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TITLE: ENERGY SPREAD IN SLC LINAC WITH LANDAU DAMPING

The possibility of using Landau damping to reduce the growth of the beam size due to transverse wake fields has been known for some time. Recently K. Bane² has calculated the effects of Landau Damping for the SLC. Basically, the beams are given a large energy spread early in the linac. The energy spread is then slowly removed so that at the end of the linac it has returned to the SLC specification of less than $\pm 0.5\%$. The purpose of the energy spread is to reduce the resonant driving of the tail of the bunch by the head. In this note the expected energy spreads within the beam are tabulated at various positions along the linac for use by those people designing momentum dependent equipment and for those interested in Landau damping.

In the calculation, the beam is cut into longitudinal slices and numerically tracked down the linac. The energy of each slice is affected by its phase in the RF wave and the wake potential of the preceding slices. The following inputs were used.

1. Beam injected at Sector 2 at $E=1.21$ GeV.
2. $\sigma_z = 1\text{mm}$.
3. All klystrons in a sector (8) have the same phase.
4. 1.75 GeV gain per sector
5. Longitudinal wake field given by ³

$$w(z) = 0.0038 \exp \left(-\sqrt{\frac{z}{1.62 \text{ mm}}} \right) \text{ volts/e}^-/\text{sector}$$

where z is the distance between an electron that generates the wake and the point at which the wake is measured.

6. The beam contains 5×10^{10} particles concentrated in $\pm 3 \sigma_z$

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7. The beam is cut into 60 slices longitudinally.

Four cases are presented here: one without and three with Landau damping. The case without Landau damping has all klystron phases at +12 degrees which compensates for the longitudinal wake field effects allowing a small energy spread at the end of the linac. The other three cases have klystrons early in the linac back-phased and klystrons late in the linac forward-phased.

CASE #	1	2	3	4
Number of Early klystrons	0	48	24	8
Phase of Early klystrons(deg)	N/A	-15	-30	-53
Number of Late klystrons	232	184	208	224
Phase of Late klystrons(deg)	12.0	19.2	16.8	15.0
Final Beam Energy (GeV)	49.6	48.1	48.0	48.3

The energy of the longitudinal slices at the one half sigma points as a function of sector number for the four cases above are listed in Table 1, 2, 3 and 4. The energy of the bunch center is considered the nominal energy. The energy of the $+\sigma_z$ and $-\sigma_z$ slices are plotted in Figure 1 as a function of sector number. Note that the peak energy spreads occur at the phase transition points. The energies of all slices in the beam are shown in Figure 2 for Sector 19, the beginning of the positron production region. Note that a +1% energy acceptance for the e^+ source electron transport beam line is a minimum.

K. Bane has analyzed the effects of the transverse wake fields for cases 1, 2, and 3. P. Bernstein kindly produced the two plots.

REFERENCES:

1. V. Balakin, et. al., "VLEPP: TRANSVERSE BEAM DYNAMICS", 12TH International Conference of High Energy Accelerators. (1983), p119.
2. K. Bane, to be published.
3. SLC Design Handbook, January, 1983.

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Table 1 Case 1: Energy offsets along the beam at the end of each sector in the linac without Landau damping. The gaussian bunch length is one millimeter. The sector number is S . All klystrons in a sector has phase ϕ (degrees).

