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BEAM PARAMETERS OF A POSSIBLE EMITTANCE-DYNAMICS TEST AREA FOR NLC STUDIES AT THE SLC*

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ABSTRACT

A group at SLAC has studied the possibility of using the Stanford Linear Collider (SLC) to generate short-bunch small-emittance beams similar to those required for the Next Linear Collider (NLC) [1,2]. The conclusion is that such beams are feasible and that an experimental area for testing many concepts related to NLC beams can be provided with a reasonable addition of hardware to the existing SLC Linac. Some of the concepts that can be tested are: 1) error tolerances of double bunch length compression, 2) wakefields of ultra-short bunches in accelerating structures, 3) the acceleration of short intense multiple bunches, 4) the generation and preservation of bunches with 100 to 1 emittances ratios, 5) beam deflections by collimators, 6) energy and energy spread control of multiple short bunches, and 7) vibration effects and trajectory stability for low emittance beams.

1 INTRODUCTION

The largest factor in the increase in luminosity of a potential future linear collider comes from the very substantial reduction of the beam emittances over that now used in the Stanford Linear Collider. Reduction factors of 10 to 1000 are needed. For example, invariant emittances of 4-10 x 10^{-8} r-m in the vertical plane are needed for the NLC compared with 3 x 10^{-5} r-m for the SLC. Furthermore, multiple bunch trains are desired containing 10 to 100 bunches with charges of 0.5 to 1.5 x 10^{10} particles each. These emittance reductions and multibunch capabilities will result from the careful design of the proposed damping rings, the linear accelerators, and the two bunch length compressors. Experimental checks of the new concepts and beam control techniques required for the NLC are needed to verify that these low-emittance multibunch beams can be produced. A potential emittance test area [3] described here would use modified SLC hardware to test many of the features not presently being addressed with other NLC tests [4,5,6].

The emittance test area would use the electron portion of the SLC 3000 m linac operated under special conditions with the addition of a second bunch length compressor near the 1000 m region (5-17 GeV). A schematic overview of this part of the SLC is shown in Figure 1. The electron gun would inject 1 to 10 bunches spaced 1.6 m apart into the electron damping ring. The ring would operate uncoupled in the energy range of 600 to 1150 MeV to provide flat bunches (small vertical emittance). These bunches after extraction would have their lengths shortened to 0.5 mm and subsequently accelerated to the 1000 m region in the SLC. At this point the bunch lengths would be shortened a second time to about 0.05 to 0.07 mm in a magnetic compression section (to be built) using a correlated energy spread in each bunch produced by offset phases of the klystrons upstream. The tolerances for this second compression section are expected to be a challenge and similar to those required of the NLC. These bunches would then be either reinjected into the linac where acceleration and strong wakefields could be studied or directed to an alignment or acceleration test section, as shown in Figure 2. Overall, this emittance test area would look like the full injector complex of an NLC.

2 MULTIBUNCH GENERATION

The SLC thermionic gun produces two bunches of about 10^{11} e^- each spaced by 60 nsec. About 4.5 x 10^{10} particles in each bunch are captured in the damping ring. The addition of extra bunches between these two would be a minor change to the injector system as the sub-harmonic bunchers naturally allow bunches with 5.6 nsec spacings. Therefore, for these emittance tests 10 or so bunches of 1 x 10^{10} e^- each would be produced in 60 nsec. Beam loading in the 1 GeV accelerator and injection into the damping rings of these 10 bunches are not expected to be difficult, as the average current values would be similar to those presently handled. No ring kicker changes are needed.

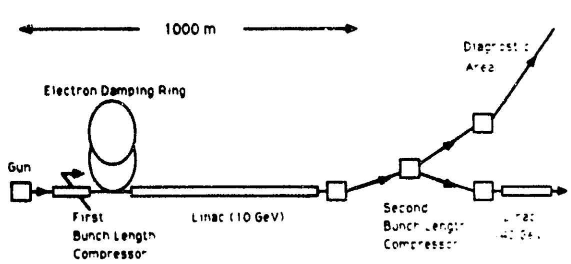

Figure 1 Overview of the portion of the SLC of interest for an emittance test area. The electron gun, damping ring, and the 50 GeV linac presently exist. A second bunch length compressor and a diagnostic area require construction.

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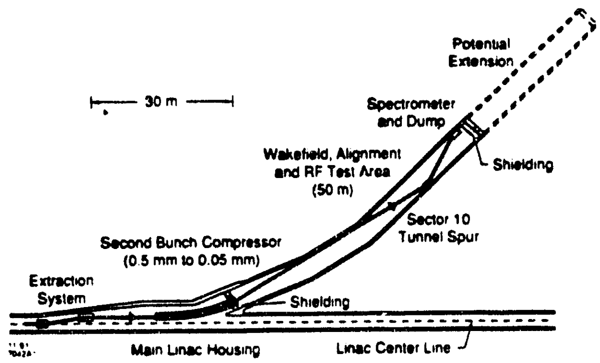

Figure 2 Schematic layout of one option for the second bunch length compressor at the 1000 m location in the SLC showing a possible test area for wakefield, alignment, RF, and bunch emittance parameters.

