3D SIMULATIONS OF A NON-AXISYMMETRIC HIGH AVERAGE CURRENT DC PHOTOCATHODE ELECTRON GUN

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Abstract

At high average currents, GaAs photocathode based electron guns are limited by the short operational lifetime of the photocathodes. One method to improve the cathode lifetime is to situate the photocathode off-axis to reduce the flow of ions back-bombarding the emitting surface. The results of 3D electrostatic and beam dynamic simulations are presented to demonstrate the feasibility of this scheme and the resultant beam quality achievable.

INTRODUCTION

High voltage DC electron guns based on GaAs photocathodes are used and proposed for a number of machines around the world, particularly energy recovery linac based light sources and free electron lasers. DC guns offer significant advantages over RF guns when high average currents and CW operation is required. However, maintaining high quantum efficiency of the photocathodes over a long lifetime limits their performance. In modern extra high vacuum guns, GaAs photocathodes have shown no measurable loss in quantum efficiency after exposure to vacuum for several months when no voltage is applied [1]. This suggests that ion back bombardment is the principal cause of photocathode degradation. When the gun is in operation, ions are produced by collision of the electron beam with residual gases and accelerated directly back towards the cathode. These ions acquire a large acceleration but little transverse displacement. Therefore, citing the photocathode off-centre should result in fewer ions striking the photocathode surface, thus increasing the photocathode lifetime. One method currently in use is to direct the drive laser off-centre on the photocathode [2]. When designing a new gun, two further options present themselves - situating the photocathode off-centre on the cathode ball, or situating the whole cathode ball off-axis. Both options are explored here in connection to the forthcoming upgrade to the ALICE (formerly ERLP) electron gun at Daresbury Laboratory [3].

CATHODE BALL DESIGN

This upgrade features a preparation facility for GaAs photocathodes with an emission surface diameter of 10 mm, which will be side-loaded into the cathode ball without breaking the vacuum. The change from rear to side-loading of the photocathode necessitates a redesign of the cathode ball. CST Studio [4] was used to simulate the electrostatic fields of the gun chamber, with fields of less than 10 MV/m present at the 450 kV required for conditioning of the gun. The ball requires a slot in the side for loading of the photocathode. This has been positioned on the cylindrical part of the ball surface to keep the field distortion low. However, the photocathode has to be moved forward into position, requiring a second slot in the cathode ball for insertion of a magnetic screwdriver to drive the winding mechanism.

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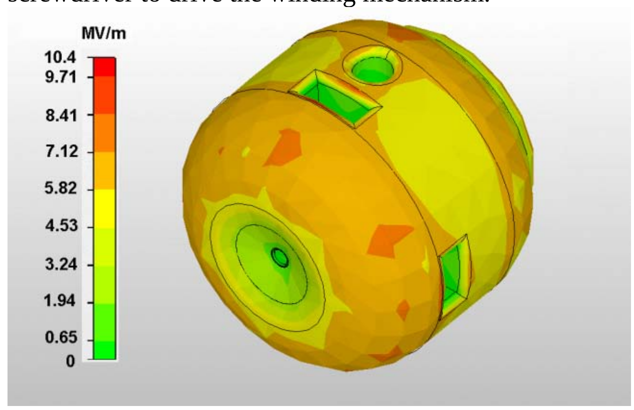

Figure 1: Electrostatic simulation of the cathode ball at 450 kV. A view hole has been added perpendicular to the photocathode loading slot to show that is it possible, if necessary, to include one.

The gun features a 20° focusing angle and will operate at a nominal voltage of 350 kV with a 77 pC bunch of electrons. The following beam dynamic simulations all feature a 4 mm diameter beam with a flat top spatial distribution and a 20 ps flat temporal distribution.

