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Higher Order Beam Jitter in the SLC Linac*

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Abstract

The pulse-to-pulse behavior of the beams in the SLC linac is dominated by wakefields which can amplify any other sources of jitter. A strong focusing lattice combined with BNS damping controls the amplitude of oscillations which otherwise would grow exponentially. Measurements of oscillation amplitude along the linac show beam motion that is up to six times larger than that expected from injection jitter. A search for possible sources of jitter within the linac uncovered some problems such as structure jitter at 8 to 12 Hz, pump vibrations at 59 Hz and 1 Hz aliasing by the feedback systems. These account for only a small fraction of the observed jitter which is dominantly white noise. No source has yet been fully identified but possible candidates are dark current in the linac structures (not confirmed by experiment) or subtle correlations in injection jitter. An example would be a correlated *x-z* jitter with no net offset visible on the beam position monitors at injection. Such a correlation would cause jitter growth along the linac as wakefields from the head of the bunch deflect the core and tail of the bunch. Estimates of the magnitude of this effect and some possible sources are discussed in this paper.

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1 Introduction

After the sawtooth instability [1] in the damping rings of the Stanford Linear Collider (SLC) was fixed (reduced) by changing the impedance of the vacuum chamber [2], the current in the linac could be raised from about $3 \cdot 10^{10}$ to $3.5 \cdot 10^{10}$ particles per bunch in the 1994/95 run. This resulted in an enormous amount of transverse beam jitter of $\Delta y/\sigma_y$ = 0.6-0.8. Many correction schemes for measuring the beam properties evolved, but some reduction in e^- jitter was achieved by splitting the phase advance to generate a decoherence in the long-range wakefield excitation [3]. The jitter still remained big and besides some distinct frequency lines [4], the jitter is coming from a white noise source which grows by a factor of up to six in the linac [5]. Possible candidates were: (a) dark currents in the structure exciting transverse kicks (this could not be confirmed), and (b) higher order jitter effects. Under this term we understand, that the whole jitter is already fully developed, but hidden at the beginning of the linac. The easiest understanding would be an *x*-*z* correlation jitter, where the head and tail distribution cancels the jitter in the beginning but it develops an *x* jitter down the linac due to the wakefield of the offset head particles. Another type of 'hidden' injection jitter is due to bunch length variations, which would change the linac transport properties. In the sections that follow we discuss those two sources of hidden jitter after reviewing the characteristics of the linac jitter growth.

2 Correlated and Uncorrelated Jitter

By launching a betatron oscillation and looking at the amplitude and phase down the linac, one can measure the effective R_{12}'s and their determinant. Transverse wakefields and BNS-damping change the behavior compared to the model lattice.

Since the jitter could be partly visible and partly hidden, the complex correlation of (*x, x'*) in the beginning with (*x, x'*) at the end could uncover some of that higher order jitter. But there was still the biggest factor uncovered (see Fig. 1).

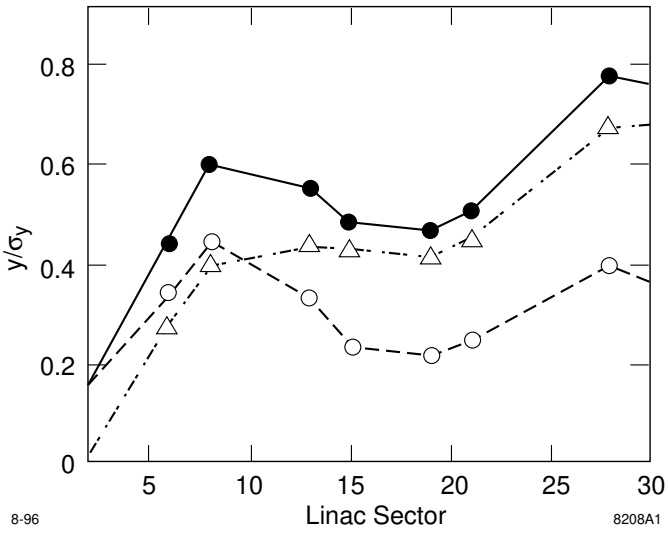

Fig. 1: Measured correlated and uncorrelated jitter development in the linac. While the correlated part (dash) shows the expected jitter profile (up and then down), the uncorrelated part (dash-dotted) grows steadily.

3 Definition and Examples of Higher Order Jitter

Under the definition of higher order jitter we would like to understand any jitter, which is fully present, but hidden at the beginning of a system (e.g. linac) and gets only altered, amplified, or uncovered in that system. No other source in that system (linac) should be counted to "higher order jitter", it is only the hidden, incoming jitter.