3 LOW EMITTANCE PRODUCTION

At bunch intensities of 1 x 10^{10} e^-, the SLC electron damping ring produces the design coupled invariant emittances of about 1.8 x 10^{-5} r-m. Calculations by one of us (TR) were made to study the operation of the ring at low energy with uncoupled tunes. Two of these calculations are shown in Figure 3 and 4, indicating that emittances of 1.5 x 10^{-5} r-m horizontally and 1.5 x 10^{-7} r-m vertically may be possible. Studies of multibunch instabilities are underway, including the effects of beam loading and multibunch extraction. These emittance tests will also verify the calculations of intra-beam scattering and multibunch instabilities, important for future damping rings.

4 DOUBLE BUNCH LENGTH COMPRESSION

The SLC bunch length compressor just after the damping ring [7] presently shortens the two damped bunches from 6 mm to 0.5 mm (sigma) with negligible emittance enlargement at 1 x 10^{10} e^- [8]. It is expected that it will work equally well for 10 bunches with small vertical emittance if the beam loading in the compressor is corrected and additional control of vertical dispersion is provided.

The second bunch compressor at about 10 GeV must be designed with the same error tolerances as needed for a future collider [9]. Two acceptable compressor designs have been studied: (1) a 45 degree bend (eight dipoles and 32 quadrupoles) and (2) a straight ahead chicane (three dipoles), allowing reinjection into the main linac. Second order optics issues, error tolerances, and construction details are being investigated. Emittance growth from synchrotron radiation in the horizontal bends is not expected to be a problem.

5 MULTIBUNCH ACCELERATION

The energy spreads of the bunches will be controlled by placing the mean phase of the bunch ahead of the RF crest by about 5 degrees to partially cancel the longitudinal wakefields with the curvature of the RF wave. The resultant spread is shown in Figure 5. If the bunches are to be reinjected into the main linac after the second bunch compressor, the downstream wakefield compensation will require a larger phase offset (20-30 degrees) to maintain a small energy spread. Multibunch beam loading will be controlled by staggering the timing of the RF pulses for differing klystrons so that the mean energy of all 10 bunches are nearly equal [10]. Energy and spectra control are important components of these tests.

6 EMITTANCE CONTROL STUDIES

The bunches exiting the damping ring must be accelerated and manipulated without degradation to their low emittances. This is particularly true for the small vertical emittance. Therefore, care must be taken to control dispersive and transverse wakefield effects along with coupling of x to y motion. After the second bunch compression, single bunch transverse wakefield effects will be much less severe as the bunch length is sufficiently short. A simulation of the transport of single bunches in the linac with 1 x 10^{10} particles shows that emittances of 2 to 4 x 10^{-7} r-m may be transported to 10 GeV, although advanced steering correction may be necessary [11,12]. See Figure 6. Furthermore, long range transverse wakefield effects from bunch to bunch are expected. In the SLC linac, these long range effects have been observed with about 10 nsec bunch separation but required large bunch

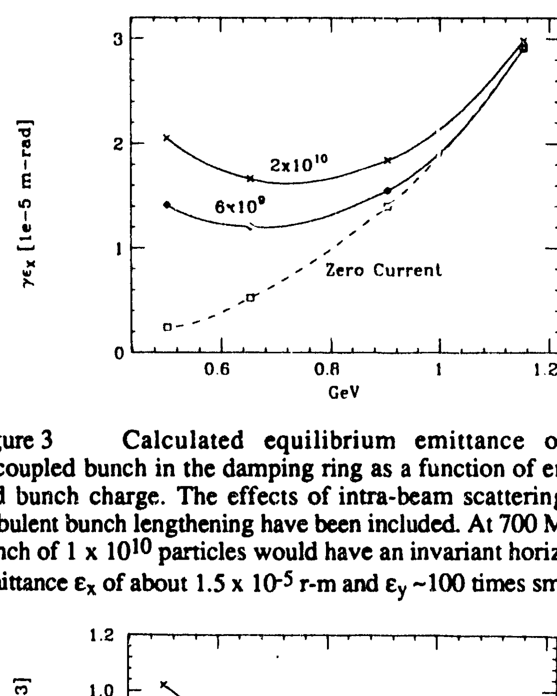

Figure 3 Calculated equilibrium emittance of an uncoupled bunch in the damping ring as a function of energy and bunch charge. The effects of intra-beam scattering and turbulent bunch lengthening have been included. At 700 MeV a bunch of 1 x 10^{10} particles would have an invariant horizontal emittance ϵ_x of about 1.5 x 10^{-5} r-m and ϵ_y ~100 times smaller.

