THE EFFECT OF INITIAL ENERGY SPREAD ON LONGITUDINAL BEAM MODULATIONS IN AN ELECTRON GUN

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Abstract

Computer simulations are used to investigate the evolution of longitudinal density and energy modulations of an electron beam in a linear accelerator system. This study examines the effect of initial energy spread on the modulations as the beam is accelerated in the electron gun.

INTRODUCTION

Electron beams with periodic longitudinal density modulation may produce terahertz radiation in a linear accelerator. Terahertz radiation is useful for a wide range of applications and research interests, including advanced accelerator applications. In other cases, it may be desirable to suppress unwanted terahertz radiation caused by unintended fluctuations of the electron beam. Whether the radiation is desired or not, it would be useful to understand how the modulations of an electron bunch evolve as the beam is transported through a linear accelerator system. Recent studies, including those by the authors ([1] and [2]), show that density modulated beams with small bunch charge (20 pC) can maintain the density modulation through the accelerator system. However, the simulations in these studies assumed zero energy spread at the cathode. This study examines the effect of the energy spread on the density modulation of the beam as it is accelerated in the electron gun. Simulations are performed using PARMELA and original software codes. Recent results [3] have shown that initial energy spread has a significant effect. This study provides more quantitative insight into the effect of initial energy spread.

SUMMARY OF PREVIOUS WORK

PARMELA is used to simulate electron beams accelerated through a SLAC-type linear accelerator with an ATF 1.6-cell photoinjecting rf electron gun that accelerates electrons to approximately 5 MeV. A charge of 20 pC per electron bunch is used in these simulations, to avoid the effect of space charge.

A pre-modulated beam may be created by applying several pulses of a Ti:sapphire laser to the photocathode of the electron gun [4]. This beam begins with density modulation, but no energy modulation. During acceleration in the gun, the density modulation causes the beam to become energy modulated as well.

In this study, various amounts of energy spread are introduced to the beam at the cathode to see how it affects the density and energy modulation of the beam.

When initial energy spread is present in the beam at the cathode, as is the case with an actual beam, the beam may lose its density modulation. In more extreme cases, such as a beam with rms initial energy spread equal to 5% of its mean value, the beam loses all of its density modulation.

Figure 1 shows a typical density modulated beam at the cathode as well as the beam at the end of the electron gun for various amounts of initial energy spread. For all but the last case, the density modulation remains in the beam. For applications that require a density modulation, these results are encouraging, in that density modulation can be maintained in an accelerator system. However, it also implies that features of a beam that cause unwanted radiation may remain in the beam and would continue to cause unwanted radiation that saps energy from the beam.

Although not shown here, energy modulation behaves similarly. While the beam is not generally energy modulated at the cathode, the density modulation results in energy modulation during the acceleration process, as reported in the authors' previous studies [1-3]. With no initial energy spread in the beam, the resulting energy modulation is significant at the end of the electron gun. As initial energy spread is increased, the energy modulation is reduced, similar to the behavior of density modulation.

THE EFFECT OF INITIAL ENERGY SPREAD

To quantify the amount of modulation in the beam, a curve is fit to the density and energy profile data. The quality of fit corresponds to the amount of modulation. A high enough order fit would have fit a curve to the small-scale features in the modulated beam, rendering this method ineffective. However, for a fit of order 10 or less, the curve fit to the Gaussian-like shape and not to the superimposed modulation. A least-squares fit is used, which minimizes the value

$$\chi^2 = \sum_i \left| f(x_i) - y_i \right|^2 \qquad (1)$$

where the i is a count of data points. For density modulation, indicated by a graph of current versus time, x_i is the time for data point i, y_i is the current for data point i at time x_i, f is the fit function for the data, and $f(x_i)$ is the current for the time represented by time x_i according to the fit function f. Energy modulation is indicated by a graph of $\beta\gamma_z$ versus z. For relativistic energies $\beta\gamma_z$ is

