# SIMULATIONS OF JITTER COUPLING DUE TO WAKEFIELDS IN THE FACET LINAC*

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*Abstract*

Facilities for Accelerator Science and Experimental Test Beams (FACET) is a proposed facility at SLAC that would use the initial two-thirds of the linac to transport e+ and e- beams to an experimental region. A principal use of this facility is to identify the optimum method for accelerating positrons in a beam driven plasma wakefield accelerator. To study this, a positron bunch, followed an rf cycle later by an electron bunch, will be accelerated to an asymmetric chicane designed to move the positrons behind the electrons, and then on to the plasma wakefield test stand. A major focus of study was the coupling of jitter of the positron bunch to the electron bunch via linac wakes.

Lucretia is a Matlab toolbox for the simulation of electron beam transport systems, capable of multi-bunch tracking and wakefield calculations. With the exception of the lack of support for tracking of electrons and positrons within a single bunch train, it was well suited to the jitter coupling studies.

This paper describes the jitter studies, including modifications made to Lucretia to correctly simulate tracking of mixed-species bunch trains through a lattice of magnetic elements and em wakes.

## INTRODUCTION

The Facility for Advanced Accelerator Experimental Tests (FACET) [2] at SLAC National Accelerator Laboratory is a multi-purpose experimental research facility that has been designed in such a way as to allow the continuation of the plasma wakefield acceleration (PWA) tests that began at SLAC's Final Focus Test Beam (FFTB).

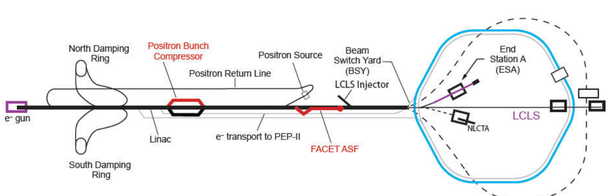


Figure 1: Schematic of the planned layout of FACET.

The proposed layout of this facility is shown in figure 1. It is located in the upstream two-thirds of the linac, and terminates at Sector 20, just before the LCLS injector. The main changes are the addition of a positron bunch compressor, and the Accelerator Science Facility (ASF), at which is located the experimental interaction point (IP).

A principle mode of operation of this machine will be to accelerate a bunch of positrons, followed half an rf cycle later by a bunch of electrons, to the IP. During this process, the bunches will be passed through an assymmettric "sail-boat" chicane, where the path lengths of the positron and electron chicanes will be such that the bunches emerge swapped in their longitudinal positions; i.e. with the electron bunch leading the positrons. The purpose of this chicane is to allow the higher charge electron bunch to drive the PWA, while protecting the positron bunch from the deleterious effects of strong linac wakes generated from the highly populated electron bunch.

It is still of some concern that linac wakes generated by the positrons may, despite the lower charge of this bunch, excessively degrade the electron emittance and beam stability. This paper outlines studies to determine the magnitude of this wakefield-based coupling between the electrons and positrons.

## LUCRETIA

Lucretia[1] is a Matlab toolbox for the simulation of electron beam transport systems that is capable of multi-bunch tracking and wakefield calculations, and was used for this analysis.

Due to the lack of ability to track differently charged particles, it was necessary to alter the source code to add the notion of oppositely charged particles, and to enable them to be treated correctly when tracking through magnetic fields, and when generating/experiencing wakefields.

Multiple changes were required for correct operation, and they are as follows:

- *Bunch representation*: Add a 'charge-type' field to the bunch representation structure. If this value is $+1$, or is absent, then Lucretia will assume that it should perform its default tracking (i.e. electrons), while if the value is $-1$, it will track positrons. The reason for this is so that these changes will fit in with the current operation of Lucretia, and will not break any previously written routines.
- *Magnetic tracking*: When tracking through each magnetic component, add a test for the value of the charge-type, and use this to set the sign of the magnetic field(s). Since Lucretia was designed for electron machines, the magnetic lattice initially has the appropriate sign for an electron beam. It is important that care is taken to perform this operation on all magnetic fields in an element, and not to neglect, for example, fringe fields or edge angles in dipoles.

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- *Acceleration*: Similarly to magnetic tracking, the voltage that the particles experience should be corrected by the sign of their charge-type field in such a way that acknowledges the fact that the initial voltages of the design lattice will be correct for electron bunches.

- *Short range wakefields*: No correction is needed here, since the type of the charge is defined for each bunch; i.e. no mixed particle bunches are allowed. Thus, the error in the sign of the wakefield voltage by positrons will be cancelled out by the sign error in applying that wake to the trailing particles in the bunch.