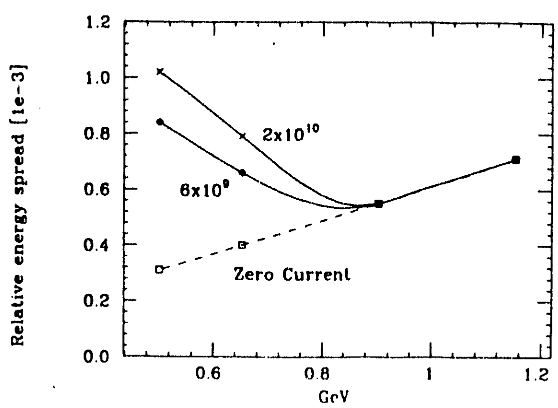

Figure 4 Calculated equilibrium energy spread versus ring energy for the calculations in Figure 3. The small variations in the energy spread should not affect bunch length compression.

oscillation amplitudes to be seen. Calculations for 5.6 nsec separations are underway. Experiments to study inter-bunch steering correction are also possible using several special SLC pulsed magnets located at the 100, 500 and 600 m linac positions. The magnets have a rapid rise time (20 nsec), a short duration (60 nsec), and pulse profiles that can be shaped.

7 WAKEFIELDS AT VERY SHORT BUNCH LENGTHS

The wakefields for a structure become less known when the bunch length become very short compared to the accelerator iris diameters [13]. For example, both the transverse and longitudinal wakefields are not known to a factor of two or so in the SLAC structure for bunch lengths of the order of 50 μm. The capabilities of the system described here would allow, for the first time, experimental studies of short bunch transverse and longitudinal wakefields in the NLC regime of parameters.

Another important issue is that of collimation in the NLC. A discontinuity in the vacuum chamber (collimator) very near the beam can cause large emittance changes [14]. The bunch lengths and bunch charges in the SLC are such that these effects can not be studied effectively. With single bunch operation at high currents (4×10^{10}) and with the second length compressor, these collimator effects can be directly measured with the proposed test area.

8 ALIGNMENT AND STABILITY STUDIES

Two of the most important tolerance questions for the linac of the NLC are alignment and stability. Vibration control must be at the few nanometer level. With the 45 degree compressor and a 50 m downstream diagnostic region as shown in Figure 2, it will be possible to study these issues with NLC-like beams. Precise and remote mechanical alignment devices could be tested and compared with beam based measurements in the same region. These tests could also be performed straight ahead in the linac but access to the equipment would be restricted due to other SLAC programs.

9 POSSIBLE RF TEST REGION

The test area described above in the tunnel spur could provide a straight tunnel of 110 m with an extension, allowing a 100 m

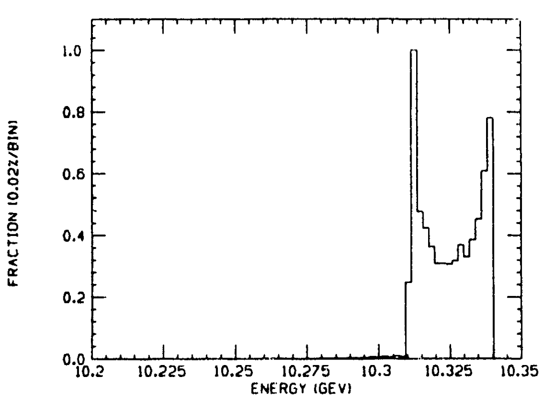

Figure 5 Calculated energy spread of a single bunch at 1000 m in the SLC linac with 1×10^{10} electrons and a bunch length of 0.5 mm. This spectrum has an rms value of about 0.14 %.

test section of x-band RF accelerator with operation under actual tunnel conditions and with NLC specification beams.

10 CONCLUSIONS

The feasibility of performing multibunch flat-beam emittance studies at the SLC with beam tolerances similar to those needed for the injector complex of a future collider appears to be reasonable. Work is continuing to better define the tolerances and the required hardware modifications, including instrumentation. The advantage of using the SLC hardware is that questions relevant to the NLC can be addressed immediately with very few infrastructure changes. Recent efforts have concentrated on designing the second compressor option allowing the bunches to be reinjected into the main linac.

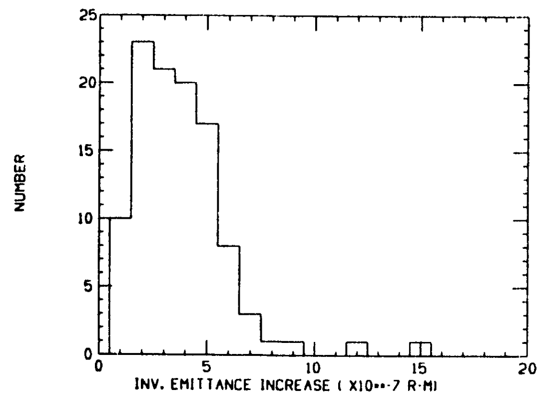

Figure 6 Expected emittance increase for a bunch entering the linac with zero emittance and subjected to random misalignments of 100 μm for the quadrupoles, 70 μm for the position monitors, and 300 μm for the accelerating structures for the first 1000 m. Simple beam steering has been used in the simulations but induced oscillations for emittance reduction have not been used [12].

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