Super-ASSET: A Technique for Measuring and Correcting Accelerator Structure Misalignments at the SLC

F.-J. Decker, R. Assmann, M.G. Minty, P. Raimondi, G. Stupakov

Stanford Linear Accelerator Center[†], Stanford University, Stanford, CA 94309 USA

Abstract

Transverse wakefield kicks from misaligned accelerating structures in the SLC linac contribute significantly to emittance growth. If these kicks could be measured directly, it would be possible to align and/or steer the beam to a kick-free trajectory. In the Accelerator Structure Test Facility at SLAC, ASSET [1], the kicks due to a drive bunch are measured with a witness bunch at varying bunch separations. In ASSET, the first bunch is discarded and only the second bunch is measured. Super-ASSET is an extension of this technique where both bunches are accelerated down the entire linac together and a "sum trajectory" of both bunches is measured with beam position monitors (BPMs). The trajectory of the second, kicked bunch can be calculated by subtracting the orbit of the first bunch, measured alone, from the sum trajectory. This paper discusses BPM response issues and the expected resolution of this technique together with alignment and steering strategies.

1 INTRODUCTION

In the SLAC Linear Collider (SLC), misalignments of the accelerating structures may cause transverse wakefield kicks which deflect the tail of the bunch and create emittance growth. In addition to several indirect techniques summarized in the next section, we will discuss here the most direct approach to measure locally the kick of the bunch head to the bunch tail. Two bunches are accelerated down the linac very close together in time, a few wavelengths λ) apart. For e^+ and e^-, possible choices are $\pm\lambda/2$, $\pm 3\lambda/2$, $\pm 5\lambda/2$, . . . so that they are both accelerated. This method probes the short-range wakefields. A perfect wakefield free orbit would produce no kicks for all bunch separations, but the real situation is more complicated. If the linac is not totally straight, the steering kicks of the magnets create dispersion which must be compensated.

2 DIFFERENT TECHNIQUES

Many other alignment techniques have been suggested to reduce emittance growth. After mechanical alignment, beam-based measurements are used to center the beam position monitors (BPMs), quadrupoles, and structures. Most of these techniques rely on assumptions which may not be valid. With the following table we try to give an overview.

Technique	Assumption (<u>B</u>PM, <u>Q</u>uad, <u>A</u>cc.)	Achievement
1 Alignment (all)	mechanical,	mechanical
a) initial	electric center	resolution,
b) beam based	change is right	beyond that
2 Steering (B, Q)	B, A offset = 0	BPM reading
a) 1-to-1	Q to B offset = 0	bpm center
b) DF,TBDFS	B offset for $e^{+/-}$	quad center
c) SVD	ave. alignment	less corr. kick
d) ballistic	no elec/mag field	get B offset
e) quad scaling	no elec. kicks	get Q offset
3 Wakefield (A)	wake big effect	signal reading
a) dipole signal	A to signal = 0	S center
b) ΔI or $\Delta\sigma_z$[4]	clean distiction	calc. effect
c)hi order wake	no asym coupler	hi wake center
d) Super-Asset	BPM response	beam-S center
4 Bumps (global)	end result o.k.	smaller emit.
a) oscillations	error within oscil.	minimum
b) local 360º	meas. and corr.	and stable

Table 1: Alignment and emittance reduction techniques (DF [2]: dispersion free, TBDFS [3]: two beam DF steering, SVD: single value decomposition).

3 SUPER–ASSET

The basic idea of Super-ASSET is to measure the wakefield kick from one bunch closely following another. It is necessary to take the first bunch orbit x_1, and subtract it from the "sum orbit" x_Σ of both beams to get the kicked beam orbit x_2:

$$x_\Sigma = (q_1\, x_1 + q_2\, x_2\, f(t)) \,/\, q_\Sigma \qquad (1)$$

with $q_\Sigma = q_1 + q_2\, f(t)$ and $f(t)$ is the response function of the BPM: $f(t) = 0$ for a large time separation t of the two bunches, and $f(t) = 1$ for $t = 0$.

3.1 BPM Response

The BPM response function $f(t)$ was measured by combining positive ($1.5{\cdot}10^{10}$) and negative$\cdot$($-1.06{\cdot}10^{10}$) signals in a test setup. Figure 1 shows the result compared with a theoretical response. Since the BPMs are self-triggered by the signal, the sum signal must exceed a certain threshold: $q_1 + q_2 \geq q_{trig}$ ($\approx 2{\cdot}10^9$ particles).

