SUPPRESSION OF TERAHERTZ RADIATION IN ELECTRON BEAMS WITH LONGITUDINAL DENSITY MODULATION

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Abstract

Electron beams with periodic longitudinal density modulation may produce terahertz radiation in linear accelerators. While terahertz radiation is useful for a wide range of applications and research interests, in some cases it may be desirable to suppress unwanted terahertz radiation caused by unintended fluctuations in the longitudinal density of an electron beam. This study explores the possibility of using a wiggler to convert the density modulation to energy modulation. Simulations are performed using PARMELA. Simulated beams with only density modulation are inserted into a linear accelerator to see how the density and resulting energy modulation evolve. Results provide a better understanding of the evolution of modulated electron beams and may provide a method to suppress unwanted terahertz radiation. Parameters in the simulations are chosen to correspond to existing accelerator systems so that the results may be used to support an experimental study.

INTRODUCTION

The purpose of this study is to investigate the possibility of removing periodic density modulation from an electron beam in a linear accelerator. Such modulation, which may have developed from fluctuations in the beam density, could produce unwanted radiation. It is helpful to understand how these modulations evolve [1, 2] and, if desired, how to remove them.

A typical modulated electron beam has both density and energy modulation. In previous work, the authors have simulated beams with only density modulation and only energy modulation in order to understand how these modulations evolve as the beam is transported through a linear accelerator system. It was shown that density modulation retains its character and does not diminish much. Energy modulation was shown to diminish significantly. It is shown in this study that in some cases energy modulation induces density modulation.

The current study investigates the possibility of using a wiggler to remove density modulation. It is important to note that in these simulations using PARMELA, the effect of the beam's radiation on the beam is not considered. Thus, the process of microbunching, as in a single-pass FEL, is not considered here. Rather, only the effect of the wiggler field on the beam is simulated. For the short wigglers used in this simulation, this is an acceptable approximation.

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METHOD OF STUDY

PARMELA is used to simulate electron beams accelerated through a SLAC-type linear accelerator. The accelerator model used is that of the DUV-FEL at the Source Development Lab at Brookhaven National Laboratory. An ATF 1.6-cell photoinjecting RF electron gun accelerates electrons to approximately 4 MeV, and one of four linac tanks, each 3 m long, accelerates the electrons to approximately 33 MeV. A charge of 20 pC per electron bunch is used in these simulations. Thus space charge effects are not significant.

To create the beams, PARMELA is run up to specified points on the accelerator system, such as just after the gun. The data for the beam is then extracted, processed, modified, and then reinserted into the accelerator system at the same place and with the same phase.

The wiggler has a length of 1 m, a wiggler period of 2.86 cm, an rms magnetic field of 3536 Gauss, and an rms wiggler parameter of .941. If the wiggler were to be used to create radiation, its peak wavelength would be 342 μm. The results of the simulations were not sensitive to moderate changes in wiggler parameters.

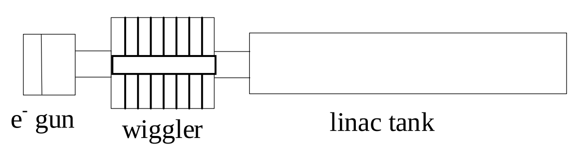

Figure 1: Accelerator system for low energy beams.

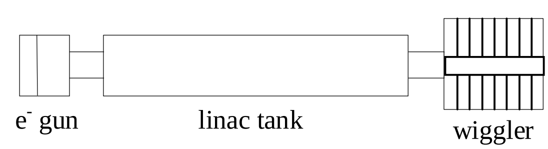

Figure 2: Accelerator system for higher energy beams.

Two configurations were considered. To study low energy behavior, the wiggler is placed between the electron gun and the accelerator tank (see Figure 1). The modified beam is inserted just after the gun, where it has an energy of approximately 4 MeV. To study higher energy behavior, the wiggler is placed after the accelerator tank (See Figure). The beam is inserted just after the accelerator tank, where it has an energy of approximately 34 MeV. The density profile and the energy profiles of the beam are examined at three stages: 1) Just after the electron gun, 2) just after the wiggler, and 3) just after the accelerator tank.

