CHARACTERIZING TRANSVERSE BEAM JITTER IN THE SLC LINAC

F.-J. Decker, R. Pennacchi, R. Stege, J. Turner, SLAC[1], Stanford, CA 94309, U.S.A.

Abstract

Transverse pulse-to-pulse trajectory instability, 'jitter', in the linac of the SLAC Linear Collider (SLC) can be caused by various sources, including mechanical vibration, poor power supply regulation, and malfunctioning of trajectory feedbacks systems. Additionally, the linac can amplify pulse to pulse centroid motion that originates in the damping ring or the transport line that connects the ring to the linac. The purpose of this study is to identify and characterize these sources and to apply corrections and fixes. Transverse jitter has been reduced in the last year from 0.5 to 0.2 in *x* and 1 to 0.3 in *y*, measured in units of beam size. Jitter is estimated using position monitor data from a large sample of successive pulses. The FFT power spectrum of the data often indicate roughly equal contributions from motion at 59 Hz due to the accelerator cooling water pumps, 10 Hz motion due to mechanical vibration or power supplies, and <0.4 Hz due to the feedback loops. Some of the broadband, or random, pulse to pulse motion can be correlated with the microwave instability in the damping ring. In this paper we describe the data analysis and interpretation that can be used to help locate the subsystem component which is causing the instability.

1 INTRODUCTION

The effect of transverse pulse-to-pulse trajectory variations, or jitter is significant in two respects, the increase in effective spot size and in the background behavior of the beam. To quantify the contributions let's take an example: If the jitter is 30% of the beam size (σ) the effective spot size is increased by 4.4% = $(1 + 0.3^2)^{1/2}$. The background issue is much more difficult to quantify, since it seems to be much more sensitive than the 4% spot size increase would imply. It is often the background behavior where jittery beams are observed first. A 59 Hz line in the FFT (fast Fourier transformation) of the beam trajectory was observed and finally tracked down to water pumps which feed the accelerator structures and that caused the nearby quadrupoles to vibrate [1,2]. Many improvements have reduced the problem, but never to a level that it could be ignored. Here we present a method to identify which of the 30 accelerator water pumps has the biggest effect on the beam, so that it can be worked on (e.g. new impeller, different pump, etc.). This method has also helped to identify and quantify other sources.

2 THE FFT-VS-*Z* METHOD

If a jitter source has a characteristic frequency (say 59Hz) it can be found by taking many BPM (beam position monitor) data in a row (e.g. 512) along the linac (e.g. 116) and make a fast Fourier transformation or FFT (Fig. 1). In the frequency spectrum a line at 59 Hz should peak up indicating the problem. To identify where the problem is originating, we just plot that FFT-bin versus *z*, the length along the linac (Fig. 2). Other lines due to different sources were identified in the same way.