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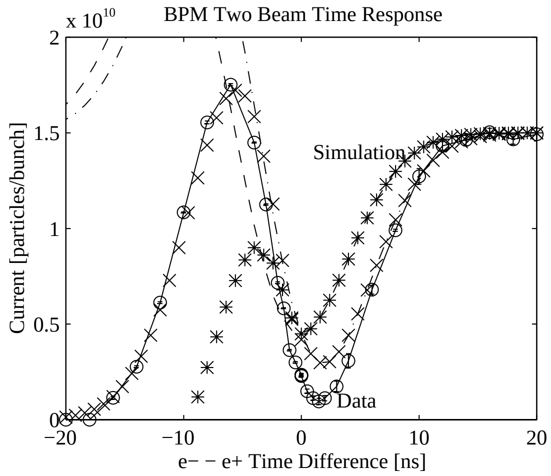

Figure 1: Measured (o) and calculated (*) BPM response. Due to the slow rise time of pulses used in the test setup, the minimum is shifted to +2 ns, which can be also modeled (x). The dashed and dash-dotted lines in the top left, would be the curves, if the BPM were triggered externally and not self-triggered by the beam. The dashed curve is 1.5E10 (1–0.7 $f(t)$).

When superimposing bunches of different sign charge, the BPM resolution can be significantly increased because the measured offsets are normalized to the total beam current, which is small. For example, $4\cdot10^{10} - 3\cdot10^{10} = 0.4\cdot10^{10} = q_\Sigma$, $x_2 = 0$, $x_\Sigma = q_1\, x_1 / q_\Sigma = 10\, x_1$. The BPM readout will saturate for big offsets, so only ±0.8 mm offsets can be measured rather than the full ±8 mm.

3.2 Wakefield Kicks

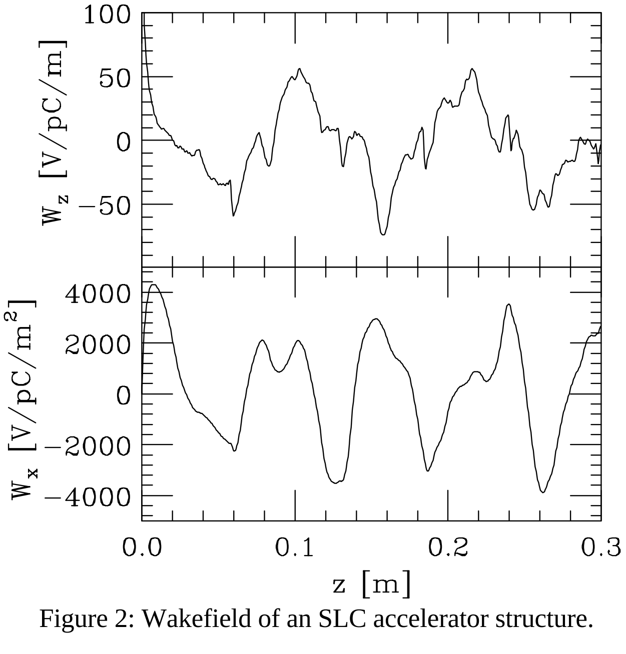

Figure 2: Wakefield of an SLC accelerator structure.

The maximum wakefield of an SLC accelerator structure is about $W_\perp = 5$ V/pC/mm/m (Fig. 2). Therefore for $N = 5\cdot10^{10}$ particles (8 nC), an offset $\Delta x = 1$ mm, and a 12 m long structure (L), the transverse kick $\theta_\perp$ is 480 keV / E:

$$\theta_\perp = e\, N\, L\, \Delta x\, W_\perp / E. \qquad (2)$$

This kick will affect the beam differently at different points along the linac depending on the energy E and the betatron function β of the focusing lattice. Averaged over a bunch length of about 1.2 mm the wakefield is only $W_{\perp \mathrm{ave}} = 1$ V/pC/mm/m or 20% of the peak. Table 2 shows the effect of this wakefield at different locations in the linac. At the beginning of the linac (Li02) there is only a 3 m structure between quadrupoles. The region about 500 meters along the linac (Li05) is the most sensitive by a factor of 2.5–3, because the quadrupole spacing becomes large and the energy is still relatively low. Li30 is the end of the linac.

	Li02	Li05	Li30
E [GeV]	1.2	7	46
$\beta_{\max}$ [m]	10	40	50
σ_y' [μrad]	14	3	1
$\theta_\perp$ [μrad]	80 (/4)	14	2
σ_y [μm]	140	115	50
Δy [μm]	200	540	100
ratio=θ/σ'	1.4	4.7	2

Table 2: Effective kick of a 1 mm accelerator structure offset between quadrupoles compared with the angular divergence σ_y' for an emittance of $\gamma\varepsilon_y = 0.45\cdot10^{-5}$ m-rad.

