PULSE TO PULSE STABILITY ISSUES IN THE SLC [*]

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ABSTRACT

Although the SLC achieved record luminosity in 1994, a major hindrance to further increases is pulse-to-pulse stability of the machine, often referred to as *jitter*. Raising the intensity of the SLC beams has gained luminosity but the intensity-normalized luminosity has decreased due to additional emittance dilution and to increasing jitter at higher intensities. Precision tuning of the final focus using beam-beam deflection scans is hampered by the pulse-to-pulse variations in both beam position and beam size. These were traced to position, intensity and energy jitter in various subsystems of the collider. Contributions to both the origin and amplification of the jitter have been identified as coming from wakefields in the linac, instabilities in the damping rings, acceptance limitations and feedback performance. The intensity fluctuations from the source can easily be amplified as a result of the SLC configuration of accelerating the two electron and positron bunches in the same linac.

I. INTRODUCTION

Linear colliders are inherently less stable than storage rings, and instabilities on a wide range of time scales must be controlled in order to achieve high luminosity. During the 1994 SLC run [1] the beam intensities were limited to around 3.5×10^{10} particles per bunch at the interaction point (IP) due to the increase of jitter with intensity. The larger effective overlap of the two beams is less important than the fluctuations in estimated beam size (σ). With successive beam size measurements varying by as much as a factor of two, tuning becomes less efficient and may no longer optimally converge. Detector backgrounds may also increase when tails in the beam distributions are intermittently intercepted by collimators.

In addition to orbit (0.3-0.5 σ rms) and IP beam size variations (about 0.4 σ rms), pulse-to-pulse jitter in intensity (1-3% rms) and energy (0.05% rms) may degrade performance. At the SLC there are numerous mechanisms where jitter may be transformed from one type to another and it can be difficult to distinguish between cause and effect throughout the various machine subsystems. A variety of techniques were used to characterize and correlate jitter sources. This paper reviews the measurements and improvements during the 1994 run.

II. JITTER MEASUREMENT

The primary tool for measuring beam stability throughout the SLC is the beam position monitor (BPM) and toroid data acquisition system. In the simplest mode, a few pulses of data are acquired automatically every few minutes and the rms value recorded in a time history. Fig. 1 shows the rms intensity value at different toroid monitors along the SLC, starting at the electron gun and ending at the IP. The jitter is seen to grow steadily along the length of the machine. The two curves represent the separately measured jitter of the positron and electron beams. While intensity jitter is not in itself a critical factor at the IP, it is indicative of other effects.

Another mode of BPM acquisition allows analysis of several hundred consecutive machine pulses. The time dependent data can be displayed along with the mean and rms variation within the sample. Machine-wide data is recorded simultaneously so that correlations can be made between upstream and downstream variations in the beam. The data can also be Fourier analyzed to look for signature frequencies of particular sources of jitter. Commonly observed frequency components are in the range of 10-20 Hz.

Transverse jitter is characterized by fitting the beam trajectory over a range of BPMs. The feedback software that is used to control the orbit at many different points along the machine [2] calculates the rms of angle and position which is recorded in a time history. Trajectory reconstruction of data sampled at the full repetition rate of the beam can be analyzed offline [3]. This technique has been used to fit the coherent betatron oscillations observed at the IP back towards their point of origin upstream. In many instances the amplitude of the jitter is seen to increase uniformly along the linac, indicating a distributed source of jitter within the linac. This data has also been processed with an autocorrelation analysis [4] to quantify the degree of correlation between any two points at given frequencies.

Estimates of both orbit and beam size jitter can be derived from wire scans performed throughout the SLC. Position monitor data acquired as a wire is scanned across the beam is used to correct the centroid position on a pulse-to-pulse basis. This provides an estimate of both the single

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[*] Work supported by Department of Energy Contract DE-AC03-76SF00515.

