INTENSITY EFFECTS OF THE FACET BEAM IN THE SLAC LINAC*

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Abstract

The beam for FACET (Facility for Advanced aCcelerator Experimental Tests [1]) at SLAC requires an energy-time correlation ("chirp") along the linac, so it can be compressed in two chicanes, one at the midpoint in sector 10 and one W-shaped chicane just before the FACET experimental area. The induced correlation has the opposite sign to the typical used for BNS damping, and therefore any orbit variations away from the center kick the tail of the beam more than the head, causing a shear in the beam and emittance growth. Any dispersion created along the linac has similar effects due to the high (>1.2% rms) energy spread necessary for compression. The initial huge emittances could be reduced by a factor of 10, but were still bigger than expected by a factor of 2-3. Normalized emittance of 3 μm-rad in Sector 2 blew up to 150 μm-rad in Sector 11 but could be reduced to about 6-12 μm-rad, for the vertical plane although the results were not very stable. Investigating possible root causes for this, we found locations where up to 10 mm dispersion was created along the linac, which were finally verified with strong steering and up to 7 mm settling of the linac accelerator at these locations.

INTRODUCTION

After three years of not using the first two third of the SLAC two-mile linac it got "fired up" [2] for experiments in Sector 20, the last third is used for the LCLS (Linac Coherent Light Source). It was quite a struggle, but most of the equipment came back faster than expected. It also helped to have a quick two-month turn-on run the year before. But it turned out that tuning the beam emittances and small beam sizes at the final focus (FF) seemed quite tricky. It didn't help that the final linac emittance measurement location was in sector 11 (Li11), while a strange oscillation behaviour was visible downstream in Li13 to Li15 (see Fig. 1). So it wasn't at all obvious, whether the bigger FF spot sizes were the result of not being optimized in the complicated W-shaped chicane just before the FACET FF or whether the linac beam emittances were too big.

This triggered investigations of adding an additional emittance measurement station located just in front of the chicane, finally implemented as a single wire scanner where we can make quadrupole scans to determine the beam emittances. The strange behaviour was localized at a place where three nearly maxed out correctors had to fight against a sinking linac creating a lot of local dispersion, which was finally fixed by a big alignment of about half the linac between sector 2 and 20.

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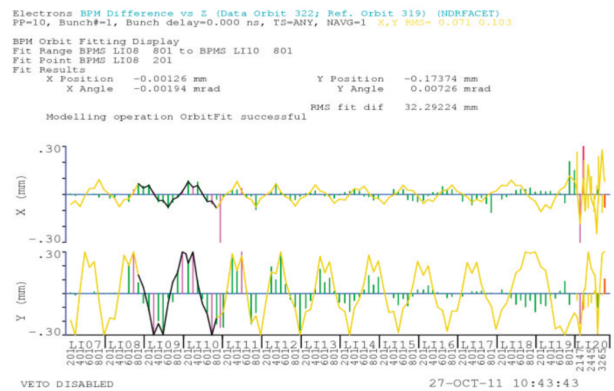

Figure 1: Orbit oscillation (green) die out near Li13 to Li15, the extrapolation (yellow) of the fit (black) shows the expected behaviour.

LINAC ALIGNMENT

The laser interferometer data (Fig. 2, red) confirmed known soil settling in sector 13 and 15 and we decided not to smooth out the spikes locally but to raise the whole low part by up to 6 mm. In the early sectors a rapid changed got smoothed out too (Fig. 2, blue).

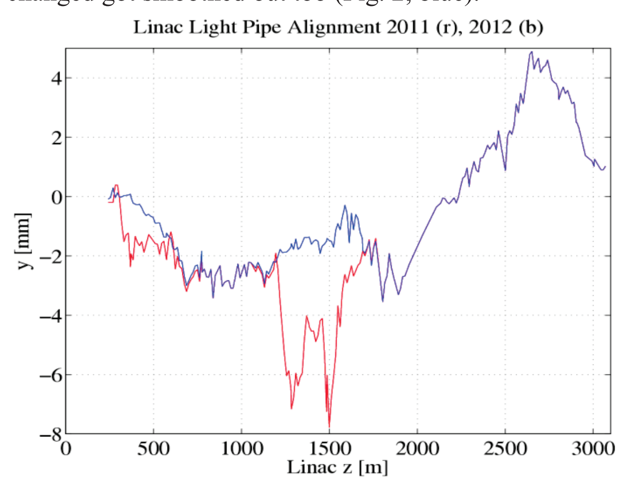

Figure 2: Vertical Linac alignment.

DISPERSION

Simulations

Making a 1 mm three-corrector closed bump in a 90° lattice generates a 4 mm dispersion wave. Making an orbit oscillation which is not closed, but which oscillates down the linac, generates more and more dispersion. Figure 3 shows an example where a 0.7 mm oscillation generates up to 100 times more dispersion (70 mm). With an correlated energy spread along the bunch length of 1.5% (chirp) the 70 mm dispersion causes a 1 mm difference orbit for the different energies, cancelling the observed orbit (beam head and tail oscillate up and down against each other at 180º), explaining the observed disappearance in Fig. 1.

