ELECTRON GUN WITH VARIABLE BEAM PROFILE FOR COSY COOLER

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Abstract

Electron gun with variable beam profile is used on COSY 2 MeV cooler to optimize the cooling process. Further development of the gun is achieved with the help of the four-sector control electrode that provides some new features. Combined with BPMs it gives the possibility of the electron beam shape estimation. Application of the gun for stochastic cooling is also discussed in the article.

INTRODUCTION

The electron gun design is based on the slightly changed gun previously used for CSRe,CSRm [1] and LEIR coolers. The only difference is the four-sector control electrode (fig.1) with separate feeding of all sectors via additional feedthroughs. This small change, nevertheless, opens a new possibility for non-axially modulation of the electron beam profile, which could be used in some applications. Combined with BPMs this feature of the gun provides beam shape monitoring when it passes transport channels.

One more perspective is to use the gun as 3D kicker.

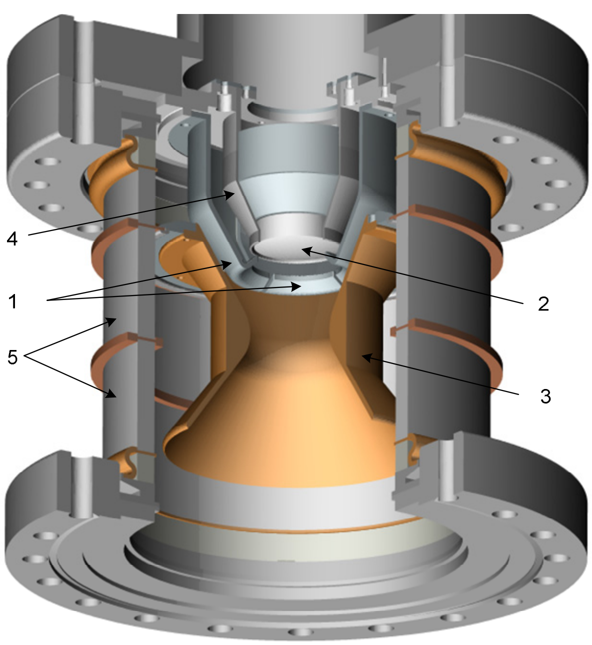

Fig.1 The sketch of the electron gun for COSY 2 MeV cooler.

1 – four-sector control electrode, 2 – oxide cathode, 3 – anode, 4 – cathode housing, 5 – ceramics.

Since the electron gun of the COSY cooler is embedded in longitudinal magnetic field, its characteristics depend on field strength. Emissive ability of oxide cathode (2) is about 0.5 A/cm^2, so the maximum possible current is about 3A for 29 mm cathode diameter. Another important characteristic of the gun is the electron transverse temperature, which entirely determines cooling process. One of the tasks for cooler's electron guns design is keeping the transverse temperature as low as possible. On the other hand the electron current density should be increased to provide high efficiency of electron cooling at high energies. Following results of simulations (fig.2), made with UltraSAM code [3], specify the electron beam parameters depending on anode voltage and magnetic field strength.

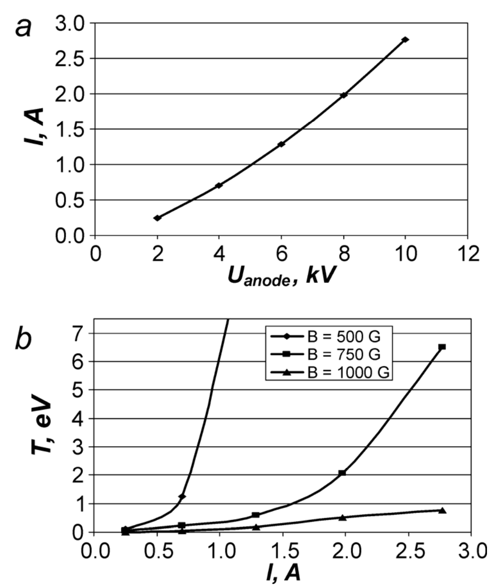

Fig 2: Current (a) and transversal temperature (b) of homogeneous electron beam.

With the current increase the transversal temperature grows also (Fig. 2b). For COSY cooler electron gun 3A current is achievable with few electron-volts transverse temperature at 600 G longitudinal magnetic field and about 10kV anode voltage.

BEAM PROFILE SIMULATIONS AND MEASUREMENTS

Specification of the electron gun characteristics is very important for further electron cooler operation. Every time when a design of the gun is changed it should be tested before installation on the cooler. For this purpose special test bench was constructed at BINP to perform all required measurements. Following are current-voltage characteristics of the gun with four-sector control electrode. As it was mentioned above, optics of this gun is similar to previous ones [2], those also provides variable beam profile.

