STATUS OF THE POLARIZED SRF PHOTOCATHODE GUN DESIGN*

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Abstract

A polarized SRF photocathode gun is being considered as a high-brightness electron injector for the International Linear Collider (ILC). The conceptual engineering analysis and design of this injector, which is required to deliver a large emittance ratio, is presented. The delivered beam parameters we predict are compared to the required performance after the ILC damping ring. The analysis indicates that it may be possible to save cost by eliminating the damping ring though higher values of the emittance ratio are still to be demonstrated.

INTRODUCTIONS

Advanced Energy Systems, Inc. (AES) is collaborating with Brookhaven National Laboratory (BNL) to investigate the generation of polarized electron beams using a Superconducting Radio Frequency (SRF) photocathode electron gun. The use of an RF gun with a magnetized cathode in place of a DC gun for the ILC may reduce the requirements for emittance damping rings. Maintaining adequate lifetimes for the Gallium Arsenide (GaAs) cathode material requires vacuum levels in the 10^{-11} torr range. While vacuum levels around the 10^{-9} torr range are common in normal conducting RF guns, the cryogenic pumping of the cavity walls of an SRF gun should maintain vacuum in the range needed for GaAs cathode longevity.

The AES/BNL team is developing an experiment to study the quantum lifetime of a GaAs cathode in an SRF cavity, and to investigate long-term cavity performance in the presence of the cesiated cathode. We review the performance of the existing AES/BNL 1.3 GHz and 703.75 MHz SRF photocathode guns. We then discuss efforts to develop a 350 MHz photocathode SRF gun capable of generating polarized electron beam for the ILC injector.

EXISTING SRF GUN DEVELOPMENT

We have already developed 1.3 GHz and 703.75 MHz SRF guns. At BNL, the thrust of these SRF gun efforts is respectively, polarized electron beam R&D and high-current ERL demonstration with application to RHIC electron cooling.

1.3 GHz SRF Gun

A 1.3 GHz half-cell SRF gun project has recently produced significant results [1]. The gun cavity was designed and fabricated by AES with testing conducted at JLAB and BNL.

*This work was supported by the U.S. Department of Energy, under Contract No. DE-FG02-06ER84450.
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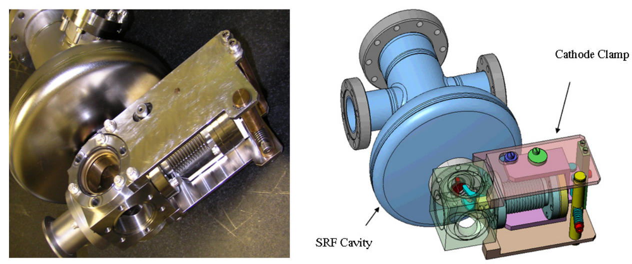
A clamp system is used to secure the cathode in the SRF cavity during operation. This system is capable of securing the cathode while maintaining the beam line cleanliness required for SRF operation. The clamp system design and fabricated hardware are shown in Figure 1.

The heart of the experiment is a cesiated GaAs cathode installed in a ½ cell 1.3 GHz SRF cavity located inside a 100 L cryostat that is cooled down during operation. The cathode clamping system is located on the back face of the cavity. The cavity is oriented vertically and supported from the cryostat cover where the RF power input, RF pickup and instrumentation are fed into the system. Figure 2 shows other system components, including a Non-Evaporable Getter (NEG) vacuum pumping plenum, a solenoid focusing magnet and a bending magnet that directs the beam into a Faraday cup to measure beam current.



CATHODE CLAMP SYSTEM

Figure 1: Cathode clamp system hardware (left) and solid model (right).

703.75 MHz SRF Gun

The 703.75 MHz high-current photocathode SRF gun [2] shown in Figure 3 is again a collaboration between AES, BNL and JLAB. This gun was designed and fabricated to deliver 0.5 A to the ERL test ring that is presently being installed at BNL [3]. The high current requires a substantial departure from the FZR 3½-cell design at 1.3 GHz. Firstly, we chose a ½-cell gun configuration at the lower frequency of 703.75 MHz, which is a subharmonic the RHIC RF frequency. This was done to accommodate the higher currents required to demonstrate application to the proposed RHIC electron cooling rings and to the e-RHIC collider concept. Secondly, primarily because of thermal issues, we determined to utilize a quarter wave RF choke joint [3]. This is shown in Figure 3 to the left of the ½ cell cavity.