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An example is a jittery x-z correlation at the beginning of the linac. Compared to the normal transverse jitter, which puts the whole bunch to an offset $<\Delta x> \neq 0$, it puts the head and the tail to opposite directions $\Delta x_{\text{head}} = -\Delta x_{\text{tail}}$ so that $<\Delta x> = 0$. The development in the linac is shown in Fig. 2.

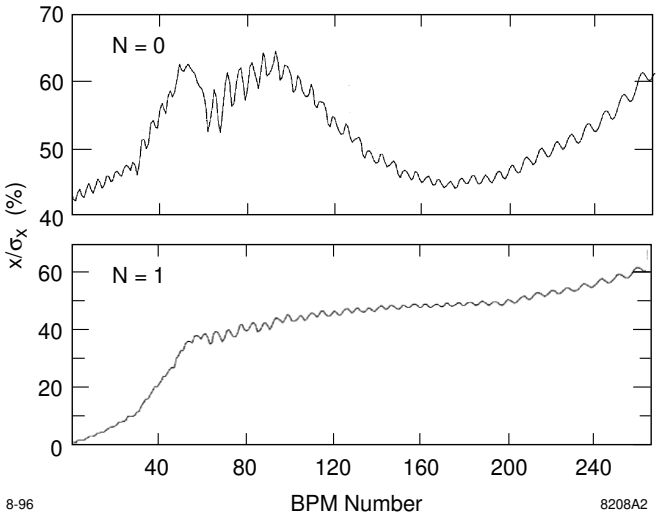

Fig. 2: The normalized jitter in the linac is not constant for high current, but can grow or damp depending on the BNS damping setup. A typical SLC behavior is shown at the top ($N = 0$), while a higher order jitter ($N = 1$, bottom) is invisible with a normal BPM at the beginning, but then grows to the same amplitude.

The jitter amplitudes at the beginning were chosen that there is a 60% jitter ($\Delta y/\sigma_y$) at the end for all cases with a normalized emittance of $3\cdot10^{-6}$ m-rad and $3.5\cdot10^{10}$ particles per bunch. The necessary initial jitter scales like

$$\sigma_{\Delta x}(z) = 20\ \mu\text{m}\cdot(z/\sigma_z)^N/2^N.$$

One source of such a jitter is a bunch length change $\Delta\sigma_z$ in the damping ring, which creates an energy spread change $\Delta E/E$ in the bunch length compression systems. If, additionally, η, η' or their higher order terms (T_{i66}, U_{i666}) are not exactly zero, a higher order transverse offset change is introduced. A linac bunch length change is also visible as higher order jitter [6].

4 'Weak' Sawtooth Instability

Since the 1993 vacuum chamber upgrade of the damping rings, the turbulent microwave instability (called sawtooth instability in the SLC [1]) has changed its character from strong (r and φ-modes couple) to weak (only radial modes couple) [7]. The sawtooth amplitude was reduced and the diagnostic signals went down below the detectable level. Therefore it took about one year till a small correlation of the linac jitter with some sawtooth signal could be found [9]. Since then major work and considerable progress had been made on the signal processing, so that the 180 kHz signal of one bunch can be studied in amplitude and phase (Fig. 3).

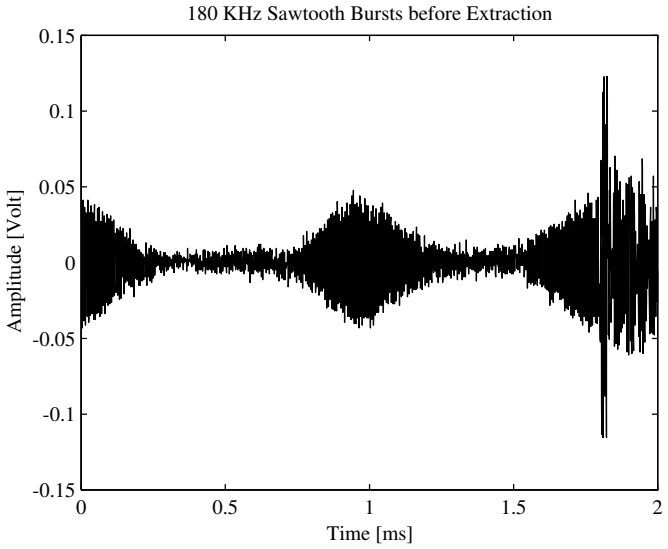

Fig. 3 Eight "sawtooth" bursts happen in about 8 ms. Here three are visible just before extraction (spike). The burst can or cannot happen at extraction time.

