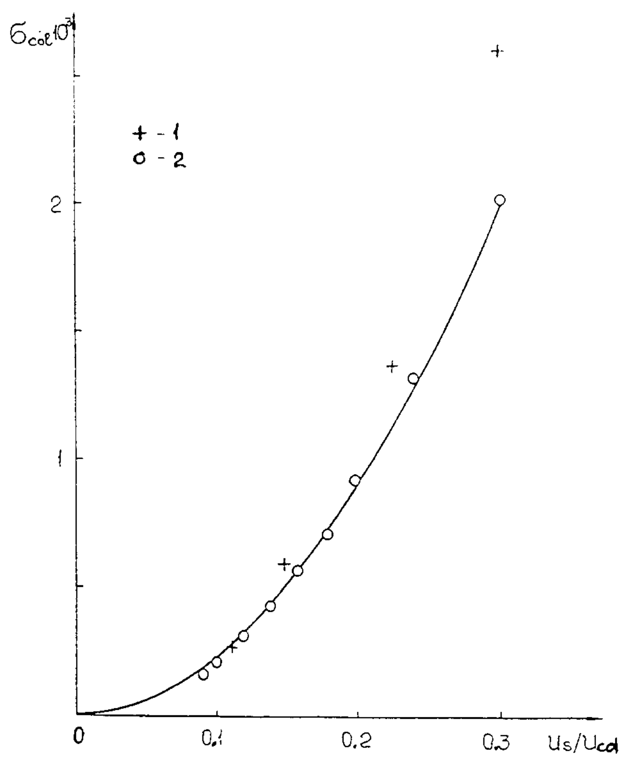

Fig.2. The collector secondary emission coefficient as function of the potential barrier depth. B_0= 0.1 T, I= 0.5 A, U_{hvps}= 30 kV. 1- U_s= 0.45 kV, U_{col} changes, 2- U_{col}= 5 kV, U_s changes.

$$\Delta_1 = 2\alpha\rho_0 > R_b + R_0,$$
$$\rho_0 = \frac{m}{eB_0}\sqrt{\frac{2W}{m}} \qquad (2),$$

where α is a turn angle of the trajectory (π for CELSIUS), $W \approx eU_{hvps}$ is the energy of these electrons, e,m are charge and mass of electron, B_0 - is magnetic field strength, R_b is the radius of the beam, R_0 is the minimal radius of electrodes on ground potential, $2\pi\rho_0$ is the gyro wave length of the electrons.

For the CELSIUS system the condition (2) can be controlled by the current I_{hvps} and the current of the gun anode power supply as a function of the value of ρ_0 (fig.1). As ρ_0 increases, the secondary beam strikes first the gun anode having the minimal diameter, and then the grounded electrode. The valuesof Δ_1, for which the gun anode current is zero, agrees with the condition (2). For $\rho_0 > 0.8$ cm $\sigma_{col} = \frac{I_{hvps}}{I}$.

Shown in figure 1 are results of two sets of measurements. For the first set the value of ρ_0 is changed by a increase in the energy of electrons, and for the other one by the magnetic field strength,. The results agree with an accuracy of 10%. It means that, firstly, the current losses are determined uniquely by the magnitude of σ_{col} and a relation between beam-electrode gaps and ρ_0. Secondly, the magnitude of σ_{col} depend weakly on the magnetic field strength.

To estimate the collector secondary emission coefficient, in the ref.[4] a simple formula is proposed:

$$\sigma_{col} = k\left(\frac{U_m}{U_{col}}\right)^2 \frac{B_c}{B_m} \qquad (3)$$

where U_m is the potential in the electrostatic barrier, U_{col} is the collector potential, B_m and B_c are the magnetic fields in the barrier and at the collector surface, respectively, the magnitude of the coefficient k depends on the collector material and vacuum conditions. The measured values of σ_{col} (fig.2) are quadratic in $\frac{U_s}{U_{col}}$ in agreement with (3). Taking U_m to be equal to a suppressor potential U_s and $\frac{B_c}{B_m}$=0.15, we obtain for CELSIUS collector conditions (a copper surface, the vacuum $5 \cdot 10^{-7}$ Pa) k= 0.15 (solid curve in figure 2).