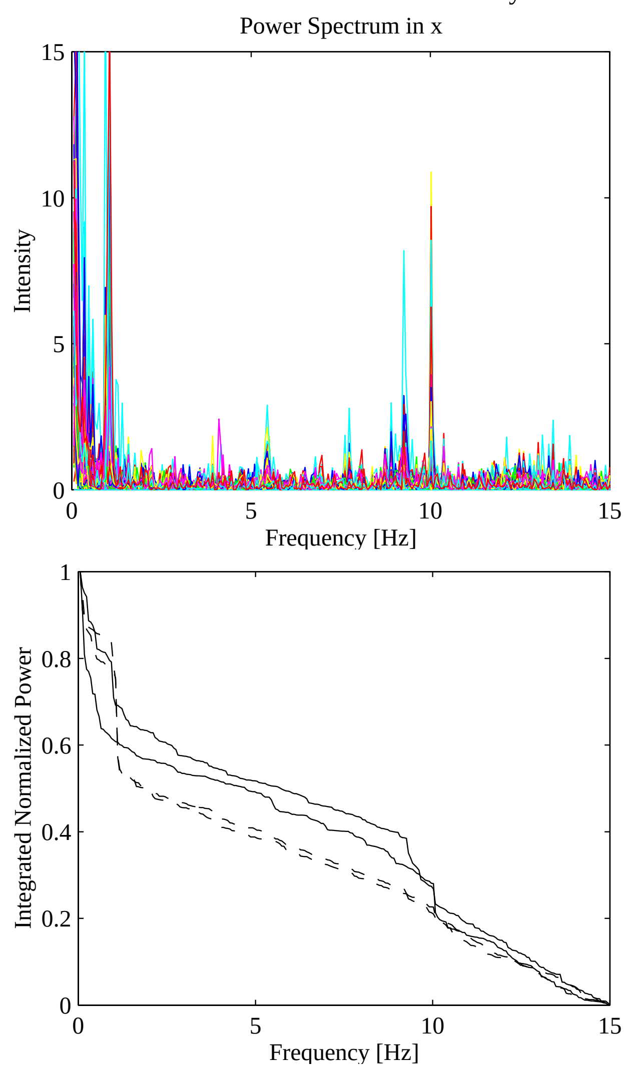

Figure 1: Transverse power spectrum and integrated part. The beginning (solid) shows a 10 Hz line while at the end (dashed) of linac the 59 Hz (aliased to 1 Hz) is stronger.

[1] Work supported by the Department of Energy, contract DE-AC03-76SF00515.

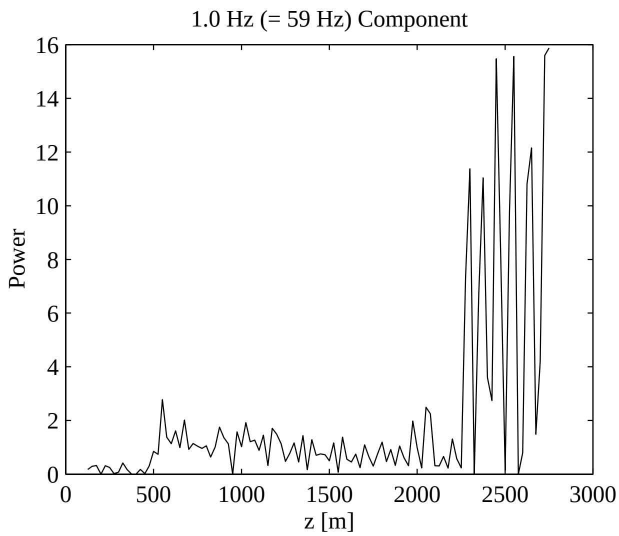

Figure 2: 59 Hz line plotted along the linac.
Two water pumps at z = 500 and 2300 m were identified.

3 59 HZ PROBLEM

The accelerator water pumps have asynchronous motors so they run slightly below 60 Hz. The exact frequency depends on the load and might lay somewhere between 58.8 and 59.1 Hz. By collecting data over a longer period of many seconds, the frequency bins in the FFT get smaller so individual frequencies and therefore pumps can be distinguished. The different frequencies make also the problem much worse, since two pumps can be slowly beating against each other. The beam can look good and then minutes later there is “the wave” of 1 Hz background spikes and then it is fine again for some time. The 1 Hz is the beating frequency due to the 120 Hz data taking.

The variations in water pressure were also measured [2] and they gave a first hint which of the pumps was the worst. After eliminating the worst offenders, the pressure sensor technique needed to be supported with the method described in this paper to find the next pump to be replaced. There was only a short time of a couple of days when the 59 Hz problem was “solved”, then a pump broke and with the new one the 59 Hz line was back, but at a reduced level.

Finally the fast feedback at the end of the linac was modified to cancel variations around 60 Hz which also reduced the centroid motion of the beam at the 59 Hz line [3], but any higher order disturbance like wakefield tails in the beam is not corrected.

