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HIGH BRIGHTNESS ELECTRON GUNS FOR NEXT-GENERATION LIGHT SOURCES AND ACCELERATORS*

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Abstract

Next-generation light sources and accelerators are being proposed that set unique requirements for the electron source parameters. No single source is suitable for the diverse applications, which have operating characteristics ranging from high-average-current, quasi-CW, to high-peak-current, single-pulse electron beams. Advanced Energy Systems, in collaboration with our various partners, is developing a variety of electron gun concepts for these important applications.

INTRODUCTION

The success of many of the evolving future accelerator applications is contingent upon the development of an appropriate source to generate the electrons. These applications include next generation linear colliders, advanced light sources, and linacs for scientific research. While beam quality is the driving factor for all of these applications, each requires a different set of beam parameters. This leads to performance trade-offs, and in most instances, to very different injector configurations. Thus, no single gun design is optimal for the differing uses.

High brightness beams and ultra-short pulses are most easily produced through the utilization of photocathode electron guns. Advanced Energy Systems (AES), in conjunction with various collaborators, has been active in the development and application of advanced, high-brightness electron sources for different applications.

Some of these photocathode-based electron gun and injector projects are described below. The devices range from high-power, CW to ultra-high-brightness, high-peak but low-average-current beams. The first three injectors described provide high-brightness beams that are suitable for use in high-power FEL systems and energy recovery linac (ERL) based light sources[2]. These three injectors have similar output currents but utilize quite different approaches to deliver the required performance. The first approach is based on a DC gun that is closely coupled to a superconducting RF (SRF) accelerating structure. The second is an RF gun that is fully superconducting except for the cathode region. The third utilizes a water-cooled normal-conducting CW RF gun. We also describe two other projects that seek to deliver extremely bright but lower average power beams. One is a CW fully superconducting gun that utilizes the niobium itself as the photocathode emitter. The other is an axisymmetric RF gun to produce extremely bright, 1 nC level electron pulses.

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CW DC GUN AND SRF INJECTOR

A DC photocathode gun closely coupled to an SRF accelerator system as shown in Figure 1 is a promising high-power injector. The device begins with a Jefferson Lab designed 500 kV DC gun[3] followed by an emittance compensation solenoid[4] which captures the electron beam and transports it to a 748.5 MHz SRF cryomodule consisting of three single cell cavities that accelerate the beam to 7 MeV.

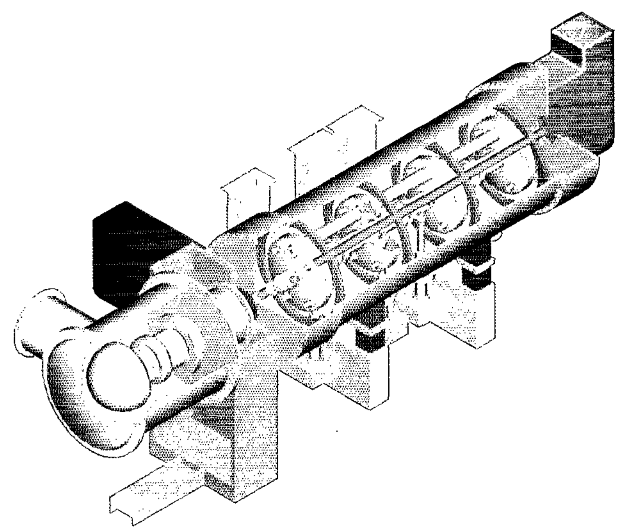

Figure 1. Engineering model of the DC gun and SRF cryomodule high-power CW injector.

When every RF bucket is filled with 133 pC, this provides an average current of 100 mA and an average electron beam power of 700 kW. The sequence of single cell cavities provides latitude for adjusting the longitudinal phase space through different cavity phasing. The single cavity approach also permits scaling to higher bunch charges.

100 mA average current simulations project that the beam quality delivered meets the requirements of a 100 kW upgrade to the Jefferson Lab IR FEL[5]. As the bunch charge is increased beyond 133pC, space-charge aberrations begin to dominate the beam quality. To

counter this, a separate project will study the effect of adding a longitudinal phase space correction cavity that operates at a harmonic of the fundamental RF frequency.

Device fabrication will be completed in 2004 with cyromodule assembly schedule for 2005. Initial testing at Jefferson Lab will use the full bunch charge, but lower bunch repetition rate, due to installed RF power limitations.