For each value of the beam current there is a minimal possible value of the suppressor potential $(U_s)_m$ and a corresponding value of σ_{col} In experiments the magnitude of the barrier perveance [3]

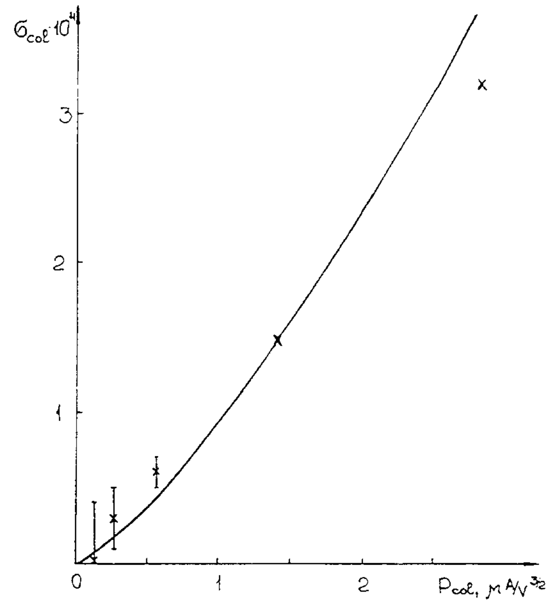

Fig.3. The minimal value of σ_{COL} as function of collector perveance. U_{hvps} 150 kV, B_0= 0.1 T, U_{col}= 5 kV, U_s is the minimum possible for each current.

$P_b = \frac{I}{(U_s)_m^{\frac{3}{2}}}$ is constant with good accuracy. Using eq. (3) iit is possible to predict a relationship between the collector secondary emission coefficient and the collector perveance:

$$\sigma_{col} \sim P_{col}^{\frac{4}{3}} = \frac{I^{\frac{4}{3}}}{U_{col}^{2}} (\qquad (4).$$

The function σ_{col} (P_{col}) is the main characteristic of recuperator properties. For the CELSIUS recuperator it is presented in figure 3 and fits in the formula (4) (solid curve in figure 3).

Recuperators with an electrostatic barrier created by a tube-shaped suppressor are popular now (see, for example, [5], [6]). Therefore, these results of measurements of the collector secondary emission coefficient are useful also for other electron cooling systems.

3. MEASUREMENTS OF CHARACTERISTICS OF RECUPERATOR WITH FLAT ELECTROSTATIC MIRROR.

These measurements were performed with a prototype of the new collector on the INP straight test bench (fig.4).

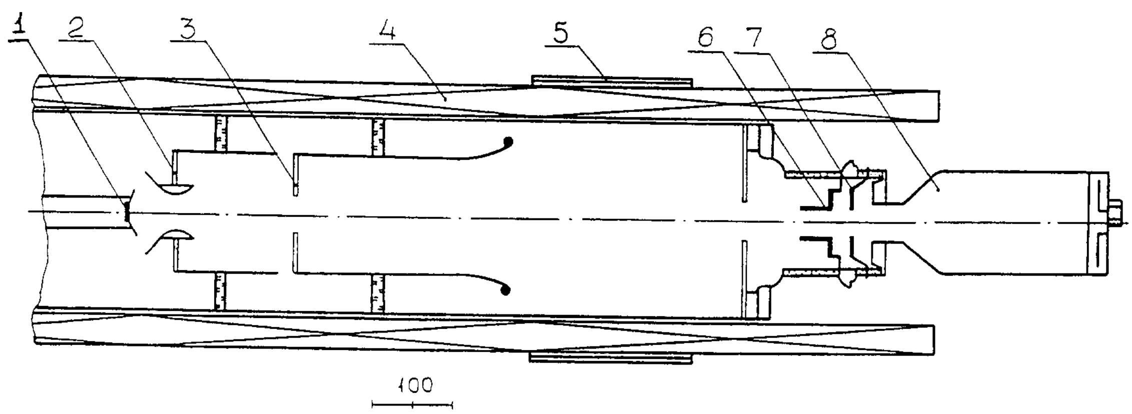

Fig.4. The BINP test bench. 1- cathode, 2,3- gun anodes, 4- solenoid, 5- correction coils, 6- collector anode, 7- diaphragm, 8- collector.

In straight systems the relative current losses are considerably lsmoller than the collector secondary emission coefficient, because the high voltage electrode current is created only by deviation of secondary electron trajectories from the primary beam ones on a value of [4]

$$\Delta = 2\rho_m = 2\frac{m}{eB_0}\sqrt{\frac{eU_m}{m}}. \qquad (5).$$

Therefore, the losses depend not only on a secondary electron flow from the recuperator, but also on distance between electrodes and the beam boundary as well as on the magnetic field strength. The goal of the measurements was a comparison of the losses for two methods of creating the potential minimum. This comparison was performed for the same geometries of the magnetic field and electrodes.