4 10 HZ LINE

The 10 Hz problem consists actually of two lines 9 and 10 Hz, which slowly vary by a little amount of ±0.3 Hz. It is only electrons in x and y, and its source is near girder 5 in the NRTL (north ring-to-linac transfer line). Typical supports have a natural frequency around 10 Hz. This is due to the fact that supports need a certain stiffness, so your house, your table, etc. also vibrate at around 10 Hz. This was verified by investigating girder 5. It was oscillating near the observed frequency for many seconds after a shock excitation. This high quality resonator can be easily excited by the white noise of running cooling water (which was turned off for other reasons during the test). An additional stiffening of the support (e.g. to the wall) will increase the frequency and reduce the amplitude which was successfully done at many places in the linac [2] and is on the list for the RTL.

Another investigated possibility for the RTL is an oscillating power supply for the quadrupoles. It was observed that after changing lattice parameter (R_{56}), that the beam was less stable. It had a strong 18 Hz component, which was finally identified as a quadrupole power supply running somewhat higher at 90% of its maximum value and oscillating a little. It was finally fixed, but a search for the 10 Hz being a power supply problem was unsuccessful. By the way this search was done by varying all the quadrupole and sextupole power supplies and seeing if the amplitude or mainly the frequency of the 10 Hz problem would change.

Since the 10 Hz problem has components in x and y of about the same absolute amount, it is much worse in y relative to the smaller y-emittance. On top of that the y-plane for electrons is the most sensitive plane in the linac, it is the smaller emittance and compared to positrons, it has less BNS damping due to the split tune betatron lattice. It is often observed that e^-_y is a big source of spiky background in the SLD detector, but because the spikes are infrequent enough a correlation to 10 Hz can not be observed, but also cannot be excluded.

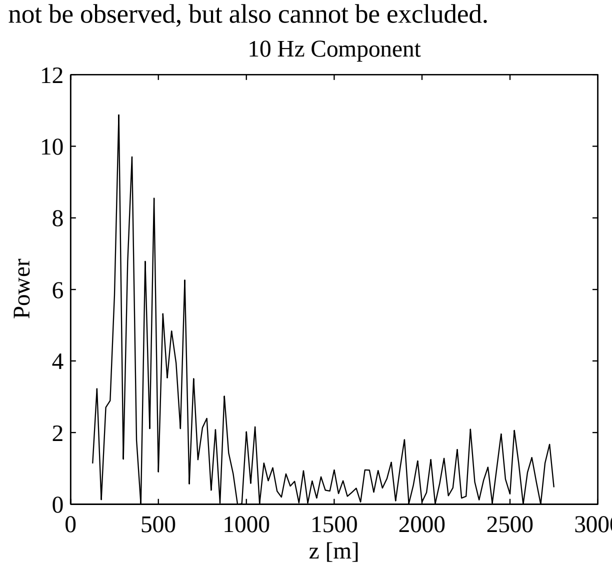

Figure 3: 10 Hz line plotted along the linac.

5 BELOW 0.4 HZ

Very slow oscillations are mainly due to transverse feedback loops which use BPM information and correctors, and which are not perfectly calibrated. The effect can be big compare Fig. 4. There are many studies about slow correctors, varying corrector speeds when going through zero, calibration versus model-derived feedback parameters and so on [4], but the bottom line is that they can easily start to make problems. The oscillations are barely visible in the linac which makes it a tricky problem, but on a screen near the final focus you see a tail coming and going creating background. Therefore the gain of these feedbacks is set to a very small value. This reduces the frequency and also the amplitude of the oscillation, and still keeping the DC-orbit fixed. To avoid this problem the software has to be changed to allow a damping of the feedback itself, so that a small mis-calibration doesn't move the feedback from the aperiodic damped case into oscillations. The gain parameter seems to fulfill this job, but looking into the details it just reduces the amount of the implemented change. The feedback software still assumes for the next pulse, that this implemented change did really happen exactly. A part (or none) of the assumed implementation would damp the system.

