The RF Design of an HOM Polarized RF Gun for the ILC*

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Abstract

The ILC requires a polarized electron beam. While a highly polarized beam can be produced by a GaAs-type cathode in a DC gun of the type currently in use at SLAC, JLAB and elsewhere, the ILC injector system can be simplified and made more efficient if a GaAs-type cathode can be combined with a low emittance RF gun. Since this type of cathode is known to be extremely sensitive to vacuum contamination including back bombardment by electrons and ions, any successful polarized RF gun must have a significantly improved operating vacuum compared to existing RF guns. We present a new RF design for an L-Band normal conducting (NC) RF gun for the ILC polarized electron source. This design incorporates a higher order mode (HOM) structure, whose chief virtue in this application is an improved conductance for vacuum pumping on the cathode. Computer simulation models have been used to optimize the RF parameters with two principal goals: first to minimize the required RF power; second to reduce the peak surface field relative to the field at the cathode in order to suppress field emitted electron bombardment. The beam properties have been simulated initially using PARMELA. Vacuum and other practical issues for implementing this design are discussed.

INTRODUCTION

There are some important advantages to generating the ILC electron beam with an RF rather than a DC gun. An RF gun, operating at significantly higher extraction fields, can produce the high charge density, short bunches required by the ILC. [1] Thus the source laser beam can be used to define the bunch profile without the need to use post-extraction RF or magnetic bunchers. The result is a low emittance beam for which the accelerating-RF capture efficiency will be higher and beam losses at the injector and also, significantly, at the damping ring will be lower.

The standard RF gun design consists of a half pill-box cell plus one or several full cells operating in the TM010 π-mode. These guns typically operate with a pressure of about 10^{-9} Torr, whereas a pressure of 10^{-11} Torr or better required for GaAs photocathodes. Thus the conductance between the cathode and pump must be significantly improved and the outgassing rate of the structure must be decreased. A more promising design for increasing the conductance is the single cell operated in a higher order mode (HOM) TM012, [2] which is effectively the RF equivalent of a 1.5-cell structure but without the internal iris.

In this paper we explain how we have optimized the HOM design for application as the ILC source, and then present preliminary beam dynamics calculations. Finally we discuss some of the practical problems to be overcome before GaAs photocathodes can be accommodated by this or any RF gun design.

Table 1: Basic parameters for a polarized RF gun

RF Cavity	f	1300 MHz
	Q_0	31230
	T_f	1.9 μs
	E_c	40 MV/m
Bunch Structure	Charge/Bunch	5 nC
	Bunch Train	2820 Bunches
	Bunch Spacing	0.337 μs
	Train Length	1 ms
	Repetition Rate	5 Hz
Laser	Transverse	1 cm dia., round, flat top.
	Longitudinal	42.7 ps (20° RF) Gaussian 4 σ
Cathode	Material	GaAs
	Size	1 cm

RF STRUCTURE DESIGN AND OPTIMIZATION

The goal of the RF design optimization is:

- To minimize the RF power requirement;
- To minimize the maximum surface electrical field for lowest possible field emitted current;
- To minimize the maximum surface magnetic field for reduction of pulse heating and ease of cooling.

for a certain electrical field amplitude on the cathode.

We have made RF parameter studies through several design options. The RF is fed from downstream coaxially. Figure 1 shows four typical cases with different iris radii and cell rounding for comparing their RF parameters. The location of the maximum surface field for each case has been indicated with a black dot. In order to make the cathode surface electrical field

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*Work supported by U.S. Department of Energy, contract DE-AC02-76SF00515 (SLAC) and W-31-109-ENG-38 (ANL).

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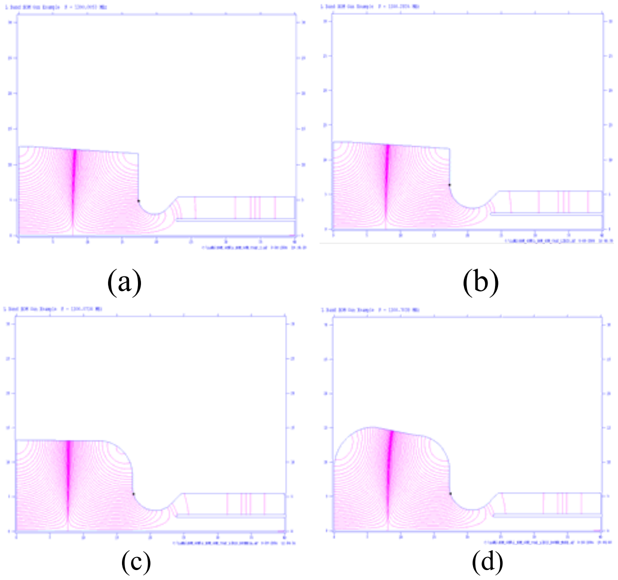
equal to the second maximum electrical field on the gun axis, properly tapering the outer cell wall was done for all the examples. The typical electrical field distribution is shown in the Figure 2. Some important RF parameters are listed in the Table 2.


