Progress Report

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As the lattice element develops it seems to replicate results observed in the experiments more and more. When the element was first written there was little to no evidence of tune shift between bunches in the same train. Now shifts are being observed and everything seems to be responding more or less as expected to the supplied electric fields. Hopefully, this concludes the burdensome programming aspect of this project - from this point forward my work will be concentrated in determining the best method to reproduce the output from *ecloud.f*

This is not to say that *bmad* woes are behind us, I still need to discuss the possibility of implementing a generalized version of the cloud element (which we could, for example, superimpose over every `SBEND` or `DRIFT` easily, instead of the current model which requires rewriting most of the lattice layout) with Prof. Sagan. Furthermore there still exists and interesting crash when the E-field is scaled by certain values (i.e 10 and 0.1, but 1 is fine).

The first evidence available of the inter-bunch tune shifts was gathered from running a 1.0mA beam through the *periodic.lat* test lattice. The E-field data was pre-generated using *ecloud* with similar conditions. The 30 bunch train was run through 5000 cycles in the test lattice, each bunch had an initial offset of 1mm on the x axis to reduce noise in the tune calculations. The tune is analyzed by taking the position of the bunch, and performing an FFT over the course of the 5000 cycles, see figure 1, we can then plot the peaks for each bunch in the train to obtain graphs like figure 2

The FFT below the x position graph shows four major peaks, though either side is a reflection across

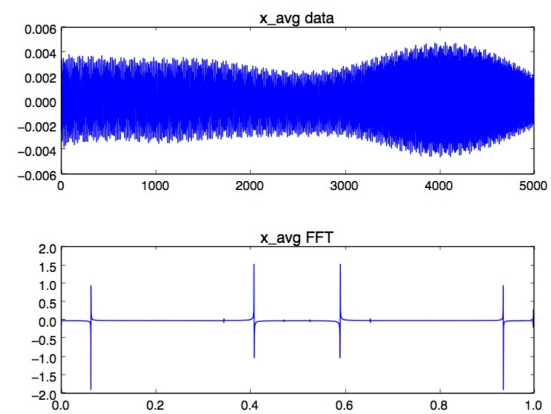

Figure 1: x position and FFT (bunch 2)

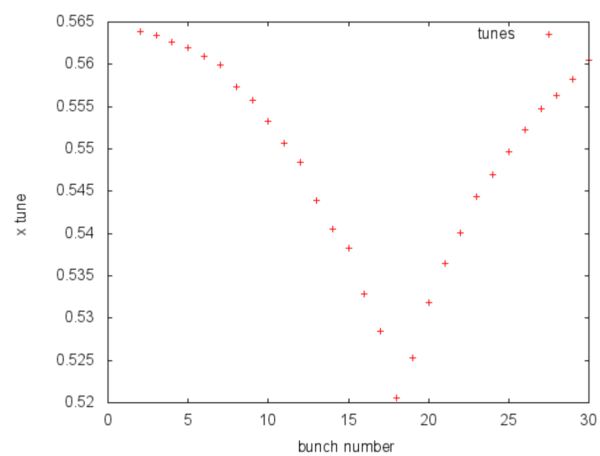

Figure 2: x tune for train (*periodic.lat*)

the 0.5 mark. For consistency with experimental graphs, we will consider the primary tune to be the third peak, just after the 0.5 mark. figure 1 shows the variable for the second bunch in the train, by plotting the tune shift over all 30, plus the shift imparted on "witness" bunches at index 30-60 we can compare this data to the April 2014 tune experiments at CESR-TA (see figure 3).

In order to run simulations with the cloud element as part of the CESR-TA *Bmad* lattice I need to fix two issues:

- Firstly, I have to run an ecloud simulation with 60 bunch-like measurements, the first 30 will be filled bunches which produce photoelectrons, the following 30 will be empty "buckets" which serve only to be placeholders for witness bunches later on. The problem is that *ecloud* does not report the electron cloud density nor the general electric field (found in *ef.data*) for the "bucket" bunches, furthermore the electric fields in the local beam area, found in *beamfield.data*, are suspicious. They, along with the later filled bunches, demonstrate discontinuities which seem to violate $\nabla \times \mathbf{E} = 0$, an example of this problem can be seen in figure 4. I attempted to solve this problem by increasing the macro particle count, and thus the accuracy of the simulation, but the problem persisted.

- The second problem lies in the parsing of the *Bmad* lattice file with the cloud elements introduced. The cloud elements are made to overwrite each kind of bend in the lattice. The code for overwriting a bend goes as follows:

```
t_B01: SBEND, L = ..., ANGLE = ..., &
  E1=..., E2=...
B01: t_B01, field_calc=custom, &
  tracking_method=runge_kutta, &
  num_steps=100, ds_step=0.1, &
  mat6_calc_method=tracking
```

This will parse correctly for `SBEND`s, however the parser will not recognize `runge_kutta` as a valid integration method for `RBEND`s despite claiming that the only difference between the two is how the angle and length attributes are interpreted[1].

