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Measurement of Wakefields Generated in Accelerator Test Structures Using the SLC*

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ABSTRACT

Research is underway at SLAC to develop accelerator structures for the next generation linear collider. An important feature of the design is a detuning of the dipole modes of the cells to suppress the long-range transverse wakefield by two orders of magnitude. This paper describes a facility, called ASSET, that will be incorporated into the SLAC Linear Collider (SLC) to test the long-range wakefield suppression and also to measure the other components of the wakefields generated in accelerator test structures.

1 INTRODUCTION

The designs being considered at SLAC for the Next Linear Collider (NLC) employ multi-bunch operation in a high acceleration gradient X-band linac. The limitations in this approach come in part from the transverse and longitudinal wakefields generated in the accelerator structures of the linac. A particularly troublesome problem is the long-range transverse wakefield, which if not controlled, will produce a large growth in the transverse motion of the bunches. The currently favored cure for this problem is to detune the dipole mode frequencies of the cells of the structures so the sum of the wakefields generated in each structure decohere [1]. Since a two orders of magnitude reduction is required, and the theoretical calculations of the suppression [2] have some uncertainty, it is important that the performance of the structures be verified before they are produced for use in an accelerator.

Thus far, measurements of the wakefield suppression have been made on short-length detuned structures at Argonne's Advanced Accelerator Test Facility [3]. Although the results look promising, this facility currently does not have the measurement precision required for the NLC structures being developed, nor the capability of measuring the wakefields beyond a few *ns* compared to the few hundred *ns* needed. In the future, the plan is to do the measurements at SLAC with a dedicated facility called the Accelerator Structure SETup or ASSET [4]. It exploits the "asset" of the SLC in its capability to independently inject two low emittance bunches (electrons and positrons) into the linac with individual control of the bunch timing and intensity.

The layout for ASSET is shown in figure 1. It is divided into two sections that will take the place of the first two 3 *m* long S-band accelerator structures in the SLC linac. The first section will contain the structure to be tested. It will be installed just prior to the wakefield measurements and will be removed thereafter. In the second section, a combination chicane and beam dump will be installed that will serve to dump the positron bunch while rerouting the electron bunch back into the linac. The vacuum chamber in this system will be large enough to permit normal operation of both bunches in the linac when the chicane magnets are turned off. The chicane will also contain a wire scanner and profile monitor that will be used for beam loading and single bunch transverse wakefield measurements. The details of these measurements can be found in reference 4.

2 BUNCH-TO-BUNCH COUPLING MEASUREMENT

The key requirement of ASSET is that its sensitivity to long-range transverse wakefields be such that the measurements will yield a meaningful prediction of the performance of an NLC linac made from the type of structure tested. Thus the sensitivity should be below the tolerances on the wakefield strength in the NLC. These tolerances have been investigated by simulating multibunch transport for various NLC linac designs. In each case, the increase in the betatron amplitudes of the bunches that occur from the wakefield coupling are computed [1]. Since this growth is a complicated function of the wakefield strength ($\equiv W_t$) at the locations of the bunches, it is difficult to simply characterize the limits on W_t. However, the general criterion that emerges from these studies is that the condition $W_t < 1.0\ MeV/m^2/10^{10}e$ at each bunch location should be adequate, but that a simulation of the multibunch transport using measurements that are sensitive to at least a third of this strength should be made as a further check.

Achieving this level of sensitivity using the SLC is non-trivial and requires many of the control and analysis techniques that have been developed for colliding beam operation. In the method proposed, the positron beam will serve as a drive bunch and will be injected into the linac from the transport line (SRTL) connecting it to the South Damping Ring. The bunch will then pass through the test structure and enter the ASSET beam dump. The electron beam from the North Damping Ring, which will be injected into the linac via the NRTL at a controlled time after the positrons, will serve as a witness bunch and be transported through the chicane and back into the linac where its betatron motion will be analyzed using Beam Position Monitors (BPMs).

In preparation for the measurements, the witness and drive bunches will be established with an intensity of $5 \cdot 10^9$ and $3 \cdot 10^{10}$, respectively, and with the minimum possible bunch lengths ($\approx 0.5\ mm$). The witness bunch will be injected along the axis of the accelerator structure to be tested, and will not be tuned during the measurements. The injection of the drive bunch, however, will be varied in a step wise

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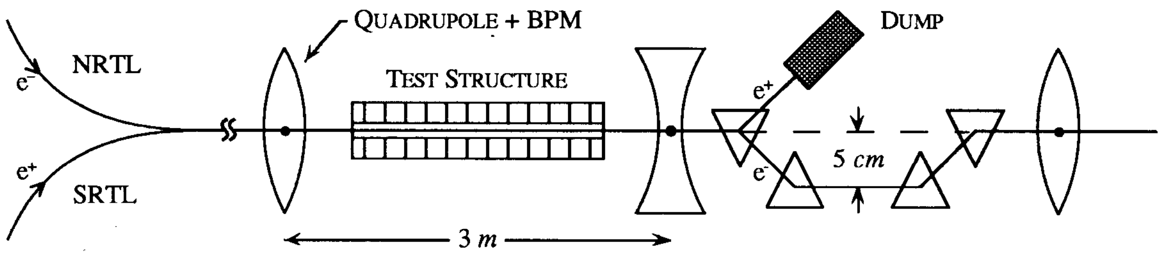