CW NORMAL-CONDUCTING RF GUN

The second high-power injector approach is a normal-conducting, CW, photocathode RF electron gun. Los Alamos performed the physics and RF design of this 700 MHz, 3 nC, 100 mA device. The crucial issue for this concept is the extremely high average power and the peak power densities that result from the resistive losses in the copper of the gun. As such, the initial engineering study focused on cooling strategies and the thermal analysis of the gun cells.

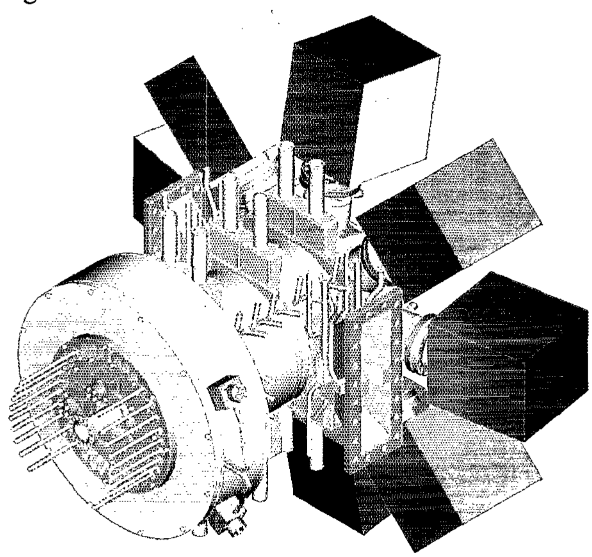

Figure 2. Engineering model of the normal-conducting CW RF gun.

A cold model has been fabricated and tested, verifying the RF design of the gun cavities and input coupler. In addition, a test article was manufactured to verify the cooling flow characteristics of the gun. In particular, the goals were to determine whether there are any areas of starved flow, quantify the effects of blockage with thermal transient, and compare the results to the analytical model. It was found that the cooling channel design is satisfactory. This gun is also in fabrication with initial thermal testing scheduled at Los Alamos in 2005.

CW SUPERCONDUCTING RF GUN (with normal conducting cathode)

This gun is under development in collaboration with FZ Rossendorf, Brookhaven, and Jefferson Lab. The approach is similar to the concept under development at FZ Rossendorf[6], but adapted for high-average-current applications. Thus, the design is a 0.5 cell gun at 748.5 MHz rather than the 3.5 cell 1.3 GHz FZR design. The engineering model for the gun followed by a booster cavity is shown in Figure 3. Beam dynamics calculations for this configuration show very promising beam performance. Although an FZR approach is baselined, we are considering alternate choke joint designs in order to simplify the fabrication. A novel cathode concept is being studied for integration with the choke joint [7].

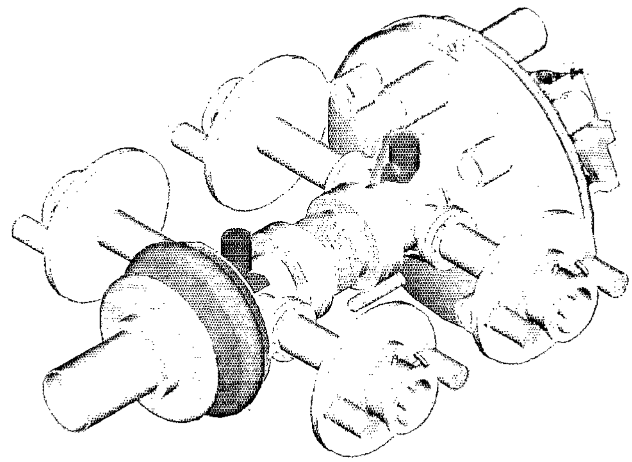

Figure 3. Half cell SRF gun followed by a booster accelerating cavity.

FULLY SUPERCONDUCTING RF GUN (with niobium cathode)

This 1.3 GHz 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

Fabrication of the gun is complete, and the Q factor test results are shown in Figure 4. The cryomodule is assembled and quantum efficiency testing is expected to begin this summer. The test setup is shown in Figure 5.

