The Trajectory Control in the SLC Linac*

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Abstract

Due to wake field effects, the trajectories of accelerated beams in the Linac should be well maintained to avoid severe beam break up. In order to maintain a small emittance at the end of the Linac, the tolerance on the trajectory deviations become tighter when the beam intensities increase. The existing two beam trajectory correction method works well when the theoretical model agrees with the real machine lattice. Unknown energy deviations along the linac as well as wake field effects can cause the real lattice to deviate from the model. This makes the trajectory correction difficult. Several automated procedures have been developed to solve these problems. They are : an automated procedure to frequently steer the whole Linac by dividing the Linac into several small regions ; an automated procedure to empirically correct the model to fit the real lattice and eight trajectory correcting feedback loops along the linac and steering through the collimator region with restricted corrector strengths and a restricted number of correctors.

I. INTRODUCTION

Due to the transverse wake field effects in the 3 km linac of the Stanford Linear Collider (SLC), it is necessary to keep the beam trajectory rms deviation less than a few hundred microns in order to avoid large emittance growth. Because the transverse wake kick is linearly proportional to the beam intensity, the tolerance on the trajectory deviations become tighter when the beam intensities increase. The existing two beam trajectory correction method works well when the theoretical model agrees with the real machine lattice. Unknown energy deviations along the linac as well as wake field effects [1] can cause the real lattice to deviate from the model. This makes the trajectory correction difficult. In this paper we present several automated procedures which have been developed to solve these problems. The algorithms of two beam steering of the SLC linac in which e^- and e^+ bunches must be steered simultaneously appear elsewhere.[2]

The SLC linac consists of 30 sectors, *ie.* sector 1 to sector 30. Each 100 m sector contains eight girders ; at the end of each girder of a typical sector is one quadrupole magnet of the FODO lattice. The first sector after the damping rings, sector 2, has four times as many quads, and sectors 3 and 4 have twice as many in order to provide stronger focus which is needed because of lower energy beams are more sensitive to wake fields. The phase advance per cell is 90° in sectors 2 - 4 and 76° in sectors 5 - 14, then tapers to 45° at sector 30 as the quadrupoles saturate.

II. AUTOMATED PROCEDURES

A. *Auto-Steer Macro*

The disagreement between the real lattice and the model accumulates as the length of the region which we try to steer increases. Therefore, we developed a Button Macro[3] which automatically divides the whole linac into four regions with about equal phase advances. The linac is then steered region by region from upstream to downstream with iterations of steering. All we need to do is just push the button once. This button macro has been successfully tested. The advantage of this button macro is that it frees the operators' attention and steers the linac in pieces precisely the same way every time. It can also be implemented in an automatic procedure which executes every few minutes in a manner similar to slow feedback loops along the linac.

B. *Model Updating Macros*

When the unknown energy deviations along the linac as well as wake field effects cause the real lattice to deviate from the model too much, the trajectory steering will become very difficult even after dividing the linac into several pieces. A "lattice diagnostic" program[4] has been developed to find the discrepancies. The existing "Linac Energy Management (LEM)" program[5], was then used to implement the results to adjust the real lattice (quadrupole magnets) such that it agrees with the model.

There are two reasons to change the above technique. First, since both e^- and e^+ beams use the same set of quadrupoles, we can only adjust the lattice to fit either the electron model or the positron model. To make it right for both the electron beam and the positron beam, instead of adjusting the lattice, we need to adjust the models of both beams. The second reason is that in the high intensity regime as we operate in SLC now (3 - 4.5 x 10^{10} particles per bunch), the discrepancies between the real lattice and the model is usually dominated by wake field effects. Thus, from the optics point of view, we would also like to adjust the models to ease steering while keeping the lattice unchanged so that the beam's

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Twiss parameters will be well matched with the lattices' Twiss parameters. This is easily understood by imagining slicing the beam longitudinally, the transverse dipole wake kick will not change the beam's Twiss parameters of each slice and therefore, we like to keep the matched lattice unchanged.