Measuring the signal with a gated ADC over a short gate (ns) it is possible to correlate it with BPMs or other devices in the linac. There are two effects which reduce the correlation:
1. The timing must be right; a big correlation at one time setting of the gated ADC gives a negative correlation 2.75 μs later, and none at 1.375 μs.
2. Even the biggest correlation is suppressed due to the bursts; a medium gated ADC value can come from the crest of the 180 kHz signal of the rising or falling part of the burst, or it comes off-crest (+ or –) from the center part of the burst. Signal Splitting and two ADC at 0 and 1.375 μs would give the whole information.

5 Measurements

An ensemble of 512 beam pulses at 120 BPMs (about 1/2 of the linac), the bunch length, the sawtooth signal and some other parameters was studied. The correlation factor (mean subtracted)

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

between the sawtooth ADC signal and y-data from a BPM at the end of the linac was measured to be $r = 0.64$, which means that at least $r^2 = 0.41$ of the whole jitter power is coming from the sawtooth. This is a much bigger single source than 30 water pumps generating 59 Hz (0.1 of power) and 8-10 Hz due to water turbulence and quad support (0.2 of power).

The correlation development down the linac is shown is Fig. 4. The *x* component shows a behavior of a higher order jitter, while the *y* is slowly decreasing. The last point with less jitter is after the collimators.

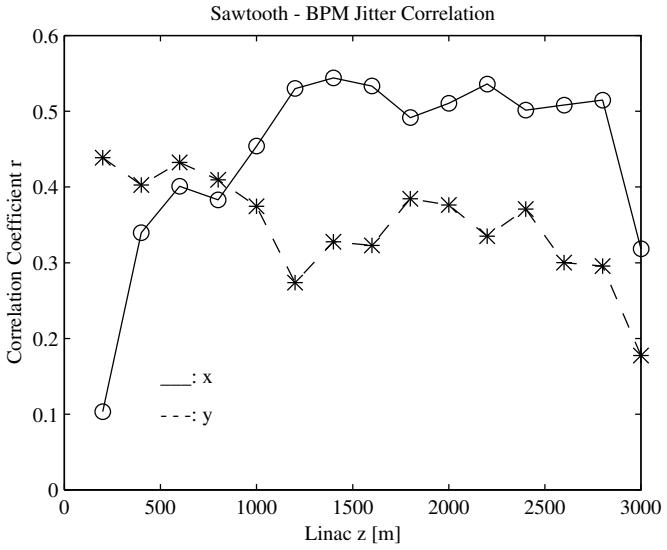

Fig. 4: Sawtooth to jitter correlation versus *z* in the linac (*x*: solid, *y*: dashed).

There was also a correlation of the sawtooth signal with the bunch length which jittered by 10% ($\Delta\sigma_z/\sigma_z$) with $r = 0.62$ (39% of power spectrum), see Fig. 5, and only a small correlation with the current jitter $r = 0.31$ (10% of power).

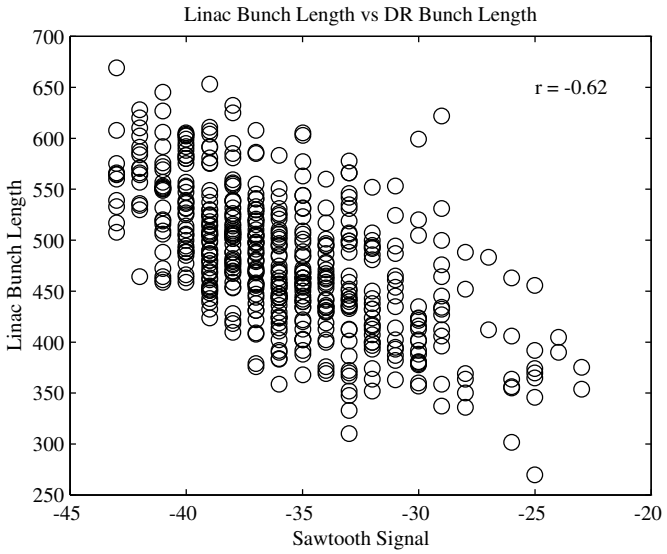

Fig. 5: Linac bunch length jitter versus sawtooth signal.

By exciting a bunch length oscillation about 1 ms before extraction, the sawtooth amplitude at extraction was much reduced and less frequent. This resulted in a reduction in linac jitter of 30%, which is somewhat more than expected if all the correlation could be reduced:

$$j_{new}/j_o = \sqrt{1-r^2}\ .$$

This suggests that some of the correlation was reduced, which could be the mentioned amplitude/phase ambiguity of the sawtooth signal or a not perfect timing setup of the gate.

5 Summary

Hidden, incoming jitter or "higher order jitter" can have big effects in the linac due to the high currents and wakefields. A source from the damping ring (sawtooth) has been identified to be a good example of such a hidden jitter. It could be substantially reduced.

Acknowledgment

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