EMITTANCE CONTROL FOR DIFFERENT FACET BEAM SETUPS IN THE SLAC LINAC*

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Abstract

The linac beam at SLAC requires different setups for different users at the FACET (Facility for Advanced aCcelerator Experimental Tests) area, like highly compressed, intense bunches, or lower charge, long bunches. These require typically a lengthy tuning effort since with an energy-time correlation (or "chirp") the bunch transverse wakefield kicks can be compensated with dispersive trajectory oscillations and vice versa. Lowering the charge or changing the bunch length will destroy this delicate balance. Besides the typical steering to minimize BPMs (Beam Position Monitors) with correctors, we applied different techniques to try to localize beam disturbances like dispersion with phase changes, RF-kicks and RF quadrupole fields turning a klystron off and on, or varying the phase, and finally wakefield kicks with different beam intensities. It is also important to quantify BPM to quadrupole offsets with "bowtie" plots and that the correctors give the expected kicks with orbit response matrix measurements.

INTRODUCTION

Good transverse beam emittances at different places along the SLAC Linac get typically achieved in the following way. The beam gets steered relatively flat (< 0.5 mm) using BPMs (Beam Position Monitors) and then with a lengthy tuning scheme, linac oscillations or bumps are introduced which minimize the emittance measured with wire scanners. Over the years this process typically achieved small emittance growth numbers of 50 to 100% over the initial values of 30 and 2.5 mm-mrad for x and y, so 50 by 5 mm-mrad was expected for the FACET beam in Sector 20.

Typically twice that amount and often more was only achieved. There are a few explanations (excuses) which could cause this. The typical beam rate was 10 Hz, so tuning was three times slower than at 30 Hz. The FACET chicane needed special attention, so linac tuning was cut short. And the final spot sizes after the chicane and final focus were about the same, like 30 µm, even if the emittance just in front of the chicane changed by a factor of three (300 → 100 mm-mrad in x), discouraging further linac tuning.

Additionally, frequent user requested beam changes in current and bunch length made it necessary to tune the beam emittances up again, which would make it even trickier for smaller emittances. It is assumed that the main root cause for this is that after just steering flat the initial emittance is as high as 1200 mm-mrad, and the subsequent tuning cancels this with equally large corrections. When these cancelations are not local, or are charge / bunch length dependant, small say 10% variations will create 10% of 1200 mm-mrad = 120 mm-mrad.

So the goal is to localize and reduce emittance increasing effects. For that we try to find and categorize all possible mechanisms, like dispersion, wakefield, RF-kicks, and develop procedures like special steering methods and component alignment.

Goal: Get Linac closer to good emittances with BPMs etc. so the tuning part is less.

1. BPMs
2. Correctors
3. Quads (old BBA: straight orbit)
4. BPM-to-Quad: bowtie plot or Quad change
5. Corrector strength (LOCO, R12 meas.)
6. Lattice (Quad) strength: Oscillation data
7. RF-kicks: a) sin-cos, b) dipole-quadrupole-lens
8. Measure dispersion
9. Measure with different charge (wakefield)
10. Measure with different bunch lengths
11. Others

The different methods (numbers in ( ) below) and their relevance are discussed in the following sections.

STEERING TECHNIQUES

Steering the beam to the center of a BPM (1) gets the beam down the linac relatively fast, but usually ends up with big beam emittances. Additionally we can look at the corrector (2) values along z and check for certain patterns, e.g. stronger values with + – + might indicate a BPM with a big unreal offset. With our "SVD Steering" we can adjust a gain parameter to prefer BPMs (gain high) or correctors (gain low), but this method just supports what is believed more correct.

The next step is also using the quadrupole (3) strengths in a way to get a straight trajectory. When a BPM reading is say Δx =1 mm and the corrector strength is cor = 0.03 kG-m, the two can be compared by dividing cor by the quadrupole strength Q = 20 kG: cor/Q = 1.5 mm. So the beam gets more bend up by the corrector than the $Q\Delta x$ bends it down (focussing magnet). Figure 1 shows an example where the orbit was steered flat (below 0.3 mm) but its corresponding cor/Q-values are up to 1.3 mm. This led to a global alignment of the Linac of up to 7 mm [1]. Equalizing the two locally will give a straight non-bend beam orbit and therefore no dispersion is generated. But an offset in a BPM might indicate also an offset in the RF nearby structure, causing wakefield kicks.

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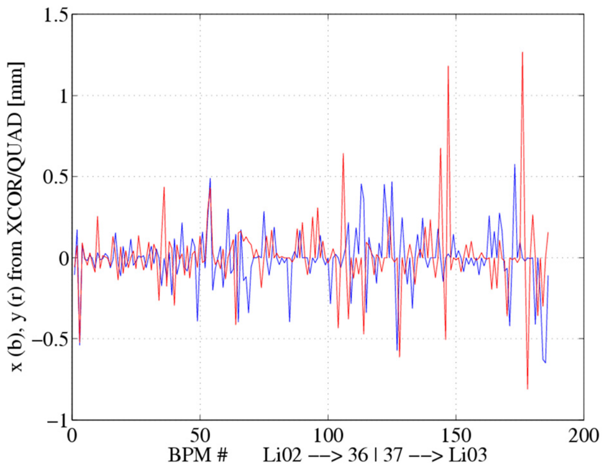

Figure 1: The absolute orbit is steered flat, but the corresponding corrector/quadrupole values for x (blue) and y (red) indicate big bending around 145.

