INITIAL RESULTS OF THE NEW HIGH INTENSITY ELECTRON GUN AT THE ARGONNE WAKEFIELD ACCELERATOR *

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Abstract

We report on the status of the new short bunch, high intensity electron gun at the Argonne Wakefield Accelerator. The 1-1/2 cell L-band photocathode RF gun is expected to produce 10 – 100 nC bunches with 2 – 5 ps rms pulse length and normalized emittance less than 100 mm mrad. The beam energy at the exit of the gun cavity will be in the range 7.5 – 10 MeV. A standing-wave linac structure operating at the same frequency (1.3 GHz) will increase the beam energy to about 15 MeV. This beam will be used in wakefield acceleration experiments with dielectric loaded structures. These travelling-wave dielectric loaded structures, operating at 7.8 and 15.6 GHz, will be excited by the propagation of single bunches or by trains of up to 32 electron bunches.

1 INTRODUCTION

High current short electron beams have been a subject of intensive studies [1]. One of the particular uses for this type of beam is in wakefield acceleration applications. High current (kA) short electron beam generation and acceleration did not materialize until the advent of RF photoinjector technology[2]. Although most photocathode RF gun development has been concentrated on high brightness, low charge applications such as free electron laser injectors, there have been several relatively high charge RF photocathode based electron sources built and operated[3,4,5]. In general, there are two approaches to attaining high peak current. One approach is to generate an initially long electron bunch with a linear head-tail energy variation that is subsequently compressed using magnetic pulse compression. The advantage of magnetic compression is that it is a well-known technology and can produce sub-picosecond bunch lengths. However, due to strong longitudinal space charge effects, this technology is limited to relatively low charges (<10 nC).

Another approach is to directly generate short intense electron bunches at the photocathode and then accelerate them to relativistic energies rapidly using high axial electric fields in the gun [3]. The advantage of this approach is that it can deliver very high charges, for example, 100 nC if one uses an L-band gun. This would satisfy the requirements of most electron driven wakefield experiments for both plasma and dielectric structures, if the pulse length is short enough (< 10 ps FWHM). So far, the Argonne Wakefield Accelerator (AWA) has demonstrated the capability of producing 100 nC, 25 — 35 ps (FWHM) electron beams at 14 MeV. This unprecedented performance was obtained using a half cell photocathode gun cavity and two standing wave iris-loaded linac sections [6]. The AWA machine has reached its design goal and has been used for dielectric wakefield [7] and plasma [8] experiments. The initial results are encouraging [9]. Achieving higher gradients in wakefield experiments would require the drive electron pulse to be even shorter and have a lower emittance. In this paper, we discuss the design of a new RF photocathode gun with the capability of producing 10 - 100 nC with 2 - 5 ps (rms) pulse lengths.

2 DESIGN CONSIDERATIONS

In order to generate high charge and short bunch lengths from a photocathode RF gun, the electric field on the cathode surface has to be very intense. In this way the electrons leaving the cathode surface are quickly accelerated to relativistic velocities, minimizing the bunch lengthening and the emittance growth that the space charge forces produce [10,11]. There is also bunch lengthening and transverse emittance growth at the exit iris of the gun cavity due to the defocusing forces of the RF fields. Thus, this effect also calls for high accelerating gradient and high beam energy at the exit of the gun. It is therefore desirable to have a multicell gun with high accelerating gradient. Practical considerations (mainly a finite amount of RF power) limit the design to 1 – 1/2 cells. The choice for our new gun design is a Brookhaven type 1– 1/2 cell cavity [12] scaled up to L band operation. This gun will be followed by one of the present linac tanks that exist at the AWA facility.

A detailed numerical study [13, 14] of this gun was performed with the codes SUPERFISH and PARMELA [15]. Table 1 summarizes the parameters used in the simulations. These extensive numerical simulations showed a strong dependence of bunch length and emittance with respect to the accelerating gradient in the gun cavity (Fig. 1). Based on these studies, it was

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decided that an accelerating gradient of 80 MV/m on the cathode surface was a good operating point. This requires 10 MW of RF power to be coupled into the gun cavity, which still leaves enough power to run one of the linac tanks. This accelerating gradient yields good values of emittance and bunch length, while still not high enough to make the RF conditioning of the gun a challenging task. (In fact, we recently conditioned a duplicate of the present AWA gun up to a gradient of 125 MV/m [16].)

Table 1. The gun design parameters as calculated using SUPERFISH.

Inner Radius of the Cell, b (cm)	9.03
Radius of the iris, a (cm)	2.75
Width of the iris, d (cm)	1.5
Aperture of the exit (cm)	2.5
Operating frequency (GHz)	1.3
Initial beam radius (cm)	1
Quality factor, Q	26008
Shunt impedance (MΩ/m)	36.47

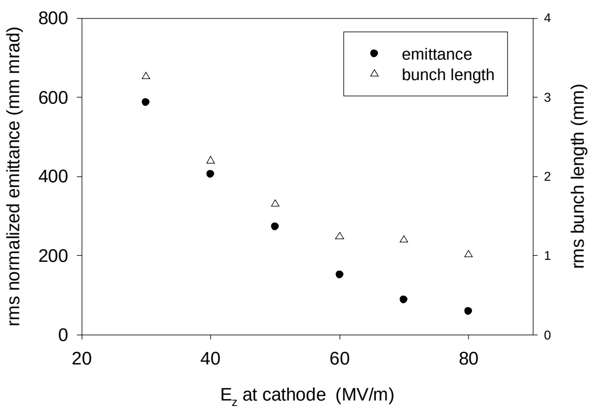

Figure 1: Emittance and bunch length as a function of the accelerating gradient on the cathode surface, for a 40 nC bunch.

