Extended Version of an S–Band RF Gun*

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Abstract

A 4.5 MeV rf gun has been in operation at UCLA as a part of a 20 MeV linac. To improve the photoelectron beam parameters without changing the major characteristics of the driving laser and rf systems, a revised and extended version of the present rf gun has been investigated. The new gun consists of 6 full cells terminated at either end by one half cell each. The gun operates in π -mode at 2.856 GHz. Accelerating fields and mode structures have been studied, and based on this, particle dynamics has been simulated. An aluminum prototype has been built for cold tests. Description of the gun is presented along with initial computational and experimental results.

Introduction

Photoinjectors have been successfully used at a number of laboratories to produce high brightness, low emittance electron beams[1,2,3]. The electron beam out of a photoinjector is subjected to further acceleration by a linac that follows the injector. At UCLA, a 4.5 MeV beam will be boosted by the plane wave transformer(PWT) to a 20 MeV beam energy[4].

When high brightness means more charge per bunch and lower emittance, these two compete against each other because of space charge effect. A solenoid focusing the beam to reduce the divergence produced at the gun exit, tends to distort the phase space distribution. The angular divergence at the gun exit and space charge effects decrease with increasing beam energy, which pushes us to design a higher energy gun[5]. Also, the radial electric fields provide periodic focusing and defocusing forces to the beam, whereas the axial fields accelerate the beam so that the beam energy is roughly linear to the axial length of the structure. This gives rise to a net focusing of the beam[6].

From the engineering point of view, combination of photoinjector and a linac introduces some complexity in distribution of the driving rf power, in terms of amplitude and phase. If one klystron can drive one structure to generate a beam of comparable energy and probably better quality, this minimizes requirements for hardware in handling high power rf. And this is partly the motive behind investigation of a multicell structure.

Computational Modelling

The starting point of the new structure is the $1\frac{1}{2}$ -cell photocathode rf gun, to be referred to as Gun A, which is in operation at UCLA and at Brookhaven. The Gun A has two resonance modes, 0-mode and π -mode. They are about 2 MHz apart. There are more resonance modes as more cells are added, but the frequency span between the 0-mode and π -mode remains about the same. The separation of the π -mode and the nearest neighboring mode becomes smaller accordingly. As the inner radius of the aperture is increased, a larger separation between the modes is realized.

To be sure that we drive only the π -mode we require a mode separation much larger than the klystron bandwidth. For a klystron pulse duration of 2.5 μ s we have $1/\tau_{rf} =$ 0.4MHz. When the aperture radius is increased from 1.0 cm to 1.5 cm for a $(6+2 \times \frac{1}{2})$ -cell structure, to be referred to as Gun B, the $\frac{6}{7}\pi$ and π modes are roughly 1 MHz apart. Enlargement of the aperture is accompanied by overall upshift in resonance frequencies of all the modes, which is compensated for by an increase in cell diameter.

We chose the present configuration to achieve a beam energy of 20 MeV. The second half cell gives larger angular divergence, but it was needed to maintain the field balance between the cells. This will be changed in the future. The frequencies of resonance modes are found by SUPERFISH[7] in a frequency scan. The field distribution and other relevant parameters are found from the output of the code and by using post processor. Some of the results are shown in Figure 1.

The design parameters of the Gun B are summarized in Table 1.

Based on SUPERFISH output data, we computed a set of Fourier coefficients for the PARMELA[8] code to use for spatial distribution of the wave electric and magnetic fields. Using the same initial conditions, the two guns were simulated with a space charge effect of 1 nC photo-

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Figure 1: SUPERFISH output for the Gun B. The first half cell followed two full cells of the structure, with the electric field lines(top). The resonance frequencies are when the curve crosses zero from the positive side (middle). The axial electric field along the axis(bottom)

Table 1: Design parameters of Gun B

| overall length | 36.75cm |
|-----------------------|---------|
| cell inner radius | 4.30cm |
| cell length | 5.25cm |
| aperture inner radius | 1.50cm |
| shunt impedance | 84MΩ |
| beam energy | 20MeV |
| photocharge | lnC |



Figure 2: Emittance along the z-axis for the guns A and B.