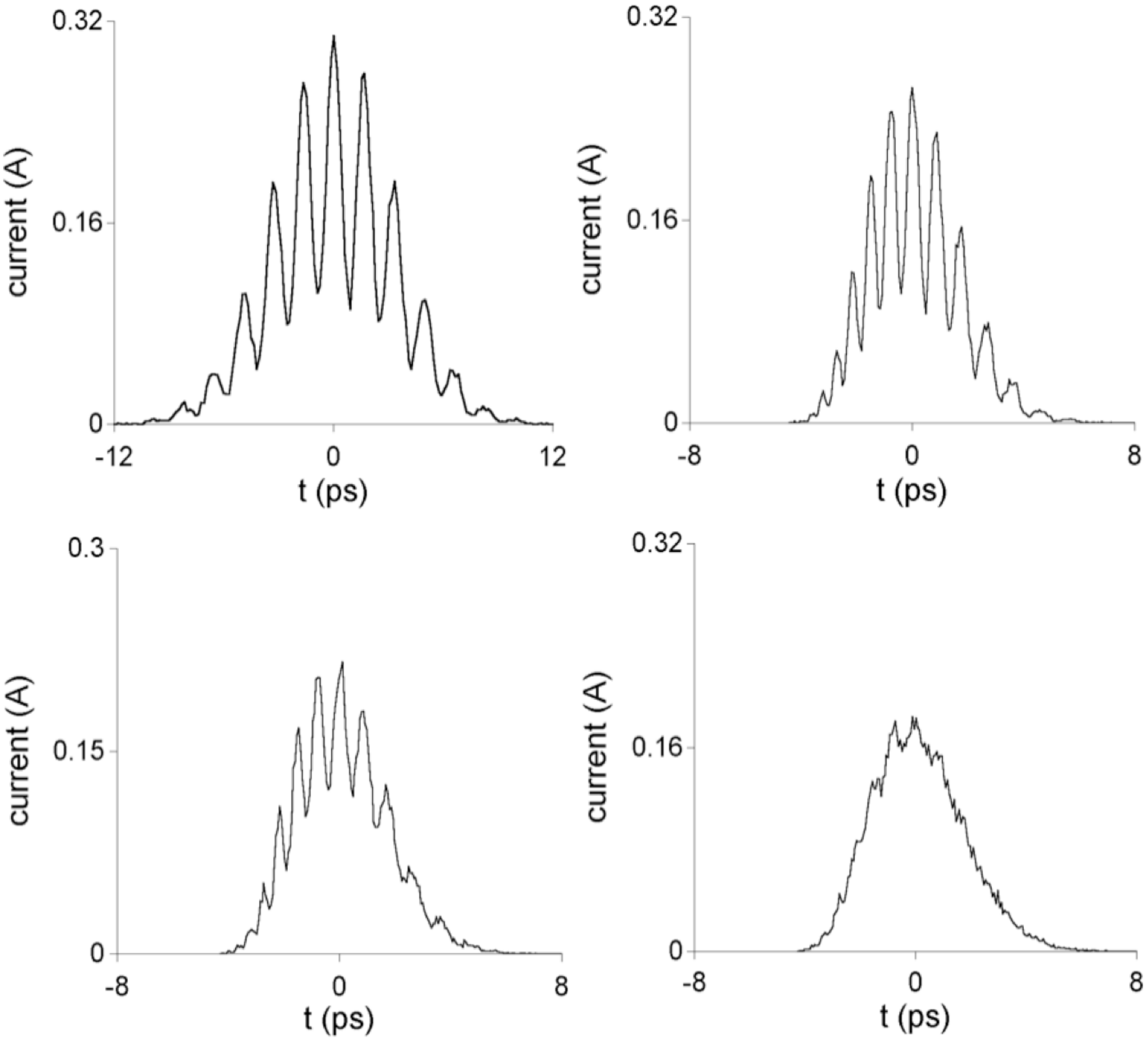

Figure 1: Density profiles of modulated beams. Top left: Density modulated beam at the cathode. Top right: Beam at the end of the electron gun, with no initial energy spread. The beam retains its density modulation. Bottom left: Beam at the end of the gun, with 1% initial energy spread. Density modulation is slightly diminished. Bottom right: Beam at the end of the gun, with 2% initial energy spread. Density modulation is greatly diminished. Note that in general, the amount of modulation becomes more diminished as initial energy spread is increased.

approximately equal to the dimensionless energy γ_z. For this case, x_i is the longitudinal position z for data point i, y_i is the quantity $\beta\gamma_z$ for data point i at position x_i, f is the fit function for the data, and $f(x_i)$ is the energy for the position represented by time x_i according to the fit function f.

The value of χ^2 indicates the smoothness of the beam profile. For a beam with no modulation, the value of χ^2 would be low. For a beam that retains its modulation, the value of χ^2 would be high. See Figure 2 for an example.

Figure 3 shows the relationship between χ^2 and the initial energy spread for the density modulation of the beam. It can be seen that χ^2 is high for a beam with no initial energy spread, indicating that the beam retains its modulation. A beam with 5% initial energy spread loses all of its density modulation. Notice the sharp drop in χ^2 at around 1% initial energy spread. This indicates that this range of initial energy spread is significant. Figure 4 shows the relationship between χ^2 and the initial energy spread for the energy modulation of the beam. The behavior is similar to the case of density modulation and shows that the modulation becomes washed out for higher values of initial energy spread and changes rapidly at an energy spread of approximately 1%.