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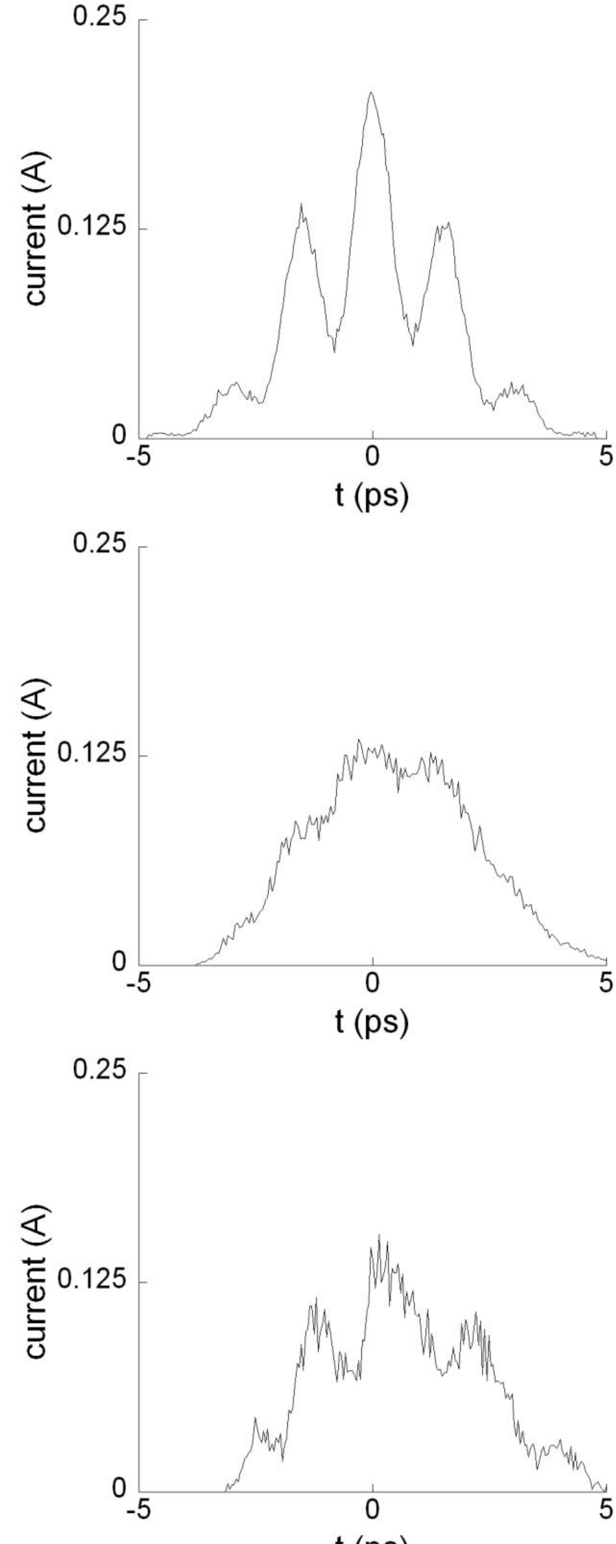

Figure 3: Density profiles of the low energy beam just after the gun (top), the wiggler (middle), and the accelerator tank (bottom). Density modulation diminishes in the wiggler and reappears in the accelerator tank.