Figure 1. Layout of the Accelerator Structure SETup (ASSET) in the SLC.

manner in the vertical plane using corrector magnets in the SRTL. The betatron injection phase will remain fixed but the amplitude will be varied over the maximum range permitted by the apertures of the test structure. For each setting of the drive bunch amplitude, the BPM readings of the witness bunch downstream of the chicane will be recorded. The slope of the vertical BPM position versus drive amplitude will be computed for each monitor and these data will then be fit to determine the betatron amplitude of the witness bunch per unit amplitude of the drive bunch, a quantity that is proportional to W_t. This procedure will then be repeated for different bunch separations to determine the temporal dependence of the transverse wakefield.

3 DESIGN CONSIDERATIONS

To reduce systematic errors in the measurement of long-range wakefields with the SLC, we wanted a signal that depended only on W_t. The choice of varying the drive bunch amplitude to generate a signal is preferred in this regard to varying the transverse position of the test structures or the drive bunch intensity, for example. This choice requires that no S-band structure precede the apparatus as the wakefields generated in it would also affect the witness bunch motion. Hence the test structures need to be located at the beginning of the linac. At this location, the bunch energy is smallest, 1.15 GeV, which is an advantage from the signal-to-noise point of view but a disadvantage from the strong effect of the short-range transverse wakefields on the witness bunch motion. To minimize this effect, the witness bunch intensity and length will be made as small as possible.

The vertical plane was chosen to do the measurements because the jitter in the transverse position and angle of the bunches at injection into the linac is generally smaller in this plane, probably as the result of the fewer bends in the transport line preceding it. This injection jitter contributes to the error on the signal measurement as does the linac BPM resolution. To measure the total noise level, data were taken in a manner similar to that described above for the wakefield measurements but with no drive bunch or test structure. Hence the fit values of the betatron amplitudes reflect the noise spectrum that will be encountered when the actual measurements are made. The typical amplitude observed was 5 μm when data were taken over 20 pulses from the 30 BPMs immediately downstream of the proposed chicane location. The goodness of the fits and their match to the NRTL BPM data indicates that the noise is dominated by injection jitter. Thus correcting for this jitter using the NRTL trajectory data should further reduce the noise.

The choice of the number of structures to use and the drive bunch parameters was based on optimizing the signal. This was complicated by the fact that the strong short-range wakefields in the structures increase the transverse size of the drive bunch and hence limit the gain in signal that would normally be achieved by increasing the drive intensity or amplitude. To study the tradeoffs, simulations of the measurements were done for the proposed SLAC X-band structures. Six structures of 1.8 *m* length were assumed to be centered within 3 *m* spacings between quadrupoles but not powered. A lattice similar to that in the linac with a 90° phase advance and an average beta, $(\beta_{max} + \beta_{min})/2$, of 6 *m* was used. The two possible configurations, one with a focusing quadrupole before the first structure, and one with a defocusing quadrupole before it, were each simulated. The short-range wakefields assumed were those computed for these structures, and W_t was set to 1.0 $MeV/m^2/10^{10}e$.

Different drive bunch intensities were simulated with bunch length profiles corresponding to those obtained from full compression in the SRTL. In the simulation, the bunches were represented by a series of 41 transverse slices at uniformly spaced longitudinal positions in the range of ± 3 times the rms bunch length. The bunch energies were assumed to be those at the beginning of the linac but no initial energy spread within the bunch was simulated as it has little effect on the drive bunch trajectories for the cases considered. The witness bunch intensity, which one wants to be small as possible, was assumed to be $5 \cdot 10^9$ since the linac BPM resolution degrades rapidly below this intensity.

For each choice of drive bunch intensity, the injection amplitude was fixed and a simulation done for a full range of injection phases. At every phase, the amplitude of the witness bunch trajectory was computed at the exit of each of the six structures. These signals were then normalized to the injection amplitudes that would correspond to the onset of drive bunch loss on the structure irises upstream of the point where each signal was evaluated.

As an example of the results from the simulation, figure 2 shows some of the drive bunch slice trajectories with both quadrupole configurations for $I = 3 \cdot 10^{10}$ and zero injection phase. The rapid growth of the beam tail illustrates the limitation that occurs in trying in increase the signal by