S	ϕ	$E(\text{GeV})$	Energy offset (%) along the bunch									
			$-3\sigma_z$	$-2\sigma_z$	$-1\sigma_z$	Center	$+1\sigma_z$	$+2\sigma_z$	$+3\sigma_z$			
2	12.0	2.9	1.3	0.9	0.6	0.2	-0.1	-0.1	0.0	0.2	0.3	0.1
3	12.0	4.5	1.6	1.2	0.7	0.2	-0.1	-0.2	0.0	0.3	0.3	0.1
4	12.0	6.2	1.8	1.3	0.8	0.3	-0.1	-0.2	0.0	0.3	0.4	0.1
5	12.0	7.9	1.8	1.4	0.8	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
6	12.0	9.5	1.9	1.4	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
7	12.0	11.2	1.9	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
8	12.0	12.9	2.0	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
9	12.0	14.5	2.0	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
10	12.0	16.2	2.0	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
11	12.0	17.9	2.0	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
12	12.0	19.5	2.0	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
13	12.0	21.2	2.1	1.5	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
14	12.0	22.9	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
15	12.0	24.5	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
16	12.0	26.2	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
17	12.0	27.9	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
18	12.0	29.5	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
19	12.0	31.2	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.4	0.2
20	12.0	32.9	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
21	12.0	34.5	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
22	12.0	36.2	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
23	12.0	37.9	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
24	12.0	39.5	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
25	12.0	41.2	2.1	1.6	0.9	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
26	12.0	42.9	2.1	1.6	1.0	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
27	12.0	44.6	2.1	1.6	1.0	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
28	12.0	46.2	2.1	1.6	1.0	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
29	12.0	47.9	2.1	1.6	1.0	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
30	12.0	49.6	2.1	1.6	1.0	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2

