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IMPROVEMENTS IN EMITTANCE WAKEFIELD OPTIMIZATION FOR THE SLAC LINEAR COLLIDER*

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Abstract

The transverse emittances in the SLAC Linear Collider can be severely diluted by collective wakefield effects and dispersion. For the 1997/98 SLC/SLD run important changes were implemented in the way the emittance is optimized. Early in the linac, where the energy spread is large due to BNS damping, the emittance growth is dominated by dispersion. In this regime emittance tuning bumps may introduce additional wakefield tails and their use is now avoided. At the end of the linac the energy spread is minimal and the emittance measurement is most sensitive to wakefield emittance dilution. In previous years, the emittances were tuned on wire scanners located near but not at the end of the linac (after about 90% of its length). Simulations show that emittance growth of up to 100% can occur in the remaining 10%. In this run wire scanners at the entrance of the Final Focus, the last place where the emittances can be measured, were used for the optimization. Screens at the end of the linac allow additional real time monitoring of the beam sizes. We show that the different tuning strategy provided significantly improved emittances at the interaction point of the SLC.

1 INTRODUCTION

The SLAC Linear Collider (SLC) is the first linear collider that has been built and operated. In terms of beam dynamics and achievable luminosity the collider can be classified in several major components: the source, the damping rings, the accelerating linac, the arcs, the final focus, and the collimation system. Each of those systems has a major impact on the accelerator performance and must be in optimal shape for the large increase in the SLC luminosity that has been achieved during the 1997/98 run [1]. In this paper we report improvements in the understanding and optimization of the emittance transport through the linac and into the Final Focus.

2 EMITTANCE GROWTH IN THE SLC LINAC

The SLC linac accelerates high current and small emittance beams from an initial energy of 1.19 GeV to about 47 GeV. The parameters for the beam current I and the beam emittances ϵ_x and ϵ_y put SLC into a beam dynamics regime where strong wakefields naturally cause large emittance growth $\Delta\epsilon/\epsilon_0$. The wakefield growth due to misaligned RF structures is compenstaed with so-called emittance bumps [2]. In addition, the coherent wakefield effects (beam break-up) are compensated through BNS-damping [3] that induces a strong variation of the single bunch correlated energy spread δ along the linac. The resulting SLC energy spread is shown in Fig. 1.

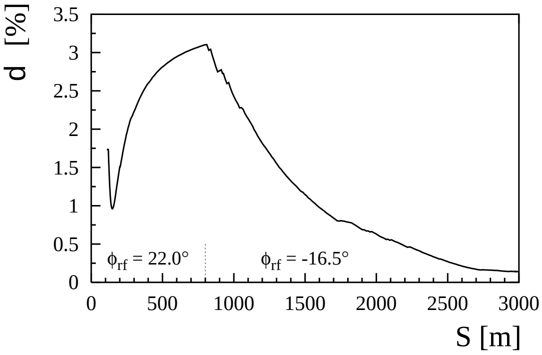

Figure 1: Typical BNS relative energy spread δ along the SLC linac.

For simplicity we consider a longitudinal position s with maximum dispersion ($\eta' = 0$). The emittance ϵ can then be written as:

$$\epsilon \approx \epsilon_0 + \frac{\eta^2(s) \cdot \delta^2(s)}{\beta} + \Delta\epsilon_{\mathrm{wf}}(s) \tag{1}$$

Here, ϵ_0 is the incoming emittance, $\Delta\epsilon_{\mathrm{wf}}$ is the emittance growth due to wakefields, η is the centroid dispersion, and β is the beta-function. It is seen that there are two driving causes for the increase in the beam emittance:

1. Wakefield deflections.
2. Dispersion.

If the energy spread is small then only wakefield emittance growth is important. At the end of the linac the energy spread within a single bunch is reduced to about 0.15% and dispersive emittance growth is suppressed. However, as we see from Fig. 1, the linac energy spread can be as high as 3%. Dispersive emittance growth can now be several 100 times more important than at the end of the linac. In addition it was realized in 1997 that dispersion is amplified by wakefields [4]. As is shown in Fig. 2, the centroid

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dispersion at high currents is enhanced by almost a factor of 10 compared to the wakefield-free case.