[1]See *Bmad* manual page 42

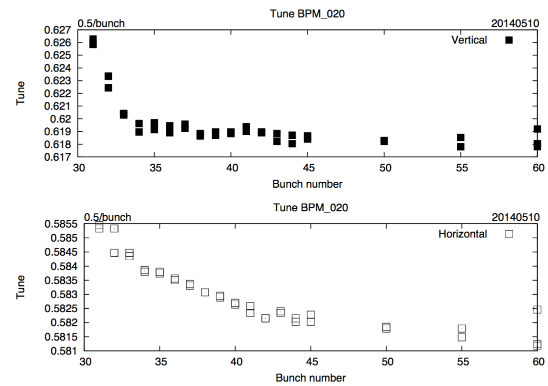

Figure 3: Experimental data (4/10/14)

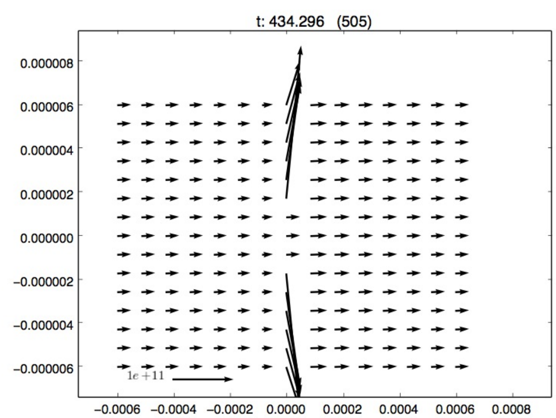

Figure 4: Problem E field in bunch

Finally, I am also working on the mathematical approach to calculating the E field for a given particle at a given time and space relative to the head of the bunch train. I hope to accomplish this by utilizing a rolling count of the number of particles which have passed through the element, then subtracting the decay rate of cloud (which likely depends on the density) then utilizing the relationships I have already found between the electron cloud density and the E field in the local beam area. In order to do this, however, there are, again, a few problems I have to solve:

- *Bmad* makes counting individual particles difficult. The subroutine we overwrite to provide the E field to *Bmad*, named `custom_field_calc`, is provided with limited information about the lattice as a whole. The inputs at our disposal do not allow us to query bunch train information, only individual particle information (though not the index). Furthermore counting the number of calls to the subroutine is not an option since any integration method used will make multiple calls to the subroutine for each particle.

- I have still not investigated the growth and decay rate of the electron cloud. This would be necessary to calculate the E field of each particle without running an *ecloud* simulation prior to the *Bmad* simulation, which would be the ideal outcome of this project.

- Lastly, the "intercept problem" - As discussed in my previous report, the E fields across the local beam area change linearly across their respective axis (E_x across x and same with E_y and y). The slope of this linear change, or the rate, is proportional to the electron cloud density[2]. There is no discernible pattern, however, for the intercepts of these linear relationships between E_x and x, and E_y and y, except that they themselves have a component which is proportional to the density, and a component which varies wildly. This gives an overall equation for the E field as follows (with ρ_e the cloud density):

$$\mathbf{E} = \begin{pmatrix} (a\rho_e + b)x + (c\rho_e + d) \\ (f\rho_e + g)y + (j\rho_e + k) \end{pmatrix} \quad (1)$$

[2]There are minor exceptions which I have label "perturbations". These manifest as erratic wavelike phenomenon. I believe they will be solved when the problem in figure 4 is solved

ρ_e varies with time t, a, c, f, and j are constant, but b, d, g, and k follow no discernible pattern.

As you can see, progress has been good, though there are a few problems standing between us, currently, and a finished product. However there are also several possible solutions to each of these problems. I hope to, next week, discuss each of these problems with authorities on the subjects to better understand them. I have already asked about the electron cloud growth and decay.

A final consideration to a mathematical model would be the inclusion of secondary yield electrons in high powered beams. The issue does not seem to present itself in the *ecloud* simulations with 0.5mA at 2.085Gev, however if we want to develop a lattice element capable of performing at higher energy levels, this would absolutely need to be included as the effects of the secondary yield electrons grow enormously to the point at which the electron cloud does not decay at all between bunches in the train (assuming 14ns spacing) but actually grows, though eventually hits a "maximum capacity" at which point the decay rate overtakes the photoelectrons plus secondary yields.

Final Remarks:

- I somehow ended up with a planned presentation at the next electron cloud meeting, Wednesday at 1pm, and will be discussing most of this document, plus any developments between now and then. This means I will likely spend the weekend preparing a short powerpoint on this subject.

- I realize the fancy "A" at the beginning of the document is not very professional, however I found the LaTeX package and couldn't resist.

- The same applies to the flourish below.