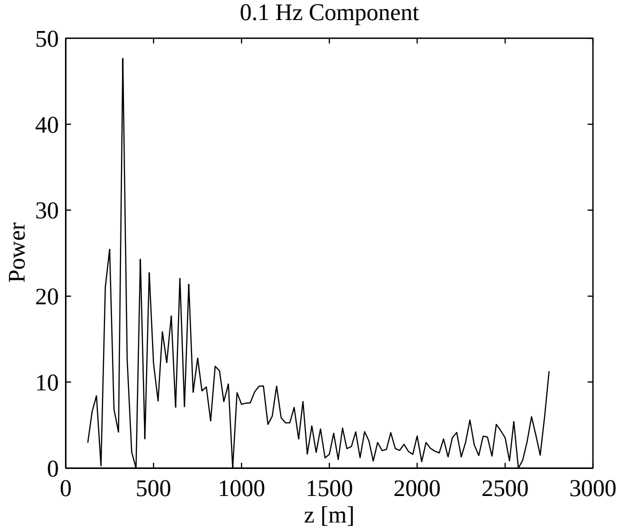

Figure 4: Low frequency line plotted along the linac.

6 RANDOM, WHITE NOISE

The random or white noise part of the frequency spectrum is more difficult to connect with a specific source using the FFT alone. Here two different techniques have shown success. First you know or have a suspicion about a particular source, like the microwave (or sawtooth) instability in the damping ring. Then you correlate a signal of the instability (e.g. the bunch length) with the BPMs and from the correlation coefficient you can derive the amount of jitter due to the instability [5]. A bunch length jitter of 5% was too unstable, 3% was o.k., while 1% is the noise floor from intensity variations.

The other technique is just getting developed [6] and uses the time structure of many pulses along the linac with many BPMs. This model independent analysis sees the time structure change downstream of a jitter source which creates a new eigenvector in this model. By correlating this with a jitter source (like bunch length) or create "jitter" (= dither), we can find not only the amount of the correlation, but also where in the linac are the most sensitive places where longitudinal phase space (e.g. bunch length) couples into the transverse. This gives hints of wakefields due to misaligned accelerator structures or dispersion due to kicks (from energy changes). This technique promises to be very precise by taking lots of data (5000 pulses), but the analysis has to be automated to give a faster turnaround time to fix the detected problems.

7 QUANTIFICATION

The area of a line in frequency space, compared to the area under the whole curve, gives the ratio of the line in the power spectrum. In amplitude or rms the improved value is the square root of the remaining power. So a 20% effect in power (which add up linearly) is only a 10% reduction of the rms jitter! To get the amplitude A from the height of an FFT peak P, you have to know the number of bins n and calculate:

$$A = P^{1/2}/n.$$

So 16 in power is about 16 μm in amplitude with 512 pulses ($\sqrt{16}$ / 256 in mm). In the SLC online display the "power" spectrum is already the square root of the power, so that a single noise line looks much less dramatic compared to the white noise floor.

In the correlation case the power is r^2 with:

$$r = \frac{<\Delta x \Delta y>}{\sqrt{<\Delta x^2>}\sqrt{<\Delta y^2>}}$$

being the correlation coefficient and assuming that one is the source of the other and there is no third source (like current jitter) which might influence both.

SUMMARY

Different jitter sources in the SLC linac and techniques to find them are discussed. Four specific sources are identified and quantified to about 10-20% each in jitter power (after fixing the big 59 Hz in Fig. 1). So there is no single source responsible, but many nearly equal ones.

REFERENCES

[1] J.L. Turner et al., "Vibration Studies of the Stanford Linear Accelerator", PAC95, Dallas, 1995, p. 665.
[2] R.E. Stege, J.L. Turner, "Beam Jitter and Quadrupole Motion in the Stanford Linear Collider", BIW98, Palo Alto, May 1998.
[3] L. Hendrickson et al., "SLC Fast Feedback Performance Improvements at Higher Frequencies", PAC97, Vancouver, 1997.
[4] M.G. Minty et al., "Feedback Performance at the Stanford Linear Collider", PAC95, Dallas, 1995, p. 662.
[5] F.-J. Decker et al., "Higher Order Jitter in the SLC Linac", Linac96, Geneva, 1996.
[6] C. Wang et al., "Model Independant Analysis", to be published in Linac98, Chicago, Aug. 1998.