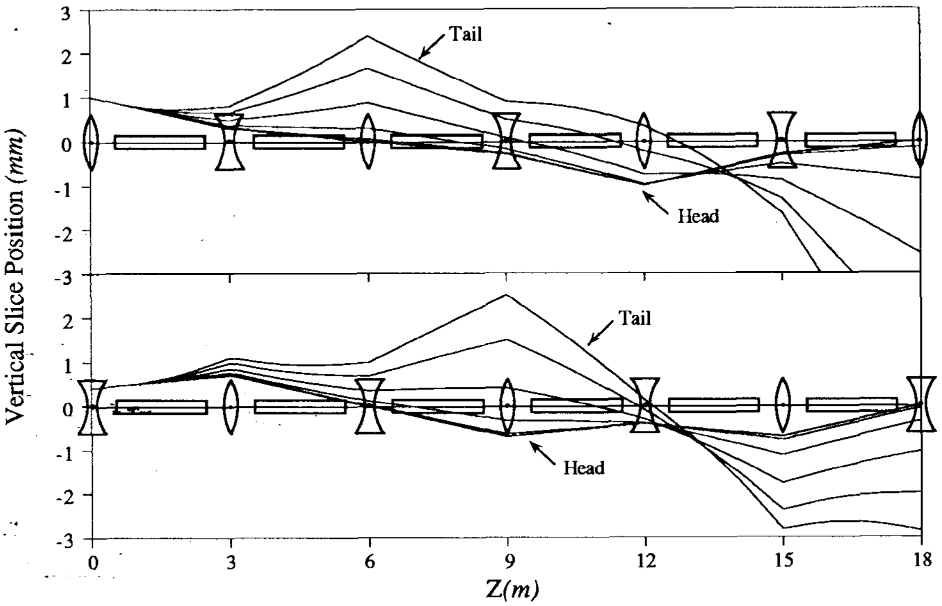

Figure 2. Vertical trajectories of seven transverse slices of a 2 • 10^{10} particle bunch through six unpowered X-band structures in two FODO lattices (β_{max} = 10.2 *m*) which differ by only the initial quadrupole polarity. The longitudinal slice positions are spaced in increments of the bunch length (σ_z), and range from $+3\sigma_z$ to $-3\sigma_z$.

increasing the number of structures. In fact, when the normalized witness bunch amplitudes are computed, one sees that the signal does not grow much after the first structure. Also, the effect of the beta function is observed in that the signal is generally larger for an even number of structures when the initial quadrupole is focusing, and for an odd number of structures when it is defocusing. An example of the dependence on the number of structures is shown in figure 3 where the normalized amplitude after each structure is plotted as a function of injection phase for I = $3 \cdot 10^{10}$ and the quadrupole configuration giving the largest signal on average. The lack of a strong dependence on the number of structures is also seen when such comparisons are made for other drive bunch intensities in the range of $1 \cdot 10^{10}$ to $4 \cdot 10^{10}$. In general, for I > $2 \cdot 10^{10}$ and two to four structures, the limitation from the beam tail size cancels all or more of the gain from an increase in intensity or in the number of structures. For a single structure, this saturation occurs at a higher intensity ($\approx 3 \cdot 10^{10}$), while for five or six structures, it occurs at a lower intensity ($\approx 1 \cdot 10^{10}$).

From these results, it was decided to use only one test structure in ASSET as it will yield most of the signal achievable with more structures. Running with a drive intensity of $3 \cdot 10^{10}$, which is routinely achievable for colliding beam operation, a wakefield strength of 1.0 $MeV/m^2/10^{10}e$ will produce a betatron amplitude of 70 μm compared to an expected noise level of < 5 μm. Thus the minimum design requirements for the structures should be easily verifiable. Also, wakefield strengths at least a factor of five times smaller should be measurable so accurate simulations of the performance of an NLC linac can be made.

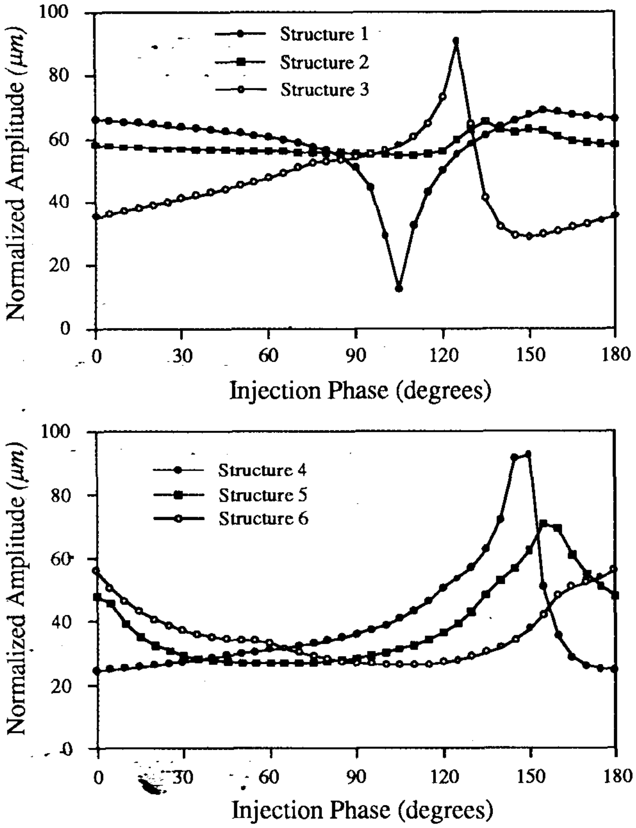

Figure 3. Normalized betatron amplitude of the witness bunch as a function of the drive bunch injection phase. In the top (bottom) plot, the amplitudes at the end of the first (last) three structures are shown.

References

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