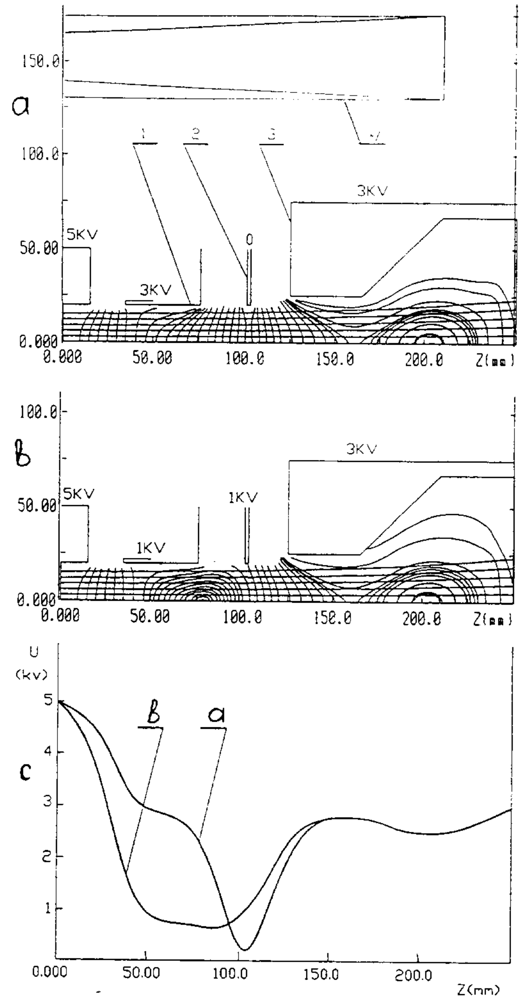

Fig.5. Results of simulation of two variants of recuperator a- tube-shaped suppressor, b- diaphragm-shaped one, c- potential distribution. 1- collector anode, 2- diaphragm, 3- collector, 4- solenoid. I=0.7 A, B_0= 50 mT.

For the first variant the suppressing potential is given to a diaphragm arranged symmetrically between the cylindrical entrance of the collector and the cylindrical collector anode. Potentials of the collector and the collector anode are equal.. The second variant models a tube-shaped suppressor used at CELSIUS: the suppressing potential is applied to the collector anode connected with the diaphragm. Results of simulations of both variant are shown in fig.5.

An electron gun with a barium oxide 30 mm cathode is used. To decrease the magnetic field on the cathode it is possible to switch off proper sections of the solenoid. The measurements were made mainly in such a regime with the 20 mm beam diameter at the recuperator entrance.

Both variants of recuperator have a good enough efficiency, and for the magnetic field strength being typical for the CELSIUS electron cooling device (about 0.1 T) the current losses are too low to be registered with good accuracy. Therefore the comparative measurements were made at the lower field level (fig.6). The losses for the diaphragm-shaped suppressor are drastically less almost in the whole range of the field strength. Note, that the level of these losses changes approximately proportionally with vacuum and is determined, apparently, by electrons created by ionization of the residual gas. A rapid growth of the losses at low magnetic fields is explained by a reflection of a peripheral fraction of the primary beam due to the development of transverse velocities of electrons in the gun at the field strength of the order of ten mT.

The minimum losses in the experiments with the diaphragm-shaped suppressor are achieved for the minimal possible potential on the diaphragm. This regime corresponds to a position of a zero equipotential near the beam boundary. Experimentally it can be observed by measuring of the current losses as a function of the transverse

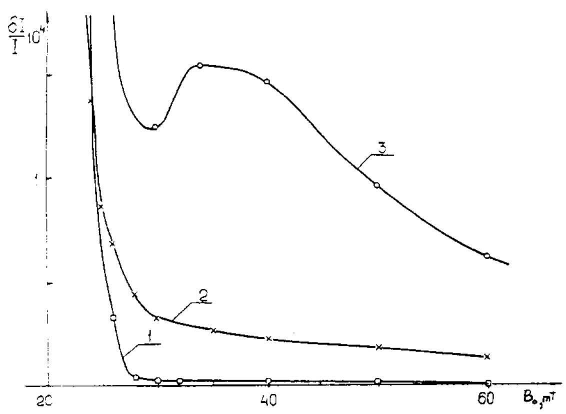

Fig.6. The current losses as a function of the magnetic field strength near the recuperator entrance. I=240 mA, U_{col}= 3 kV. 1- diaphragm- shaped suppressor, U_s= -300V, 2,3- tube-shaped suppressor, U_s= 0.75 kV (2), 1.5 kV (3).

