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PRELIMINARY RESULTS OF THE DARK CURRENT MODELLING FOR THE POLFEL SUPERCONDUCTING LEAD PHOTOCATHODE

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Abstract

Preparation for the construction of the Polish Free Electron Laser (POLFEL) has been launched at NCBJ. POLFEL is a 4th generation light source driven by a continuous wave or long pulse operating superconducting electron accelerator. The concept includes all-superconducting injector, with a thin-film lead superconducting photocathode, dedicated for generation of low-current (~25 µA), low-emittance beam.

One of the issues which emerges in connection with operation of high gradient electron guns furnished with dismountable photocathode plugs is the dark current (DC) emitted from the cathode plug edges and surface inhomogeneities, which degrade the accelerator performance.

The purpose of this paper is to present an approach to dark current investigation and the preliminary results obtained. Specific features of the geometric configuration like rounded plug edges, a gap between the plug and back wall as well as surface roughness have been taken into account for the electron emission and RF field calculations.

THz SOURCE

The POLFEL will consists of a linear accelerator that will delivers 30 MeV (100 MeV in the second step) electron beam, used to emit a THz-IR ranged electromagnetic radiation in plane, variable gap undulator.

The construction of the first Polish FEL is planned for 3 years. The POLFEL will be used in two parallel experimental end-stations that will foster major advances from materials studies such as diffraction imaging with spatial and temporal resolution, spectral investigations of photoionized plasmas by direct or multiphoton ionization of molecules.

DARK CURRENT

One of the main problems of a dismountable photocathode plug is dark current. Incoherently propagating electrons may collide with photocurrent beam, load the cryogenic system, may cause activation or damage of accelerator components and induce cavity quenches. Moreover, dark current caused by field emission limits lifetime of photocathodes.

The main dark current sources of the RF gun cavity are:

- the photocathode plug,
- the cavity backplane close to the cathode,
- the irises because of the strong surface field.

The dark current is preferably emitted from the rough fragments of arc deposited lead layer, and from the plug bends. The intensity of dark current depends on the cavity and photocathode surface finishing.

There are developed dark current reduction methods:

- Suppressing field emission by improved surface preparation.
- Lowering RF gradient at the cathode.
- Applying a collimator.

The main topic of this publication is modeling of surface roughness and it influence of the DC generation. Special attention was paid for RF field calculation, taking into account specific features of the geometric configuration like rounded plug edges, a gap between the plug and back wall as well as surface roughness.

At the FLASH [1] injector, the normal conducting RF gun operated at the nominal gradient of 40–44 MV/m, produces a steady DC electron flux of 200–300 µA as measured with a Faraday cup near the exit of the gun structure. The dark current rises exponentially, regards to the max RF field at the cathode (see Fig.1).

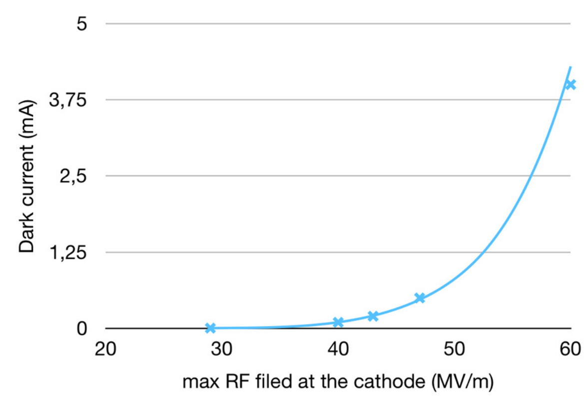

Figure 1: Relationship of dark current to RF field.

CALCULATION METHOD

The main part of calculation was performed using: Astra (A Space Charge Tracking Algorithm) [2] and FEM [3] codes. The FEM uses finite element approximation based on the mesh optimised to map curvilinear boundary of gun resonator. It was used to calculate the RF field in the cavities. For the particles tracking simulation, the Astra program was used.

RESULTS

Work was performed in following steps. Firstly, the RF field distribution with the FEM program, was calculated inside the gun cavities, with the flat back wall surface. Fig. 2 and 3. The programme calculates two-dimensional field distribution assuming cylindrical symmetry relative to the longitudinal z axis.