350 MHZ SRF PHOTOCATHODE GUN

The ILC requires flat, high brightness electron and positron beams. The electron beams must also be

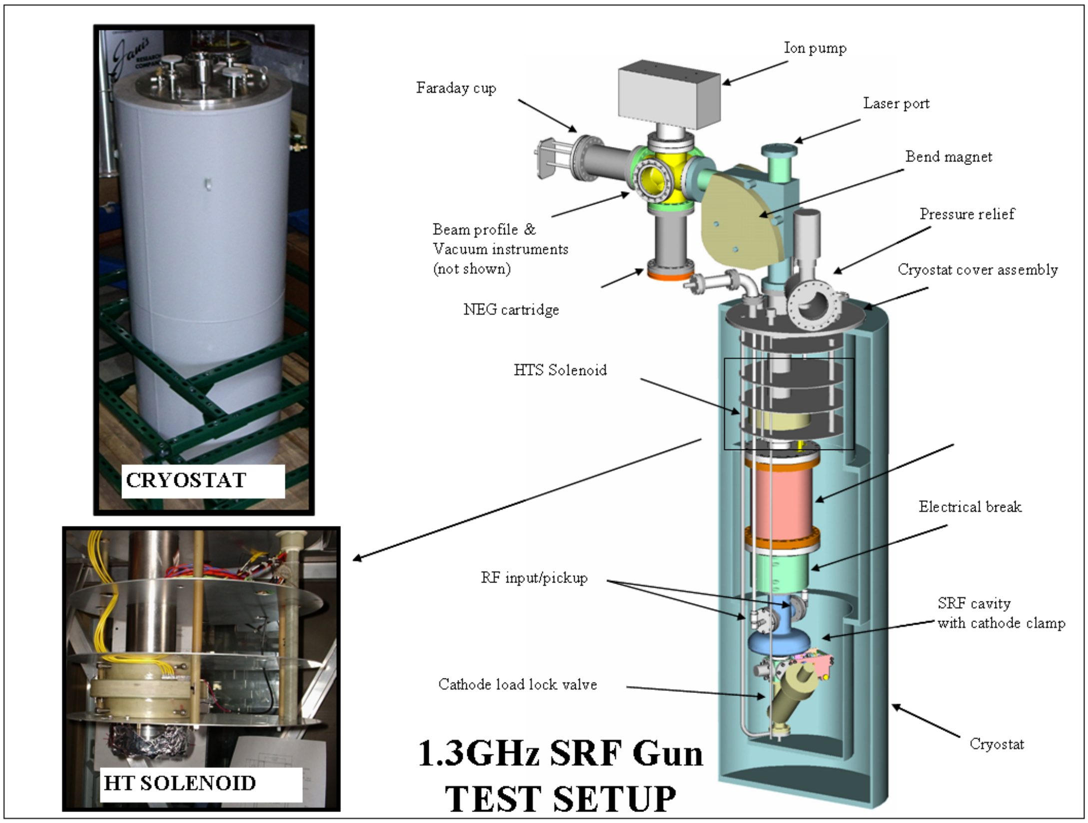


Figure 2: Test setup for a ½ cell 1.3 GHz SRF cavity with a cesiated GaAs cathode assembled inside a 100 liter cryostat for cool down during test operations.

polarized, whereas for the positrons, polarization is an option. The current design of the ILC [4], whose parameters are illustrated in Table 1, includes two damping rings, one for each species. A DC electron gun with a GaAs cathode and an X-ray positron source feed trains of 2625 bunches into the damping rings. These must be large enough to hold the entire bunch trains. The electron source and damping ring could be replaced by an SRF photo-injector.