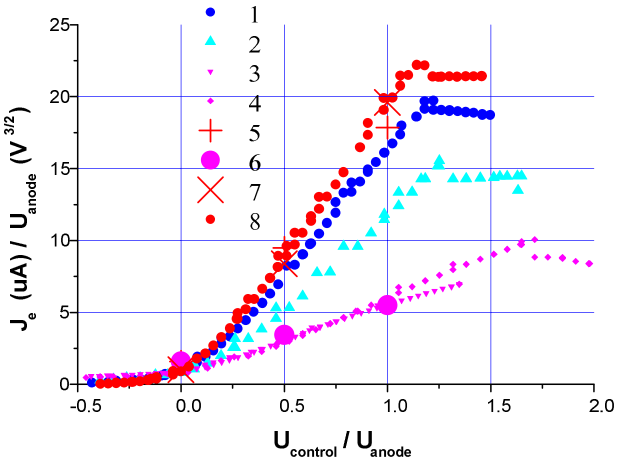

Fig.3. Current-voltage characteristics (perveance) of the gun: 8 – all sectors connected to $U_{control}$, 1 –one sector connected to U_0, 2 – two sectors connected to cathode, 3,4 – three sectors connected to cathode (3 – U_{anode}=500 V, 4 – U_{anode}=300 V. 5,6 – simulations with 3D model, 7 – simulations with 2D axially symmetrical code [3].

Red cycles show data when all four sectors are connected to $U_{control}$ power supply, blue points – when one sector from four is connected to cathode, triangles up – two sectors from four are connected to cathode potential. Triangles down and diamonds show measurement results when three sectors form four are connected to cathode (for 500 V and 300 V applied to anode).

As one can see, results of the measurements and simulations are in a good agreement.

Another important thing is definition of a correspondence between the electron beam profile and voltages applied to the gun electrodes.

Simulations of beam profiles for the new version of the gun were made with 3D model as well as 2D axial code [3].

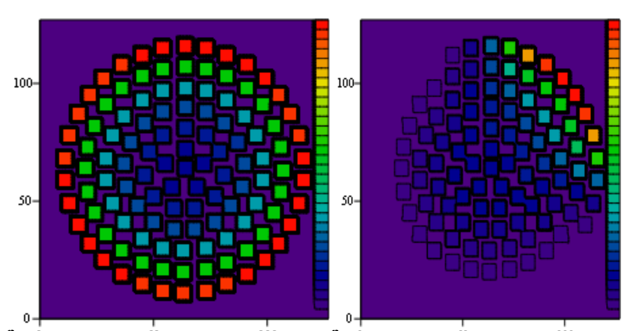

Fig.4. 3D simulation of the electron beam profile for DC current: four sectors on the left, one sector on the right.

Following parameters were chosen for the simulation of the beam profile shown in fig. 4: $U_{control}$=500V, U_{anode}=1000V. The electron current obtained in this case was 0.3 A and gun microperveance was calculated as 9.5 uA/$^{V3/2}$.

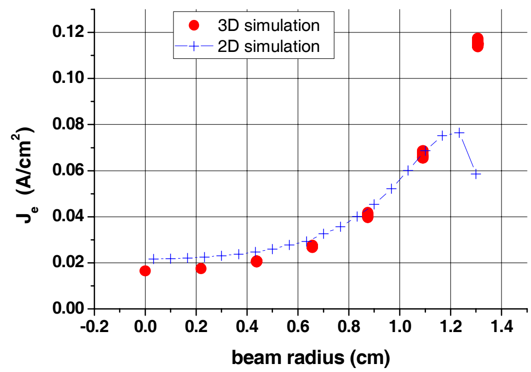

Fig.5. Radial profiles of the electron beam for 3D model (red points), and 2D code simulation.

Difference between two approaches of simulation is shown in fig.5. Results are similar for the main part and rather different for the beam edge. This effect results from lack of accuracy for both methods in area where electron current distribution increases sharply.

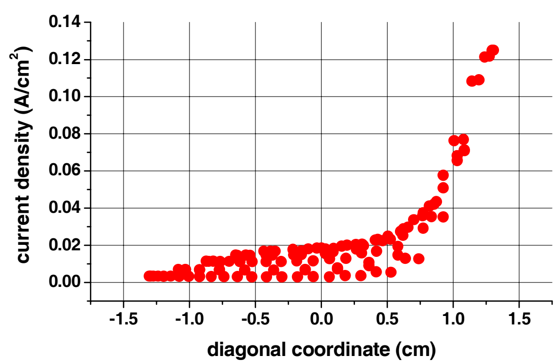

Fig 6. The profile calculation for $U_{control}$=500 appied to one sector when all other three sectors have the cathode potential.

The electron gun has the perveance which corresponds to simulations made with 2D and 3D codes. It means that predicted profile, based on simulations, corresponds to real electron beam profile.

ELECTRON GUN AS A PART OF BEAM DIAGNOSTIC

For beam diagnostic purposes the suggestion was made to reject axial symmetry and to divide control electrode into 4 segments. The position of the beam center as well as beam sizes can be measured by applying small potential variation on one of these segments. Beam current modulation decreases at high frequencies of potential oscillation, thereby to realize this technique the cutoff frequency must be found. The calculation results shown in fig. 7 give 200 Mhz cutoff frequency for this type of the gun.

