RECEIVED

AUG 04 1997

ANL/ASD/CP-94043

CONF-970706--

Preliminary calculations of ballistic bunch compression with thermionic cathode rf guns

J.W. Lewellen and S. Milton

Advanced Photon Source, Argonne National Laboratory

Argonne, IL 60439

ABSTRACT

Preliminary calculations using the computer code PARMELA indicate that it is possible to achieve peak currents on the order of 1 kA using a thermionic-cathode rf gun and ballistic bunch compression. In contrast to traditional magnetic bunching schemes, ballistic bunch compression uses a series of rf cavities to modify the energy profile of the beam and properly chosen drifts to allow the bunching to occur naturally. The method, suitably modified, should also be directly applicable to photoinjector rf guns. Present work is focusing on simultaneously compressing the bunch while reducing the emittance of the electron beam. At present, the calculated normalized rms emittance is in the neighborhood of $6.8 \pi \text{ mm mrad}$ with a peak current of 0.88 kA, and a peak bunch charge of 0.28 nC from a thermionic-cathode gun.

Keywords: bunch compression, emittance, rf gun, thermionic cathode

1. INTRODUCTION AND MOTIVATION

High-brightness electron beams – those with simultaneously high peak currents, low normalized transverse emittance, and low energy spread – are very desirable for both future linear colliders and as drive beams for linac-based free-electron lasers. The usual methods for generating such beams begin with good transverse emittances and modest currents. After some initial acceleration the beam is then compressed longitudinally to increase the peak current. During this procedure care must be taken to preserve the transverse emittance.

1.1 Bunch compression methods

The current method of choice for generating high-brightness beams is the use of a photocathode rf gun to generate a low-emittance electron beam with modest beam current. The standard space-charge force decreases as γ^2 , where γ is the relativistic Lorentz factor. Bunch lengths are kept purposely long until the energy is high to retain low charge densities. This keeps space-charge driven dilution of the emittance in check. Bunching is then achieved by giving the beam a suitable energy slew and passing it through a magnetic chicane. Depending on the final energy and the required peak current, this process may be repeated in two or more stages. Another magnetic bunching method that has been used successfully involves passing the beam generated by a thermionic-cathode rf gun through an α -magnet.¹ This method takes advantage of the natural correlation between energy and longitudinal position within the beam created by a thermionic-cathode gun; however, maintaining the transverse emittance in this process is difficult.

1.2 Problems with bending techniques

There is a problem common to all magnetic bunch compression techniques. Essentially, when the beam is being bent and longitudinally compressed, it is in a noninertial reference frame, and there is a component of the space-charge force, due to the noncancellation of the electric and magnetic fields, which does not scale inversely with beam energy. This noninertial space-charge force depends on the bend radius, length of the bunch, and peak current, but not the beam's Lorentz factor.² ph

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Further author information –

J.W.L. (correspondence): Email: Lewellen@aps.anl.gov; telephone: 630 252 5252; fax: 630 252 4732

S.M.: Email: Milton@aps.anl.gov; telephone: 630 252 9101; fax: 630 252 4732

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

In practice, this would appear to place an upper limit on the attainable brightness of electron beams, since this force will tend to increase the beam emittance as the peak current is increased independent of the beam energy.

1.3 Ballistic bunch compression

As an alternative method, an electron beam may be longitudinally compressed by placing a suitable velocity spread on the beam and allowing it to drift. Simplistically speaking, faster-moving particles at the rear of the bunch will overtake slower-moving particles at the head, and the bunch length will continue to decrease until the faster-moving particles overtake those moving more slowly, at which point the bunch length will begin to increase again. The process is known as ballistic compression and has been used in klystrons for decades to produce bunched beams. To date, however, little work has been done towards using this method with a relativistic electron beam source such as an rf gun. Its primary advantage over conventional magnetic bunching techniques is the lack of reliance on a magnetic field to perform bunching. Therefore, noninertial space-charge force is not an obstacle to achieving arbitrarily short bunch lengths. If one also keeps the transverse emittance in check, this method provides a powerful alternative to the first stage of magnetic bunch compression in the production of a high-brightness electron beam.

2. THEORY OF BALLISTIC BUNCHING

2.1 No-charge, two-particle bunching equation

In ballistic bunch compression, particles at the tail of the bunch are given a larger velocity than particles at the head of the bunch. After passing through a drift space with a length determined by the relative velocity between the particles, the particles originally at the rear of the bunch will be in the same longitudinal plane as the particles at the head of the bunch. This is the point of maximum compression. Figure 1 illustrates the process.

Figure 1. Two-particle ballistic bunching in the absence of space charge. Length of the arrows indicate the magnitude of the leading and trailing particle velocities.

The two-particle relativistic ballistic bunching relationship is

$$d_i = \left(\frac{\sqrt{1 - \frac{1}{\gamma_L^2}}}{\sqrt{1 - \frac{1}{\gamma_T^2}}} - 1 \right) \cdot d_b, \quad (1)$$

where γ_L and γ_T are the Lorentz factors of the leading and trailing particles, respectively; d_i is the initial separation between the leading and trailing particles; and d_b is the distance over which bunching takes place.

As an example, consider an electron bunch 10 mm in length. This is seen in Figure 2, which exhibits the required γ vs. longitudinal position within the bunch in order to obtain perfect bunching (in the absence of space charge). Given a bunching distance of one meter, bunches with leading particle having $\gamma_L = 3$ and 5 both have very reasonable γ vs. position profiles. The situation changes when the bunching distance is reduced to $\frac{1}{2}$ meter. The bunch with $\gamma_L = 3$ still has a reasonable profile. The bunch with $\gamma_L = 5$, however, cannot have a bunch length much longer than 10 mm, or it is physically impossible for the bunch to fully compress within $\frac{1}{2}$ m drift space. The profile exhibited for a leading $\gamma_L = 5$ and $\frac{1}{2}$ meter bunching distance, while physically possible, would not easily be achievable in practice due to the large energy spread compared to the bunch length.

Figure 2. Lorentz factors required for perfect bunching for various leading particle γ and initial trailing distances, given two different bunching distances.

2.2 Other factors

The simple calculations above indicate that ballistic bunch compression is at least within the realm of possibility, for reasonable choices of γ , bunching distance, and initial bunch length. There are several immediately apparent problems with using ballistic bunch compression, however, which cannot be taken into account using the simple analysis shown above.

First, the simple fact that the beam is charged poses a difficulty. As the bunch is compressed, both the longitudinal and transverse space-charge forces within the bunch will increase. Since the ballistic bunch compression is taking place at low energy, this may act to increase the beam emittance and lower the efficiency of the bunch compression process. At higher beam energies the space-charge force is reduced, but the required bunching distances can rapidly increase to the point of impracticality.

Second, the beam generated by the cathode cell of a thermionic or photocathode rf gun is unlikely to have the proper longitudinal energy distribution. One or more independently powered rf cavities must be used to properly modulate the beam for ballistic bunch compression. Proper modulation will rely on proper matching between the beam profile leaving the cathode cell, the field profiles, strengths, and phases in the bunching cavities, etc. Further, the energy modulation of a particular particle will be influenced by its velocity upon injection into the bunching cell(s), and the relative velocity spread within a bunch can be quite large in the case of a thermionic-cathode rf gun.^{3,4}

In a related problem, because the intent is more to provide an energy modulation or slew to the bunch rather than to increase the total kinetic energy of the bunch, the rf gun system will not be operating in a π mode; therefore, portions of the bunch may be passing cell nose cones when the field is at its peak value and radial rf fields are strong. This may have a deleterious effect upon the beam emittance.

Finally, within a single longitudinal slice of the bunch, particles may have different energies depending on the particle's radial point of emission from the cathode. This effect alone will place an absolute lower limit on the achievable bunch length.

3. SIMULATION METHODOLOGY

Although the mechanics of simulating a thermionic-cathode gun and a photocathode gun are somewhat different, there are many shared problems and techniques. Problems common to both include the difficulties inherent with a dramatically changing longitudinal bunch size as a function of distance, proper representation of rf and static magnetic fields, etc. The overall methods of simulation control, parameter optimization, and data analysis are also shared by both types of gun simulation.

3.1 Common difficulties

Choice of a proper mesh for space-charge calculations is critical to accurate modeling of an electron beam. PARMELA⁵, the computer code used in the majority of these simulations, uses a 2-dimensional mesh for charge position to calculate space-charge forces[†]. The mesh spacing of the space-charge grid must be fine enough to accurately reproduce the major features of the bunch; but the overall number of mesh points should also be kept reasonable in order to minimize run times and, indeed, to permit the space-charge grid to fit within available computer memory. The optimal space-charge grid also varies over time. A space-charge grid with acceptable mesh spacing at the start of the bunch compression drift space will be (given reasonable compression) both far too large longitudinally and too coarse by the time the bunch reaches the end of the drift space. To deal with this difficulty, the mesh dimensions are varied during the course of the simulation. A "test" beam is propagated (without space charge) through a reasonable number of steps. The particle distribution is analyzed to obtain mesh parameters used to propagate the "real" beam through the same number of steps. The "real" beam is then used as the basis for the next "test" beam propagation, and so forth. For both photocathode and thermionic cathode simulations, the mesh spacing is chosen such that no more than 5% of the total charge is encompassed in a single longitudinal mesh spacing. For a thermionic cathode gun simulation, the mesh extent is chosen to encompass at least 50% of the beam. This is not as poor an approximation as it might sound at first, because most of the neglected charge is contained in the low-energy tail and may be safely neglected. The 50% figure is a compromise between accuracy and the computational speed. For a photocathode simulation, the mesh extent is chosen to encompass all of the beam. Similar mesh parameter selection can be done in the radial dimension as well.

The choice of boundary conditions at the cell-to-cell interface for rf guns operating in a π -mode is relatively straightforward. Moreover, what cell-to-cell coupling does exist merely tends to slightly raise or lower the field strengths in adjacent cells. The choice becomes somewhat more questionable when the gun is taken out of a π -mode, as is done in ballistic bunch compression. In this case the cell-to-cell coupling can have an effect on the beam distribution. This is due to an effective phase shift as well as field strength change in the adjacent cells when coupling is taken into account.⁶ Since the phase and field strengths of the bunching cells are independently controlled, however, the effective phase shift should pose no real difficulties.

As for the choice of boundary conditions influencing simulation results, the simulations have been carried out with both Dirichlet and Neumann boundary conditions used when generating the field profiles; little difference in obtainable bunching was observed. (There were small differences in required phases and field strengths, but nothing large enough to indicate that the choice of boundary conditions was vital. Again, the flexibility of having independently controlled cavities allows one to compensate for many things.)

3.2 Common techniques

There are a large number of adjustable parameters in any rf gun simulation. For these simulations, the adjustable parameters include the microwave field strength in the cathode cell; the current density from the cathode; cathode radius (to an extent); the number of bunching cells; field profile and magnitude in the bunching cell(s); the phase relationships between the cells; and the length of the drift spaces, not only following the last cell but also between the cells. A schematic of such a beamline is shown in Figure 3. In addition, for a photocathode gun the starting phase and, to an extent, duration of the electron emission is variable. Finally, coils may be used to provide beam focusing and emittance compensation control; both coil current and longitudinal position along the beamline may be varied. Performing a grid search over all of these parameters would be impractical. Therefore, a new computer code was written to perform parameter optimization using the downhill-simplex method. This code, *overlord*, repeatedly runs PARMELA to determine the optimum parameters for bunch compression, given a description of the beamline and information as to which parameters may be varied. *overlord* can optimize the bunch length, emittance, or a normalized brightness factor using any of several different methods for calculating those quantities. Simulations are performed using PARMELA with the 2-d mesh-based space-charge calculation and adaptive longitudinal grid size approach described above. A second code, *pest*, was written to perform the adaptive mesh parameter beam propagation described above. *pest* exists in two forms: as a stand-alone

[†] PARMELA also provides a fully 3-d, point-to-point space-charge calculation, but in this mode simulation run time is related to the square of the number of particles. It is impractical for this particular problem.

program and as a subroutine incorporated into overlord. In its standalone form, it should operate properly with any valid PARMELA input file.

Figure 3. Sample of a simple beamline used in bunch compression simulations. All simulations include at least one cathode and one full cell; some simulations also include additional full cells and solenoid coils.

Initial simulations of both types of guns are carried out without space charge; this is done to quickly determine the approximate values of the optimized parameters. These rough values can in turn be used as a starting point for optimizations performed with space charge and the adaptive grid parameter method, saving considerable time.

Simulations of both thermionic-cathode and photocathode guns have been performed with the partial (cathode) and full cell profiles shown below.⁴ Figures 4 and 5 are plots of the cavity cross sections and longitudinal field strength along the axis for the cathode and full cells, respectively. This gun design was originally created for use with a thermionic cathode in an α -magnet bunch compression scheme. The cavity designs, however, are reasonably good at controlling emittance growth and have proven to be reasonable initial geometries for these simulations. As an alternative, initial thermionic-cathode gun simulations that allow the full cell field profile to vary (by optimizing on the spatial harmonic content of the field) show promise that alternate cell designs may perform better for ballistic bunch compression. As a final statement, there is no guarantee that both photoinjector and thermionic-cathode gun systems would have the same ideal field profile; however, there is some indication that this may be so.

Figure 4. Cathode cell (a) cross section and (b) on-axis field as a function of axial position.

Figure 5. Full cell (a) cross section and (b) on-axis field as a function of axial position.

3.3 Thermionic-cathode gun simulations

There are two difficulties associated with the simulation of a thermionic-cathode rf gun, both relating to the continuous nature of electron emission from the cathode. First, because a thermionic cathode is always emitting electrons, the velocities of particles in the cathode cell of a thermionic-cathode gun range from effectively zero to almost lightspeed. A code that takes into account only particle position and not current flow can encounter difficulty in dealing with such a beam. Second, the beam is typically long – on the order of 40 - 50 ps – which, if the mesh has fixed spacing throughout its extent, requires a large number of mesh points to adequately encompass the beam extent.

Since PARMELA does not take into account current flow in its grid-based space-charge calculations, and because the point-to-point space-charge calculation would take too long, a separate code is used to propagate the electron beam from the thermionic cathode to the exit of the cathode cell. This code, *spiffe*, is a fully self-consistent particle-in-cell code and incorporates the interaction of the beam with the cavity fields as well as with the space charge and current flow. It does require significant amounts of computer time and memory, however, and is therefore not used to simulate the entire beamline. By the time the beam reaches the exit of the cathode cell, those particles which will be useful in ballistic bunch compression can be adequately tracked via PARMELA. The disadvantage to this approach is that *overlord* cannot directly control the cathode radius, cathode emission current density, or cathode cell field strength. Drawing some analogies and lessons from the photocathode simulations, however, the most commonly used beam distribution was generated with peak on-axis field gradient of 50 MV/m, a 3 mm-radius cathode, and a cathode emission current density of 40 A/cm². We are working on an analytical model for beam distributions from the cathode cell, to allow *overlord* to optimize those parameters as well.

The beamline from the exit of the cathode cell to the measurement point is simulated using PARMELA. In general, it is assumed that all rf cavities in the line, with the exception of the cathode cell, share the same field profile. If the field profile of the full cell(s) is being optimized, the field is represented by Fourier coefficients; otherwise a field distribution generated by SUPERFISH is used. In this preliminary investigation, emittance compensation coils have not been generally used with the thermionic-cathode gun simulations. The exit aperture of the rf cavities is taken to be 0.508 cm in radius, and the radii of all drift spaces are 1.25 cm.

3.4 Photocathode gun simulations

In a typical photoinjector simulation, the total electron emission time is on the order of 10 ps or less. In this regime, PARMELA's method of space-charge calculation is reasonably accurate, and there is no need to use *spiffe* to propagate the

beam from the photocathode to the exit of the cathode cell. Also, a shorter longitudinal mesh (which does not imply a coarser mesh spacing) may be used than with a thermionic-cathode simulation.

Unlike a thermionic cathode, the electron emission from a photocathode is effectively gated by the timing between the rf field in the cavity and the drive laser. Likewise, the temporal (or longitudinal) and radial profiles of the beam are controlled by the shape of the incident laser pulse, whereas a thermionic cathode emits electrons more or less uniformly over the entire cathode surface and continuously over all time. For these simulations the drive laser pulse is assumed to be square and flat-topped, that is, uniform electron emission in time and over the radius of the spot. In several of the optimization runs performed, *overlord* was allowed to vary the phase offset between the drive laser pulse and the rf field in the cathode cell, as well as the strength of the rf field in the cathode cell.

The field profile of the cathode cell is generated using SUPERFISH, and the space-charge computation while the beam is in the cathode cell assumes a metal plate at $z = 0$ to simulate the back wall of the cathode cell. The remainder of the beamline is treated identically to that used in the thermionic-cathode gun simulations, including the ability to optimize on the Fourier space-harmonic coefficients of the full cell field profile.

4. SIMULATION RESULTS

Many optimizations have been performed on both thermionic-cathode and photocathode rf gun systems, and throughout the process the optimization and space-charge grid control methods have been continuously refined. The results presented below in some sense represent the "best" we have to date in terms of our modeling procedure and were done using the latest version of *overlord* and the charge density mesh adaptation routines. Fortunately, once past the initial learning phase, the calculated results did not degrade too severely with successive refinements of the simulation procedure.

4.1 Thermionic-cathode guns

Figure 6(a) shows the beam kinetic energy vs. exit time for the beam exiting the cathode cell, generated by *spiffe* assuming 40 A/cm^2 current emission density, a 3 mm-radius cathode, and 50 MV/m peak field. Figure 6(b) is the current vs. cathode cell exit time from the same simulation. All of the results from the thermionic-cathode cell simulations presented below used this distribution as the input into PARMELA, which has just over 1 nC being emitted from the cathode cell per rf period. The slight thickness of the curves in both plots is not an artifact; rather, it results from the variation in field strength over the cathode radius.

Figure 6. Typical *spiffe* output of (a) beam kinetic energy and (b) current vs. exit time from the cathode cell shown in Figure 4. For this simulation, the peak accelerating gradient was 50 MV/m, the cathode radius was 3 mm, and the current density from the cathode was 40 A/cm^2 .

The distribution shown in Figure 6 was propagated through two full rf cells using optimized field strength and phase parameters, and an optimized drift distance following the second full cell, with the optimizer instructed to maximize the amount of charge contained within a 0.2 ps window. In this simulation no attempt was made at using solenoids to compensate growth in normalized transverse emittance. The results are shown in Figure 7. Figure 7(a) shows particle kinetic energy vs. time of exit at the end of the beamline, and Figure 7(b) shows peak current as a function of time within the bunch. The peak current has been increased by more than an order of magnitude to 0.88 kA. Normalized rms emittance of the beam within the region of peak current is 6.8π mm mrad, and the charge under that peak is approximately 0.28 nC. The total charge reaching the end of the beamline is approximately 0.8 nC, with the loss of 0.2 nC occurring mainly on the nose cones of the full cells. Most of the lost particles are from the low-energy tail.

Using this same beamline arrangement, it is possible to generate beams with lower peak currents and lower emittances by using alternate field strength and phase settings in the full cells. So there is in some sense a trade between beam emittance and peak current, and in fact it may be more useful to define a "brightness" parameter in terms of the eventual requirements for the beam. For instance, in the case of a single-pass free-electron laser it may be more realistic to maximize a brightness defined as the ratio of peak current to beam emittance.

Figure 7. PARMELA output of (a) beam kinetic energy and (b) current vs. exit time at the end of the beamline. The simulation used as input the beam shown in Figure 6 and two full cells for energy modulation.

4.2 Photocathode guns

Figure 8 shows the results of propagating a 1 nC bunch, originally of 10 ps duration, through a beamline consisting of a cathode cell, two full cells, and a drift space. The emission start time, field strength in all cells, field phases in the full cells, and length of the final drift space were all optimized to generate these results. The cathode and full cell designs were the same as those used in the thermionic-cathode gun simulations and shown above. The peak current achieved, 2.3 kA, is very reasonable for a first attempt, but the emittance, 6.1π mm mrad (normalized rms), is too high. These calculations were done without the use of emittance compensation coils, however, and it is expected that their incorporation will help to reduce the final beam emittance without overly degrading the longitudinal compression. Total charge under the peak is approximately 0.57 nC, with some of the beam lost on the nose cones of the rf cells and the remainder in the tails of the exiting beam. A redesign of the rf cells will probably help to improve beam transport through the gun and to increase the amount of charge under the peak. Since R/Q is not a problem at these moderate field strengths, a simple enlarging of the apertures could work to achieve higher total charge delivery; care would have to be taken to avoid increasing cell-to-cell coupling-induced problems, however.

Figure 8. PARMELA output of (a) beam kinetic energy and (b) current vs. exit time at the end of the beamline, assuming a photocathode with 2 mm radius, 1 nC charge, and emission over 10 ps, and using two full cells for energy modulation.

4.3 Summary of optimized parameters and results

The optimized parameters and the results obtained are listed in Table 1. The E_n 's refer to the peak on-axis field strength in the n -th cell, with cell 0 being the cathode cell. The phase offsets of the cells are given by the ϕ_n 's, using the cathode cell phase as a reference. L_d is the drift length following the last full cell; the bunch peak current is measured at the end of this drift. For the photocathode, Φ_0 and $\Delta\Phi$ refer to the starting phase and duration of electron emission from the photocathode, respectively; these are not applicable for the thermionic cathode. The cathode radius in mm is given by r_{cath} . Q_{cath} is the total charge emitted from the cathode, and Q_{peak} is the charge under the compressed peak at the end of the beamline. I_{peak} is the peak current recorded, and $\epsilon_{n,\text{RMS}}$ is the normalized rms emittance for the portion of the beam under the current peak. Field strengths and phases which are bold-faced were allowed to vary in obtaining the results shown.