BEAM BASED ALIGNMENT

Besides the global alignment of the Linac using optical targets inside the accelerator supporting light-pipe, there are several methods using the beam to find misalignments and then fix them. The last paragraph indicates already one such approach. Instead of steering so that $\Delta x = cor/Q$ we can align the quadrupole and accelerator locally by moving it in the $+x$ direction by Δx and putting the corrector to zero. This was done in a few places and needs to be done at all locations. But before doing this we need to be sure that the values of Δx, *cor, Q* are correct.

The BPM reading Δx can have an offset x_{off} with respect to the quadrupole and this can be measured with the beam by the bowtie-scan method (4). By varying one corrector in front of the quadrupole and measuring the effect of a downstream BPM for two different quadrupole settings versus the BPM inside the quadrupole you get a bowtie-like plot where the center of the bowtie gives the BPM offset x_{off}. This method is very lengthy requiring a few setting for each quadrupole setting and again for the other plane *y*. A faster but not as precise method is using just the difference orbit for the two different quadrupole settings and using the focussing model (R12s) to determine the kicks in *x* and *y* at the same time. This method should be about ten times faster and will allow us to get the BPM offsets for all BPMs in quadrupoles.

Checking the corrector strengths (5) is next and done typically by varying a corrector over a certain range that the beam is not lost and then the response matrices R12s from the corrector (point 1) to downstream BPMs (points 2) are compared to the expected from the model. When everything is aligned the exact values are not too critical since the correctors are close to zero, but to get there and for steering and for making closed three-corrector bumps (see below) it is helpful to have the right values.

The lattice or quadrupole strength (6) can be check with oscillation data, where two correctors in *x, x'* and two in *y, y'* generate oscillations which then can be fitted with expected behaviour calculated with the model. Figure 2

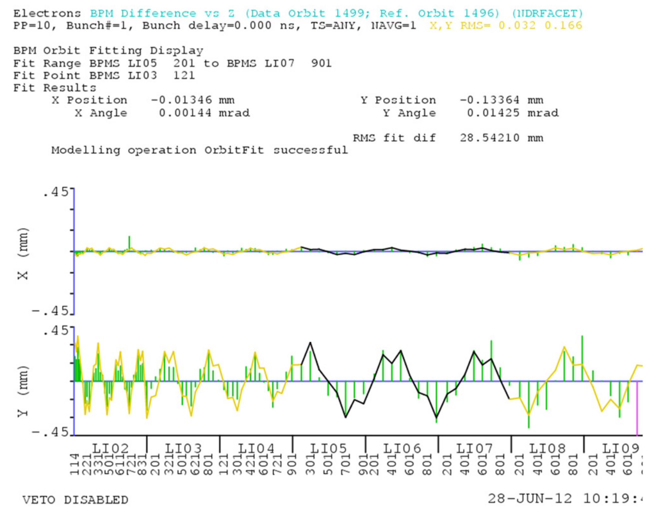

Figure 2: Oscillation data in *y*, at Li07 501 there seems to be an additional kick pointing to a weaker quadrupole.

shows an example where there seems to be a 15% weaker quadrupole at Li07 501. A wider grid scan can point out nonlinearities, while a few more corrector settings can trace out the design matched beam ellipse in phase space which then can be checked down the linac. With this method (at LCLS) sudden mismatches, coupling and 3% BPM scale errors were found.

RF KICKS

All the above mentioned steering and compensation techniques get messed up by RF kicks (7), and their behaviour is quite interesting. There can be sin and cos terms, an *x* and *x'* part, dipole-, quadrupole-, or lens-type kicks, even 2nd harmonic part was observed (Fig. 3).

To distinguish whether it is an angle or position effect two (nearly) closed bumps were made, one with the maximum at the beginning of the accelerator structure and one at the end (Fig. 4).

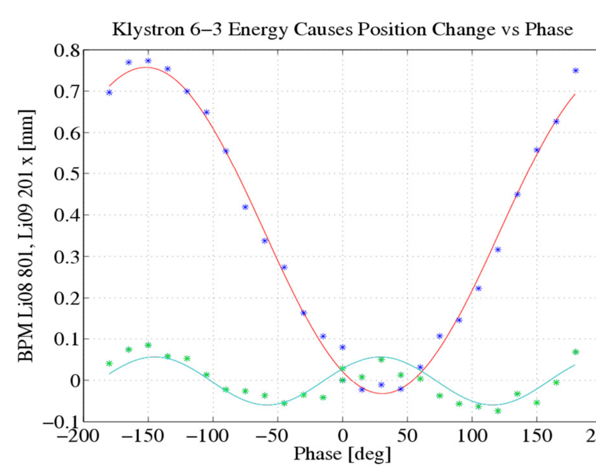

Figure 3: The phase of klystron 6-3 was varied and the resulting downstream orbit observed. At BPM Li09 201 it was up to 800 µm and in phase with acceleration, two BPMs earlier, near the zero-crossing, a 100 µm 2nd harmonic-like effect was seen.