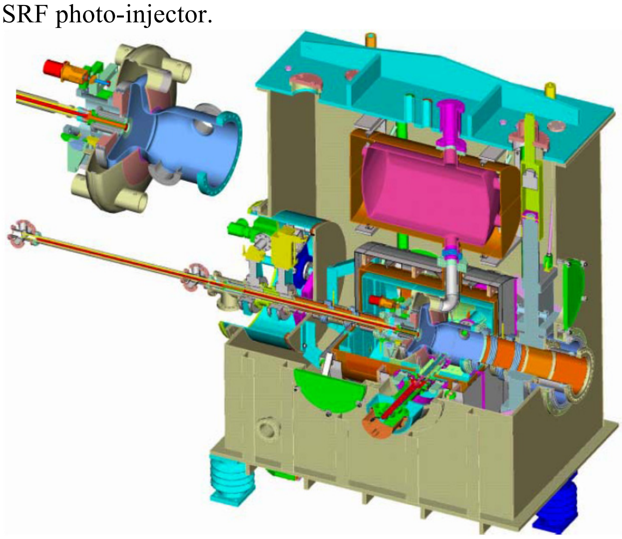


Figure 3: 703.75 MHz photocathode SRF gun cryostat and its half-cell cavity in the upper left detail.

Table 1: Beam Requirements for the ILC

Parameter	Nominal	Low Charge
Emittance X	8 μ	8 μ
Emittance Y	0.02 μ	0.02 μ
Energy spread	0.15 %	0.15 %
Bunch length	0.3 mm	0.2 mm
Bunch charge	3.2 nC	1.6 nC

A Half Cell SRF Photocathode Gun

AES has designed a new half cell SRF electron gun for the ILC, that will utilize cesiated GaAs. The gun resonant frequency is 350 MHz The cesiated GaAs generates the ILC-specified polarized electron beam.

Various gun configurations were tested, and in each case, the gun shape was optimized using SUPERFISH. The selected configuration is the 350 MHz half-cell gun shown in Figure 4. This cavity has a quarter wave choke (QWC) structure to minimize thermal loss and arcing and a high temperature superconducting solenoid (HTS) to produce the magnetized beam that results in the required 5 MeV flat output beam. The peak fields on the cathode and cavity walls are 24.5 and 43 MV/m respectively. Beam dynamics analysis used the PARMELA code to optimize the cathode location and the required skew quadrupole layout. Figure 5 shows the axial transverse emittance evolution as a function of cathode position.

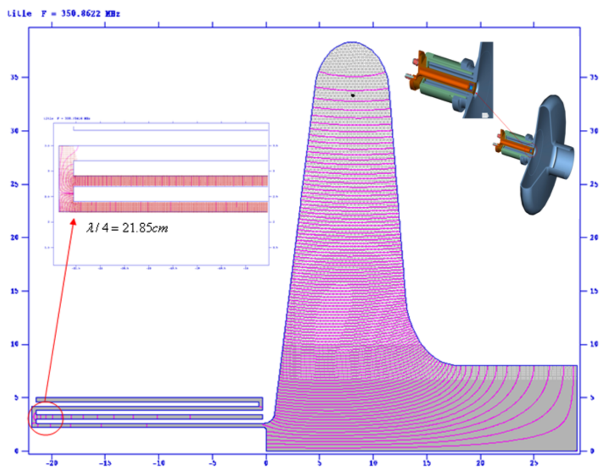


Figure 4: 350 MHz SUPERFISH half-cell SRF cavity with the optimized 21.85 cm QWC geometry (upper left) and HTS (upper right).

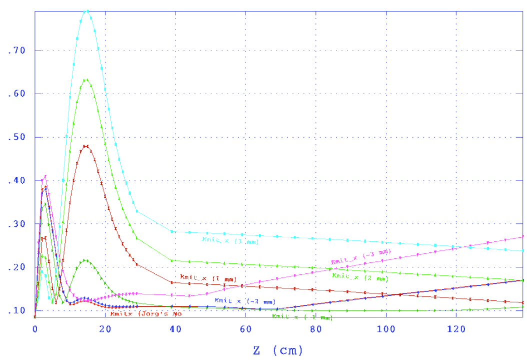


Figure 5: Gun axial emittance profiles varying the cathode location by ± 3 mm.