COMPARISON WITH EXPERIMENT

Experimental studies [4], using the same beam parameters as used in this study, have shown that density modulation may have survived the acceleration process. It is not clear what the initial energy spread was, as it is a nontrivial quantity to determine. Future work could include an analysis of initial energy spread or experiment work to determine actual initial energy spread.

CONCLUSIONS

The effect of initial energy spread is seen clearly. The results show that density and energy modulations become washed out for initial energy spreads of greater than approximately 1% of the mean value. These results show that density modulation can be maintained in a beam, provided the initial energy spread is kept to a minimum. For applications where unintended density modulation is not desired, the results show that the modulation can be expected to wash out during the acceleration process if initial energy spread is large enough.

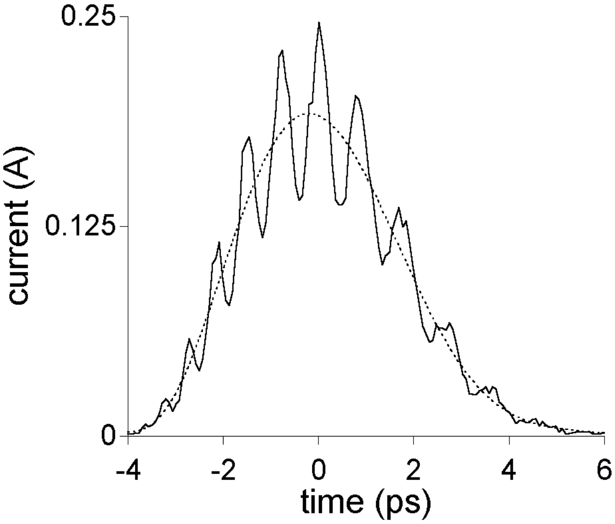

Figure 2: A curve (dotted line) fit to a density profile plot, for initial energy spread of 1%. Mathematically this is a "poor" fit. The high value for χ^2 indicates a profile that is not smooth and that modulation is retained in the beam.

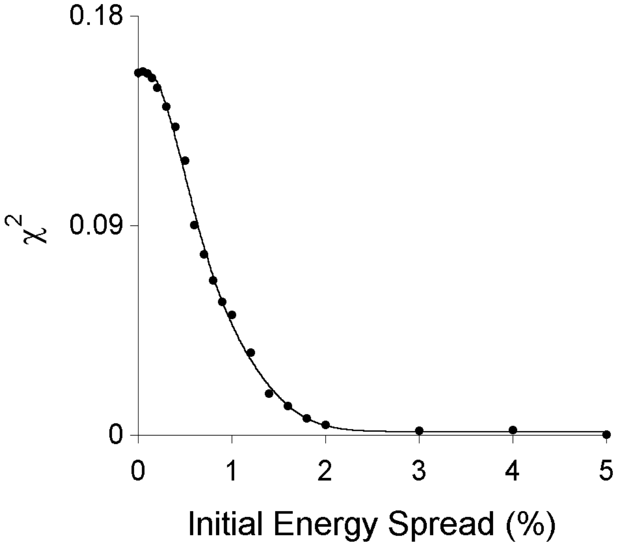

Figure 3: The relationship between χ^2 and initial energy spread for the density modulation of a beam. The solid line is a curve fit to the data.

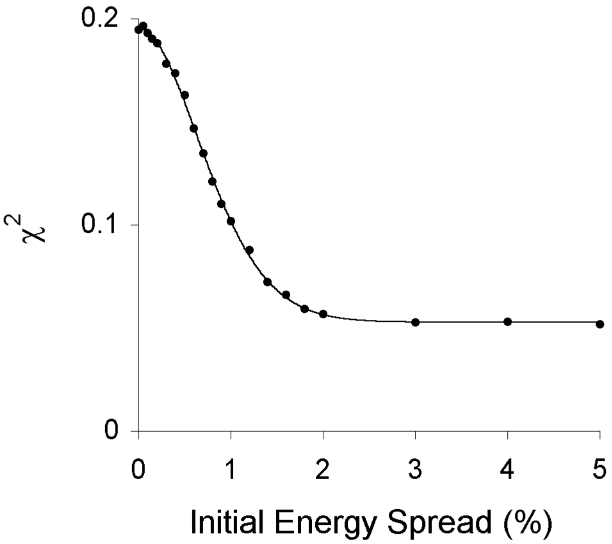

Figure 4: The relationship between χ^2 and initial energy spread for the energy modulation of a beam. The solid line is a curve fit to the data.

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