Previously to adjust each model , it took about 50 manual operations and was very difficult to do it correctly each time. That software was not capable of simultaneously adjusting both electron model and positron model correctly. The model updating macros were created to accomplish the model updating by only pushing three buttons and they are capable of adjusting both beam's models simultaneously. They have been successfully tested and are now used routinely. Each time after we update the models we can steer the whole linac in one piece. The models remain good on the order of one week or when the beam currents are significantly changed.

A measured example of these procedures is included to illustrate their effectiveness. Fig. 1 shows the result of an incorrect model. There is a big phase discrepancy between the measured oscillation (solid line) and the curve which is predicted by the model (dashed line) by fitting the earlier part of the oscillation. As we pointed out previously, the bad fitting is due to the discrepancies between the real lattice (measured oscillation) and the model (fitting curve). Fig. 2 shows a good agreement in phase advance between the measured oscillation and the fitting curve after the adjustment of the model. The amplitude discrepancy is due to the decoherence of the beam signal. This data was taken after we used the model updating macros to update the models.

C. Trajectory Correcting Feedback Loop

Once good beam trajectories have been established using the steering techniques described above we want to keep the beams on those trajectories. To accomplish this there are eight trajectory correcting feedback loops [6] spaced along the linac. They are centered at sectors 2, 3, 4, 6, 11, 18, 23, and 27. Each loop reads the positions of the electrons and positrons from 12 to 16 beam position monitors which are spread out over 360 to 720 degrees of betatron phase advance. From these readings a loop calculates the position and angle of the beams and then sets eight correction magnets to keep the beams on the desired orbit. These measurements, calculations and corrections are presently repeated at 20 Hz and we plan to increase that rate to 60 Hz. The loops quickly correct orbit changes caused by klystrons turning on or off or caused by changes of magnet power supplies.

D. The Collimator Steering

A special steering algorithm is required near the end of the linac where the beam passes through two sets of collimators, each of which consists of two pairs of collimators in both planes. Each pair is separated by 90 degrees in phase advance, and electrons and positrons are collimated in alternate pairs. For the collimation to be effective, both beams have to be centered in the collimator jaws to the 100 micron level. For this purpose, eight corrector magnets are used for each set of collimators to steer both beams based on the readings from four BPMs located near the collimators.

In principle, the eight correctors can be used to zero the four BPM values for both beams since there are eight constraint conditions. In practice, the phase advance between the correctors is such that magnet strengths would exceed their maximum limits to correct the orbits given the approximately 100 micron quadrupole misalignments in that region. As an alternative, a steering algorithm was developed which does a least squares minimization of both the orbit deviations and the magnitude of the corrector strengths to determine the corrector settings. The relative weighting of the two constraints was adjusted empirically. The result is that both beams can be steered to within 100 microns of each other and to within 200 microns of zero at all eight BPMs without exceeding the maximum corrector magnet strengths. After steering, the collimator jaws can be centered about the average position of the two beams to better optimize the collimation. In the operation of the linac, the steering is done every few days while the collimator alignment is done a few times a year.

III. CONCLUSION

Using the above techniques, we were able to control the SLC production electron and positron beam trajectories. However, the scavenger beam trajectory is not so well controlled. A three beam steering method is under developed now. The trajectory control is vital for the issue of the emittance preservation of the linear collider. The experience, we learned, from controlling the SLC beam trajectories should be helpful for further development of the next generation linear collider.

IV. ACKNOWLEDGEMENT

The success of the trajectory control is a result of the efforts of many people. We would like to thank all of them.