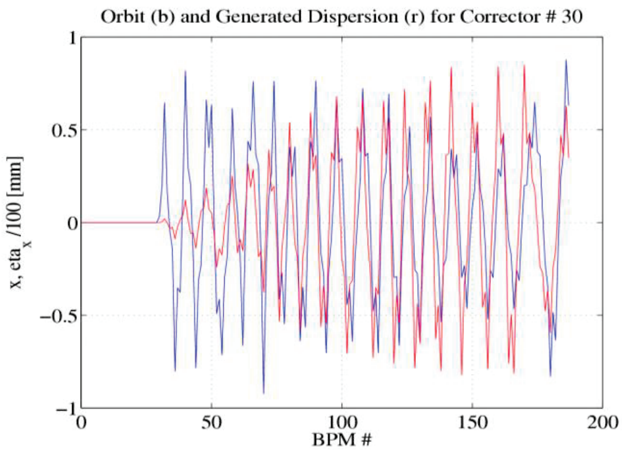

Figure 3: Orbit oscillation (blue) generates dispersion (red) up to 70 mm down the linac.

Measurements

The dispersion of a beam line is measured by changing the beam energy and measuring the transverse orbit. The energy change can be achieved in different ways in the linac resulting in different "dispersions". Since we are interested in the behaviour of the beam tail to the beam head we introduced a change in the injection phase into the linac ("phaseramp") and measured the response of all linac beam position monitors (BPMs). It was quickly recognized that the phase jitter from the damping ring caused about 10% of the introduced phase variation and is enough to get a rough measurement (Fig.4).

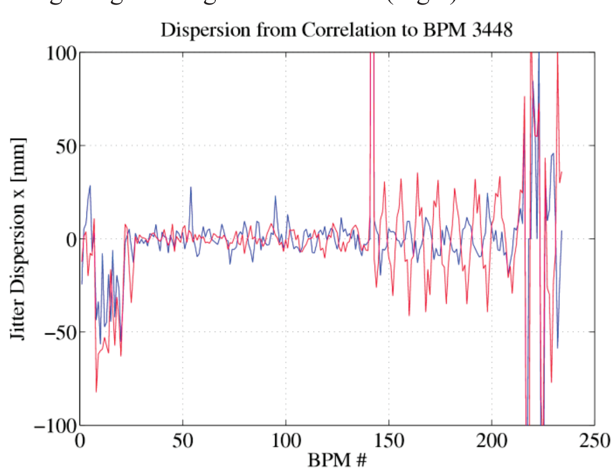

Figure 4: Dispersion measured by correlation with a high dispersion BPM in the sector 10 chicane. The initial high dispersion (red) was cancelled (blue) with weak quadrupoles inside the chicane.

EMITTANCE TUNING

The initial flat beam normalized emittances out of the damping ring are about 30 by 3 µm-rad. They blow up very quickly along the linac and have to be reduced. Figure 5 shows a typical projection of the beam distribution in sector 11, where about half the beam is to the side instead of behind the core.

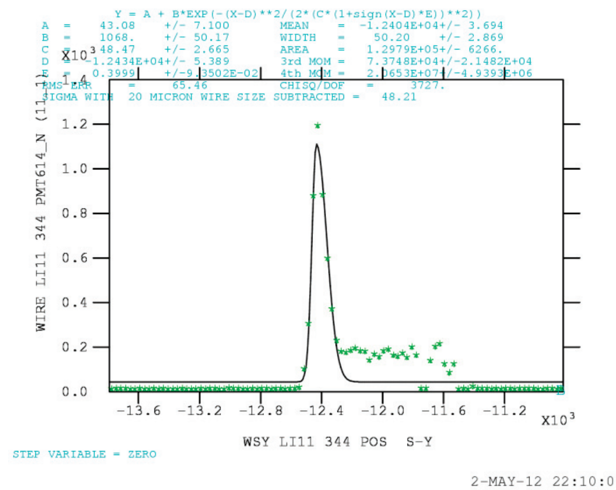

Figure 5: Wire scanner beam projection with long tail.

