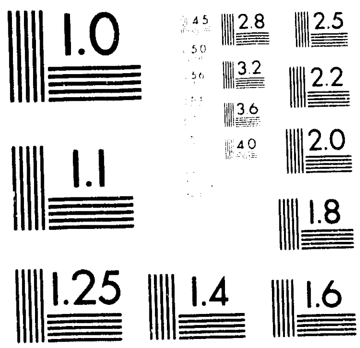
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Transverse Effects of Longitudinal Wakefields at High Dispersion

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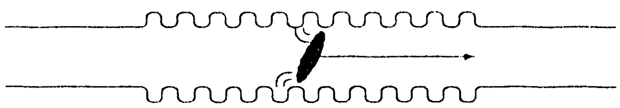
Abstract

In high energy linear colliders the transverse beam emittance has to be preserved in order to achieve small interaction spots. Beams with trajectory offsets in cavities excite transverse wakefields which kick the tail of the beam leading to an undesired emittance growth. Here we will concentrate on the longitudinal wakefield creating an energy deviation ΔE_W within the beam. At high dispersion η the beam will be spread out corresponding to its initial (and/or correlated) energy spread ΔE_o (or ΔE_{rf}) and is therefore very sensitive to energy changes. The energy variation ΔE_W will cause a transverse emittance blow up in the high dispersion regions. The effect can be estimated by comparing the betatron size $\sigma_x = \sqrt{\beta\varepsilon}$ with displacement $\Delta x = \eta\Delta E_W/E$. Some kicks and displacements will compensate each other along the beam line. Simulation results are presented showing how much is really compensated and the final emittance contribution of this effect for the SLC Ring-To-Linac transport line. To minimize it, any vacuum pipe irregularities, like bellows, diameter steps, collimators, etc. should be smoothed or avoided at higher dispersion areas.



1 Introduction

At the SLC, the 10 mm long bunch of the damping ring (DR) is compressed in the RTL section down to the necessary 1 mm length for the main linac. The compression is achieved by introducing an longitudinal energy correlation with a compressor cavity followed by a high dispersive region (η), where particles of different energy travel along different trajectories. Particles at $\pm\sigma_l$ (bunch length $\sigma_l \approx 10$ mm) get an energy difference of $\Delta E/E = \pm 1.4\,\%$ and therefore at $\eta = 1.0$ m $\Delta x = \pm 14$ mm is about 100 times bigger than the betatron size.

$$\Delta x = \eta \cdot \frac{\Delta E}{E} \quad \text{and} \quad \Delta E = E_{rf}\sin(2\pi\sigma_l/\lambda), \qquad (1)$$

with an energy $E = 1200$ MeV, rf-amplitude of $E_{rf} = 30$ MeV and $\lambda = 105$ mm. Additionally to the intended path length difference, the off axis particles also experience any nonlinear kicks coming from transverse wakefields or higher order magnetic fields causing an emittance blow up [1].

Besides these transverse kicks which are most severe at high beta points, there is a mechanism with longitudinal wakefields creating an effective beam offset which is worse for low beta points ("longitudinicity"). The indirect effect over several phase space axes and the compasion with the transverse effect are given at the example of the RTL.

2 Direct and Indirect Phase Space Correlation

Wakefields introduces normally a direct curved correlation between the longitudinal axis z and the energy E by the longitudinal wakefield, or z and the transverse position x or y by the transverse wakefield. These first order linear (e.g. linear in x) excitations are the most common source of emittance blow up for instance in the linac. A correlation to another phase space axis (say z, E e.g. by BNS phasing) starts a filamentation of x, x' which makes the initial emittance blow-up practically unrecoverable. Indirect effects need more than one correlation for instance E, x at high dispersion plus z, E from the longitudinal wakefield.

2.1 Sensitivity to Direct Effects

Direct effects in the transverse are most sensitive to big offsets e.g. at high dispersion or wrong off-axis steering, and where the disturbed phase space axis (x' or y') is small which is at high beta points (RTL lattice and final focus are sensitive). At high dispersion even the higher order wakefields near the aperture have to be considered. The longitudinal correlation between z, E is given by the induced wakefield and energy gain and therefore a constant over the acceleration if no other correlation (like BNS) are involved. It is not easy possible to cancel the correlation by the same technique since there is no longitudinal focussing.