3 CONSTRUCTION AND RF MEASUREMENTS

The RF gun will be operated with a focusing solenoid and a bucking solenoid to cancel the magnetic field on the plane of the cathode. These two solenoids are exactly next to each other, with the photocathode plane as their plane of symmetry. This maximizes the space available for the RF power coupler over the full cell of the gun. There is a vacuum pumping port in the full cell, located diametrically opposite to the RF coupler, both being at the equator line of the full cell. An RF pickup probe is placed near the vacuum pumping port, relying on the evanescent RF fields present in that location. An RF tuning plunger is located half way along the circumference of the full cell between the RF coupler and the vacuum pumping port. This breaks the symmetry of the full cell, but it is acceptable in our L-band size cavity. The perturbation of the field lines near the axis of the cavity is negligible. In the half cell, the cathode holder can also function as a tuning plunger, allowing us to adjust the parameters of the two cells, in order to achieve the right resonance frequency for the π mode and field balance in the cavity. The cooling channels are drilled along the cylindrical wall of the gun, and also run over part of the back and front plates of the cavity.

Numerical simulations of this final design yield values for the emittance and bunch length that are slightly worse than the ones obtained in reference [13, 14]. This results from the fact that the location and dimensions of the solenoids are not dictated only by the optimization of the beam parameters, but also by other physical constraints. The degradation is however very small, and the gun is still expected to generate very short bunches with low emittance. Results of numerical simulations with PARMELA are shown in Fig. 2. These plots show emittance, bunch length, energy and radial coordinate as a function of the longitudinal coordinate along the accelerator for a bunch charge of 40 nC. At the exit of the linac the code predicts a normalized rms emittance of 66 mm mrad and an rms bunch length of 3.7 ps.

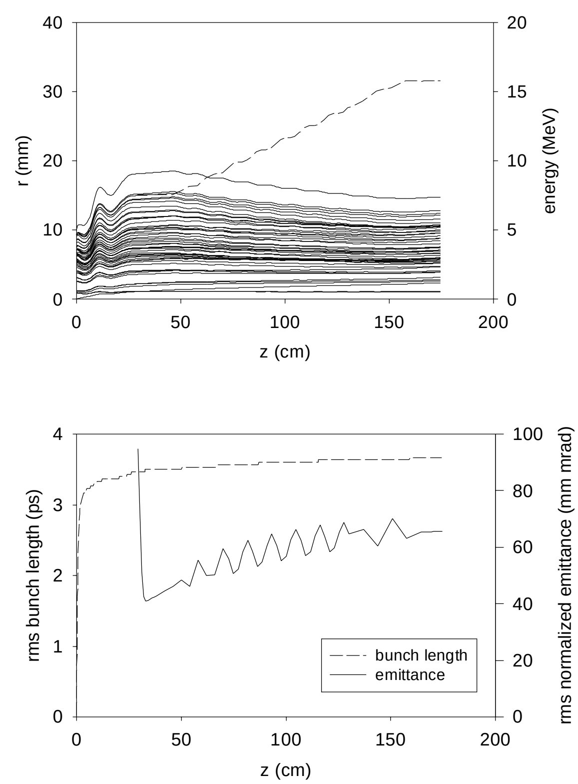

Figure 2: Numerical simulations of a 40 nC electron bunch as it propagates along the gun and linac

structures: (a) energy and trajectories in the transverse plane; (b) bunch length and emittance.

The gun is presently at the very last step in construction (Fig. 3). The final RF tuning has been performed and the internal surfaces of the cavity have been polished. The last step consists of brazing the cells together and welding the vacuum flanges on the various tubes. The value of the unloaded quality factor (Q_0) of the gun is presently 9500, but this number should obviously increase after the final brazing cycle. Figure 4 shows the profile of the axial electric field along the axis of the cavity measured by the usual bead-pulling technique.

Figure 3: Gun before final brazing cycle.

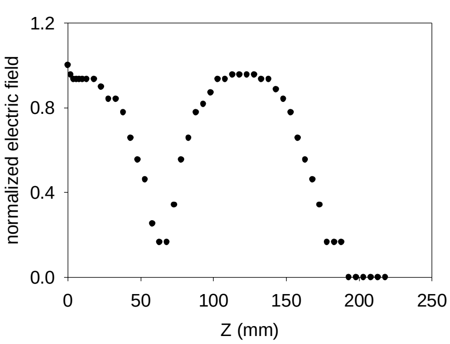

Figure 4: Profile of axial electric field along the axis of the cavity.

4 CONCLUSION

The new AWA photocathode RF gun will dramatically improve the capabilities of our program to study wakefield acceleration in dielectric loaded structures and plasmas. The electron beam produced by this gun is expected to excite wakefields in plasmas with accelerating gradients in excess of 1 GeV/m with a plasma density of ~10^{14} /cm^3.

In dielectric loaded structures, this beam will also make a significant improvement over presently attainable gradients. One can use this beam to directly demonstrate collinear wakefield acceleration gradients in excess of 50 MV/m corresponding to 200 MW of RF power generated in 30 GHz dielectric structures.

It is worth pointing out that the present AWA photocathode RF gun has achieved unprecedented values of charge per bunch, and has allowed us to advance the understanding of wakefield acceleration in plasmas and in dielectric structures. However, the present gun was designed when only a very limited amount of RF power was available for the experiment (2 MW). Thus, the beam parameters, namely, bunch length and emittance, suffered serious limitations due to this relatively low level of RF power. The newly designed gun will take advantage of the higher level of RF power now available in the facility, yielding better beam parameters and, consequently, higher accelerating gradients in the wakefield acceleration experiments.

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