"HOLLOW" CATHODE GUN FOR ELECTRON COOLING PURPOSE

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Abstract

Characteristics of an electron beam, generated by a "hollow" cathode gun in a cusp magnetic field are investigated. Measurements are carried out on a prototype designed in the framework of CRYSTAL Storage Ring Project. Main criteria required to reach a beam quality useful for cooling purpose are established.

1 INTRODUCTION[1]

The efficiency of the well-known electron cooling technique [1] is strictly related to the electron beam parameters. Moreover perturbations due to bending magnets in standard electron cooling devices limit cooler performance.

A prototype of an electron cooler with no bending magnet was proposed and tested [2, 3] in a frame work of CRYSTAL Storage Ring project [4].

At this moment clear criteria required to reach a useful beam for cooling purpose are established.

2 SETUP AND MEASUREMENTS

2.1 Experimental Setup

The setup of the system is represented by fig. 1.

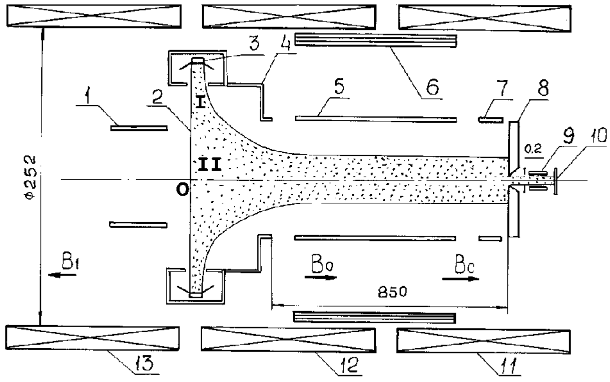

Figure 1: Scheme of the apparatus. 1-gun reflector, 2-beam boundary, 3-cathode, 4-anode, 5-drift tube, 6-steering coils, 7- suppressor, 8-, 9- and 10- analyzer , 11-, 12- and 13- magnets.

Electron beams emitted by a BaO cathode are guided by the cusp magnetic field (generated by two oppositely polarized magnet), accelerated and transported through the drift tube.

The length of the drift section 1 m, while the minimum diameter of the electrodes is 50 mm.

The magnetic system consists of three 0.5 m long solenoids. The homogenous magnetic field in the drift section can be set in the range 0.2- 2 kG. The hollow cathode is located in the symmetry plane of magnetic field. The hollow collector is located outside the solenoids and the magnetic field on its surface can be reduce by a factor 10-100 with respect to B_0.

High care was taken also for the potential distribution, the relative electrical circuitry and water cooling system in order to simplify the high voltage connection [3].

Main parameters of the prototype are given in the table I.

Table I. Design parameters for the prototype.

Electron energy [keV]	1-20
Beam current [A]	0-1
Beam diameter [mm]	30
Magnetic field [kG]	0.2-2
Current losses $\Delta I/I$	$<10^{-4}$
Vacuum [Torr]	10^{-10}

2.2 Measurements

Measurements where performed in two step.

In the first one the apparatus was concerned as a whole. Beam production, collection and vacuum condition were analyzed and optimized.

In the second step the "hollow" collector was replaced by an energy analyzer [5] (fig. 1) for current density and energy distribution measurements. Additional steering coils allow X-Y scanning of the beam across the analyzer surface.

3 RESULTS

Current-voltage characteristic measurements shown hysteresis due to the influence of the drift tube potential. This behavior was corrected by changing the geometry of the electrodes in order to have no influence on the extracted current from the tube potential (fig. 2). The

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measured value was in fair of accuracy with simulation results [3].

Concerning the "hollow" collector, required to allow the ion beam passing through, after a deeply analysis on reflected and lost electrons the relative current losses reached values less than 10^{-4} [3].

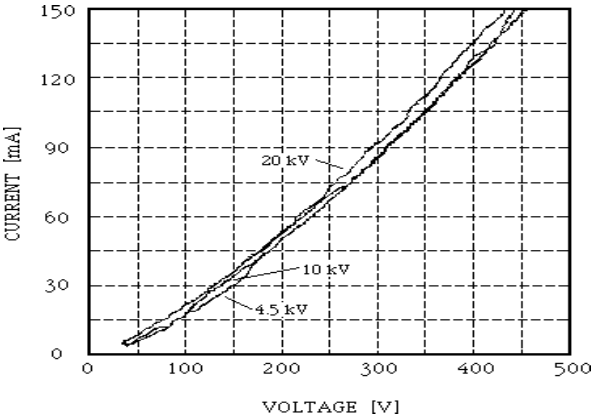

Figure 2: Current-Voltage characteristics of the gun..

In the second step the analysis on a part of the beam, cut by a hole of 0.2 mm, provides more information on the beam quality for different condition and geometry.

The energy analyzer provides measurements on current density and energy distributions. The energy spread δW and the displacement of the maximum of the distribution ΔW are deduced from the energy distribution curves. Measurements are recorded as in fig. 3, on the abscissa the current required to shift the beam from its centered position is presented.

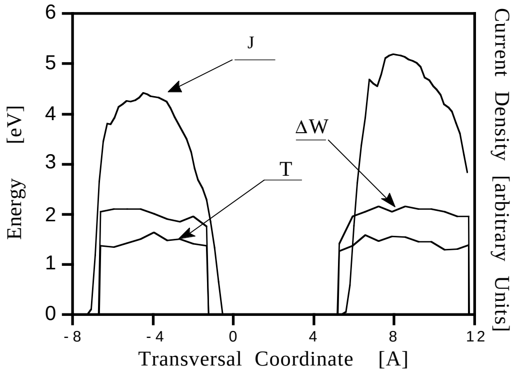

Figure 3: Current density (J), energy spread (δW) and displacement of the maximum of the energy distribution (ΔW) in function of the transverse coordinate of the beam.