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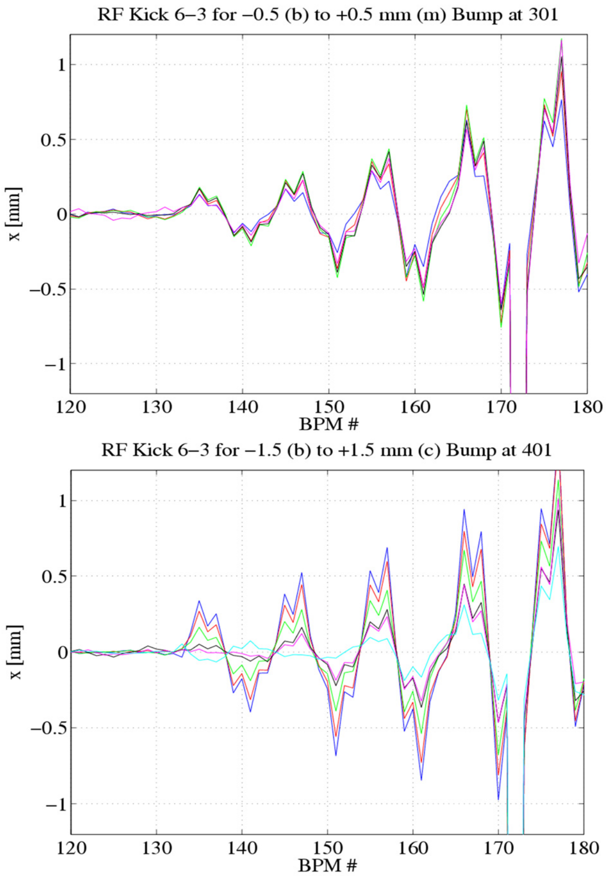

Figure 4: The RF kick of klystron 6-3 (between BPM # 132 and 133) is barely influenced by a bump with the maximum at its front at 301 (top), while at its end at 401 a +1 mm bump cancels the RF kick (bottom). Further downstream seems to be more and more dispersion.

MEASUREMENT FOR SETUP CHANGES

When the beam parameters like charge, bunch length, energy profile change the beam emittances are typically negatively influenced. By localizing and fixing the before mentioned effects as local as possible emittance growth should be minimized. Checking how much dispersion (8) the beam has at a certain point seems to be easy. The energy gets changed by ΔE and with the measured transverse position x: $x = \eta_x \cdot \Delta E/E$ the dispersion η_x is defined. The problem with the linac is that there are many ways to change the energy and on top of that there can be a change due to RF kicks when a klystron is turned off. We typically want to know how the head and the tail of a bunch having different energy due to an energy chirp might behave differently. To check that, we vary the injection phase into the linac by ±1° and then we look at the difference orbit. Since the average chirp phase before the chicane in Sector 10 is about –24° the energy change at the chicane should be about ΔE = 7.8 GeV · (cos(23°)–cos(25°)) = 111 MeV or 1.23% at 9 GeV. Any resulting orbit change in the linac is like dispersion and can be reduced with bumps or dispersion free steering methods.

The beam charge (9) and the bunch length (10) are parameters often asked by the FACET user to be changed. By dithering the damping ring capture phase the throughput and so the number of particles down the linac was varied from 2E10 to 1E10. The resulting orbit changes hint where wakefields might be an issue and where observed early in the linac (Li03). The amplitude of the RTL (Ring-To-Linac) bunch compressor can be adjusted similarly quickly to vary the bunch length, but this fast method wasn't tried yet.

To be more complete other methods and effects (11) should be mentioned too. A) There were the ballistic data measurements, were all quadrupoles, correctors and klystrons are turned off in a sector or two and the BPMs analysed before beam losses occurred. B) Hysteresis in the correctors makes the results questionable. C) Similar to the LCLS undulator where different energies are used to align the undulator, we can scale the quadrupoles and correctors while the actual energy profile and RF kicks stay fixed. With positrons which are bend magnetically in the opposite directions, while the RF kicks are typically the same (dipole kicks) the different effects can be better separated [3]. D) Electronic noise from klystrons causes a different reading for the BPMs in a nearby crate whether the klystron is on beam time or on standby.

Finally two more things should be mentioned. We changed the basic setup of the linac in two ways to make it less susceptible to dispersion. First a "staggered" chirp was introduced, which slowly increases the energy versus z correlation, and 2[nd] a lower 76 deg per cell lattice was used to be less susceptible to the necessary energy spread.

SUMMARY

The beam emittance control for FACET is basically done by tuning, starting at very high values (sometimes 250 times higher). This paper discusses more than twelve possible approaches to reduce the initial value locally as good as possible, so that any longitudinal or intensity changes are not coupled into the transverse dimensions.

ACKNOWLEDGMENT

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