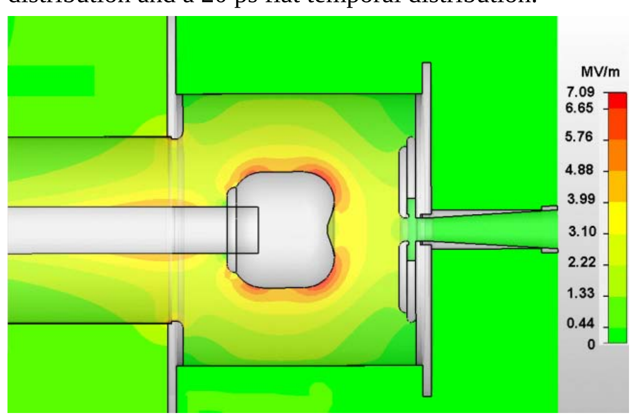

Figure 2: The electric fields in the gun chamber.

OFFSET CATHODE BALL

The cathode ball shown in figures 1 and 2 was modelled without the slots and then moved vertically by 5 and 10 mm. 3D field distributions from the gun were exported from CST and used as input for the GPT code [5] which was used for particle tracking with space charge in 3D. 10,000 macroparticles were used for the simulations. The electrons were tracked up to a distance of 1 m from the cathode.

GPT was also used to compare 3D, 2D and 1D fields from CST with 2D and 1D fields from POISSON [6] for the existing ALICE gun - a copy of the JLab IR-FEL gun [7]. This gun is completely symmetric and features no electrode focussing. The results were found to match each other to within a few percent. The 1D fields were also used as input for the ASTRA code [8], and the results matched those from GPT to within a few percent again.

Figure 3 shows the beam trajectories from the offset ball simulations. As can be seen, the final beam size does not vary a great deal. Of concern for large offsets is that of the beam being close to the apertures of the system, the smallest being of radius 19 mm. A solenoid was added, as in the ALICE beamline, centred at 0.25 m with a peak field strength of 320 G. Corrector coils within the solenoid can be used to steer the offset beams back on-axis. These have yet to be simulated.

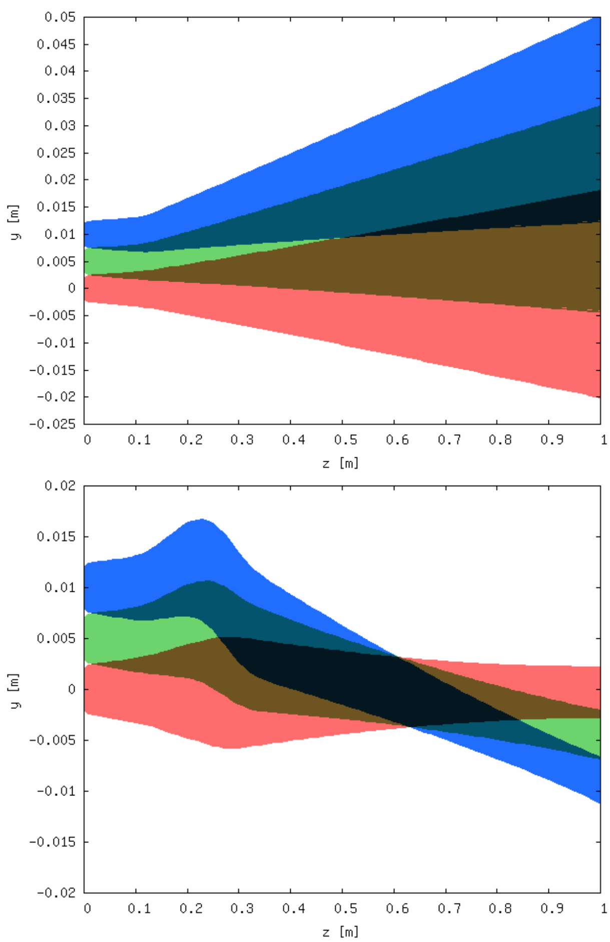

Figure 3: Beam trajectories for on-axis (red) and displaced by 5 mm (green) and 10 mm (blue) cathode balls for just the gun (top) and with the solenoid (bottom).

Figure 4 shows the evolution of the emittance with and without the solenoid. The emittance was calculated using the hypervolume in *x-x'-y-y'* space to account for the fact that the electrostatic fields in the *x* and *y* planes are different due to the offsets and that the solenoid introduces coupling between them.