Table 2 Case 2: Energy offsets in the beam with Landau damping with the first 48 klystrons backphased. The bunch length is 1 mm, the sector number is S, and all the klystrons in a sector have phase ϕ (degrees).

Energy offset (%) along the bunch														
S	ϕ	E(GeV)	$-3\sigma_z$	$-2\sigma_z$	$-1\sigma_z$	Center	$+1\sigma_z$	$+2\sigma_z$	$+3\sigma_z$					
2	-15.0	2.9	-3.8	-3.3	-2.8	-2.4	-1.8	-1.0	0.0	1.1	2.0	2.7	3.1	3.4
3	-15.0	4.5	-4.9	-4.2	-3.6	-3.0	-2.3	-1.3	0.0	1.3	2.5	3.4	4.0	4.4
4	-15.0	6.1	-5.4	-4.6	-4.0	-3.3	-2.5	-1.4	0.0	1.5	2.8	3.7	4.4	4.8
5	-15.0	7.8	-5.6	-4.9	-4.2	-3.5	-2.6	-1.5	0.0	1.6	2.9	3.9	4.6	5.0
6	-15.0	9.4	-5.8	-5.0	-4.3	-3.6	-2.7	-1.5	0.0	1.6	3.0	4.1	4.8	5.2
7	-15.0	11.1	-5.9	-5.1	-4.4	-3.7	-2.8	-1.6	0.0	1.6	3.1	4.1	4.9	5.3
8	19.2	12.7	-4.6	-4.0	-3.5	-3.0	-2.4	-1.3	0.0	1.4	2.6	3.5	4.0	4.2
9	19.2	14.3	-3.5	-3.1	-2.8	-2.5	-2.0	-1.2	0.0	1.3	2.3	3.0	3.3	3.4
10	19.2	15.9	-2.7	-2.4	-2.3	-2.1	-1.7	-1.0	0.0	1.1	2.1	2.6	2.8	2.7
11	19.2	17.5	-2.0	-1.9	-1.8	-1.8	-1.5	-0.9	0.0	1.0	1.8	2.3	2.3	2.1
12	19.2	19.1	-1.5	-1.4	-1.5	-1.5	-1.3	-0.8	0.0	0.9	1.7	2.0	2.0	1.6
13	19.2	20.7	-1.0	-1.0	-1.1	-1.3	-1.2	-0.8	0.0	0.9	1.5	1.8	1.6	1.3
14	19.2	22.3	-0.6	-0.7	-0.9	-1.1	-1.1	-0.7	0.0	0.8	1.4	1.6	1.4	0.9
15	19.2	23.9	-0.2	-0.4	-0.6	-0.9	-0.9	-0.6	0.0	0.7	1.3	1.4	1.1	0.6
16	19.2	25.6	0.1	-0.1	-0.4	-0.7	-0.8	-0.6	0.0	0.7	1.2	1.2	0.9	0.4
17	19.2	27.2	0.3	0.1	-0.2	-0.6	-0.8	-0.6	0.0	0.6	1.1	1.1	0.8	0.1
18	19.2	28.8	0.6	0.3	-0.1	-0.5	-0.7	-0.5	0.0	0.6	1.0	1.0	0.6	-0.1
19	19.2	30.4	0.8	0.5	0.1	-0.4	-0.6	-0.5	0.0	0.6	0.9	0.9	0.5	-0.2
20	19.2	32.0	1.0	0.6	0.2	-0.3	-0.5	-0.4	0.0	0.5	0.9	0.8	0.3	-0.4
21	19.2	33.6	1.2	0.8	0.3	-0.2	-0.5	-0.4	0.0	0.5	0.8	0.7	0.2	-0.5
22	19.2	35.2	1.3	0.9	0.4	-0.1	-0.4	-0.4	0.0	0.5	0.8	0.6	0.1	-0.7
23	19.2	36.8	1.5	1.0	0.5	0.0	-0.4	-0.4	0.0	0.5	0.7	0.6	0.0	-0.8
24	19.2	38.4	1.6	1.2	0.6	0.0	-0.3	-0.3	0.0	0.4	0.7	0.5	-0.1	-0.9
25	19.2	40.0	1.7	1.3	0.7	0.1	-0.3	-0.3	0.0	0.4	0.6	0.4	-0.1	-1.0
26	19.2	41.6	1.9	1.4	0.7	0.1	-0.3	-0.3	0.0	0.4	0.6	0.4	-0.2	-1.1
27	19.2	43.2	2.0	1.4	0.8	0.2	-0.2	-0.3	0.0	0.4	0.6	0.3	-0.3	-1.2
28	19.2	44.8	2.1	1.5	0.9	0.2	-0.2	-0.3	0.0	0.4	0.5	0.3	-0.4	-1.3
29	19.2	46.5	2.1	1.6	0.9	0.3	-0.2	-0.3	0.0	0.4	0.5	0.2	-0.4	-1.3
30	19.2	48.1	2.2	1.7	1.0	0.3	-0.1	-0.3	0.0	0.4	0.5	0.2	-0.5	-1.4