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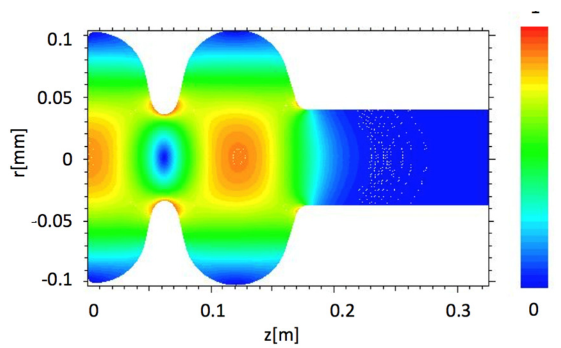

Figure 2: Simulated magnitude of the electric field in the e-gun cavities.

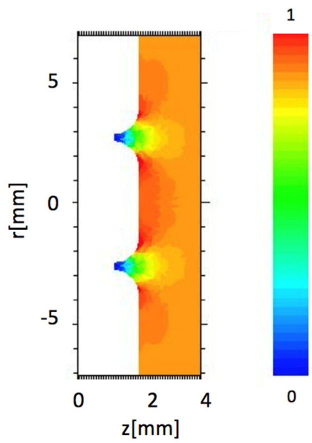

Figure 3: Magnitude of the electric field in the vicinity of the cathode plug.

In the second step, the RF field near the bumps –representing roughness and potential dark current emitters of 50 and 30 µm radii, was modelled. To keep accuracy of the result and overcome program limit in the number of nodes, only selected part of the cavity was simulated. For an optimal FEM mesh density, resonator transverse dimension was matched to various bump sizes. Fig. 4 presents mesh of photocathode surface, bump in the middle, with 50 µm radius and two rings with 30 µm elevation.

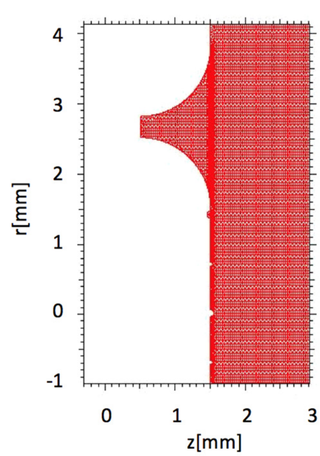

Figure 4: Mesh of photocathode in FEM program.

The results of the calculation show that the electric field is the most enhanced on the arches and on the top of the bumps, as shown in Fig. 5. It was also observed that reduction of the bump dimension reduces field perturbation in the cavity.

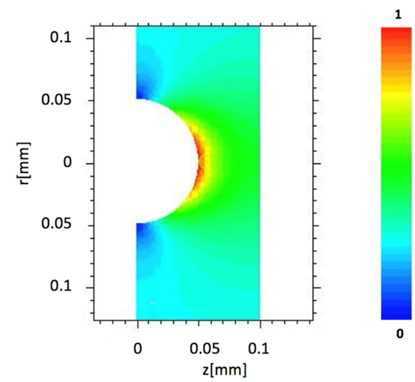

Figure 5: Normalized contour of electric field amplitude in POLFEL gun on the 50 µm bump.

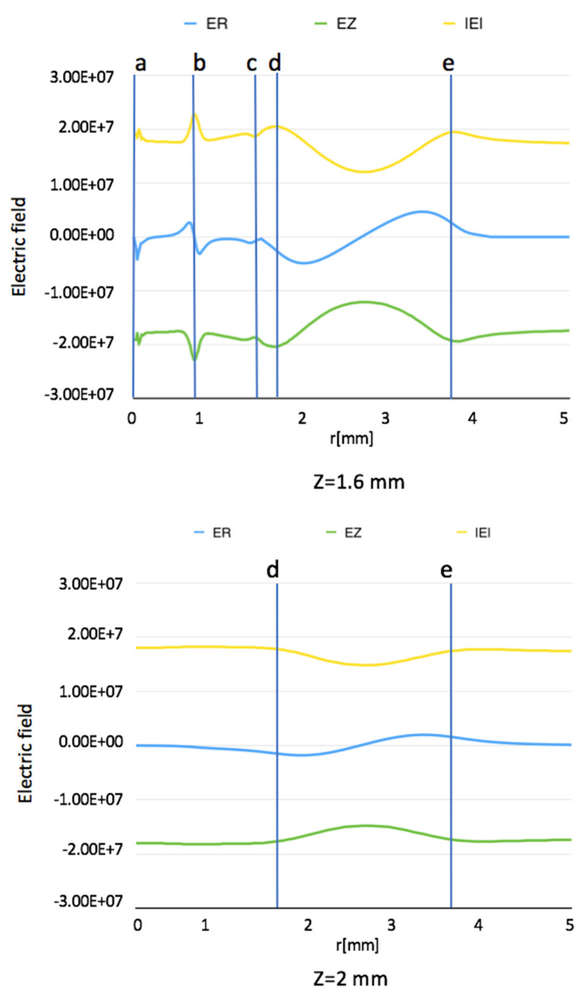

Figure 6: Electric field on the r-axis for different planes in the z-axis: z = 1.6 mm (upper plot) and z = 2 mm (lower plot). Individual points represent roughness on the surface: a) 50-µm bump, b) 30-µm bump, c) 30-µm bump, d) and e) the photocathode RF gun arc.

