RECENT ADVANCES IN HIGH-BRIGHTNESS ELECTRON GUNS AT AES*,

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Abstract

Advanced Energy Systems has a number of active projects pertaining to the development of advanced, high-brightness electron guns for various applications. These projects include a fully superconducting, CW RF gun that utilizes the niobium surface as the photocathode material. This gun is presently being fabricated with testing scheduled for Autumn 2002. Another project involves an integrated DC/SRF gun that is ideal as an injector for ERL-type light sources. This injector is in its late design stage, and its expected performance is very promising. In the early stages of design is a high-power, CW, normal-conducting L-band RF gun. The early performance figures for this gun show good promise as an injector for ERL-based light sources also. Lastly, a fully axisymmetric RF gun, operating in X-band, is being studied as a source of extremely bright electron bunches.

1 INTRODUCTION

It is clear that one of the key technology issues for many evolving and proposed accelerator applications is the source that is used to generate the electrons. These applications include next generation linear colliders, advanced light sources, and linacs for basic research. While performance is the driving factor for all of these applications, each one requires a different set of beam parameters. This leads to differing trade-offs and in some instances very different source and injector configurations to meet the individual requirements.

A common factor in these sources is that they are based on photocathode electron guns that can produce short pulse, high-brightness electron beams. Advanced Energy Systems (AES) has been active in the development and application of advanced, high-brightness electron sources for a variety of applications.

Four new photocathode-based electron gun/injector concepts are presented in this paper spanning the range from high-power, CW beams to ultra-high-brightness, high peak current, low average current beams. The first of these to be described is a CW gun capable of moderate average currents. This gun is fully superconducting and utilizes the niobium itself as the photocathode emitter. The next two injectors to be discussed have similar output currents and applications but vastly different approaches to accomplishing the required performance. One is based on a DC gun closely coupled to a superconducting accelerating structure. The other is based on a CW, normal-conducting RF gun. The high-brightness, high power beam produced by these two injectors make them suitable for use in high efficiency IR FEL systems[1], high power UV FEL's[2], and energy recovery linac based light sources[3]. Lastly, AES is investigating an axisymmetric RF gun design that is expected to produce extremely bright, 1 nC level electron pulses.

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2 SUPERCONDUCTING RF GUN

This gun consists of a single half-cell where the cathode area consists of the center portion of the backwall of the cavity. For simplicity and reliability, the cathode material is niobium, making the gun fully superconducting. The quantum efficiency of the niobium will be enhanced, through the Schottky effect, by the high electric field at the niobium emitting surface.

Thermal analysis has indicated that the primary limiting factor for this gun is the laser power density impinging on the cathode. This will serve to limit the achievable current depending on the tolerable initial beam radius. As can be seen in Figure 1 the beam radius can have a significant effect on the achievable emittance.

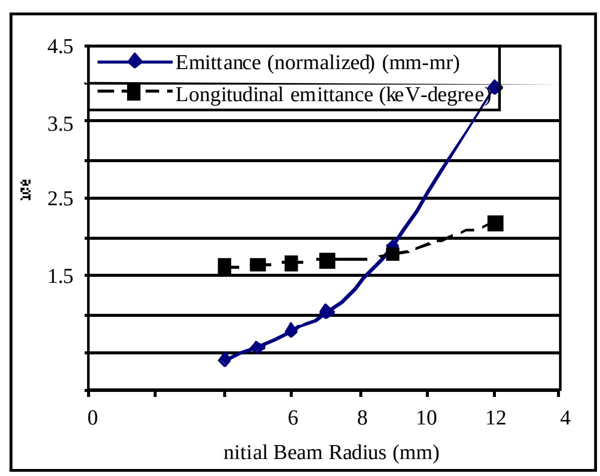

Figure 1: Emittance scaling with beam radius.

The gun system is in the final stages of fabrication. The niobium cavity has been fabricated and awaits completion of the cryostat. Testing is expected to take place at Brookhaven National Laboratory later this year with the fundamental measurement being the quantum efficiency of the niobium within an operating superconducting RF cavity.

3 CLOSE COUPLED GUN

A system that seems to have excellent potential for achieving the electron beams required for high power applications is a DC photocathode gun that is closely coupled to a superconducting accelerator. The system that is being studied begins with the Jefferson Lab design of a 500 kV DC gun[4]. This gun will ultimately be illuminated with a 750 MHz mode locked laser, generating 133 pC per bunch. The RF will also be operated at 750 MHz. Thus, with every RF bucket filled, the average current is 100 mA.

At the output of the DC gun, an emittance compensating solenoid captures the electron beam and transports it to the first superconducting accelerating cavity. In the present design, this is a single cell cavity. A series of other single cell cavities follows the first, accelerating the beam to 7 MeV. Such a system of single cell cavities allows some latitude in adjusting the longitudinal phase space through different phase relationships between the cavities.

Simulations have indicated that the beam quality that can be produced by this geometry is sufficient to satisfy the requirements of its potential applications.

The system is presently undergoing its final mechanical design with fabrication to commence later this year. Testing is anticipated to take place at Jefferson Lab in 2003.

4 CW NORMAL-CONDUCTING RF GUN

A normal-conducting, CW, photocathode RF electron gun is another possible approach for the high power advanced electron accelerators and light sources. The average current needed for these applications requires average power density depositions that are much higher than in standard RF guns. As such, the initial study of this gun focussed on cooling strategies and the thermal analysis of the gun cells.