Figure 3: Transverse beam size along the z-axis for the guns A and B.

electron bunch included. The normalized rms transverse emittance of the two cases are shown in Fig. 2 for comparison. Solenoidal focusing with a compensating bucking coil is the only active focusing applied externally.

While the electron bunch is being accelerated in the gun, the emittance growth rate is small. After passing the exit, the space charge forces the emittance to grow until the bunch loses some of its particles. Even with the energy about four times higher, the growth rate and overall emittance is lower for the case of Gun B. Other parameters of interest from this particle simulation are final transverse beam size, bunch length, beam energy, and energy spread for the two cases at distances farther than two gun lengths. These are given in the Table 2 below.

Table 2: Comparison of beams from the guns A and B

| Gun | | A | B |
|-------------------------|-----|------|------|
| beam radius | cm | 0.58 | 0.51 |
| bunch length | mm | 0.44 | 0.31 |
| Energy | MeV | 4.5 | 19.0 |
| $<\delta\gamma>/\gamma$ | % | 0.13 | 0.01 |

The above data are preliminary, and thus are subject to modification as the particle code is improved as well as the input data is better prepared. However, the contrast between the two cases will remain unchanged.

Experimental

Based on results from the computational studies, an aluminum prototype has been built. The assembly is made to be versatile, so that the configuration can be changed as needed. There are some extra cells made for the purpose. When all the primary tests are done, the gun will be eventually powered through a waveguide coupling at the center. Presently, however, there is no rf coupling structure and field quantities are measured by launching the rf waves at the end of the structure through an electric dipole probe on axis. This preserves a two dimensional nature computed by SUPERFISH.

With one end of the gun terminated by a flat metal plate, the reflected wave from the probe was monitored over a band of frequencies. The local minimum in reflection is where resonance occurs, and from a network analyzer measurement, there were seven resonances observed. According to SUPERFISH, there are eight resonances with $(n-1)\pi/7$ modes where the integer n ranges from 1 to 8. The measured frequencies were about 1.8% higher than computed values. The discrepancy may be due to poor electrical contact between the cells and/or inaccuracy in machining.

The present setup is assembled by axially clamping the cells by 16 each of 5/16-28 threaded rods with a bolt circle radius of 6.5 cm, where the cell inner radius is 4.3 cm. Geometric dimension of every cell will be checked for consistency and end faces will be contoured to improve the electrical contact between the cells. For the axial electric field distribution measurements, a frequency perturbation method[9,10] will be employed. After each modification of the cell is made, the Q value, resonance frequencies, and axial electric field will be measured. This process will continue until the parameters are within permissible ranges.

The next step is to install waveguide coupling to the cell. Numerical study in three dimension may well be made, but the limitations in resolution and computer resources can be avoided by adopting an experimental trial and error in shaping of the coupling structure. Again, the present $1\frac{1}{2}$ gun will be our baseline. One magnetic rf probe and one tuner for each cell will be used to balance the rf power between the cells. The driving rf waves may be launched through this probe for the purpose of tuning individual cells.

Conclusion

A framework for the study of multicell photocathode rf gun has been setup. Computer codes need to be refined to reveal the details of the wave fields and particle dynamics. For example, SUPERFISH does not distinguish metal and vacuum on axis, and its shunt impedance calculation on multicell structure is not realistic. In particle dynamics, preparing good input parameters is very important. The need for long computer time is now partially satisfied by running the code on NERSC Cray.

For the hardware part of the problem, optimal coupling of the rf wave to the cavity must be achieved as well as mechanical precision. The opposite end of the photocathode is presently terminated by a flat metal. This will be replaced by a small aperture iris. Breaking of axial symmetry will be compensated for by individual tuning of the cells. Realistic cold test may be done if the entire cavity is copper plated. We will continue this study in the near future.

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