Based on the FEM simulation, the dependence of the electric field on r-axis was determine for different planes in the z direction. It can be seen on the plot in Fig. 6, which presents the electric field at $z = 1.6$ mm and $z = 2$ mm plain in the r-axis. The electric field disturbance, caused by the surface roughness, is negligible at the distance of 0.5 mm from the surface. In Ref. [1], the dark current onset is for the field $E > 30$ MV/m, (Fig. 1) which is 75% of the gradient specified for the superconducting cathode. Gun operation frequency is 1.3 GHz, therefore wave period is 770 ps, which means that the dark current is generated for 152 ps in every cycle.

In the next step, a special script in the R-language was written to reflect the shape and roughness of the photocathode, with the DC emitters on the surface Fig. 7. The script file was used as input file for Astra. Based on the RF-field simulations, the areas with the local maximum RF field were assumed as the most probably locations of the dark current generation. Electric field input parameters used in Astra simulator are presented in Table 1.

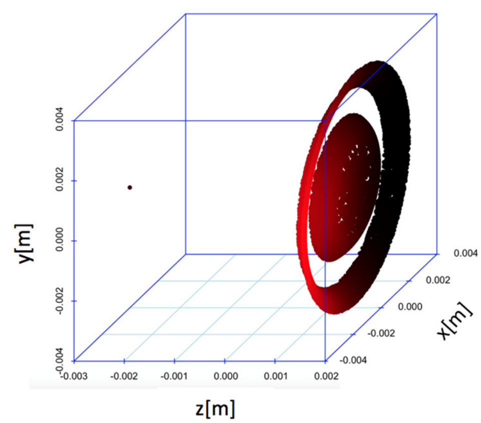

Figure 7: Visualization of DC emitters on the cathode implemented in R-language.

In the Astra simulation, the rounded plugs of the cathode with the flat surface were modeled. Roughness on the cathode surface will be implemented in the further work.

Dark current is generated unevenly during time interval, from the cathode arcs -where the electric field is the largest. Generated electrons have a delay in time and space in the z direction. During acceleration, the bunch of electrons is not coherent, as illustrated in Figure 8. It can be seen that the dark-current distribution is getting spread about 10 cm.

Table 1: Cavity Field in Astra Simulation

Frequency	1.30	GHz
Maximum gradient	40.00	MV/m

Table 2: Particle Statistic in Astra Simulation

Total number of particles on stack	21000	
Active Particle	89.56	%
Backward traveling particles	0.14	%
Particle lost on aperture	10.30	%

Particle statistics is displayed in Table 2. 89.56% particles (black points) contribute to the DC propagating along the linac, 10.3% of total number of electrons are lost on aperture (red points) and 0.14% of electrons are traveling back-ward to the photocathode (blue points).

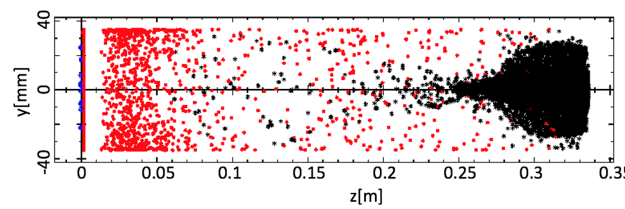

Figure 8: The Astra result.

CONCLUSION

In this paper, the preliminary DC modelling results were presented. Specific features of the geometric configuration like rounded plug edges, a gap between the plug and back wall as well as surface roughness have been taken into account for the electron emission and RF field calculations. The modelling confirms that surface roughness has significant influence on the local RF field. It was proven that local change of the RF field affects the generation of dark current which is distributed in time as space, disturbing the accelerating field.

The subsequent works will focus on the dark current generation depending on the RF field phase and more detailed calculations.

ACKNOWLEDGEMENT

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REFERENCES

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