2.2 Indirect Effects

Indirect correlations are in some way different and their effect might not be as obvious as in the direct case where big offsets and sensitive areas are the reasons. Let's take the RTL as an example andh a beam with no energy spread

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(compressor cavity off). The beam emittance is expected to be unchanged at the end. The high dispersion area enlarges the beam not very much and it stays on axis away from non-linear fields. The longitudinal phase space seems to be decoupled. But on the other hand, the longitudinal wakefields introduce an energy spread z, E creating an offset at high dispersion E, x, which will blow-up the emittance! (Therefore the name "longitudinicity" to keep indirect effects in mind).

Other indirect effects might be some coupling type correlation between e.g. x, y, where a wide x ditribution produces different kicks over z, y wakefields, which is even more severe for flat beam emittance ratios. This has not been studied further.

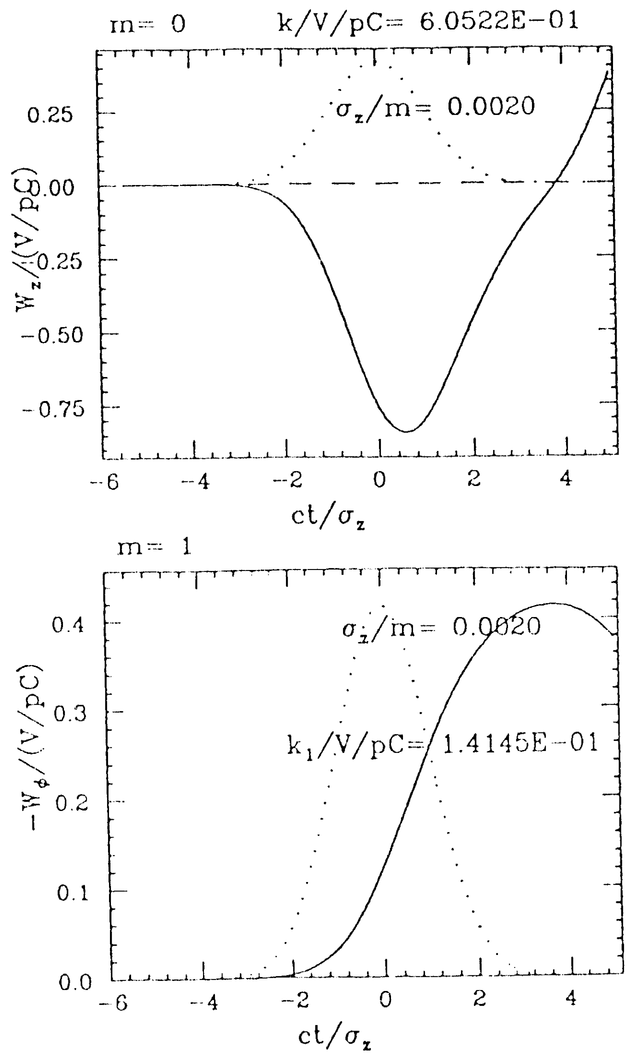

Figure 1: Wakefield Calculation.

The calculated longitudinal W_z and transverse W_ϕ wake potentials for the lowest transverse order and $\sigma = 2$ mm is shown.

3 Sources of Wakefields

First of all there is no reason to put unsleeved bellows at a high dispersion region. Even pump-outs, profile monitors, BPMs and other beam pipe transitions can be designed in a way to avoid any significant wakefield generation [2]. The only problem might be collimators which need to be close to the beam to fulfill their duty. The finals remaining parts should be the smaller resistive-wall wakefields.

But since the RTL was not designed with this in mind, we have 30 bellows in the high dispersion region of the north RTL and 25 in the south. The mostly used bellows have a diameter of $2a = 49$ mm with 20 convolutions each 6 mm high and 2.5 mm wide which gives an overall length of 3 m active bellows. Fig. 1 shows simulation results with TBCI [3] for 1/5 of a bellow with a 2 mm (σ) long bunch. The results of these and higher order wakefields are discussed and summarized in the next section.

4 Quantitative Kicks and Offsets

4.1 Single and Combined Excitations

The sizes and effects are summarized in Tab. 1. The transverse and longitudinal wakefields are taken at about one σ_z (transverse) or at their maximum (longitudinal) and multiplied by 8 nC ($5 \cdot 10^{10}$ particles). The higher order wakefields are scaled to an offset of a two and one $\sigma_z = 10$ mm particle at about $\eta = 0.9$ m (21 mm and 12 mm). Since two betatron oscillations share 30 bellows, the effect of 5 are combined. Their kicks or offsets are calculated and compared with high and low beta function values. As reference also the size due to dispersion is shown.