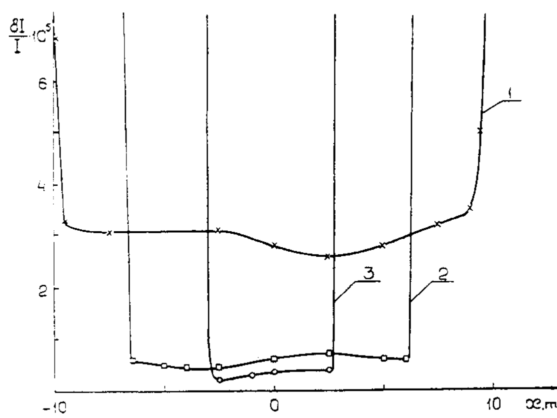

Fig.7. The current losses as function of the transverse displacement of the beam. I=240 mA, U_{col}= 3 kV, B_0= 35 mT, I= 240 mA. 1- tube-shaped suppressor, U_s= 0.75 kV, 2,3- diaphragm- shaped suppressor, U_s= -150 V (2), -300 V (3).

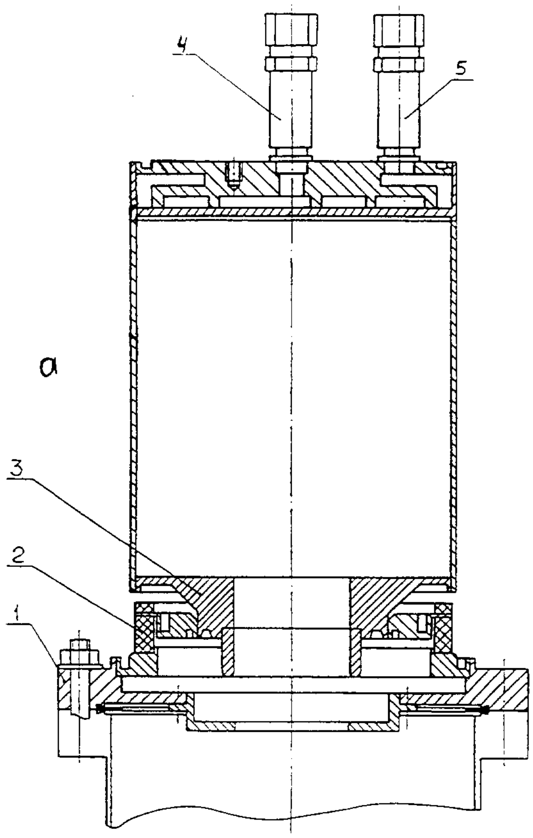

Fig.8. The new collector. 1-diaphragm, 2-isolator, 3- collector, 4, 5- input and output of water.

displacement of the beam by correction coils (fig.7). At large displacements the losses increase rapidly due to a reflection of the beam from the zero equipotential or its hitting to the collector anode. As the diaphragm potential decreases, the range of the beam positions with the low losses is reduced, which means a shift of the zero equipotential to the beam boundary.

Analogous measurements were performed also for the case of the approximately equal magnetic fields on the cathode and in the recuperator, i.e. for the beam diameter in the recuperator entrance near 30 mm. In this case the gap between the beam boundary and the collector anode is less than the one between the beam and the gun anodes, and the collector anode current is much higher than the losses. It complicates the interpretation of the results. Nevertheless, judging from the magnitude of the collector anode current, the variant with the diaphragm-shaped suppressor by optimal tuning of the diaphragm potential is essentially more effective also for 30 mm beam. Note, that for this case the collector perveance increases and for the optimal tuning is 2.4 $\frac{\mu A}{V^{\frac{3}{2}}}$.

On the base of these measurements a new recuperator for CELSIUS was made (fig.8). It consists of the collector proper, an isolator, a diaphragm, and is made to be mounted instead of the present one without an alteration of other elements of the electron cooling system. In comparison with the recuperator investigated on the test bench, the gaps between electrodes are corrected to increase the optimal collector perveance. The collector was mounted at the BINP test bench and successfully tested with a beam current of 2 A and a collector voltage of 4 kV. The results agree with those obtained previously for the prototype.

4. CONCLUSION.

The measurements made prove the advantage of the recuperator with a flat electrostatic mirror. The final result for the new collector secondary emission coefficient can be obtained only in experiments akin to those described in section 2. We hope, that with the new collector the current losses on the CELSIUS will be considerably lower.

The authors acknowledge the assistance in calculations performed by T.N. Andreeva and in the manufacturing and the assembly of the collector made by V.M. Rybkin.

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