ELECTRON GUN FOR KIEV HEAVY ION STORAGE RING

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1. INTRODUCTION

The ring elaborated in the Institute for Nuclear Research (INR) of the Ukrainian Academy of Sciences (Kiev) will store heavy ions (including neon) and accelerate them up to energy 200 Mev/u. The available cyclotron U-240 will be used as an injector. The main physical parameters of electron cooling system were determined previously [1]. At present paper the requirements to transverse velocity spread of electron beam are considered in more details. The construction of electron gun is determined.

2. REQUIREMENTS TO ELECTRON BEAM

The electron gun immersed into longitudinal magnetic field with B $\geq$ 1 kOe must ensure sufficiently small angle spread and necessary current of the electron beam. Taking in to consideration the space charge of the electron beam one can show that the optimum value of the beam current exists- $I=v_o U\sqrt{2\varepsilon/\beta_e}$. It provides the maximum cooling rate. U is an accelerating voltage in the gun, v_o is a longitudinal electron velocity, β_e is beta-function at the cooling section, ε is an emittance of ion beam. It should be noted that this expression corresponds to a gun with constant perveance since $I \sim U^{3/2}$.

The sufficiently low angle spread of electron beam velocities needed to realize so called adiabatic regime of ion - electron collisions. In this case the electron transverse degrees of freedom are excluded from consideration [2]. This requires the transverse velocity of electron $v_\perp^*$ must be less than $3\div4.10^7$ sm/sec [3]. The damping rate of betatron oscillations decreases rapidly when $v_\perp^*$ is greater than this value. The transverse electron velocity consists of the following values $v_\perp^* = v_T + v_L + v_D$, where $v_D = 2Ic/(rv_oB)$ is the drift electron velocity in crossed external magnetic field and electric field caused by electron beam space charge, c is the light velocity. v_L is the additional electron velocity caused by electron gun optics imperfection. v_T is the termal velocity of electrons emitted by cathode. As a rule, the last value is about $1\text{-}2.10^7$ sm/sec (oxide-coated cathode). Therefore when the electron gun is designed it is necessary to provide the values $v_\perp = v_L + v_D$ at the level of $1\text{-}2.10^7$ sm/sec, so that $v_\perp + v_T = v^*_\perp \leq 3\text{-}4.10^7$ sm/sec.

It should be emphasized that the requirements to quality of the electron beam are connected with $v_\perp$ namely. Nevertheless for some purposes it is more convenient to use the angle spread of the electron beam $\alpha = v_\perp/v_o$. Since longitudinal electron velocity and ion velocity must be equal at the cooling section, the desirable value of α_g is depended on the energy and mass of injected ions. Minimum possible value of angle spread is determined by the electron beam current $\alpha_m \simeq v_d/v_o$. The calculated values of I, α_g, and α_m for our case are presented in Table 1.

Table 1

W_i is an injected ion energy, W_e is an electron beam energy.

Radius of electron beam r = 1.5 sm [1]

ion	p^+;$^3He^{2+}$	N^{4+}	C^{3+};O^{4+};Ne^{5+}
W_i (MeV/u)	50	10	5,5
W_e (KeV)	26	5,4	3
I (A)	1,9	0,19	0,08
α_g (mrad)	2,2	4,6	6,1
α_m (mrad)	2,6	1,2	0,9

3. ELECTRON GUN

The main problem in electron gun design is the scattering action of the anode hole caused by the relatively high value of the transverse electric field E_r . The calculations show that in our case the classical Pierce gun gives the following velocity angle spread : $\alpha \simeq 2.4$ mrad for W_o = 3 keV; $\alpha \simeq 17$ mrad for W_o = 26 keV; $\alpha \simeq 60$ mrad for W_o = 110 keV, i.e. α exceeds necessary values almost in order of magnitude in the range of $W_o \simeq 10-100$ keV. For computer simulation we use the SAM program [4]. Here and later we assume that the gun is immersed into longitudinal magnetic field with B = 1 kOe.

The guns with "quasiresonant" and "smooth" optics are used to overcome this difficulty. The first gun type has an essential disadvantage - resonance condition is fulfilled in the narrow region of beam current [5]. Moreover, in our case the electron energy is varied from 3 to 110 keV, so the Larmor spiral step changes from 1 to 7 sm. That requires to use very complicated system of electrodes.

In "smooth" optics one try to increase the axial region length Δ with $E_r \neq 0$, since $E_r \sim 1/\Delta$ [6]. That may be done in several ways [5-7]. First of all, it is possible to use the multi-electrode gun. The first electrode is placed so close to the cathode when the beam current distribution is almost homogeneous yet. One apply to this electrode potential, enough to obtain the needed electron current density. Its magnitude is about several kV, what provides relatively low values of E_r. Further beam accelerating rate, determined by voltage on the next electrodes and their position, is to a some extent arbitrary. That allows to increase the value Δ and decrease E_r essentially. The calculations show that such gun gives velocity angle spread of the electron beam presented in table 2.

Table 2

W_o (keV)	3	14	26	50	100
α (mrad	0,9	2,0	2,8	3,5	6,3

One can see that the obtained values of $\alpha < \alpha_g$ and are closed to the minimum possible value of α_m .