Table 3 Case 3: Energy offsets in the beam with Landau damping with the first 24 klystrons backphased. The bunch length is 1 mm, the sector number is S, and all the klystrons in a sector have phase ϕ (degrees).

		Energy offset (%) along the bunch											
S	ϕ	E(GeV)	$-3\sigma_z$	$-2\sigma_z$	$-1\sigma_z$	Center	$+1\sigma_z$	$+2\sigma_z$	$+3\sigma_z$	$+4\sigma_z$	$+5\sigma_z$	$+6\sigma_z$	$+7\sigma_z$
2	-30.0	2.7	-6.8	-5.8	-4.9	-3.9	-2.9	-1.5	0.0	1.6	3.1	4.3	5.3
3	-30.0	4.2	-8.8	-7.5	-6.3	-5.1	-3.7	-2.0	0.0	2.1	4.0	5.6	6.8
4	-30.0	5.6	-9.7	-8.3	-7.0	-5.6	-4.1	-2.2	0.0	2.3	4.4	6.2	7.6
5	16.8	7.3	-6.7	-5.8	-4.9	-4.1	-3.1	-1.7	0.0	1.8	3.4	4.6	5.5
6	16.8	8.9	-4.8	-4.2	-3.7	-3.1	-2.4	-1.4	0.0	1.5	2.8	3.7	4.2
7	16.8	10.5	-3.4	-3.0	-2.8	-2.5	-2.0	-1.2	0.0	1.3	2.3	3.0	3.3
8	16.8	12.1	-2.5	-2.2	-2.1	-2.0	-1.7	-1.0	0.0	1.1	2.0	2.5	2.7
9	16.8	13.8	-1.7	-1.6	-1.6	-1.6	-1.4	-0.9	0.0	1.0	1.8	2.2	2.2
10	16.8	15.4	-1.1	-1.1	-1.2	-1.3	-1.3	-0.8	0.0	0.9	1.6	1.9	1.8
11	16.8	17.0	-0.7	-0.7	-0.9	-1.1	-1.1	-0.7	0.0	0.8	1.4	1.6	1.5
12	16.8	18.7	-0.3	-0.4	-0.7	-0.9	-1.0	-0.7	0.0	0.8	1.3	1.4	1.2
13	16.8	20.3	0.1	-0.1	-0.4	-0.7	-0.9	-0.6	0.0	0.7	1.2	1.3	1.0
14	16.8	21.9	0.3	0.1	-0.3	-0.6	-0.8	-0.6	0.0	0.7	1.1	1.1	0.8
15	16.8	23.6	0.6	0.3	-0.1	-0.5	-0.7	-0.5	0.0	0.6	1.0	1.0	0.6
16	16.8	25.2	0.8	0.5	0.0	-0.4	-0.6	-0.5	0.0	0.6	1.0	0.9	0.5
17	16.8	26.8	1.0	0.6	0.2	-0.3	-0.6	-0.5	0.0	0.6	0.9	0.8	0.4
18	16.8	28.4	1.1	0.8	0.3	-0.2	-0.5	-0.4	0.0	0.5	0.8	0.7	0.3
19	16.8	30.1	1.3	0.9	0.4	-0.1	-0.5	-0.4	0.0	0.5	0.8	0.7	0.2
20	16.8	31.7	1.4	1.0	0.5	-0.1	-0.4	-0.4	0.0	0.5	0.7	0.6	0.1
21	16.8	33.3	1.5	1.1	0.5	0.0	-0.4	-0.4	0.0	0.5	0.7	0.5	0.0
22	16.8	35.0	1.6	1.2	0.6	0.0	-0.3	-0.3	0.0	0.4	0.7	0.5	-0.1
23	16.8	36.6	1.7	1.3	0.7	0.1	-0.3	-0.3	0.0	0.4	0.6	0.4	-0.1
24	16.8	38.2	1.8	1.3	0.7	0.1	-0.3	-0.3	0.0	0.4	0.6	0.4	-0.2
25	16.8	39.9	1.9	1.4	0.8	0.2	-0.3	-0.3	0.0	0.4	0.6	0.4	-0.2
26	16.8	41.5	2.0	1.5	0.8	0.2	-0.2	-0.3	0.0	0.4	0.6	0.3	-0.3
27	16.8	43.1	2.1	1.5	0.9	0.2	-0.2	-0.3	0.0	0.4	0.5	0.3	-0.3
28	16.8	44.7	2.1	1.6	0.9	0.3	-0.2	-0.3	0.0	0.4	0.5	0.3	-0.4
29	16.8	46.4	2.2	1.6	1.0	0.3	-0.2	-0.3	0.0	0.4	0.5	0.2	-0.4
30	16.8	48.0	2.2	1.7	1.0	0.3	-0.1	-0.3	0.0	0.4	0.5	0.2	-0.5

Table 4 Case 4: Energy offsets in the beam with Landau damping with the first 8 klystrons backphased. The bunch length is 1 mm, the sector number is 5, and all the klystrons in a sector have phase ϕ (degrees).