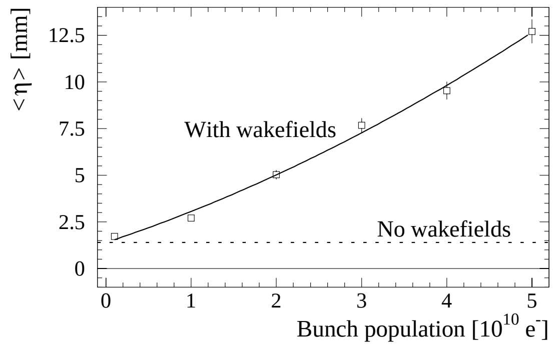

Figure 2: Expected dispersion $< \eta >$ in the end of the SLC linac as simulated for different SLC bunch currents. The wakefield-free dispersion is indicated by the dotted line. The SLC linac dispersion is driven by wakefields.

As the SLC luminosity is only determined by the outgoing emittances, large intermittent dispersive emittance growth is no worry. It is cured by the reduction in the outgoing energy spread. However, for the emittance optimization the interaction between dispersive and wakefield correction can be crucial.

3 EMITTANCE OPTIMIZATION

The vertical emittance in the SLC linac will roughly increase tenfold due to wakefields if nothing is done to correct this. Luckily, the emittance growth can be compensated with so-called “emittance bumps” [2, 5]. The bumps essentially consist of coherent betatron oscillations that are distributed along the linac. The typical scheme of emittance correction from before the 1997/98 run is shown in Fig. 3 with the simulated normalized emittance growth along the linac. Emittance was mainly corrected after about 35% and 90% of the linac length. We can observe several drawbacks of this correction scheme:

- The first emittance bump, correcting emittance 35% into the linac, minimizes emittance at a point of maximum energy spread (compare Fig. 1). It therefore acts both as a wakefield and dispersion correction, finding a compromise between the two. It can introduce additional wakefield tails.
- The second emittance bump corrects the beam emittance about 10% before the end of the linac. Energy spread is very small and the bump acts mainly as a wakefield correction. However, the vertical beam emittance is expected to roughly double in the uncorrected last 10% of the linac.
- The emittance correction depends on the optics stability over the whole length of the linac. It was shown that the beam optics in the SLAC linac can vary strongly, especially in the regions of low absolute beam energy [6].

The drawbacks were addressed during the 1997/98 run by modifying the emittance tuning scheme. Tuning in the middle of the linac was kept minimal with very small or even no bumps in the first 60% of the linac. The emittance correction was done mainly with bumps in the second half of the linac. The emittances were minimized simultaneously on the wires after 90% of the linac length, the synchrotron light screens shortly after and with priority on the wires at the entrance of the Final Focus. This new tuning scheme provides the following advantages:

- Emittance tuning in the regions of high energy spread and therefore large dispersive emittance growth is avoided. The wakefield correction is in no way compromised in order to minimize dispersive emittance growth in the middle of the linac.
- As emittance is optimized at the entrance of the Final Focus, the wakefield emittance growth in the last 10% of the linac is also corrected. The doubling of the vertical beam emittance in the end of the linac is avoided.
- As only bumps in the second half of the linac are used, the sensitivity against changes in the beam optics is significantly reduced.
- Tuning is simplified as the emittance in the middle of the linac remains unconstrained. As emittance is tuned empirically over hours, all attention can now be focussed on the end-of-linac and Final Focus emittance.

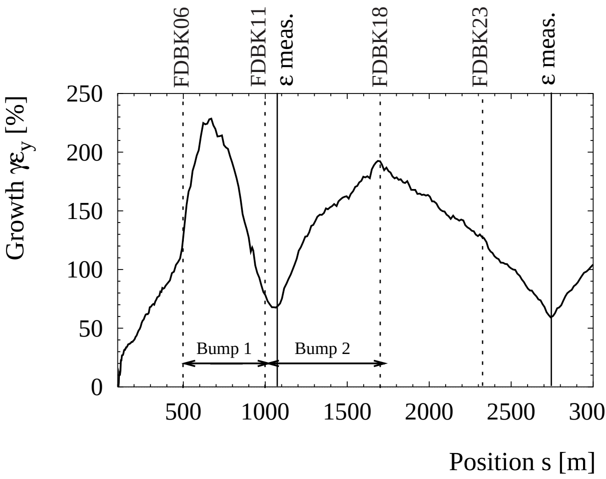

Figure 3: Overview of emittance measurement and optimization before the 1997/98 run. The beam emittances were minimized mainly on the wires in the middle and after about 90% of the linac length, using bumps mainly in the first half of the linac. The vertical beam emittance almost doubles in the uncorrected region of the linac.