It is noted in [7], that the same

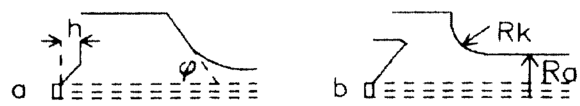

Fig 1. Schemes of the electron guns with different geometry.

result may be obtained by using more simple gun depicted on fig.1a. However physical aspects of such gun design were not considered in details. So we carry out the calculations with results presented below.

In order to solve the problem, it seems to be most expedient to consider the angle spread transformation beginning from the Pierce optics. For these purposes gun geometry depicted on fig.1b has bean chosen. The angle spread dependence on the anode hole radius R_a is shown in fig 2. One can see, that α decreases in 7 times approximately with changing R_a from 1.6 to 3 sm and then is practically constant. Simultaneously the beam current decreases insignificantly. The same effect may be obtained by increasing of the anode electrode curvature radius R_k up to value ~ 4-5 sm ($R_a \simeq 2$ sm). Such dependencies are not in agreement with model, considering the anode hole as a thin lens with focus length $f \sim -6\ _a$. The latter predicts smooth and weak dependence α on R_a. Therefore let consider the electron motion in the gun. Radial distributions of the electric field for R_a=2;4 sm are shown in the computer results on fig.3. In the first case E_r looks like a sharp peak with half-width $\Delta < \lambda_e$, and in the second case - as a smooth curve with Δ

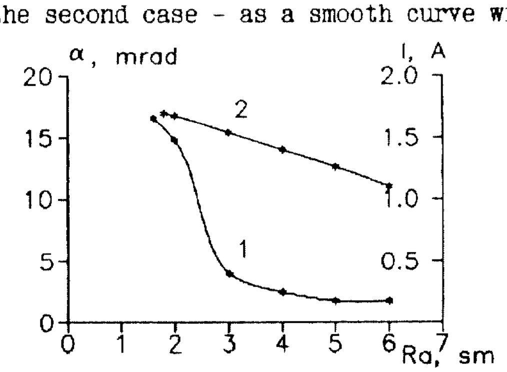

Fig 2. The velocity angle spread (1) and electron beam current (2) vs the anode hole radius

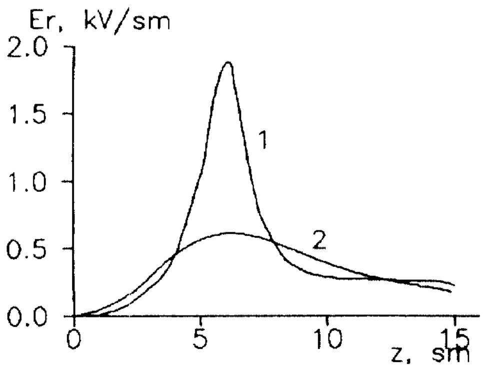

Fig 3. Axial distribution of the electric field on the electron beam edge. The radii of the anode hole of 2 and 4 sm correspond to curves 1,2.

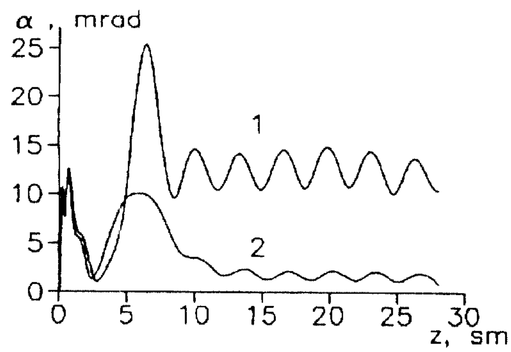

Fig 4. The variation of the electron beamangle spread along the system. The radii of the anode hole of 2 and 4 sm correspond to curves 1,2.

$\simeq 2\text{-}3\lambda_o$. The electron moving in such field gets a strong lateral blow when $R_a \simeq 2$ sm (see fig.4). For $R_a \geq 4$ sm α is in time to relax up to nearly zero values since $\Delta > \lambda_o$. Observed effect may be easy explained by the fact that anode hole has a sharp edge. E_r increases rapidly near this edge giving in the limit infinitely high and sharp peak. Increasing R_a or R_k we move away this region from the beam edge and smooth out the radial electric field distribution. The calculations show that for practically complete suppression of the anode hole scattering action it is enough to have $R_k \cong 2\lambda_m$, where λ_m is maximum possible Larmor spiral step of the electron.

The calculated values of the beam angle spread for gun with $R_a \cong 2$ sm, $R_k \cong 6$ sm are presented in the Table 3.One can see that values of α are closed to the corresponding magnitudes for multi-electrode gun (Table 2) and satisfy conditions $\alpha_m \leq \alpha < \alpha_g$.

Table 3

W_e (keV)	3	5,4	14	26	50	100
α (mrad)	0,9	1,2	1,9	2,8	4,1	7,8

4. CONCLUSIONS

The results can be summarized as follows:

1) scattering action of the anode hole is caused mainly by sharp edge of the hole, where the electric field increases rapidly. An electron interaction with such field has the resonance character when half-width of E_r peak becomes less then a step of larmor spiral. The suppression of this effect may be achieved by increasing both the radius of the anode curvature and the hole diameter;

2) the multi-electrode guns with both "quasiresonant" and "smooth" optics has no advantage over the diode gun at least in our case and leads to technical complication only.

5. REFERENCES

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