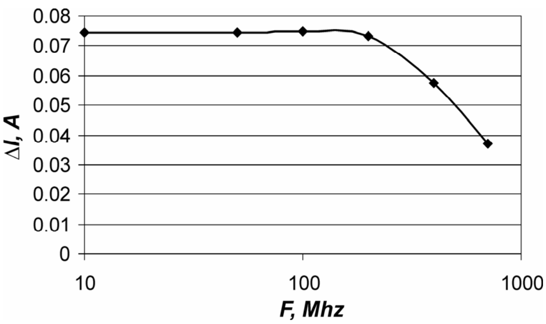

Fig. 7: Electron beam current modulation at oscillation of the control electrode potential (ΔU= 50 V, U=600 V).

To estimate how the of the modulation influences upon beam profile following model was taken. Gun operates in DC mode and small oscillation is applied to one of the segments of the control electrode (±5V). Results of simulations are shown in figures 8 and 9. On both pictures DC mode is on the left and AC current resulted from modulation in the right (DC current is subtracted).

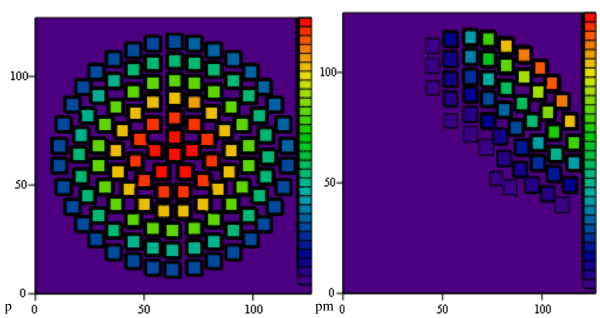

Fig 8. The DC electron beam profile for $U_{control}$=0 and j_{max}=19 mA/cm^2 on the left and AC part with electron beam density 1.4 mA/cm^{2}in the right. U_{anode} 1000V.

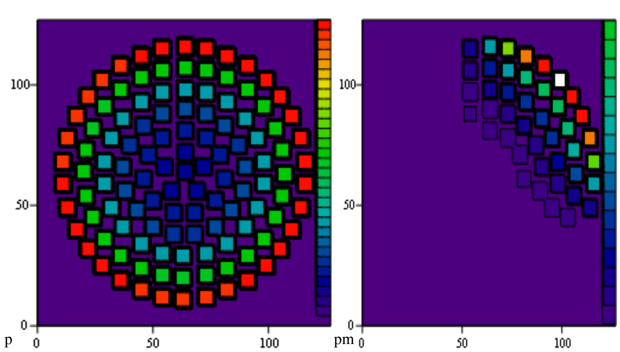

Fig. 9. Profile of the electron beam DC part on the left and AC part on the right for $U_{control}$=500 V, U_{anode} 1000V.

For the regime represented in fig.8 the integrated current is 50 mA for whole beam and 0.97 mA for the contribution due to modulation. This corresponds to 1cm shift of the beam center of mass from its axis. On the other hand when the DC part of the electron current is 301 mA the AC is only 1.3 mA (fig. 9) that corresponds to the radial shift of 1.2 cm.

While the DC current was changed by six times the AC part and correspondent shift varied slightly (change is about 20%). We can conclude that the beam shift dependence on the gun operation regime is sufficiently weak. This provides us a possibility to monitor the electron beam shape during the cooler operation. The AC current of the beam can be detected with BPMs installed along the transport channels and consequently the beam shift can be measured.

THE ELECTRON GUN FOR STOCHASTIC COOLING

The idea of combining electron and stochastic cooling in one device was discussed in COOL 07 workshop [4]. The amplified signal of the ion displacement of from pick-up electrode applied to the control electrode of the electron gun. Thus, a wave of the space charge in the electron beam is induced. This wave propagates with the electron beam to the cooling section. The space charge of the electron beam acts on the ion beam producing a kick. The effectiveness of the amplification can be improved with using a structure similar to a travelling-wave tube.

The use of the electron cooler as kicker in the middle range of the energy (0.1 ÷ 1 GeV/u) may have the following advantages: one device providing 3D kick at the same time; velocity matching of kicking impulse with ion in the wide range; free aperture; using of the existing device; frequency bandwidth may be very high; such type of the kicker doesn't restrict the frequency bandwidth at low value of ion velocity when the time-flight factor becomes the essential [4].

The method, described above, presupposes longitudinal and transversal impacts arisen from electron and ion beams interaction. For longitudinal action the electron beam has axial symmetry. On the other part there is no axial symmetry for the transversal one. Pulse voltage, applied to one of the control electrode sectors, produces transversal kick. Combination of positive and negative pulses gives an opportunity to obtain different types of the influence to the ion beam. Thereby, having four-sector control, one can vary the kick direction (3D kick) as well as its form (dipole, quadrupole).

SUMMARY

We are looking forward for 2MeV COSY cooler commissioning to start the experiments of cooling at high energies with variable electron beam profile and, as a next stage, for experiments of electron and proton beams interaction when the first one has pulse mode.

ACKNOWLEDGMENT

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