Comparison of Transverse and Longitudinal Wakefields							
	Transverse			Longitudinal			
Order m	1	2	3	0	1	2	3
$W_{\phi,z}$ [V/pC]	1.5	3.0	4.5	4	8	8	8
$W{*}8$ nC [kV]	12	24	36	32	64	64	64
at $r = 0.85a$ [kV]	10	15	16	32	46	33	24
at $r = a/2$ [kV]	6	3	1	32	16	4	1
5 bellows [kV]	30	15	5	160	80	20	5
$p = 1.2$ GeV/c							
$x' = p_\perp/p$ [μrad]	25						
$\eta = 1$ m							
$x = \eta\Delta E/E$ [μm]				132			
$\gamma\varepsilon = 16$ μm-μrad							
x, x'at $\beta = 50$ m	12 μrad			580 μm			
x, x' at $\beta = 1$ m	83 μrad			83 μm			
$x = \eta\Delta E/E$[mm]				14			

Table 1: Summary of Bellow Wakefield Effects.

Transverse wakefields induce a kick, while longitudinal wakefields cause indirectly an offset. Both have different senitivities at different beta functions.

4.2 Cancelation

The offsets and kicks are about 1.5 to 2 times bigger than σ_x or σ'_x at the corresponding sensitive beta functions. Since some of the kicks cancel out (see Fig. 2), the emittance blow-up might be not too bad, but to relay on a cancellation of big numbers is always a risk. The observed emittance blow-up with $3 \cdot 10^{10}$ particles was about from $\gamma\varepsilon = 1.6 \cdot 10^{-5}$ m-rad to $1.8 \cdot 10^{-5}$ m-rad in 1992 with round beams.

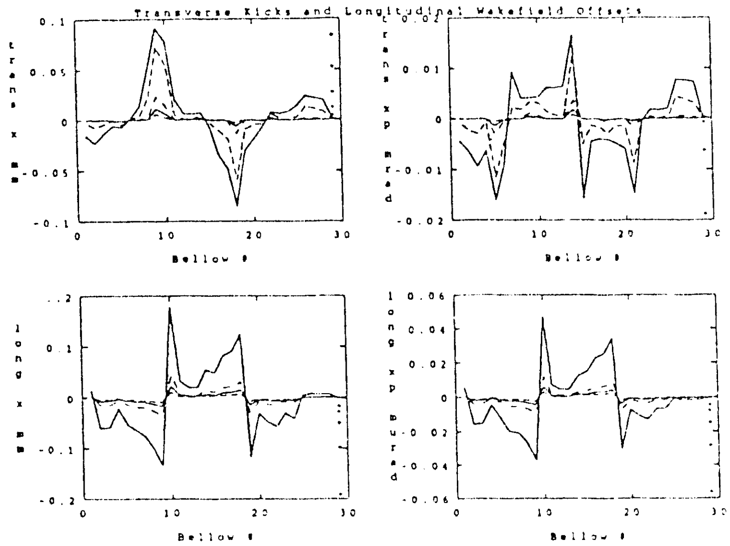

Figure 2: Summarized Kicks and Offsets.

There are 30 bellows in the north RTL which cause different kicks or offsets of a part of the beam. Here the result of each bellow is shown as a position x and angle xp variation at the entrance to the linac where $\sigma_x = 160\,\mu m$ and $\sigma'_x = 45\,\mu rad$. The transverse and longitudinal effect are studied seperately since they influence different parts of the bunch. The different curves are the effects of higher orders m at an offset which corresponds to an energy offset of a particle at σ_l. At the end (29) there are the sums for each order indicated by dots.

4.3 Less and More Sensitivity in 1993/94

With flat beams in 1993 we expected an emittance of about $3.2 \cdot 10^{-5}$ m-rad and achieved it also at the end of the RTL measured in the linac. The bigger emittance in x is less sensitive to emittance blow-ups either from wakefields or non-linear magnetic fields. In the 1994 run we will probably run with higher currents due to a new damping ring vacuum chamber against microwave instability oscillations [4], and we might reduce the horizontal emittance by creating combined functions in magnets [5]. This will make a sleeving of the RTL bellows even more urgent than now.

5 Conclusion

The transverse wakefields of a beam at high dispersion lead to dispersive abberations of higher order, which can be mainly compensated by magnetic elements, like for higher order magnetic errors. The longitudinal wakefield has a small effect on the compression process, but has an indirect effect on the transverse beam size. This chromatic like effect ("longitudinicity") should be avoided by reducing the amount of generated wakefields, e.g. with sleeves in the bellows.

Acknowledgement

I would like to thank T. Raubenheimer for some helpful discussions and his interest in "longitudinicity" especially for future compressor schemes.

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