Theoretical solution of a beam transformation requires on the point *O* (fig. 1) the condition: $E_0=U_0=0$. In a real gun it is not possible to fulfill this condition, also because the ion beam is traveling along the axis which therefore has to be free of electrodes. Moreover in the vicinity of the point *O* the electron beam experiences violation of adiabaticity condition [3].

The quality of the beam depends on the lowering of the temperature and the hole inside the beam (fig. 3). Useful parameters for the description of the gun results out to be a perveance in the gun section (*I*) P_g and another one in the section where the beam is transformed P_0.(*II*). These parameters are related to the geometry of the electrodes and the extracted current.

The criterion followed is to fulfill the theoretical requirements in the point *O*.

In fig. 4 different measurements of disturbance region D_d were recorded for different values of P_g at different geometry.

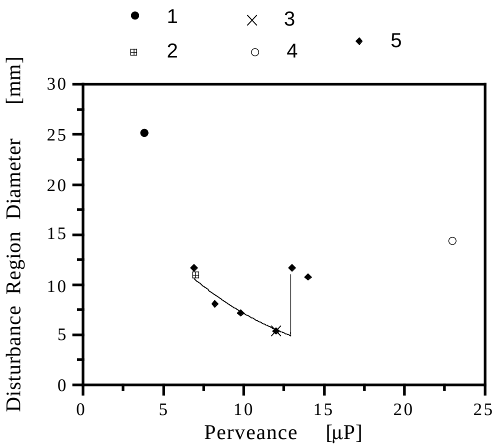

Figure 4: dependence of the disturbance region diameter in function of the perveance. Mark 1-4 in condition of space-charge limit for different P_g [µP]: 1- 3.8, 2- 7, 3-12, 4- 23. Points labeled by 5 indicated a results for a fixed geometry (P_g=14 µP) and beam perveance changed by the cathode saturation current (heater current). B_0= 1 kG, I=100mA.

Increasing the current flowing through the section *II* decreasing of the disturbance region occurs (curve 5 in fig. 4). The potential and the electric field in *O* reach their minimum due to the space-charge. When the current reach a value of I_0 a jump occurs. In this case a virtual cathode, appears (saturation condition $J_{cath}>J_0$), it reflects electrons and as a results the temperature of the beam increases.

Fig. 4 shows requirement of a precise current tuning in order to obtain a small disturbance region.

Moreover consistence between simulations and experiments exists for the $P_g \le P_0$. In saturation condition the analysis of reflected electrons is more complicated.

In addition the state with $P_g > P_0$ can be used if the hole in the beam is created by shifting the magnetic field symmetry plane. It means increasing the radius of the beam hole to be higher than the disturbance region due to the adiabaticity violation. In such a case a dependence of the disturbance region and current on the ratio B_1/B_0 is observed Fig. 5.

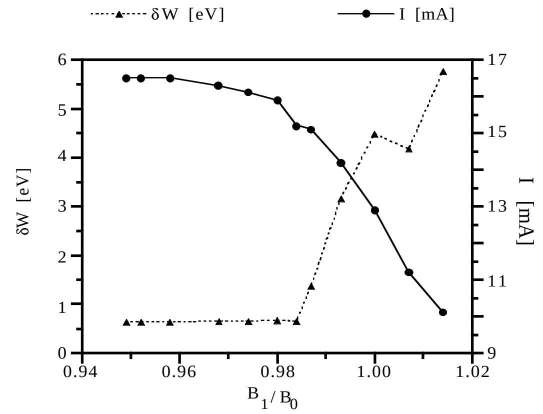

Figure 5: current and energy spread as a function of the ratio B_1/B_0 ratio (i.e. the magnetic field symmetry plane position vs cathode edge).

Increasing the ratio B_1/B_0 we generate a magnetic trap in the vicinity of the point *O* and the state with electron capture is accompanied always by an increasing temperature (fig. 5).

Finally following the given criteria the beam is optimized and it is possible to analyze the temperature of the beam for different extraction current.

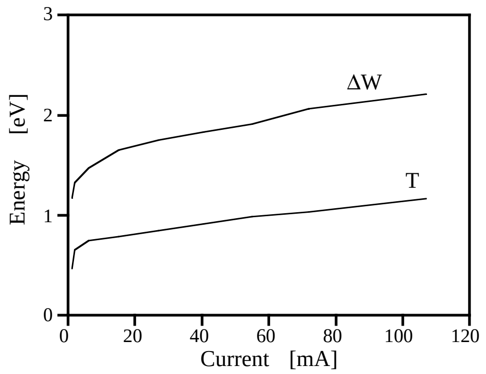

Figure 6: Longitudinal energy spread and shift of the distribution maximum as a function of the beam current.

Fig.6 shows the temperature of the beam as function of current extracted from the gun.

This measurement is in agreement with the measured temperature for standard electron beam [6].

The measurements of beam characteristics show that all problems connected with using this gun in coolers are solved (vacuum, alignment, current density distribution, temperature) [8]. A peculiarity of this gun, the hole in the center of the beam, has been reduced to a diameter less than 10% of the whole beam diameter and in principle can be suppressed.

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