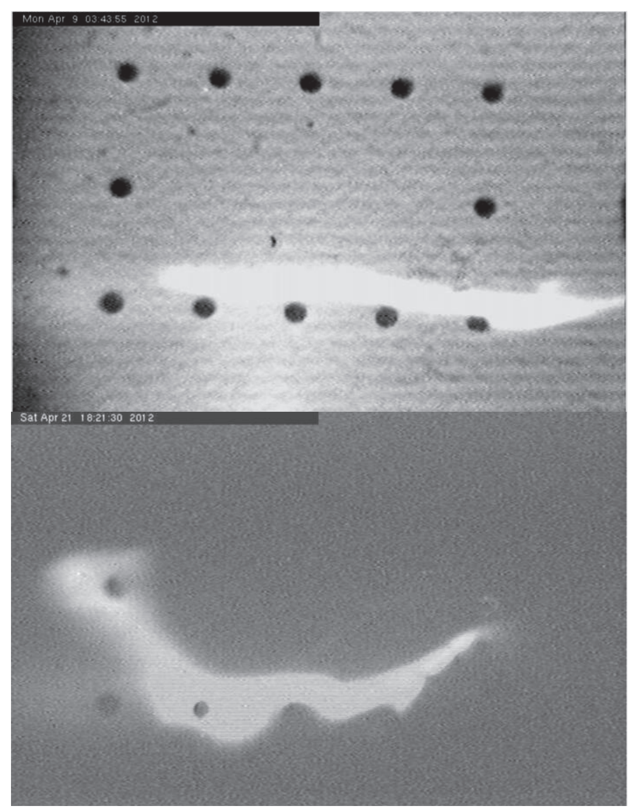

Figure 6: Beam distributions for good (top) and not so good setups. With a hole distance of 1.5 mm and 100 mm horizontal dispersion, the full energy spread is about 7 %, or 3% rms.

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Besides wire scanner, profile monitors show the beam distribution like Fig. 6 where the horizontal is in a high dispersion region of the FACET chicane, and high energy (beam head) is to the left.

Besides dispersion, the wakefields in the RF accelerating structures influence the beam. This is especially important before the sector 10 chicane where the beam is longer than afterwards. A beam blow up due to dispersion or wakefields can be reduced by orbit oscillations [3], which create both, but the best solution depends on the beam intensity, since one is dependant of charge (wakefields), while the other is not (dispersion).

SPECIAL SETUPS

Since there is not a second program going on in this part of the linac, it can be setup to optimize the beam for FACET. In the past we ran with an RF phase profile in sectors two to six of -20°, which creates a big energy spread early on in the linac, where dispersive and chromatic blow up is trickier to control due to a strong betatron lattice with up to 115° phase advance. So we went to a gradual introduction of the necessary energy chirp with staggered phasing of about 0°, -10°, -20°, -30°, -30°, x, x, 0°, -50°, for sectors 2 to 10 (sectors 7 and 8 are not used (x) and 9 includes an energy feedback). By adjusting these phases proportionally, 1° in sector 3 and 5° in sector 10 (on average 2°), the optimal compression can be set [4] (Fig. 7).

A weaker 76° lattice was developed, but not yet implemented, since with this staggered chirp setup the emittance in sector 4 is typical good.

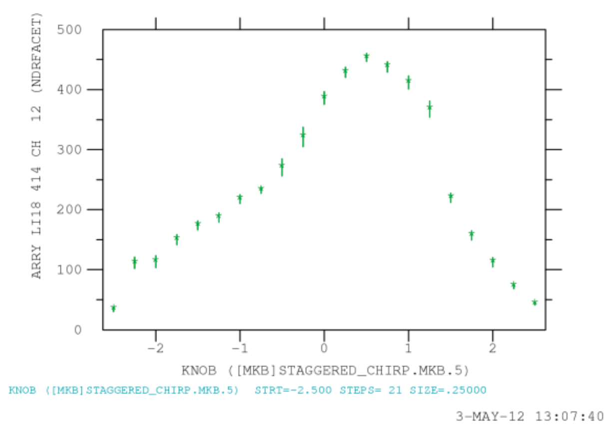

Figure 7: Peak current signal versus Linac phase indicating the right chirp for the best compression.

OTHER EFFORTS

We are also trying to make an effort to quantify all by beam measureable quantities in the linac, like BPM to quadrupole offsets with "bowtie" plots (Fig. 8), RF kicks with klystron on-off difference orbit, injection phase dithering to determine dispersion, dithering the charge to localize wakefield kicks, ballistic data with magnets and RF off and measuring the response of all correctors.

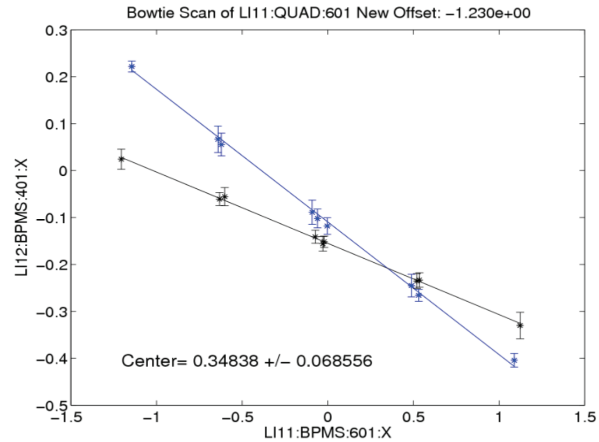

Figure 8: Bowtie scan for determining the BPM to quadrupole offset by measuring the down steam response with two quadrupole settings.

SUMMARY

It is still quite a struggle to tune the linac to good and very good performances. Trying to localize the biggest problems and compensating or fixing them there, is still no match compared to the more global tuning, where the emittances are optimized using bumps or orbit oscillation between feedback regions.

ACKNOWLEDGMENT

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