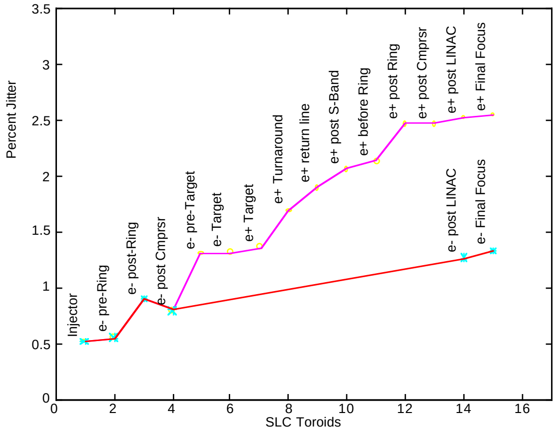

Figure 1: RMS intensity jitter (%) measured at different monitors along the SLC from the gun (left) to the IP (right). Upper trace e+, lower e-. The value plotted at each toroid is the mean of the rms jitter recorded over the entire 1994 run.

pulse beam size and the time averaged beam size over 50-100 pulses. The pulse-to-pulse beam size variations at the IP, as inferred from off-center collisions, are of the order of 200 nm, which is comparable to the IP orbit jitter [5].

III. SOURCES OF JITTER

A variety of sources of instability have been identified throughout the machine from the injector through the collimator region at the end of the linac. Significant improvements were made during the 1994 run.

The polarized electron source operates with an intensity jitter of around 0.5 % for the sum of the two bunches (fig. 1). The effects of laser instability are reduced by operating the photocathode well into saturation. Phase jitter in the injector RF together with changes in beam loading with intensity produce energy errors at the end of the injector linac. The intensity jitter is about the same at this point but then doubles as a result of the finite energy aperture of the damping ring.

The intensity jitter of the positrons at the IP is about a factor of two worse than for the electrons. The intensity jitter of the electron bunch which produces positrons is converted into energy fluctuations due to heavy beam loading in the positron capture and acceleration sections. With a finite energy aperture, these fluctuations are converted back into intensity jitter. A succession of such exchanges creates the amplification mechanism.

The extraction kicker in the electron damping ring operates with a flat top to extract both bunches. Small timing errors can place a bunch on the rising or trailing edge of the kicker pulse, which produces jitter in the extracted kick angle. This typically contributes about 20% of the observed beam jitter. Timing scans are periodically done to minimize this effect and a new feedback has been commissioned to maintain optimal timing.

Jitter in the phase of the extracted beam from the damping rings results in injection energy errors into the linac. In previous runs, a turbulent bunch length instability in the damping rings resulted in a sawtooth behavior in the beam phase above a threshold of around $3.0\text{x}10^{10}$ particles per bunch. This effect has been greatly reduced with the installation of new low impedance vacuum chambers [6].

Energy oscillations, induced by transient beam loading at injection into the damping rings, cause amplification of the intensity jitter via the limited energy aperture of the ring. RF feedback and mismatching the klystron loading angle are used to minimize the transient beam loading [7].

In 1994 bunch overcompression in the transfer line between the damping ring and linac was used to reduce the energy spread at the IP [8]. Clipping of the energy tails reduces the jitter at the end of the linac, however, about 15% of the beam is lost. With reduced energy spread and jitter, detector backgrounds at the IP were significantly reduced.

In the linac, the observed orbit oscillations at 10-20 Hz were caused in part by mechanical vibrations of quadrupoles and RF structures. In 1989 at lower beam intensities, BNS damping [9] was introduced to minimize perturbations caused by short-range transverse wakefields. With BNS, energy spread is introduced at beginning of the linac and taken out at the end. While effective in damping jitter at injection, jitter originating within the linac is not corrected. Measurements indicated amplification of the jitter along the linac by as much as a factor of six. Power supply ripple in the quadrupoles is too small to account for this, but mechanical vibration measurements have shown up to 300 nm vertical motion of the quadrupoles, which is driven by the water cooling systems [10]. Improvements to quadrupole supports and to water systems were made mid-run and further work is in progress.

