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HIGH DC INJECTION VOLTAGE PHOTOCATHODE E-BEAM SOURCES

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Abstract

Laser switched photocathode sources are typically used to produce trains of polarized electron bunches for high performance accelerators. This paper considers two high brightness, high charge-per-bunch, e-beam injector approaches that utilize laser gated cathodes followed by DC beam acceleration sections comprised of 1-3 grading electrodes. The use of grading electrodes provides reliable high voltage standoff between the plates themselves and ground. In the rectilinear beam source case in particular, we found that the uniformity of the emitted current density can have a major effect on final beam emittance and brightness.

CONVERGENT BEAM

The first approach is based upon one of the thermionic sources in [1, 2] for use in 1 THz high-power FELs. A plot of this source is shown in Fig. 1.

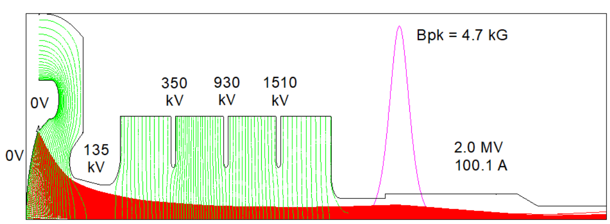

Figure 1: Simulation of 2 MV, 100.1 A, 0.0354 μperv electron beam 1 THz FEL source.

The beam optical design was developed using the DEMEOS code [3] whereas the self-consistent fields solution results from this code are in exact agreement with those from MICHELLE [4].

Next, MICHELLE was utilized in the transient mode to model the case in which 10ps long pulses are emitted from the cathode. Sample results from the movie of the evolving beam in the cathode region are shown in Fig. 2.

Figure 2: MICHELLE transient simulation of gun in Fig. 1 for 10 picosecond pulse emission.

Figure 3 shows the pulse of emitted current downstream from the movie of the transient simulation.

Figure 3: Current pulse downstream in the MICHELLE transient simulation of the source of Fig. 1 for the 10 ps pulse emission case.

The high voltage structure in Fig. 1 was designed for 2 μsec pulse standoff. In operation, a train of 10 ps pulses would lie within each 2us macro pulse.

For DC standoff operation, all the voltages must be scaled by a factor of approximately 0.4. Hence, at a body voltage of 800 kV, for constant perveance, the beam current will be 25.3 A.

Another point with this design is the challenge of full illumination of the cathode with the drive laser. This aspect is the subject of further study.

CYLINDRICAL BEAM

The second approach is a planar cathode rectilinear beam gun followed by a set of acceleration electrodes as shown in Fig. 4. The design is configured to reliably stand off the voltages DC.

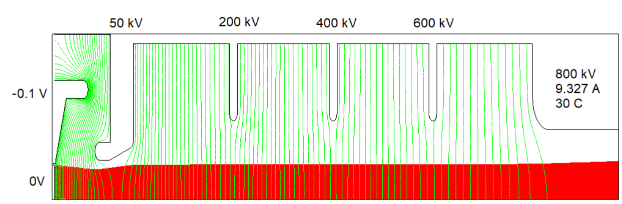

Figure 4: Simulation of 800 kV DC beam voltage, 9.327 A, 0.0130 μperv cylindrical beam source (Photo1sc).

The case in the plot assumes the cathode at room temperature or 30°C. The appearance of the beam is essentially the same for the nonthermal beam case, and for the 1100°C case. Near the problem exit at 21.0 cm, the normalized rms emittance for the cold beam is 1.619 μm, at 30°C true it is 1.848 μm, and at 1100°C it is 2.250 μm. These numbers are all outstanding. Further, normalized brightness can be obtained from Eq. (3.22) in [5]. For the 30°C case, it is 3.6E+10A/(m-rad)^2 a very high value.

The photocathode design work of this section has drawn heavily from the excellent article by Wang, et al. [6]. In their design, the DC voltage was 350 kV, current 4.5 A, perveance 0.0217 μperv. And normalized RMS emittance

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3.4 µm. For this set of parameters, for a pulse length of 1.556 nsec the bunch charge is 7.0 nC.