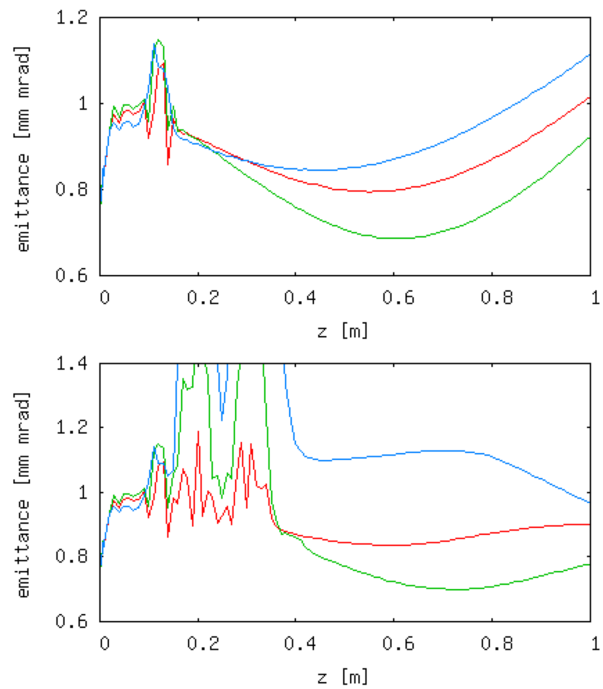

Figure 4: Evolution of emittance for the on-axis case (red) and with the cathode ball offset by 5 mm (green) and 10 mm (blue) for just the gun (top) and with solenoid (bottom).

OFFSET PHOTOCATHODE

An alternative to moving the entire cathode ball off-axis is to situate the photocathode off-axis on the cathode ball. The same electron gun design as above was used for the simulations, however, with the flat emitting surface of the cathode ball enlarged to a radius of 20 mm to enable the photocathode to be tested in various positions off-axis. To provide similar electrode focussing to the previous case, the flat emitting surface has been retracted just over 25 mm from the edge of the cathode ball to increase the electrode angle to 45°, as shown in figure 5.

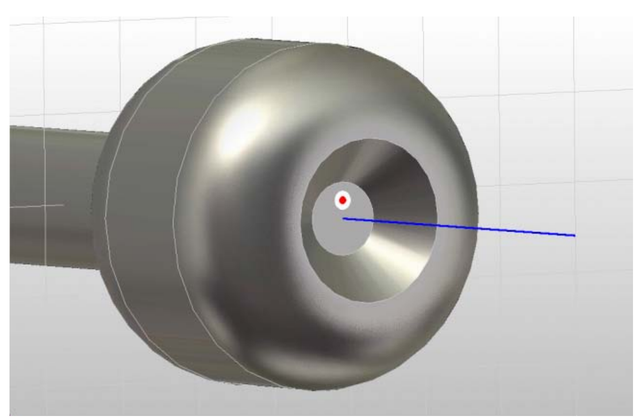

Figure 5: the cathode ball used for offset photocathode simulations. The white circle represents a photocathode 10 mm off-axis, with the red circle the intended placement of a 4 mm diameter laser spot. The blue line represents the axis of the system.

Beam dynamic simulations were then carried out in GPT as before, for the on-axis case, and with the photocathode located 5 mm and 10 mm off-axis. Figure 6 shows the normalised emittance evolution and figures 7 and 8 the beam trajectories, with and without a solenoid of strength 300 G at 0.25 m. The main difference compared to offsetting the cathode ball is that the offset beams in this case are deflected transversely due to the proximity to one side of the focussing electrode. However, the beams can be steered back on-axis by means of corrector coils.