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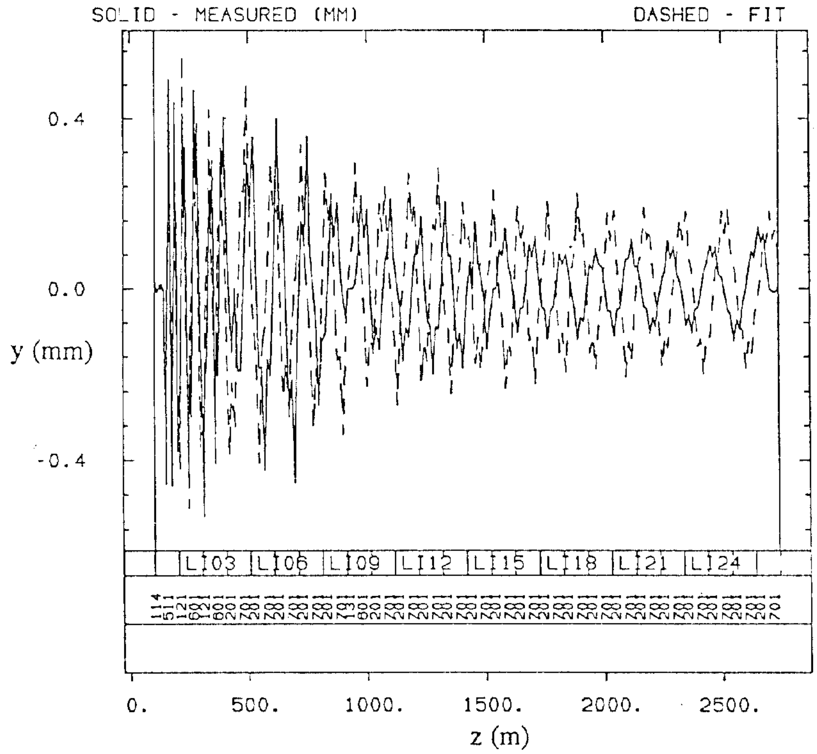

Fig. 1 Trajectory difference from an induced dipole oscillation. Data are taken before updating the model. [I = (2.0 ± 0.2) x 10^{10} e+]

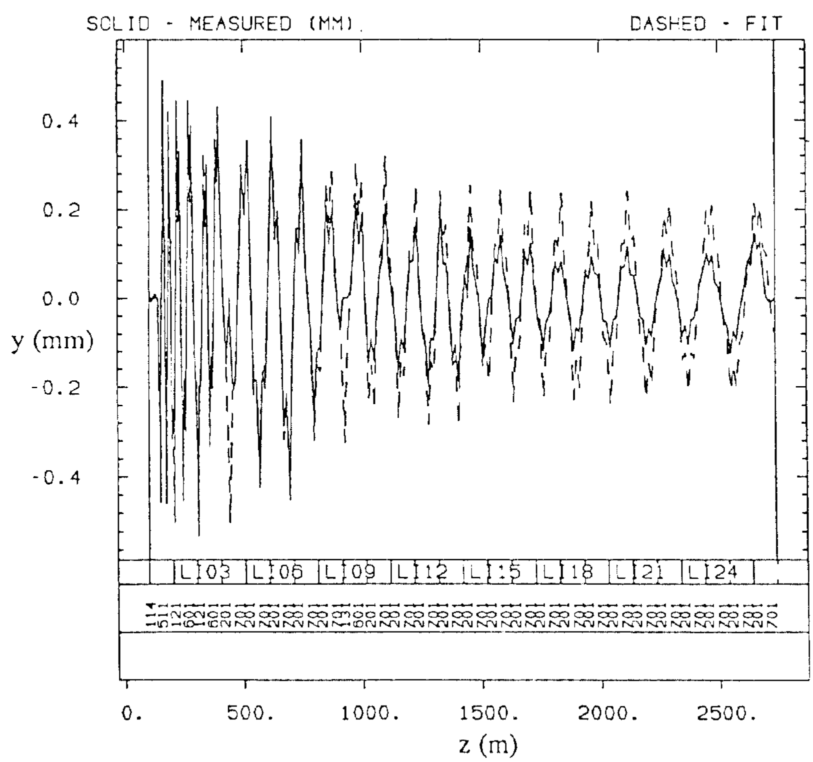

Fig. 2 Trajectory difference from an induced dipole oscillation. Data are taken after updating the model. [I = (2.0 ± 0.2) x 10^{10} e+]