(a) (b)

(c) (d)

Figure 1: Design examples for an HOM RF gun: (a) with an output iris radius of 2.4 mm; (b) with an output iris radius of 3.4 mm; (c) with a rounding radius of 5 cm on the outer cell wall at the output end; and (d) with an additional rounding radius of 6 cm.

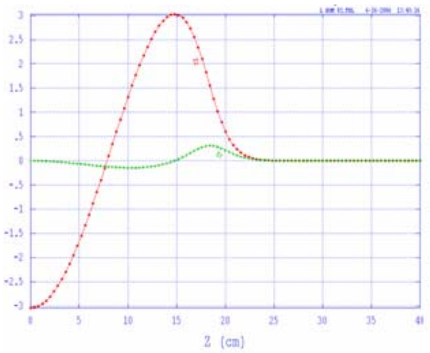


Figure 2: Typical longitudinal (red) and transverse (green) electrical fields distribution along the gun axis.

Table 2: Parameters scaled to 40 MV/m of electrical field on cathode surface

	Power (MW)	E_{max} / E_c	E_{max} (MV/m)	r (MΩ/m)	Max P_d (kW/cm²)
(a)	5.52	1.26	50.5	7.40	5.24
(b)	5.66	1.16	46.4	6.97	5.36
(c)	5.49	1.11	46.4	7.36	4.54
(d)	4.90	1.085	43.4	7.40	4.78

BEAM DYNAMICS CALCULATIONS

Preliminary beam dynamics calculations using a modified PARMELA program [3] have been made for the 1300 MHz HOM RF gun to compare its expected performance with the standard 1.6-cell BNL /SLAC/UCLA gun S-band RF gun. The calculations indicate that the HOM gun is competitive with the 1.6 cell design for the transverse emittance. The geometry used for the simulation is shown in Figure 3. Two identical, iron free, opposite polarity coils are located symmetrically with respect to the cathode plane to produce zero field at the cathode and a maximum of about 800 Gauss approximately 20 cm downstream of the cathode. A nine cell superconducting structure running at 15 MeV/m is placed 72 cm down stream of the cathode. The field at the cathode and at the second maximum is 40 MV/m.

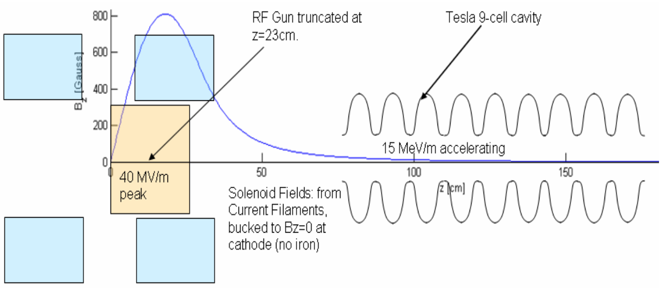


Figure 3: Layout for the beam dynamics simulation.

The evolution of the transverse RMS emittance is shown in Figure 4. The transverse emittance of 7.4 π µm is a very reasonable for a bunch charge of 6 nC starting with a Gaussian longitudinal distribution as compared with 1 to 2 π µm for 1.6 cell guns for 1 nC with a uniform longitudinal distribution.

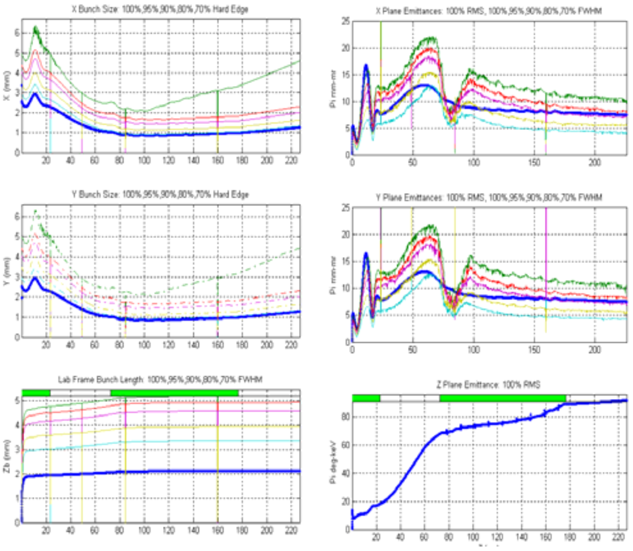


Figure 4: Plots for the transverse (top and middle) and longitudinal (bottom) envelopes (left) and RMS emittances (right).