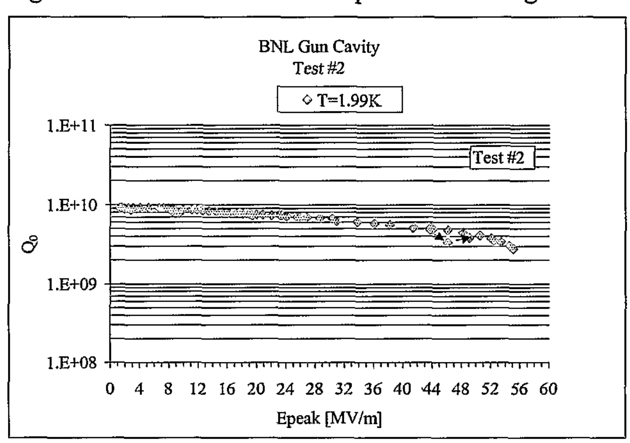

Figure 4. Results of cavity field measurements after chemical polishing and high pressure rinse.

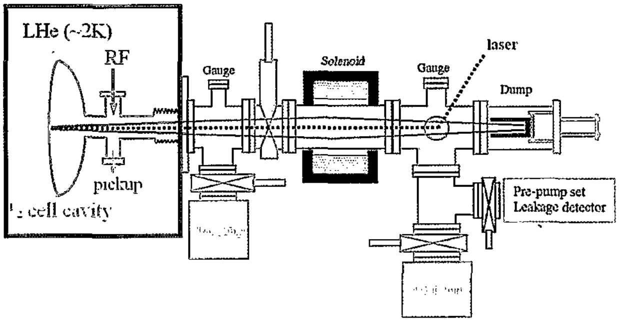

Figure 5. Test setup for quantum efficiency measurements of all niobium SC RF gun.

AXISYMMETRIC GUN

This gun represents the next step in our emittance reduction efforts where we eliminate any contributions to emittance growth from non-axisymmetric modes. In addition, it allows optimal placement of the emittance compensation solenoid over a short BNL-style gun[8]. The present design is in X-band at 11.4 GHz, but the overall concept can be scaled to any frequency. Beam dynamics analyses of the gun using PARMELA[9] have shown excellent performance characteristics over a range of bunch charge. Unlike the prior guns, this design is not intended for CW or very high-duty-factor operation. Rather it addresses very high performance, high-peak-current, low-duty-factor applications. The beam dynamics performance of this, and all the other guns discussed, is summarized in Table 1. The cold model for this gun is presently in fabrication with components shown in Figure 6. The cold model will verify the manufacturability of this gun and will confirm the capabilities of the novel tuning scheme implemented to ensure the maintenance of axial symmetry.

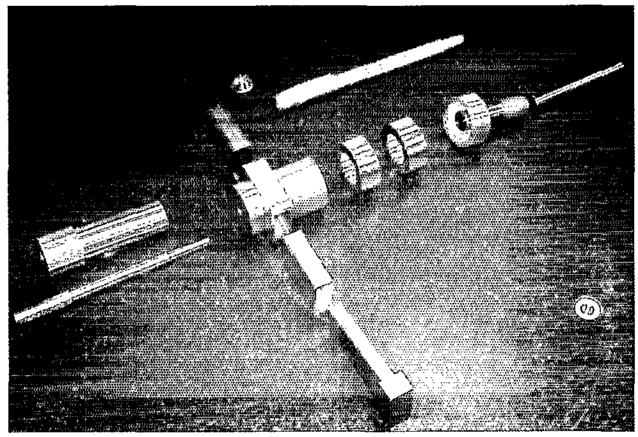

Figure 6. X-band gun cold model parts prior to assembly

Table 1: Simulated beam performance parameters for the five guns described

Parameter	CW DC Gun SRF Injector	CW NC RF Gun	SRF Gun NC Cathode	SRF Gun SC Cathode	Axisymmetric Gun	Units
Charge	0.147	3.0	1.34	0.01	1.0	nC
Beam Radius	0.98		1.2	7.3	0.34	mm rms
ε_{nx}	1.2	6	4.2	0.748	0.764	microns rms
Bunch length	6.3		9.2	1.4	1.9	ps rms
ε_{nz}	44	200	24.4	1.1	116	keV ps
Energy	7.7	2.54	3.43	2.1	8.7	MeV

SUMMARY

Five different AES photocathode electron injector projects have been described. Each of these guns has a distinct niche in the advanced accelerator arena. To fulfill their potential, they must deliver the beam performance required by their specific applications, which is met in each case by the simulation results shown in Table 1. The table shows results for a single bunch charge level. However, the complete range of gun performance with charge and other variables has been studied in each case.

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