3.3 Measurement Sensitivity and Systematic

As seen from the Tab. 2, a 1 mm offset of the beam in a structure would cause an average centroid displacment of 1.4 to 4.7 times σ_y, increasing the projected emittance. To measure these kicks, the difference orbit at two different bunch separations is used, e.g. $\lambda/2$ and $3\lambda/2$, or $3\lambda/2$ and $5\lambda/2$ ($\lambda = 105$ mm). The wakefield kick changes sign for different separations, enhancing the sensitivity of the measurement. Wakefield differences of 4 or 6 V/pC/mm/m produce effectively 5 times the offset Δy of table 2 or about 1 mm, 2.7 mm, 0.5 mm for the three locations. A typical measurement with e^+/e^- might be $2\cdot10^{10}$ positrons follow by $3\cdot10^{10}$ electrons with a difference orbit $x_{\Sigma,\mathrm{diff}} = x_{\Sigma a} - x_{\Sigma b} = 3(x_{2a} - x_{2b}) = 1.2$, 3.2, 0.6 mm. The BPM reading is about 0.5 to 3 times the structure offset, indicating that with a BPM resolution of 10–20 μm, one measures the structure offset to about the same resolution. Averaging many readings can further increase the accuracy.

4 FIRST MEASUREMENT

Although the experiment with high current electron and positron bunches has not yet been performed, preliminary tests with two electron bunches were made during the 1997 SLAC fixed target run. A charge of $3.0 \cdot 10^{10}$ in two bunches (λ = 105 mm apart), or of $1.5 \cdot 10^{10}$ in one bunch was accelerated down the linac (Fig. 3).

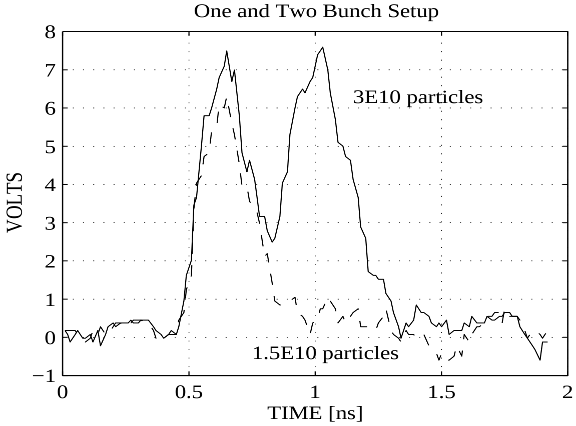

Figure 3: Gap monitor signal of one or two bunches.

The expected kick is much less for this configuration: 2.7 mm in sector 5 becomes 0.8 mm at these currents which is measured as 0.4 mm when the BPMs average two same sign bunches and is further reduced to 0.16 mm because the wakefields are 2 rather than 5 V/pC/mm/m at this separation. A closed bump of 2 mm peak (1.7 mm effective) should produce an oscillation of about 0.27 mm, in good agreement with the measurement (see Fig. 4).

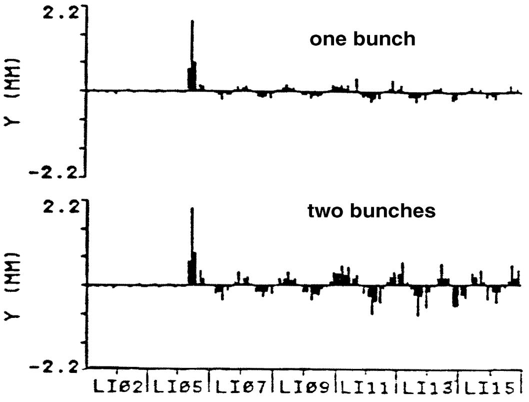

Figure 4: Wakefield kick of a 2 mm bump, top: for one bunch nearly closed, bottom: for two bunches a 250 µm oscillation starts.

5 COMPENSATION METHODS

Once the accelerator structure misalignments are known, there are two basic approaches. First, there is mechanical alignment which may be only practical for a few worst offenders. Second, one may attempt to find an optimal beam trajectory through these misalignments.

Simulations have shown that dispersive emittance growth which is normally 4 times smaller than the wakefield growth may increase dramatically if the beam is steered to the center of the structures to avoid any wakefield kicks. Clearly wakefield and dispersion effects have to be minimized at the same time. This can be done by canceling wakefield and dispersion growth separately over one betatron oscillation (8 correctors for e^+/e^-). One may also try to cancel the growth locally by trading the dispersive kick off against the linear part of the wakefield kick. The method to be used is still under study.

6 SUMMARY

With Super-ASSET, a beam based technique, we should be able to measure and locally correct the biggest source of emittance growth in the SLC linac – the transverse wakefield kicks of the accelerator structures. If successful, this method promises to be useful for future linear colliders, and might relax the tolerances for wakefield dominated designs.

7 ACKNOWLEDGMENTS

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