Figure 5 shows the R-Rprime phase space at the end of the simulation (about 2 meters from the cathode). In it we see that there are two distinct distributions: the core of the bunch which has a small high density distribution in phase space extending from 0,0 to about 1 mr, 2.8 mm and a second low density distribution extending from 0,0 to about 3.5 mr, 6 mm. When we look at the plot of R-Z trace space and the Z-Rp correlation plot it becomes apparent that the electrons in the head and tail of the bunch have crossed over, giving a large contribution to the emittance. Thus, when the initial distribution is truncated at +/- 1σ instead of +/- 2σ, the emittance drops by a third, from 7.4 π μm to 5 π μm. If a uniform longitudinal distribution were used the emittance would be even lower. Obtaining good uniform longitudinal distributions has proven to be more challenging in practice than had been expected.

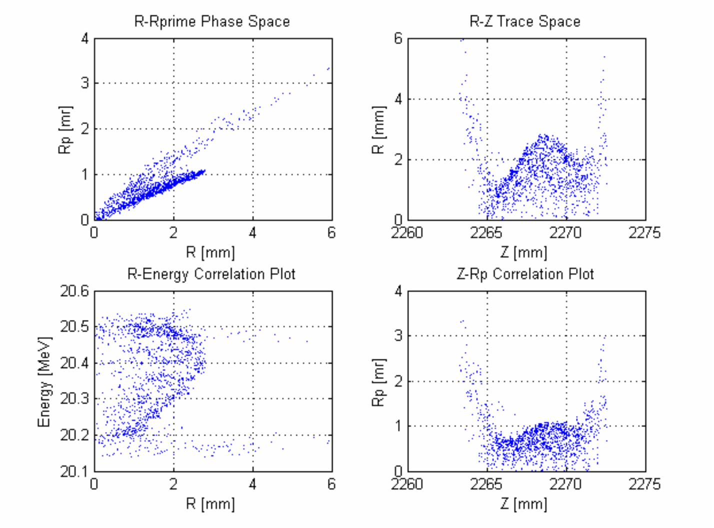


Figure 5: Plots for the R-Rprime phase space (top left), R-Z trace space (top right), R-Energy correlation and Z-Rp correlation.

In general, the simulation shows the normalized RMS emittances are $\varepsilon_x=\varepsilon_y=7.4\ \pi\ \mu m$, $\varepsilon_z=91$ keV-Deg, $\sigma_z=113$ keV (0.6%) at $<E>=20.2$ MeV and $\sigma_t=2.1$ mm. This simulation is considered to be preliminary, but it does indicate that for the large bunch charge desired for ILC that reasonable emittance should be obtainable from the HOM gun. The emittance should be comparable to that expected from a 1.6 cell gun. A provision for approximating wakefield effects and higher modes can be added to the input RF fields but this work has not been done yet.

DISCUSSION

For the QE lifetime of activated GaAs photocathodes operating in DC guns to be 100s of hours or more, it is crucial the vacuum be well below 10^{-11} Torr. Ion back bombardment is a problem principally for CW sources. However, for an RF gun, the effect of electron back bombardment is clearly a question. The only test of an activated GaAs cathode in an RF gun was conducted at BNIP in the late 1990s using a ½-cell S-band gun. [4] With the RF on, the lifetime of the cathode QE was measured in terms of 10s of pulses, most likely because of the effect of back bombardment of field emitted electrons.

Two methods to improve the vacuum at the cathode have been proposed. One method is to use a SC RF gun cavity. R&D for SC RF guns, underway elsewhere, is not discussed here. The second is to increase the conductance for pumping on the cathode by using holes or z-slots in the cavity cylinder combined with various designs to decrease the internal pumping impedance of the cavity. The HOM design appears the best choice for increasing the conductance in this manner. For a reasonable outgassing rate, a pressure at the cathode of $<10^{-11}$ seems feasible. [5]

Field emission must be reduced by careful gun design. The critical design challenges are for the RF coupler, the RF seal for the cathode plug, and the iris (es). It is clearly to the advantage of the HOM design that the internal iris, which is closest to the cathode, is eliminated. Other issues include choice of materials, machining and assembly techniques, and cleaning procedures.

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