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RECENT COMMISSIONING EXPERIENCE ON THE SLC ARCS*

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ABSTRACT

The Arc transport line, which brings high-energy, high-intensity electron and positron bunches from the SLAC linac to the Stanford Linear Collider final focus section, has been in operation for the past few years. In this paper, we will review the techniques developed for the optical tune-up and diagnostics, recent performance, and on-going improvement programs.

1. INTRODUCTION

The commissioning work of the Arcs started in September 1986.[1] A 100% transmission of electrons through the North Arc was immediately obtained, followed by positrons through the Sorth Arc by the end of March 1987. Since then vigorous efforts have been made to solve optical problems associated with random and systematic placement errors.[2] At this moment we have a good control over systematic error problems, and a fair handle over the remaining random errors. The Arcs are in a sufficiently good state for the initial physics runs of the SLC.

In this paper, we first present a brief review of the Arcs design, beam steering and major hardware issues. Then we devote the rest of the paper to an overview of the correction schemes and tools, and attempt to give a logical interconnection among them. Remaining issues concerning the beam-related backgrounds on the physics detector are discussed.

2. DESIGN

The purpose of the Arcs is to bring high-energy (~ 47 GeV), high-current ($> 1 \times 10^{10}$ particles per pulse) bunches of electrons and positrons from the SLAC linac to the Final Focus (FF) sections of the SLC, without significant emittance dilution.[3] Here we summarize only the pertinent design parameters: the Arcs consist of a very strong focusing FODO array of combined function magnets ($B \simeq 6$ kG, $dB/dx \simeq 7$ kG/cm) with sextupole components ($d^2B/dx^2 = 1.6$ kG/cm^2 for F, -2.7 kG/cm^2 for D). Each F-D cell produces a phase advance of 108° in both x and y planes. Ten cells are grouped to form a second-order achromat (6π total phase advance). The North (Sorth) Arc consists of 23 (22) such achromats, with a few matching sections.

A beam position monitor (BPM) is fixed on each magnet, reading out the x (y) coordinate of the beam position relative to an F (D) magnet entrance. The matched horizontal dispersion function at each BPM is 35 mm and the beta function is 4.2 m for both x and y. The beam pipe aperture is 12 mm (diameter), while a typical transverse beam size in the Arcs is $30 \sim 60$ μm.

Since the Arc tunnels are not in a plane, but rather follow the SLAC site terrain, achromats are rolled with respect to each other to provide the required vertical deflections. In several locations roll angles reach up to 10°, but by the Arc exit the total roll angle returns to 0 (zero), insuring that the whole Arc forms a unit beam transfer matrix, *IF individual achromats are perfectly tuned.*

3. BEAM STEERING

Because of the very high field gradient, with even the best attainable magnet alignment (~ 200 μm rms), the beams are forced out of the beam pipe after going through less than a few achromats, unless a beam steering device is introduced. This is conveniently achieved with a magnet mover (MOV) mechanism which moves the front end of each F (D) magnet horizontally (vertically) in the range of ± 1 mm. A MOV motion of 0.1 mm causes an orbit shift of 0.27 mm as measured by the BPM on the next cell.

Steering using the MOVs works very well. Figure 1 shows the orbit after the steering was done. Except for the matching sections where the steering is only empirically established, the rms orbit deviations in x and y are maintained at < 0.3 mm. As a side-product, diagnoses of various types of hardware problems (BPMs and gross alignment errors) are obtained on a cell-by-cell basis. From the rms variation of MAG MOV setting around the average, after finishing the steering, one can infer the original alignment error to be ~ 150 μm (see Fig. 2).

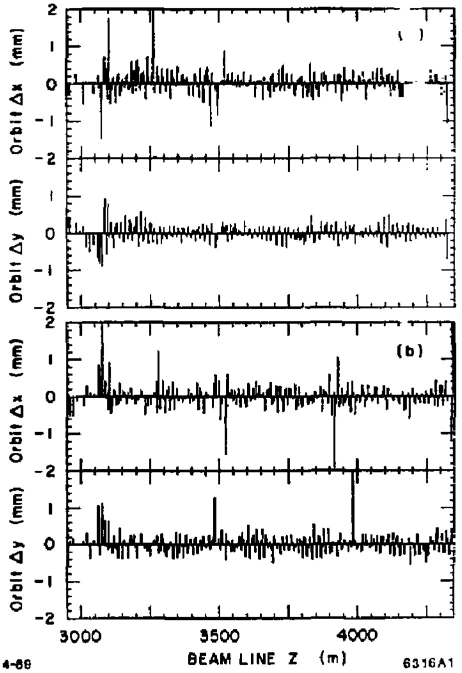

Fig. 1: The measured orbit of the electron beam in the (a) North Arc and (b) South Arc on March 10, 1989.

Optical properties of the Arcs remain remarkably stable once a MOV setup is made. For example, a configuration which was established in August 1988 can be still used in Spring 1989, after many power shutdowns and MOV cycling for maintenance work, and still produces very similar optical characteristics, following a few touchups per achromat. (< 100 μm). This indicates that (1) local ground motion in the tunnel is not (yet) significant over the past two years, and (2) the MAG MOV reproducibility is better than ~ 20 μm.

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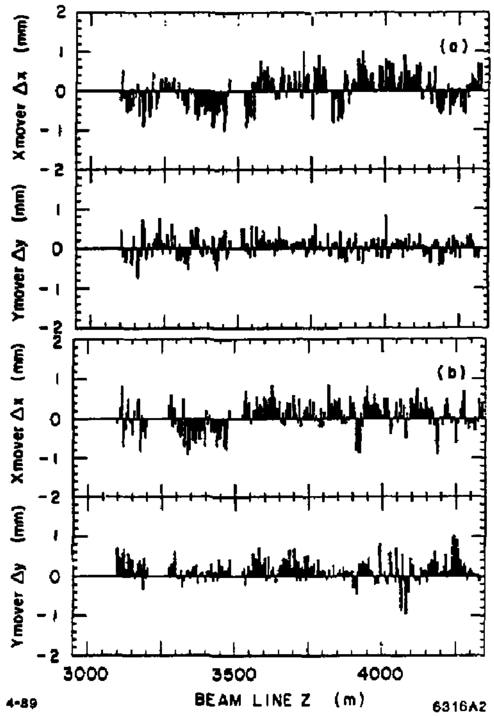

Fig. 2: Positions of the magnet movers in the (a) North Arc and (b) South Arc measured March 10, 1989.

4. HARDWARE ISSUES

Since the Arcs consist of combined function magnets with sextupole field components, errors in magnet placements would cause optical errors.[4,8] Careful preparatory work was made in the construction phase of the project.[1,5] The offsets of effective magnetic center lines (x and y) of each Arc magnet were measured and tabulated. Measurements of BPM centers were also tabulated. The alignment of the magnets and of the BPMs included these results. In spite of those efforts, and in hindsight, we believe that after the completion of construction, three classes of significant systematic errors remained:

1. The systematic difference of field strength between the D and F magnets at the point of equal gradient was measured to be +2% in the factory test, but found to be +0.7% in the field.
2. Systematic magnet placement errors in x (~ 400 μm), most likely due to errors in measurements or calculations of x magnetic center line offsets throughout the Arcs.
3. Systematic beam steering errors in y (~ 200 μm), most likely due to instrumental difficulties in measurements of BPM y offsets relative to the magnets.

The alignment work itself, long range and magnet-to-magnet, appears to have met the goal, except for a few anomalies whose impacts are still being investigated.

5. OPTICAL PROBLEMS

Systematic gradient errors in the Arcs, either in the form of upright or skew-quad fields due to the magnet placement errors, give rise to an undesirable growth of *projected* beam emittances. This is because the net sum of x–y coupling through the rolled achromat boundaries[6] would cancel only when each achromat is well-tuned. The cancellation is easily broken down by systematic tune errors.[9] