THE UNIVERSITY OF MARYLAND ELECTRON PULSE COMPRESSION EXPERIMENT*

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Abstract

For the past 5 years, the Maryland Electron Beam Transport Experiment has been devoted to the study of high perveance beam dynamics in the transverse dimensions. In that experiment, a 5keV, 240mA electron beam with a 2μs pulse length is injected into a 5m channel of periodically spaced solenoids. A newly designed injector will now extend the study to include the beam physics (emittance growth, etc.) of an electron pulse undergoing longitudinal compression. Consisting of a variable-perveance gridded electron gun followed by one induction module, this injector will produce a 50ns, 40mA electron pulse with a 5keV, quadratically time-dependent energy shear. Preliminary computations suggest that a beam with these initial conditions will compress by about a factor of 5 before reaching the end of the channel. First results from tests of the major system components are presented along with a description of planned experiments.

Introduction and Motivation

Linear accelerators for high-energy physics, induction linacs for heavy ion fusion, microwave devices such as the klystron, and other applications of intense charged particle beams require bunching, or longitudinal compression, of the beam. The electron injector for the SLAC linear collider, for instance, produces a longitudinal compression of more than a factor of 100 via subharmonic bunching. Even larger compression ratios will be required for heavy ion fusion. Although it is well known that considerable emittance growth occurs during the bunching process, the physics is not yet well understood. A systematic study of the physics could result in improved design schemes in which emittance growth is greatly reduced.

A major problem in the experimental study of electron beam devices is the short time scale of the bunches (e.g., picoseconds in S-band RF linacs). This makes it very difficult to resolve the details of the bunching process. In our experiment, we plan to operate in a nanosecond time scale (pulse length of 50ns) to avoid this difficulty. Because the experiment utilizes a low energy (about 5keV) electron beam, the physics including space charge can be studied at a reasonable cost. Furthermore, we plan to use the existing 36 solenoid transport channel that has provided the basis for our past beam transport studies[1,2]. Modifications required for compression experiments are therefore limited to the injector and diagnostic systems.

Theoretical Design Studies

Requirements for the compression system injector were determined by studying the envelope equations for a round electron beam. Assuming the beam has a K-V distribution, we have the transverse envelope equation[3]:

$$R'' + \kappa R - \frac{K}{R} - \frac{\varepsilon_T^2}{R^3} = 0 \,, \qquad (1)$$

where $R = R(z)$ is the transverse envelope of the beam, the prime denotes d/dz, κ is the periodic focusing function of the lens system, and ε_T is the transverse emittance.

$$K = \frac{I}{I_0}\frac{2}{\beta^3\gamma^3} \qquad (2)$$

is the generalized perveance where $I_0 = 1.7 \times 10^4$ A is the characteristic current for electrons, $\beta = v/c$ is the ratio of the particle velocity to the speed of light, and $\gamma = (1 - \beta^2)^{-1/2}$ is the relativistic mass factor.

For the longitudinal motion, we use the longitudinal envelope equation[4]:

$$Z''_m - \frac{3}{2}\frac{gNr_e}{\beta^2\gamma^5}\frac{1}{Z_m^2} - \frac{\varepsilon_L^2}{\gamma^4}\frac{1}{Z_m^3} = 0 \,, \qquad (3)$$

where $Z_m = Z_m(z)$ is the longitudinal envelope of the beam, z is the longitudinal distance travelled by the beam bunch center, $g = 1 + ln(b/a)$ where b is the tube radius and a is the beam radius, $N = I\tau/e$ where I is the beam current and τ is the pulse length, r_e is the classical electron radius, and ε_L is the longitudinal emittance of the beam.

During the compression process, the total number of electrons remains constant, but the current increases according to the relation

$$N = \frac{I\tau}{e} = \frac{I_i\tau_i}{e} = constant \,, \qquad (4)$$

where the subscript i stands for the initial conditions.

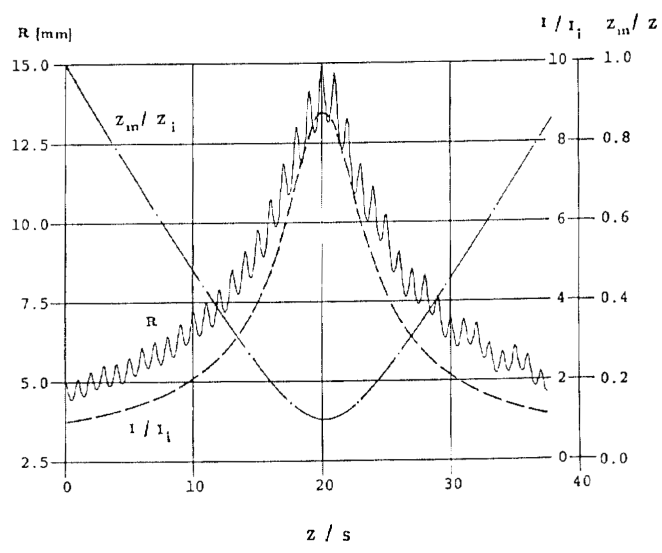

Figure 1. Results of numerically solving the envelope equations

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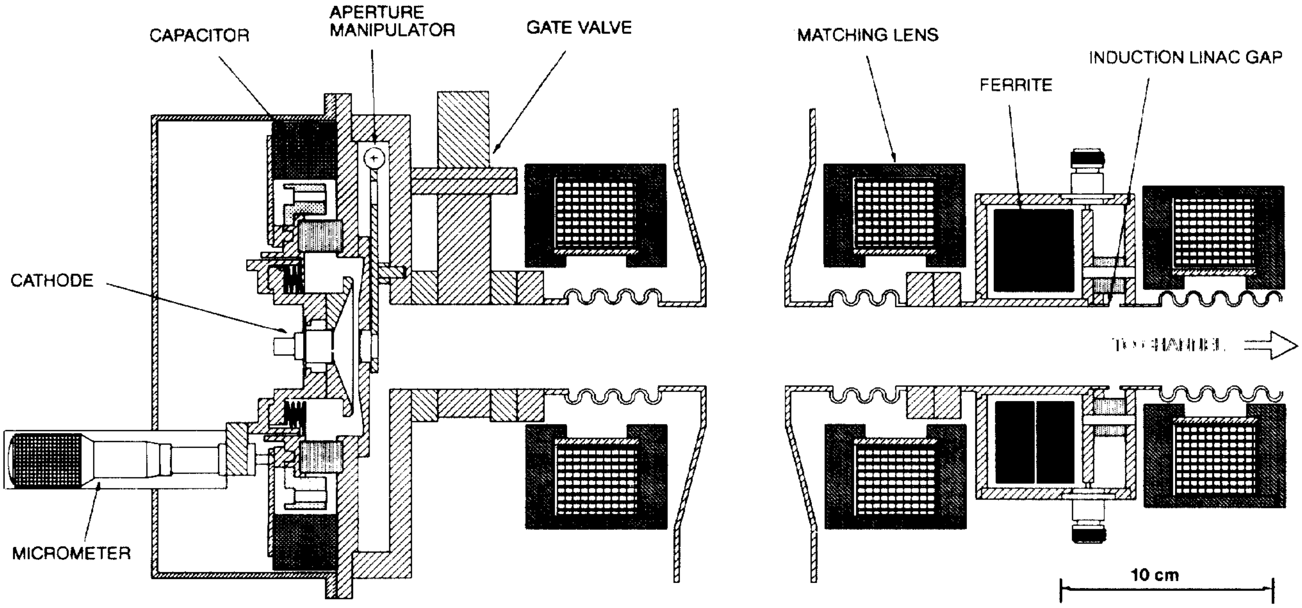

Figure 2. *Mechanical drawing of the compression system injector*

Therefore, for a linear compression we obtain the following relation for the beam current:

$$I = \frac{I_i Z_i}{Z_m} = \frac{I_i}{R_c} \quad , \tag{5}$$

where $R_c = Z_m/Z_i$ is the compression ratio of the longitudinal envelope. Using this expression for the current in equation (2), we obtain the generalized perveance during compression:

$$K = \frac{I}{I_0}\frac{2}{\beta^3\gamma^3} = \frac{(I_i/R_c)}{I_0}\frac{2}{\beta^3\gamma^3} = \frac{K_i Z_i}{Z_m} \quad , \tag{6}$$

where K_i is the initial generalized perveance.

To study the radial focusing during longitudinal compression, we use relation (6) in equation (1). We have developed a computer program for solving equations (1) and (3) simultaneously with (6) for K to obtain the compression ratio R_c, the current ratio I/I_i, and the transverse envelope R as a function of distance along the channel z/S. For our 5m long channel, s is 13.6cm. Figure 1 shows these results for I_i = 40mA, τ_i = 50ns, E_{center} = 5keV, E_{head} = 2.5keV. These are typical operational parameters expected of the new injector.

Experimental Setup

A typical scenario for producing the pulse compression in the laboratory is as follows. A 40mA, 2.5keV electron beam is launched from a gridded electron gun. The beam pulse is 50ns long and has subnanosecond rise and fall times. After travelling a short distance through two solenoids, the pulse enters an inductively isolated gap. The gap voltage rises from 0 to 5kV with quadratic time dependence. From here, the beam goes through one more matching lens and into the channel where the beam's initial velocity shear causes it to bunch almost linearly as it drifts. Diagnostics intercept the beam at various locations in the channel and record the energy, charge, and current as a function of both time and transverse position. The gun, the induction linac , and the diagnostics must all be synchronized to within one nanosecond to produce meaningful results.

For the compression system, a new electron gun has been designed and constructed. Significant features include: variable cathode-anode spacing, easily replaced field-shaping electrodes, a 1 cm diameter cathode that can be replaced without dismounting the gun, an integral wideband current transformer, an in vacuum manipulator for beam mask selection, a mount with 4 degrees of freedom, and a gate valve. The mechanical geometry of the gun is shown in Figure 2. The electrodes of this gun are shaped to form a Pierce geometry with a gridded anode. The entire cathode assembly is mounted on three micrometers to allow continuous variation of the cathode-anode spacing. With the available range of adjustment the gun will be able to produce currents from less than 10mA up to about 1A. Because these adjustments can be made while the gun is in operation, alignment and current variation can be performed interactively with real-time feedback from beam profile and current monitors.