The 3-D thermal analysis included all of the relevant features of an RF gun. The model included penetrations for the primary power coupler, a vacuum pumping port, RF pick-up port, two oblique incidence laser ports, a cathode port, and RF tuner ports. The thermal analysis showed that with appropriate cooling, the maximum temperature on the gun RF surface reaches about 116.5 C. The maximum coolant (water) temperature is 91 C. The operating gun temperatures were then applied to the structural model to determine the stresses present in the gun assembly. The stress analysis included the vacuum load on the outer surface and the pressure load due to the coolant flow. The results of the stress analysis are shown in Figure 2. This analysis showed that an adequate yield margin can be obtained for a well designed, water cooled CW gun when the cathode field gradient is limited to 15 MV/m. Further improvements may allow an increase in the allowable cathode field gradients.

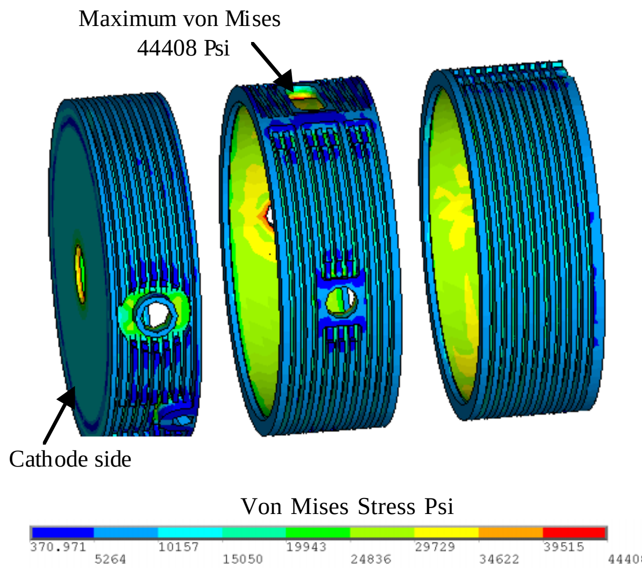

Figure 2: Stress results from three-dimensional model

This gun is presently in the preliminary design stage, but the initial results are promising.

5 AXISYMMETRIC GUN

This gun represents the next step in emittance reduction efforts. It seeks to eliminate any contributions to emittance from non-axisymmetric modes. In addition, it will allow optimal placement of the emittance compensation solenoid over a short BNL-type gun. The present design is in X-band, but the overall concept can be scaled to any frequency. Beam dynamics analyses of the gun using PARMELA[5] have shown excellent performance characteristics over a range of bunch charges. Unlike the previous guns, this design is not intended to operate at CW or very high duty factors. Rather it is intended for the very high performance, high peak current, low duty factor applications. The beam dynamics performance of the gun is summarized in the next section in Table 1 along with the other guns described previously.

This gun, like the previous one, is in the preliminary design stage.

6 SUMMARY

Four different photocathode gun projects undertaken at AES have been described. Each of these guns has its individual niche in the advanced accelerator arena. To fulfill their potential, these guns will have to deliver the beam performance required by their potential applications. Table 1 summarizes the beam dynamics simulation results for each of these guns. Two were simulated at only a single bunch charge level, but the CW normal conducting gun and the axisymmetric gun were simulated at two different charge levels. Thus, they have two columns devoted to them in the table. It should be noted that none of the results are fully optimized. For the CW normal conducting gun, in particular, the beam performance numbers represent only a very quick study of the gun performance. All of the others have been optimized to a certain extent, but they probably do not represent optimal performance. Also note that the high charge case of the axisymmetric gun includes a short (4-cell) booster accelerator, thus the higher energy. Lastly, the SRF gun does not include any solenoid. Thus, the final transverse beam size in the SRF gun is quite large, and it does not have any emittance compensation in the simulation results.

Table 1: Simulated beam performance parameters for the guns under development

			CW normal-conducting gun		**Axisymmetric gun**		
Parameter	**SRF gun**	**DC/SRF injector**	**Low charge**	**High charge**	**Low charge**	**High charge**	**Units**
Charge	0.01	0.145	0.15	5.0	0.10	1.0	nC
Beam Radius	7.3	0.69	2.1	9.7	0.28	0.34	mm rms
ε_{nx}	0.748	1.1	0.85	36	0.165	0.764	mm-mrad rms
Bunch length	1.4	6.3	7.6	24.7	1.0	1.9	ps rms
Energy Spread	0.4	0.5	1.2	5.3	1.3	1.5	% rms
Energy	2.1	7.7	2.1	2.1	3.3	8.7	MeV

All of these guns/injectors met our performance targets or came very close to meeting our performance targets, except for the high charge case in the CW normal-conducting gun. However, as noted above, very little time was spent on the beam dynamics simulations for this gun, and with some more work, we expect to be able to reduce its emittance significantly.

Each of these guns is intended to overcome some part of the limitations of existing photocathode RF guns and open up new application areas with their improved performance.

7 ACKNOWLEDGEMENTS

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8 REFERENCES

[1] G. Neil et al., "Sustained Kilowatt Lasing in a Free-Electron Laser with Same-Cell Energy Recovery," Phys. Rev. Letter 84 (4), 662-665 (2000).

[2] Jefferson Laboratory Laser Processing Consortium, http://www.jlab.org/FEL/LPC/applications.html

[3] http://erl.chess.cornell.edu

[4] C.K.Sinclair, Nucl.Instr.Meth. A318 (1992) 410-414.

[5] http://laacg1.lanl.gov/laacg/services/parmela.html