MULTIBUNCH ENERGY CONTROL TOLERANCES IN NLC

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1. Parameters and conditions

We use a linearly-ramped RF pulse to do the multibunch energy compensation. Parameters of the ramp are chosen to give a loaded energy gradient of 50 MV/m. Charge per bunch is taken to be $1 \times 10^{10}$ and the bunch spacing is 16 rf buckets ($\sim 1.4$ ns). Figure 1(a) shows the energy and 1(b) shows the fractional energy deviation, in a single 1.8 m accelerating section, for each bunch. In this Figure, we have ignored the effect of dispersion of different frequencies in the RF pulse as it travels through the structure. Figure 2(a) and 2(b) show the same things, but with dispersion included.

We must also run the bunches off-crest to do intra-bunch energy compensation of the short and long range wake fields. The short range wake field [obtained from K. Bane, private communication] is shown in Figure 3.

Assume each bunch has an approximately Gaussian distribution, and divide the charge into nine equally spaced macroparticles, with Gaussian weight. Take the $\sigma_z = 100 \mu$m. We seek the optimum phase for minimizing the energy spread by varying the RF phase, while also adjusting the height of the ramped RF pulse to keep the steady-state bunch centroid energy gain constant; the resulting energy spread as a function of RF phase at the bunch centroid is shown in Figure 4.
We see that the optimum intrabunch energy compensation is obtained by putting the bunches 13° ahead of the RF crest. Figure 5(a) and 5(b) show the slice energies and fractional energy deviations for this condition. The length of the plotting symbol for each slice is proportional to the amount of charge in the slice. Figure 5(c) shows the average (over slices weighted by charge) energy gain of each bunch.

In addition to contributing to the intrabunch energy spread, we expect the short range wake to lower the centroid energy of the bunches by about

\[
\frac{1}{2} \sigma_z W_{srw}(\sigma_z) L_s q_b \\
= \frac{1}{2} (100\mu m)(900 V/pC/m)(1.8 m)(1600 pC) ,
\]

\[
= 1.3 MV
\]

where \( L_s \) is the length of the structure and \( q_b \) is the bunch charge. Note that this is borne out by a comparison of Figures 1(or 2) and 5.

2. Bunch length variations

Taking the bunch to be -13° off-crest, we consider the effect of varying the bunch length, while keeping all other parameters constant. The effect on the rms fractional energy spread is shown in Figure 6.
3. Bunch charge variations

Taking the bunch to be $-13^\circ$ off-crest, we consider the effect of varying the bunch charge, while keeping all other parameters constant. The effect on the rms fractional energy spread is shown in Figure 7(a). The effect on the average (over all slices in all bunches) energy is shown in Figure 7(b).

4. RF phase variations

We consider the effect of RF phase ripple superimposed on the incoming 11.424 GHz RF pulse. Suppose the ripple is a cosine with given period (in nsec) and amplitude (in degrees at the RF frequency).

It is essential to include dispersion of the RF pulse as it transits the structure, in order to treat this problem correctly (if dispersion is neglected, a given bunch sees the same phase throughout the structure, since the variation of phase velocity with frequency, away from its value $c$ at the RF frequency, is neglected). Since calculations with dispersion are quite time consuming, we have treated each bunch as a single macroparticle for the calculations of Figure 8. Thus the contribution of intrabunch energy spread to the overall beam energy spread is not included. Here the amplitude of the ripple was taken to be $4^\circ$. Figure 8(a) shows the rms fractional energy spread as a function of the period of the ripple. Figure 8(b) shows the average energy as a function of the period of the ripple. Figure 9 is similar to 8, except that the amplitude of the ripple was taken to be $2^\circ$. Note that the variation of the energy spread scales linearly with the amplitude of the ripple.

Let us take the tolerance on the rms fractional bunch-to-bunch energy spread to be 0.1%. As noted above, we ignore the contribution from the intrabunch spread,
which would add about another 0.1% to the spread. Let us also take the tolerance on the energy centroid shift to be ±0.1%. Figure 10(a) shows the approximate tolerance on the RF phase ripple amplitude as a function of the period of the ripple, to meet the tolerance on the rms energy spread. Figure 10(b) shows the approximate tolerance on the RF phase ripple amplitude as a function of the period of the ripple, to meet the tolerance on the centroid energy shift. In the middle of the range of ripple timescales, these tolerances are only approximate since they are somewhat dependent on the phase of the ripple with respect to the beam; we have tried to put down the most conservative values obtained in simulations.

5. RF field-amplitude variations

We consider the effect of ripple in the amplitude of the incoming RF pulse. Suppose the ripple is a cosine with given period (in nsec) and amplitude (in MV). We treat each bunch as a single macroparticle and include dispersion. Taking the amplitude of the ripple to be 1.0 MV, we obtain the result shown in Figure 11. Figure 11(a) shows the rms fractional energy spread (again ignoring the contribution from the intrabunch energy spread) as a function of the period of the ripple. Figure 11(b) shows the average energy as a function of the period of the ripple.

Figure 12(a) shows the approximate tolerance on the RF field-amplitude ripple amplitude as a function of the period of the ripple, to meet the 0.1% tolerance on the rms energy spread. Figure 12(b) shows the approximate tolerance on the RF field-amplitude ripple amplitude as a function of the period of the ripple, to meet the ±0.1% tolerance on the centroid energy shift. As in these are rough estimates, especially in the middle of the range of ripple timescales, since they are somewhat dependent on the phase of the ripple with respect to the beam.
Figure 1

VOLTAGE GAIN AT BUNCH CENTERS FOR SECT TYPE 1

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Voltage Gain (MV)

Bunch Number

0 20 40 60 80

89.00 89.98 89.96 89.94 89.92 89.90
FRAC. DEV. OF BUNCH-CENTER ENERGY, SECT TYPE 1

Figure 1(b)
VOLTAGE GAIN AT BUNCH CENTERS FOR SECT TYPE 1

Fig (e, f, g)
FRAC. DEV. OF BUNCH-CENTER ENERGY, SECT TYPE 1

Figure 2(c)

Dispersion included
No chill phase or ample errors
(cont'd p. 15)
AVERAGE BUNCH ENERGY GAINS IN SECTION TYPE 1

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ENERGY GAIN (MEV)
PHI_RF_VAR_AMPL = 4 DEGREES

Figure 8(a)
PHI_RF_VAR_AMPL = 4 DEGREES

Figure 8(b)

average energy [MeV]

PHI_RF_VAR_PERIOD (NS)

89.5
89.0
90.0
90.5
91.0
PHI_RF_VAR_AMPL = 2 DEGREES

![Graph showing RMS delta E/E vs PHI_RF_VAR_PERIOD (ns)]
PHI_RF_VAR_AMPL = 2 DEGREES

Figure 2.1
RF PHASE RIPPLE TOLS FOR RMS FRAC E_SPRD < 0.1%

Figure 10(a)
RF PHASE RIPPLE TOLs FOR AVG E DEVIATION

**Figure 10(b)**
EHATO_VAR_AMPL = 1 MV

Figure 11(b)
RF AMPL RIPPLE TOLS FOR AVG E DEVIATION < 0.1%