The gridded, off-the-shelf cathode assembly has an 8pF

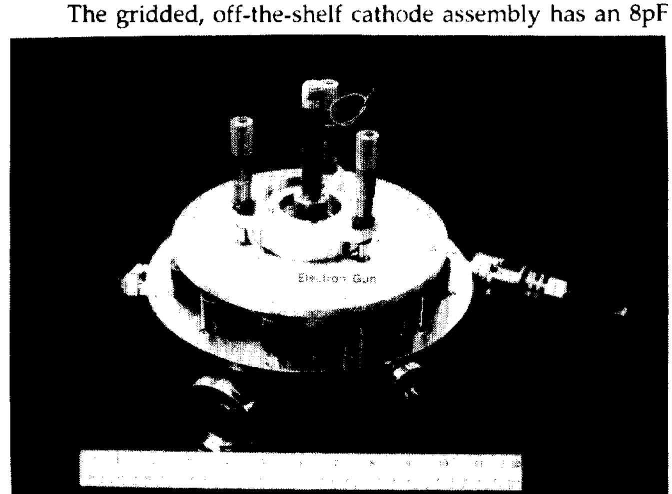

Figure 3. *Rear view of the electron gun*

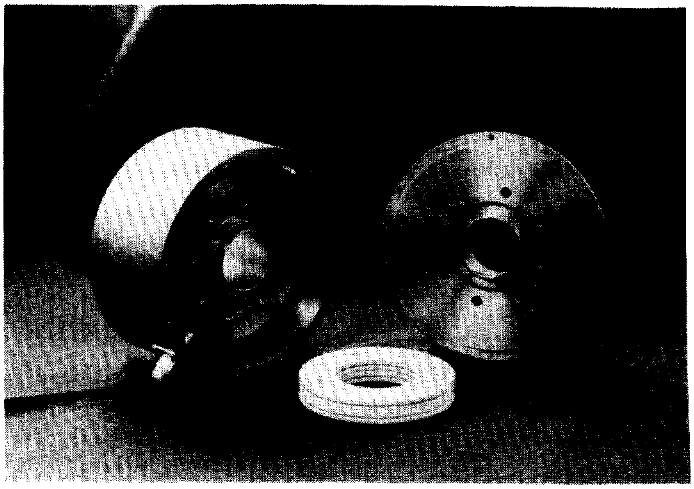

Figure 4. *Disassembled induction linac*

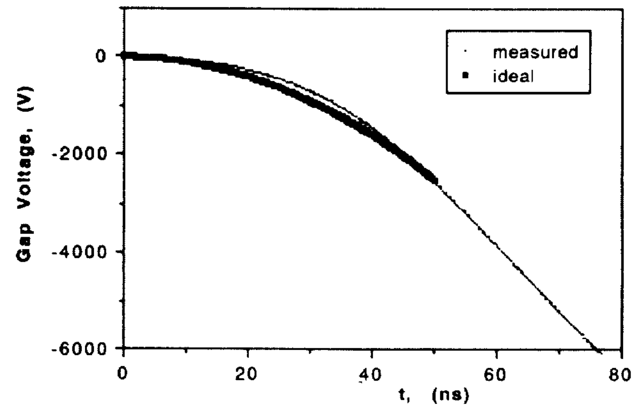

Figure 5. *Results from the induction linac test*

cathode-grid capacitance that allows a risetime of less than one nanosecond in this 50 ohm system. The cathode pulser system consists of a DC bias supply and a single stage transistor avalanche pulser. We have tested the pulser with it's terminating network and observed the required subnanosecond risetime and jitter. As of March, 1989, the gun had been assembled, mounted, and vacuum tested. Figure 3 shows the 50Ω coaxial feed and the 3 micrometers at the back of the gun.

A single gap induction linac has been assembled and tested. Figure 4 shows the disassembled linac. As illustrated in Figure 2, the linac consists of a single turn primary around 2 ferrite cores with the beam completing the single turn secondary. This arrangement forms an inductively isolated gap with a one to one voltage ratio. The primary is driven symmetrically from two drive points. By using only the first one eighth of a *(1- cosωt)* cycle, we obtain a pulse that has nearly quadratic time dependence. Therefore, the modulator for the induction linac consists of a pseudospark switched *(1 - cosωt)* pulser and an SCR switched reset pulser.

The pseudospark discharge was discovered in 1978 by Christiansen and Schultheiss[5]. It is a fast, spark-like, low-pressure gas discharge that operates on the left side of the Paschen curve. A gap geometry that supports the pseudospark discharge consists of two insulated metal electrodes with a center hole. The discharge is triggered at the cathode by a flashover initiated inside the bore hole across a thin Mylar surface. The jitter is on the order of one nanosecond and the few shots that don't fall within the desired window can simply be ignored by the data acquisition system. The induction linac and it's modulator have been fully tested. Figure 3 compares a recently measured gap voltage pulse to the desired quadratic pulse.

Proposed Experiments

The next stage of this project involves commissioning and testing the new injector. With the exception of the electron gun, all major injector components have been individually tested. A 50Ω fast Faraday cup has been designed and will be used first in electron gun tests. When used as a sole diagnostic, it has the bandwidth to measure the current risetime from the gun. When used in conjunction with beam masks, it's wide dynamic range will allow us to make emittance measurements of the monochromatic beam.

After we are convinced that the gun is operating properly, we plan to assemble the injector as a unit (see figure 2) and make detailed measurements of the beam in six dimensional phase space. A time resolving spectrometer is being designed for this purpose. It consists of a collimator (two pinholes that select one point in transverse phase space) and two sets of deflector plates (one with static voltage, the other driven by a ramp generator) followed by a phosphor screen. An intensified CCD camera will capture the image from the phosphor and the data acquisition system will then reduce this data to a calibrated plot of energy vs. time. In addition to the spectrometer, the 50Ω Faraday cup will be used to measure time resolved current profiles. These diagnostics will allow us to map the beam at injection over a wide range of gun currents, gun voltages, and bunching voltages. The same diagnostics will then be used at the end of our 36 lens channel to measure the beam's phase space after compression and transport.

Acknowledgements

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