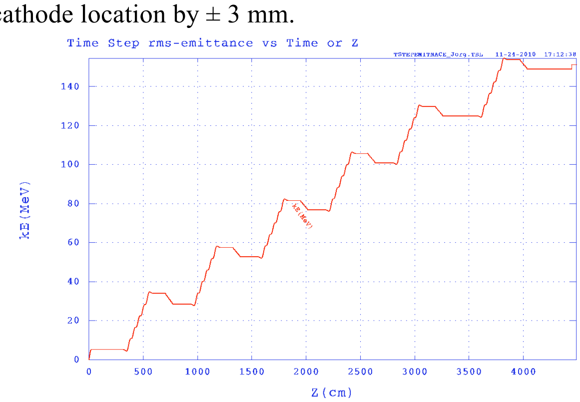


Figure 6: Beam energy evolution through six sets of subsequent fundamental and 3rd harmonic cavities.

A flat beam is produced by immersing the cathode in a longitudinal magnetic field that generates an angular momentum when the magnetized beam leaves this field [5]. A set of skew quadrupoles then transforms the round magnetized beam to a flat unmagnetized beam. Figure 6 shows the beam propagating through a subsequent set of six fundamental and 3rd harmonic cavities. Figure 7 compares the beam profiles before (the round beam lower left) and after (the rectangular beam lower right) the skew quadrupoles, showing we achieve an emittance ratio of about 10. The associated transverse beam envelopes and emittances are shown in the upper traces.

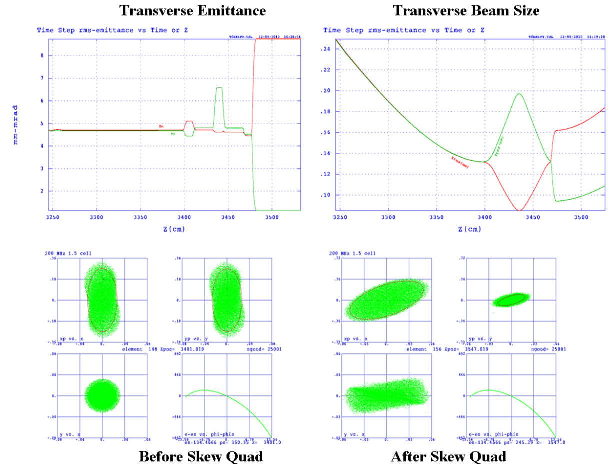


Figure 7: PARMELA beam evolution (upper) and phase space plots (lower) for the pre skew quad round (left) and post quad rectangular beams (right).

SUMMARY

In collaboration with JLAB and BNL, AES has previously developed 1.3 GHz and 703.75 MHz SRF guns. Together with BNL, we are now investigating the generation of polarized electron beams using an SRF gun with a magnetized cathode for the ILC, in place of the current baseline DC gun, because it may eliminate the need for and expense of the emittance damping rings. Adequate GaAs cathode lifetime for generating the polarized beams requires vacuum levels in the 10^{-11} torr range, which can be achieved in an SRF gun. The flat output beam that results from passing the round input magnetized beam through a set of skew quadrupoles presently achieves an emittance ratio of 10 in our simulations, as compared to the desired value of 400. We are now working on methods to increase the output beam emittance ratio.

REFERENCES

[1] M. Cole *et al.*, "RF Design and Operating Performance of the BNL/AES 1.3GHz Single Cell Superconducting RF Photocathode Electron Gun," *Proc. PAC 2005*, ISBN 0-7803-8860-7 (2005), 3514.

[2] A.M.M. Todd *et al.*, "State-of-the-Art Electron Guns and Injector Designs for Energy Recovery Linacs (ERL)," *Proc. PAC 2005*, ISBN 0-7803-8860-7 (2005), 2292.

[3] I. Ben-Zvi *et al.*, "Ampere Average Current Photoinjector and Energy Recovery Linac," *Proc. FEL 2004,* ISBN 88-87992-02-9 (2004) 355.

[4] The ILC design manual: http://ilcdoc.linearcollider.org/getfile.py?docid=182

[5] R. Brinkmann *et al.*, "A Low Emittance, Flat-Beam Electron Source For Linear Colliders," PRST AB **4**, 053501 (2001).