- *Long range wakefields*: Since these wakes may or may not act on particles of a different charge, it is important to make sure that the wakes are generated, and act with, the correct sign. To accomplish this, the sign of any wakes is corrected by the sign of the charge-type field, thus leaving electron wakes unchanged. In addition, when the calculations are performed to determine the effect of the wakes on trailing bunches, the sign of their voltage is also corrected by the charge-type of the particles.

Once these changes had been made, tests were performed on all Lucretia components, including any wakefield effects, to ensure the correct performance for particles of differing charges.

It is important to note that, at the current time, these changes have not yet made it into the official Lucretia release.

## FACET JITTER STUDIES

### *Wakefield Simulation*

The coupling mechanism with which this paper is concerned is dipole wakefields induced by the leading bunch (positrons) acting on the following electrons. While the time domain wake for the SLAC linac cavities is very well known, Lucretia only has support for frequency domain wakes, so it was necessary to use a frequency domain wake that, despite being non-physical, would provide a very close approximation to the real wake in the region of the second bunch.

Figure 2 shows the measured time-domain wake and the simulated frequency domain wake used in the Lucretia calculations. It can be seen that these two wakes match well in the location of the bunch, and that this simulated frequency wake is an acceptable substitute for the real field.

### *Excitation of Wakes*

Transverse wakes are excited by an off-centre beam trajectory, thus wakes can be generated in these simulations by misaligned cavities, or by a transverse beam jitter. For the purposes of this study, it was decided to simulate a perfect machine (i.e. one with no misalignments, or magnetic field errors), and to track a series of beams to which random jitter has been added.

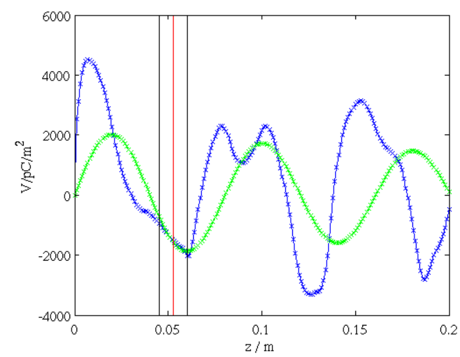


Figure 2: Measured time-domain wake (blue), compared with the simulated frequency domain wake (green), with the position of the 2nd bunch marked (red), $\pm 5\sigma$ (black).

Thus, the $e^+$ beam was input to the simulated lattice with a random, Gaussian, jitter in the four transverse coordinates, and the rms size of this jitter in each of the degrees of freedom was equal to the rms beam size in that dimension. This was then followed by the $e^-$ bunch, which was input to the lattice on the design trajectory. Any jitter measured on the $e^-$ bunch will then be solely due to coupling from the positrons.

## RESULTS

To confirm the expected linear scaling with positron charge, the tracking was performed, using 100 random seeds, for each of three charges for the $e^+$ bunch ($1 \times 10^{10}$, $2 \times 10^{10}$, and $3 \times 10^{10}$). An example from one seed is shown in figures 3 and 4 for the $y$ position of the positron and electron bunches respectively, and the input parameters for this seed are shown in table 1.

Table 1: Input positron bunch offset for seed shown in figures 3 and 4.

| Plane | Offset |
|---|---|
| x | 72.9 $\mu$m |
| x' | -35.6 $\mu$rad |
| y | -19.2 $\mu$m |
| y' | 1.1 $\mu$rad |

Remembering that the $e^-$ was simulated as having the design input orbit, and is traversing a lattice with no errors, any offsets are purely the result of coupling from the positron wakes. Thus, the $e^+$ orbit shown in figure 3 can be thought of as the driving term of the electron bunch oscillations. The $\beta$–functions can be clearly seen, alongside the damping due to the energy increase of the bunch along the linac.

Figure 4 shows the bunch entering with zero offset, and, at the location of the first accelerating cavity, it begins re-

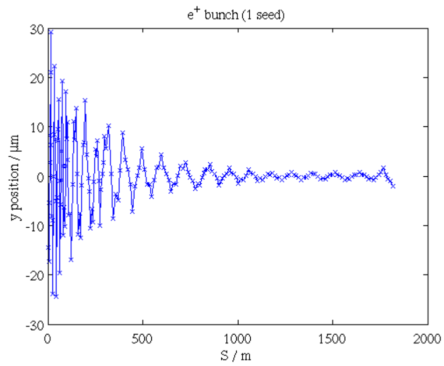


Figure 3: Example of 1 seed of tracking for the positron bunch, showing the orbit due to the off-centre initial bunch.