The old and new tuning approaches are compared in Fig. 4 for all possible emittance tuning bumps along the linac. The points show the RMS variation of the bump settings (position and angle) for the different feedback loops and two three month periods in 1996 and 1997. For illustration purposes the points are connected by straight lines. The figure clearly shows the change in tuning strategy. Tuning is now done preferrably towards the end of the linac.

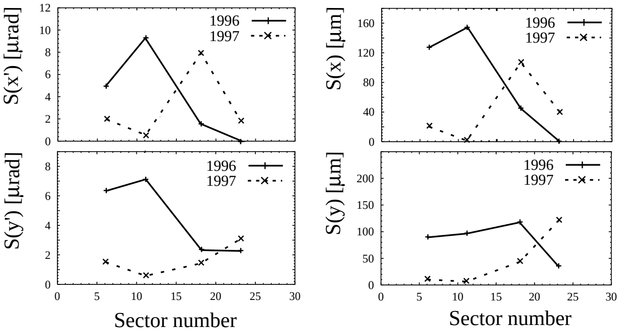

Figure 4: RMS variation S of the different feedback setpoints x', y' (left) and x, y (right) over three month periods in 1996 and 1997. The feedback position and angle offset introduce trajectory oscillations (= emittance bumps) up to the next feedback. The electron and positron setpoint variations are averaged. The bias towards later bumps is clearly seen for the new 1997/98 tuning approach.

4 IMPROVED EMITTANCE PERFORMANCE

We now consider the emittance performance for the same periods of time as in Fig. 4. Table 1 summarizes the emittance performance all through the linac and into the Final Focus. Both the average values and the observed RMS spreads in emittance are listed.

	$\gamma\epsilon$ [10^{-5} m] (1996)				$\gamma\epsilon$ [10^{-5} m] (1997)			
	e^-		e^+		e^-		e^+	
	$\bar{\epsilon}$	σ_ϵ	$\bar{\epsilon}$	σ_ϵ	$\bar{\epsilon}$	σ_ϵ	$\bar{\epsilon}$	σ_ϵ
Li02 X	3.8	1.4	4.4	0.6	3.5	0.6	4.0	0.6
Li02 Y	0.5	0.1	0.3	0.1	0.5	0.4	0.3	0.1
Li28 X	5.5	1.8	5.7	2.1	4.5	0.7	5.1	1.1
Li28 Y	1.1	0.3	0.8	0.7	0.9	0.3	0.6	0.3
FF X	5.7	1.4	5.8	3.1	5.3	0.6	5.1	0.6
FF Y	2.1	1.2	1.3	0.8	1.3	0.4	0.9	0.2

Table 1: Average emittances ($\bar{\epsilon}$) and rms variation (σ_ϵ), measured at the entrance to the linac (Li02), close to its end (Li28) and in the Final Focus, for two three-month periods in 1996 and 1997. The Final Focus data is taken from [7].

A significant improvement of the emittance transport is seen both in end of the linac and Final Focus measurements. The average emittance is an important indicator for the achievable luminosity. Considering the emittance growth in the linac ($\approx\ \Delta\epsilon_{\mathrm{wf}}$) we find that the average emittances at the end of the linac are reduced by at least 0.2 10^{-5} m-rad. On average the emittance growth in the linac is reduced by about 35% (the reduction in the vertical plane is almost 50%). Considering the emittance growth all the way to the Final Focus (thus including the last 10% of the linac and arc effects) we find an average reduction in total emittance growth of 45%. A significant part of this reduction is due to the better wakefield compensation. Last not least we note the improved stability of the emittance tuning as it is seen in the smaller emittance variations in Table 1.

5 SUMMARY

An improved wakefield emittance optimization has been implemented in the SLAC linac for the 1997/98 SLC/SLD run. The new approach is based on a better understanding of the interaction between dispersive and wakefield emittance growth in high-current, small-emittance linacs. The improved emittance correction allowed to reduce the wakefield emittance growth in the first 90% of the SLAC linac by 35% (50% in the vertical plane). The minimization of the wakefield growth in the last 10% of the linac provided an additional and important reduction in emittance growth, thus helping to achieve record emittances and luminosities in the 1997/98 SLC/SLD run.

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