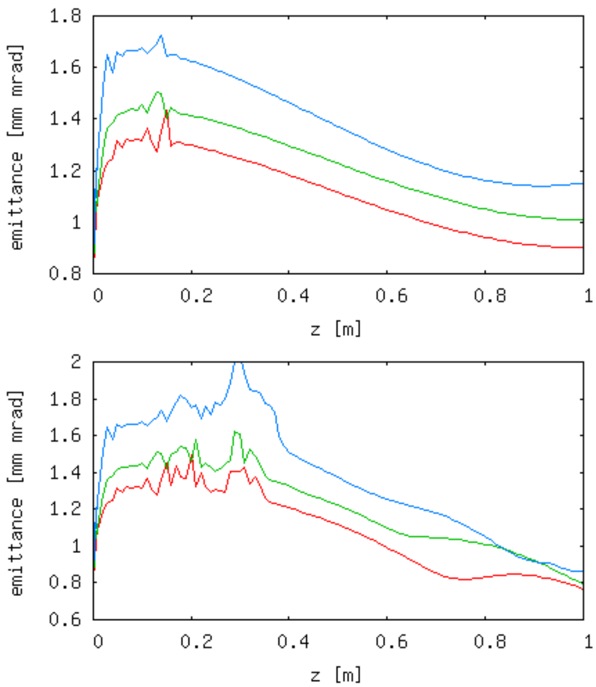

Figure 6: Evolution of emittance for the on-axis case (red) and with the photocathode offset by 5 mm (green) and 10 mm (blue), for just the gun (top) and with the solenoid (bottom).

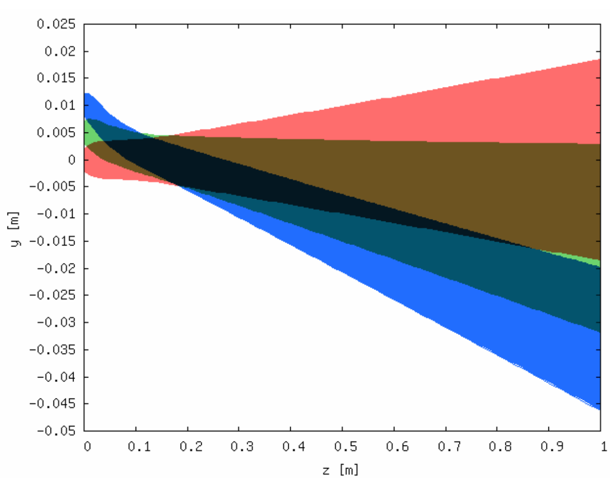

Figure 7: Beam trajectories for on-axis (red) and offset photocathodes by 5 mm (green) and 10 mm (blue) without a solenoid.

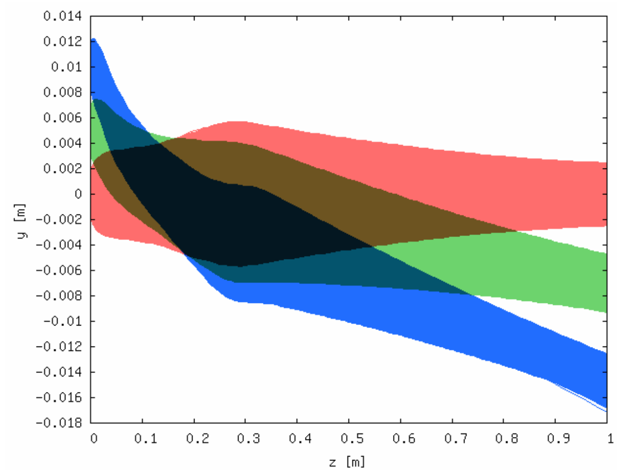

Figure 8: Beam trajectories for on-axis (red) and offset photocathodes by 5 mm (green) and 10 mm (blue) including a solenoid at 0.25 m.

SUMMARY

Simulations show that it is possible to provide a sub π·mm·mrad electron beam from a DC gun with either the cathode ball offset from the axis or the photocathode offset on the cathode ball. Beam waists can be produced in the same places with the same beam sizes and little loss in beam quality.

However, for the offset cathode ball, the beam moves parallel to the optical axis of the system and the ions generated by the beam are accelerated back and hit the photocathode at its emitting part exactly as in the case of the axially symmetric gun. The beam produced by an offset photocathode is immediately deflected by radial electric fields, and the ions are generated closer to the gun axis. After back acceleration the ions hit the central part of the cathode surface away from the emission spot.

Further simulations are required of the photocathode offset and the cathode ball shape, together with the ion dynamics in order to minimise the overlap of the emitting spot and ion beam on the cathode surface, and keep the electron beam quality within the ALICE specifications.

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