In the course of studying this amplification, it was observed that the jitter of the electron beam was greatly reduced in the absence of the leading positron beam. An unexpectedly large correlation was also seen between the jitter of the positron and electron beams. The mechanism was studied by inducing an oscillation on the positron beam and measuring the resulting deflection of the electron beam, as shown in figs. 2a,b. The coupling is due to the long range transverse wakefield from the leading positron bunch in the linac. It was possible to map the wakefield kick by varying the timing between the positron bunch and the witness electron bunch. The bunch separation of 59 ns was altered in units of 0.35 ns (one linac S-band bucket).

The coupling between the bunches was greatly reduced by making the transverse phase advance of the two beams dissimilar. The horizontal and vertical tunes were split by

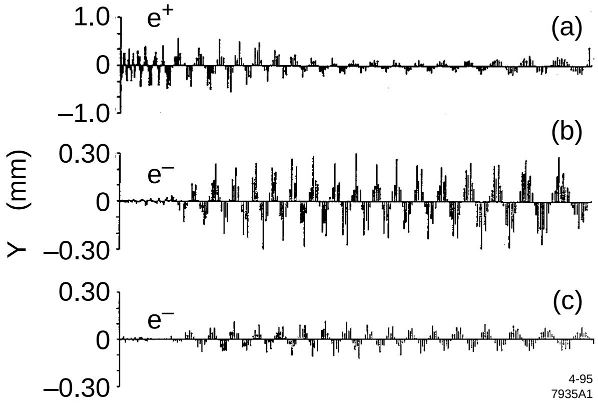

Figure 2: Vertical e+ oscillation introduced before the linac (a) and the long range wakefield induced e- oscillation (b) before and (c) after implementation of the split tune lattice.

about ±5%, to effectively separate the electron and positron tunes in each plane. The reduction in coupling with the new lattice is shown in fig. 2c. The overall electron vertical jitter downstream of the linac was decreased by 30-50%.

Wakefield kicks generated by the linac collimators may distort the beam emittance and create additional jitter. While the jaws are typically set to ±5σ of the beam, trajectory errors can cause the beam to pass off center through the collimators and receive a wakefield kick. Measurements of the wakefield kick were made as a function of collimator offset and gap at different beam intensities [11]. Periodic checks are required to ensure that the collimators are correctly positioned with respect to the beam. Feedback loops are used throughout the SLC to stabilize the beam intensity, trajectory and energy. Improper compensation or amplification of beam noise at certain frequencies can result from imperfections in the feedback modeling or from frequency aliasing. Performance is degraded by improper characterization of the lattice model, control device dynamics, or assumed beam noise spectrum. With the present feedback loop design, frequencies between about 1 and 5 Hz are amplified. The linac cooling system pumps operate with rotation rates just below the line frequency (at SLC this is one half the pulse repetition rate). The small frequency difference is seen as a 1 Hz beam oscillation due to aliasing. This can be within the anti-damping range of the feedback system for low sampling rates. This year techniques were developed to quantify the performance of a single loop or a succession of loops [12].

Transverse orbit variations affect the luminosity in at least two different ways. First, the average overlap of the two beams is reduced, causing a luminosity decrease by about 5-10% at high current. More importantly, in the presence of orbit jitter, the beam-beam deflection scans become more erratic and are harder to interpret. As a result tuning of the final focus may no longer converge to the optimum IP spot sizes. The beam size variations may be caused by upstream orbit or energy jitter. At the IP, where beam sizes are measured using beam-beam deflection scans, a jitter correction algorithm is also employed [13]. Here the algorithm is more complicated because fitting to the beam-beam deflection curve in the plane of the deflection depends also on the out-of-plane jitter. BPMs in both the linac and final focus are required to effectively sample all phases. The improved fitting algorithm is very useful in simplifying interpretation of the beam-beam scans.

IV. CONCLUSION

In the 1994 run, considerable effort has been devoted to the detection and suppression of orbit and intensity jitter throughout the SLC. Major improvements include the separation of electron and positron phase advance in the linac, a strengthening of the linac quadrupole supports, and the implementation of jitter corrected fits to the beam-beam deflection scans. The recent progress in SLC performance is partly due to these improvements.

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