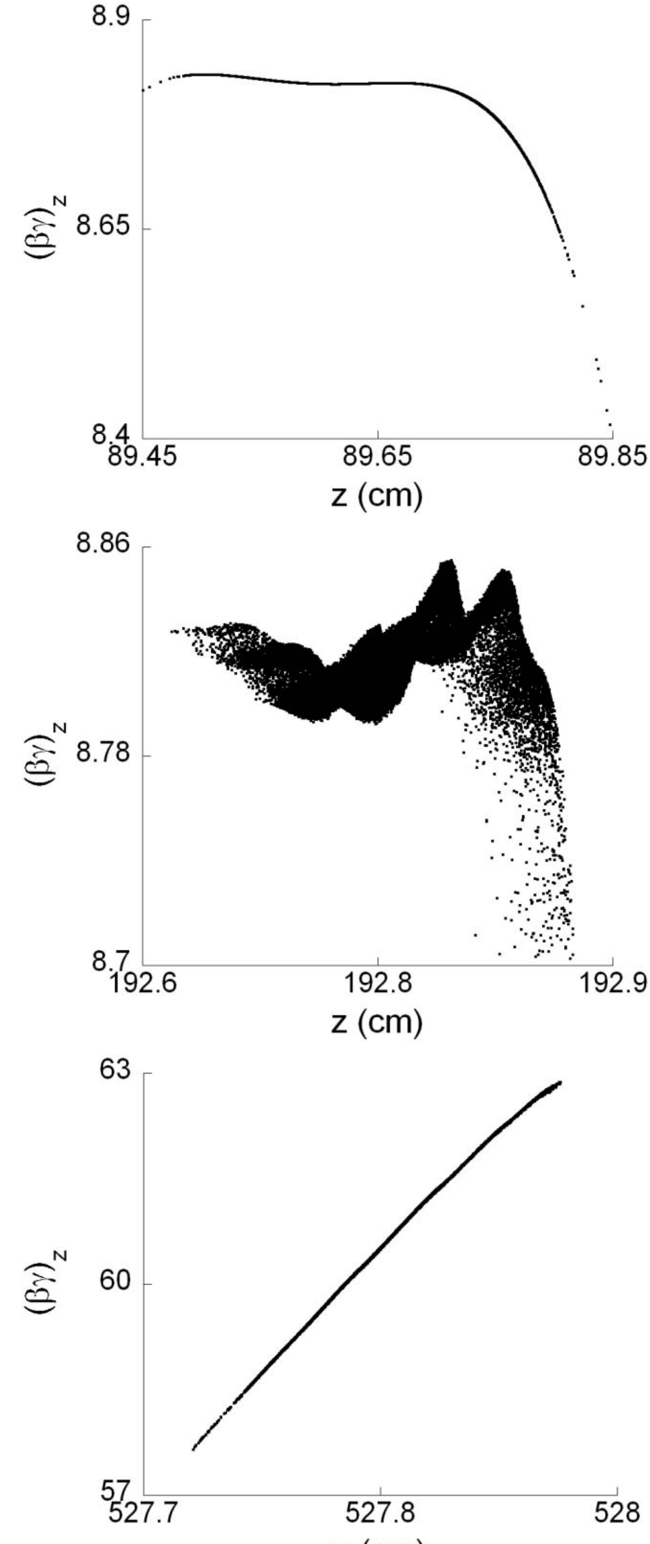

Figure 4: Energy profiles of the low energy beam just after the gun (top), the wiggler (middle), and the accelerator tank (bottom). Energy modulation develops in the wiggler and is reduced in the accelerator tank.

MODULATION AT LOW ENERGY

To study low energy beams, the system is configured as shown in Figure 1. To see if the wiggler reduces density modulation at 4 MeV, the beam’s density and energy profiles are examined at the gun, after the wiggler, and at the end of the accelerator tank. The density and energy profiles are shown in Figures 3 and 4, respectively.

Density Profile

Just after the gun, the electron beam is given a longitudinal density modulation superimposed on a gaussian profile. The modulation has a period of 479 μm. Simulations run for a modulation period of 100 μm produce similar results. The wiggler is successful in reducing the density modulation of the beam. As shown in the next section, the loss of the beam’s density modulation induces energy modulation in the beam. Just after the wiggler, the beam’s density modulation is diminished, which would significantly reduce, or eliminate, coherent radiation. The energy modulation in the beam causes the density modulation to return by the end of the accelerator tank. The density modulation is reduced in amplitude due to the incoherent energy spread introduced by the wiggler. For higher energies, this rebunching would be even more diminished since the energy modulation would result in less velocity modulation. (However, it is shown below that at higher energies, the energy modulation does not develop, and therefore the issue of rebunching is moot.)