Energy offset (%) along the bunch												
S	ϕ	E(GeV)	$-3\sigma_z$	$-2\sigma_z$	$-1\sigma_z$	Center	$+1\sigma_z$	$+2\sigma_z$	$+3\sigma_z$	$+4\sigma_z$	$+5\sigma_z$	$+6\sigma_z$
2	-53.0	2.2	-12.1	-10.3	-8.6	-6.8	-4.8	-2.6	0.0	2.7	5.2	7.4
3	15.0	3.9	-5.6	-4.9	-4.2	-3.5	-2.7	-1.5	0.0	1.6	3.0	4.1
4	15.0	5.5	-3.0	-2.7	-2.5	-2.2	-1.8	-1.1	0.0	1.2	2.2	2.8
5	15.0	7.2	-1.5	-1.5	-1.5	-1.5	-1.4	-0.9	0.0	1.0	1.7	2.1
6	15.0	8.8	-0.7	-0.7	-0.9	-1.1	-1.1	-0.7	0.0	0.8	1.4	1.6
7	15.0	10.4	-0.1	-0.2	-0.5	-0.8	-0.9	-0.6	0.0	0.7	1.2	1.3
8	15.0	12.1	0.4	0.1	-0.2	-0.6	-0.7	-0.5	0.0	0.6	1.1	1.1
9	15.0	13.7	0.7	0.4	0.0	-0.4	-0.6	-0.5	0.0	0.6	1.0	0.9
10	15.0	15.4	1.0	0.6	0.2	-0.3	-0.5	-0.4	0.0	0.5	0.9	0.8
11	15.0	17.0	1.2	0.8	0.3	-0.2	-0.5	-0.4	0.0	0.5	0.8	0.7
12	15.0	18.7	1.4	1.0	0.4	-0.1	-0.4	-0.4	0.0	0.5	0.7	0.6
13	15.0	20.3	1.5	1.1	0.5	0.0	-0.4	-0.4	0.0	0.5	0.7	0.5
14	15.0	22.0	1.7	1.2	0.6	0.0	-0.3	-0.3	0.0	0.4	0.7	0.5
15	15.0	23.6	1.8	1.3	0.7	0.1	-0.3	-0.3	0.0	0.4	0.6	0.4
16	15.0	25.3	1.9	1.4	0.8	0.1	-0.3	-0.3	0.0	0.4	0.6	0.4
17	15.0	26.9	1.9	1.4	0.8	0.2	-0.2	-0.3	0.0	0.4	0.6	0.3
18	15.0	28.5	2.0	1.5	0.9	0.2	-0.2	-0.3	0.0	0.4	0.5	0.3
19	15.0	30.2	2.1	1.5	0.9	0.3	-0.2	-0.3	0.0	0.4	0.5	0.3
20	15.0	31.8	2.1	1.6	0.9	0.3	-0.2	-0.3	0.0	0.4	0.5	0.2
21	15.0	33.5	2.2	1.6	1.0	0.3	-0.2	-0.3	0.0	0.4	0.5	0.2
22	15.0	35.1	2.2	1.7	1.0	0.3	-0.1	-0.2	0.0	0.3	0.5	0.2
23	15.0	36.8	2.3	1.7	1.0	0.4	-0.1	-0.2	0.0	0.3	0.5	0.2
24	15.0	38.4	2.3	1.7	1.1	0.4	-0.1	-0.2	0.0	0.3	0.4	0.1
25	15.0	40.1	2.4	1.8	1.1	0.4	-0.1	-0.2	0.0	0.3	0.4	0.1
26	15.0	41.7	2.4	1.8	1.1	0.4	-0.1	-0.2	0.0	0.3	0.4	0.1
27	15.0	43.4	2.4	1.8	1.1	0.4	-0.1	-0.2	0.0	0.3	0.4	0.1
28	15.0	45.0	2.4	1.9	1.1	0.4	-0.1	-0.2	0.0	0.3	0.4	0.1
29	15.0	46.6	2.5	1.9	1.2	0.5	-0.1	-0.2	0.0	0.3	0.4	0.1
30	15.0	48.3	2.5	1.9	1.2	0.5	-0.1	-0.2	0.0	0.3	0.4	0.1

Fig. 1 Energy offset of the head and tail of the SLC beam (one sigma) along the linac. n is for Case 1 (no Landau damping), s is for Case 2, and f is for Case 3.

SECTOR 19

Fig. 2 Energy offset along the SLC beam at the end of Sector 19. n is for Case 1 (no Landau damping), s is for Case 2, and f is for Case 3.