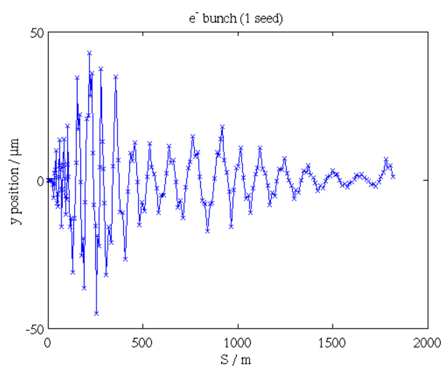


Figure 4: Example of 1 seed of tracking for the electron bunch, showing the orbit excited by coupling from the positron wake.

ceiving kicks from the wakefields. There is some evidence in this plot of the amplitude of the $e^-$ oscillations increasing due to a resonance effect that is working against the damping due to the acceleration of the beam.

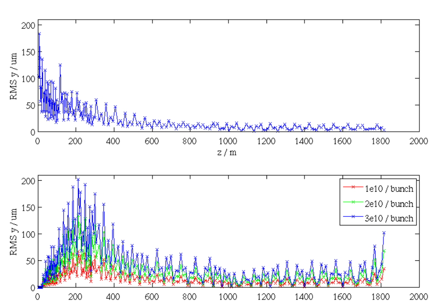


Figure 5: RMS jitter in the $y$ plane for the $e^+$ bunch (upper plot), and the $e^-$ bunch for a series of $e^+$ charges.

The results are more clearly summarised in figure 5, which shows the rms offset for all of the 100 seeds, for each of the three bunch charges ($e^+$ shown in the upper plot, and $e^-$ in the lower). Since, in the absence of wakefields, there are no charge dependent position effects, the orbit for the $e^+$ bunch is the same for each of the three charges.

In the case of the positron orbit, the $\beta$–functions are clearly visible, as is the damping of the oscillations due to the increase in charge of the bunch as it traverses the linac. Since the energy gain is, to a reasonable approximation, smooth and linear, the damping is a very close approximation to an exponential decay. One noticeable exception to this is the location of the bunch compressor ($z$ ∼120 m) where there is no acceleration for several metres, and this can be seen quite clearly in the upper plot.

In the lower plot, the rms orbit can be seen for each of the three charges, and it shows that the kick received by the $e^-$ scales linearly with the $e^+$ charge as expected.

It is also apparent that the electron bunch oscillation grows and decays in a way that is suggestive of an off resonance excitation. This is to be expected since, although both bunches are travelling through the same lattice, their differing charge means that the $x$ optics for one bunch will resemble the $y$ optics for the other, and, since the tune of the linac has been split, the $x$ and $y$ oscillations shown in this figure will, therefore, have different wavelengths. These different frequency oscillations will then beat against each other, while also being damped by the acceleration of the beam, producing the oscillation seen in this plot.

In the upper plot, there is also a hint that there is some head-tail instability in the beam. This is evidenced by the lack of the expected $\sqrt{2}$ damping in the latter half of the linac, which could be caused by short-range wakefields driving an oscillation in the tail, resulting in a larger than expected mean offset for the bunch.

## DISCUSSION

The results obtained show that this system can be modeled as a coupled oscillator acting off resonance.

The driving force is the $e^+$ oscillation, which is damped by the energy gain along the linac, and amplified by the head-tail instability caused by short-range wakes (this oscillation is resonant with the $\beta$–function oscillation).

The coupling between the oscillators is acting off resonance due to the split-tune of the linac, so the resulting oscillation will have a slow 'beating' behaviour. The electron orbit is also damped by the accleration, and amplified by its short-range wakes.

This simple model should allow theoretical approximations to this affect to be calculated without the need to resort to simulations.

## REFERENCES

[1] P. Tenenbaum, "Lucretia: A Matlab-based toolbox for the modelling and simulation of single-pass electron beam transport systems", PAC 05, Knoxville, Tennessee, 16-20 May 2005

[2] T. Raubenheimer, M. Hogan, et al., "FACET: Facility for Advanced Accelerator Experimental Tests at SLAC: A Proposal for a Multi-Purpose Experimental Research Facility using Electron and Positron Beams at SLAC", July 2008