Energy Profile

The energy profiles are shown in Figure 4. Just after the electron gun, the beam is given a density modulation but no energy modulation. The shape of the energy profile at this point is created from a sixth-order polynomial curve fit of the actual energy profile from the simulation. A curve fit is used instead of the actual energy profile to better see any changes in the energy profile. By the end of the wiggler, where the beam has lost almost all of its density modulation, the energy profile shows significant modulation, roughly on the order of the initial density modulation. In fact, the energy modulation is even more pronounced in the middle of the wiggler and has already begun to wash out by the end of the wiggler. The energy modulation gradually diminishes until it is effectively gone by the end of the accelerator tank. As the energy modulation diminishes in the accelerator tank, the modulation increases in the density profile of the beam.

MODULATION AT HIGHER ENERGY

To study higher energy beams, the system is configured as shown in Figure 2. To see if the wiggler reduces density modulation at 34 MeV, the beam’s density and energy profiles are examined after the wiggler and at the end of the accelerator tank.

The density profiles are shown in Figure 5. Unlike the lower energy case, the density modulation remains. The beam also lengthens while passing through the wiggler. The energy profiles (not shown) indicate no change. Thus, a higher energy beam is less malleable, and it is more difficult to alter the density modulation. Even simulations with wigglers as long as 10 m show very little change in the density or energy profiles of the beam (although radiative effects are not included here).

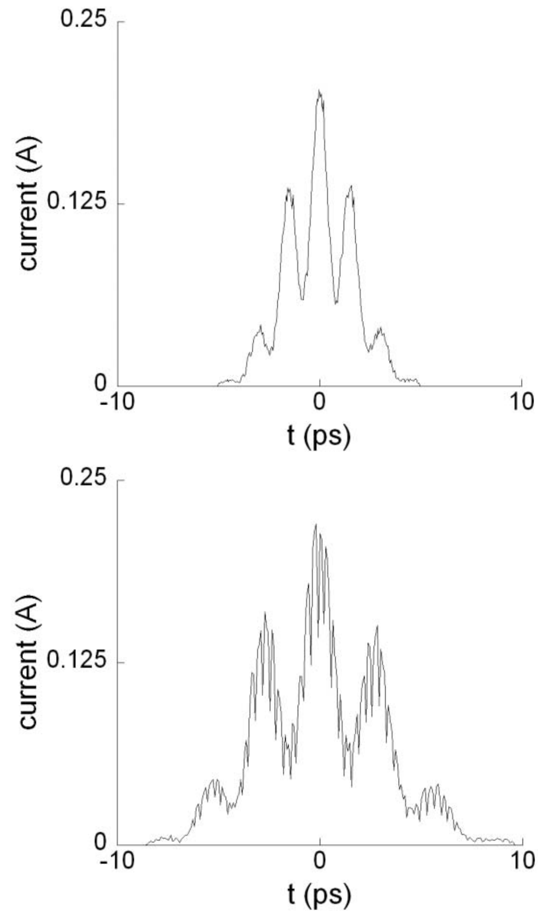

Figure 5: Density profiles of the 34 MeV beam just after the accelerator tank (top) and just after the wiggler (bottom). Note that density modulation remains in the beam at this energy.

CONCLUSIONS

The results show that it may be promising to use a wiggler to reduce density modulation in low energy beams. However, higher energy beams are not as malleable.

REFERENCES

[1] C. P. Neuman and P. G. O'Shea. “Simulation of Longitudinally Modulated Electron Beams” in *2006 Advanced Accelerator Concepts Workshop*, AIP Conference Proceedings, 877. Melville, AIP (2006) 621-6.

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