Cathode type	E_0 MV/m	Φ_0 deg.	$\Delta\Phi$ deg.	r_{cath} mm	E_1 MV/m	ϕ_1 deg.	E_2 MV/m	ϕ_2 deg.	L_d cm	Q_{cath} nC	Q_{peak} nC	I_{peak} amps	$\epsilon_{n,\text{RMS}}$ mm mrad
thermionic	50.0	n/a	n/a	3	62.8	83	72.0	268	35.2	1.0	0.28	880	6.8 π
photo	54.3	20.5	10	2	62.1	85	71.4	266	36.0	1.0	0.57	2300	6.1 π

Table 1. Parameters used in the above simulations. Bold-faced entries represent optimized values of parameters allowed to vary during the simulation.

5. CONCLUSIONS

5.1 Results to date

The results of the calculations shown above indicate that ballistic bunch compression is a viable alternative or augmentation to more traditional magnetic bunch compression. The results obtained with the thermionic-cathode gun simulations are particularly encouraging, since they show that thermionic-cathode guns may in fact be able to perform as well as photocathode guns in some applications. This has implications for self-amplified spontaneous emission free-electron laser experiments whose requirements cannot be satisfied with conventional thermionic-cathode guns, but for which a high-performance photocathode gun would be too expensive.

5.2 Future plans

Computationally, the studies of both thermionic-cathode- and photocathode-based guns will be continued. In particular, the effects of adding emittance compensation to the photocathode guns will be investigated, as well as the possibility of

providing emittance compensation to the thermionic gun. The field profiles of the full cells will be optimized, not only for peak beam current but for peak "brightness" as well, defined as peak current/emittance, for both thermionic-cathode and photocathode guns. It is also interesting to note that the fully optimized photocathode and thermionic-cathode guns have the full cells approximately 180 degrees apart and very similar field strengths, similar to a π -like mode. One possibility would be to lock these two cells into a true π -mode but vary the spacing between them in an attempt to simplify the rf power system that would be needed to drive such a gun.

Development will continue on the analytical modeling of the beam profiles at the exit of the cathode cell. To date, several spiffe-generated beam profiles can be described to within 1% longitudinally and 5% transversely, by relatively simple functions. The same functions can be used to describe behavior over a reasonably wide range of cathode cell field strength and current emission densities, using different fitted parameters. If the fitted parameters are found to vary smoothly over a range of field strengths and current densities, the model can be used to generate beam distributions from the cathode cell without the need to run spiffe. This in turn will permit the overlord simulation to more completely optimize a thermionic cathode gun.

Experimentally, we are designing a bunch compression test stand for the purpose of evaluating several bunch compression methods in conjunction with different types of rf guns. The design of the stand will be as modular as possible, with gun design testing proceeding in stages. That is, first the behavior of the cathode cell alone will be fully characterized, including measurements of emittance, beam energy as a function of beam current and microwave power input, bunch length, etc. These measurements will be repeated as additional rf cavities are added to the beamline. In this manner the experimental test of ballistic bunch compression will proceed in a piecewise fashion, instead of attempting to start with a completed system and generate a compressed bunch from the outset. This will not only help to ensure that each portion of the system is behaving as expected, but will also provide a more detailed mapping of overall system performance under varying conditions. The preliminary design of the bunch compression test stand will be reported elsewhere.

ACKNOWLEDGEMENTS

This work is supported by the U.S. Department of Energy, Office of Basic Energy Sciences under Contract No. W-31-109-ENG-38.

REFERENCES

- ¹ H-C Lihn et al., "Measurement of 50-fs (RMS) electron pulses," *AIP Conference Proceedings: Beam Instrumentation Workshop*, 333, pp. 231-237, 1995.
- ² B.E. Carlsten and T. Raubenheimer, "Emittance growth of bunched beams in bends," *Physical Review E*, 51 (2), pp. 1453-1470, 1995.
- ³ M. Borland, *A High-Brightness Thermionic Microwave Electron Gun*, Stanford University Ph.D. Thesis, 1991.
- ⁴ M. Borland, "Cavity design and beam simulation for the APS RF Gun," Advanced Photon Source Light Source Note LS-186, 1991.
- ⁵ L. Young, computer code PARMELA, revision date 14 March 1997; J. Billen, "PARMELA," Los Alamos National Laboratory document LA-UR-96-1835, revision date 14 March 1997.
- ⁶ J.W. Lewellen, *Thermionic Cathode RF Guns for Compact Free Electron Lasers*, Stanford University Ph.D. Thesis, 1997.