Since the flight time for electrons to reach 21.0 cm in Fig. 4 is 1.28 nsec, for pulses of 1.556 ns, the beam extends throughout the region so the non-transient solution is reasonable in this case. Since the beam current is 9.327 A in the case of Fig. 4, the bunch charge is 14.5 nC. Note that this can be increased further by turning up the anode voltage in the gun. Analysis of the 10 ps case using MICHELLE in the transient mode is in progress.

The design of Fig. 4 was truncated for operation at 400 kV and for added simplicity and the results are shown in Fig. 5. The current in this gun is identical to that in Fig. 4, however, the beam perveance is higher. Normalized RMS emittance is compared for these two designs in Fig. 6 and it is excellent in both of the cases.

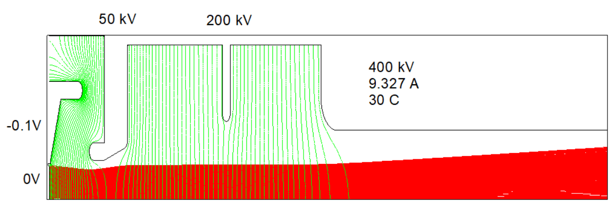

Figure 5: Simulation of 400 kV DC beam voltage, 9.327 A, 0.0369 µperv cylindrical beam source (Photo3).

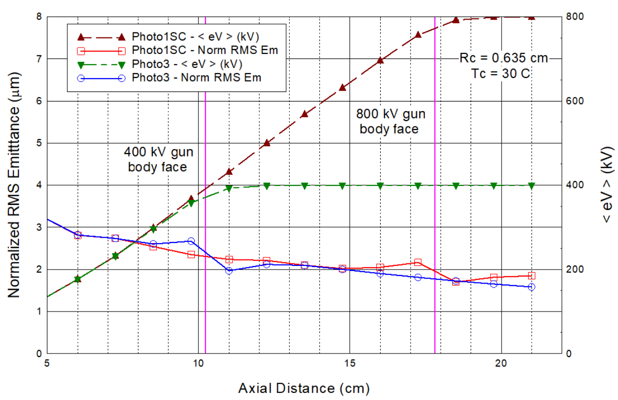

Figure 6: Normalized RMS emittance and e-beam voltage versus axial distance for the guns in Figs. 4 and 5.

GAUSSIAN EMISSION

In the article by Wang, et al. [6], their drive laser provides cathode emission having a gaussian current density profile. To explore this, we launched gaussian beams from the cathode in the design of the last section. One such example is shown in Fig. 7.

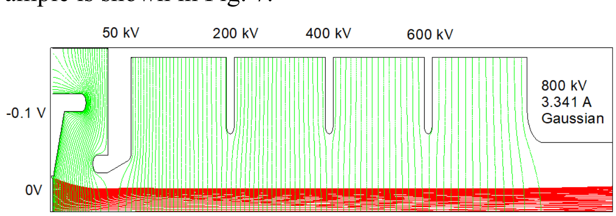

Figure 7: Nonthermal beam simulation with gaussian emission from cathode (3.34 A, 0.0047 µperv, Jpk = 12.0 A/cm^2, σ = 0.212 cm, 3σ (99%) at 0.635 cm radius cathode edge).

While the beam looks well focussed, the emittance is compromised by excessive spreading of the inner portion of the beam and overfocussing of the outer portion. In this case the normalized RMS emittance is 11.9 µm versus 1.619 µm for the case of Fig. 4 run nonthermally. Various focus electrode configurations and focus electrode voltages were explored in an attempt to correct for this effect without success.

To explore gaussian emission further, we set up a diode problem having a flat cathode with this type of injected beam as shown in Fig. 8. This represents a small gaussian beam emitted from a large cathode puck. In this case the normalized RMS emittance is 7.43 µm at z = 6.55 cm.

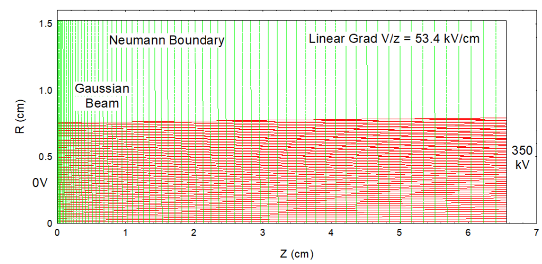

Figure 8: Nonthermal beam simulation with gaussian emission from cathode (4.50 A, 0.022 µperv, Jpk = 11.25 A/cm^2, σ = 0.254 cm, 3σ (99%) at 0.762 cm radius).

Various results are compared in Fig. 9. It can readily be seen in the figure why the emittance is so much better in the baseline uniform beam case in comparison to the gaussian beam cases.

It is also worth mentioning in the case of Fig. 8, it may be possible to straighten out the slope somewhat by including an anode orifice which functions as a dispersive lens. This can lead to a reduction in the normalized RMS emittance, however, full correction using this technique, in general, can be difficult or impossible.

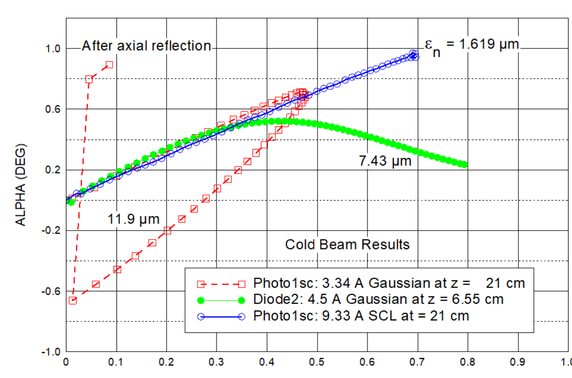

Figure 9: Slope versus radius and normalized RMS emittance for the various cases.

Another important aspect of the design is related to the uniformity of emission from the cathode. In the case of Figs. 4 and 5, the space charge limited emitted current value is 9.33 A, and the peak and average values of the current density are approximately 7.36 A/cm^2. For the case of

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Fig. 7, the current is lower at 3.34 A, however, in this case of gaussian emission, the peak current density is 12.0 A/cm^2. For Fig. 8, also gaussian, the emitted current is 4.50 A and the peak current density is 11.3 A/cm^2. The lower level of maximum peak cathode loading can have an impact on life and reliability; thus, the uniform emission designs are advantageous in this regard.

CONCLUSION

In this article we presented two laser switched photocathode sources under long and short pulse length conditions. It was found that the current in the cylindrical beam design is relatively large, and that the normalized RMS emittance is very low. Gaussian beam emission, typical from laser cathode illumination, was also explored and we found that the emittance is much higher in comparison to the uniform cathode emission case. It appears possible that a major gain in brightness and beam quality may be afforded by masking the laser for more uniform cathode emission. This is under further investigation.

REFERENCES

[1] H. P. Freund, M. V. Fazio, P. G. O'Shea, and R. B. True, "Design considerations for compact high-average power free-electron lasers/masers at terahertz frequencies," *IEEE Trans. Plasma Sci.*, vol. 51, no. 3, pp. 888–897, Mar. 2023. doi:10.1109/tps.2023.3241542

[2] R. B. True, H. P. Freund, M. V. Fazio, and P. G. O'Shea, "Superpower e-beam sources and performance estimates for compact THz FELs," *IEEE Trans. Plasma Sci.*, vol. 52, no. 7, pp. 3006–3013, Jul. 2024. doi:10.1109/tps.2024.3411775

[3] R. True, "Electron beam formation, focusing, and collection in microwave tubes," in Handbook of Microwave Technology, Cambridge, MA, USA: Academic Press, 1995, pp. 497–567. doi:10.1016/b978-012374695-5/50016-x

[4] J. Petillo *et al.*, "The MICHELLE three-dimensional electron gun and collector modeling tool: theory and design," *IEEE Trans. Plasma Sci.*, vol. 30, no. 3, pp. 1238–1264, Jun. 2002. doi:10.1109/tps.2002.801659

[5] M. Reiser (with contributions by P. O'Shea, S. Bernal, and R. Kishek), *Theory and Design of Charged Particle Beams*, Second, Updated and Expanded Edition, Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2008.

[6] E. Wang *et al.*, "High voltage dc gun for high intensity polarized electron source," *Phys. Rev. Accel. Beams*, vol. 25, no. 3, p. 033401, Mar. 2022. doi:10.1103/physrevaccelbeams.25.033401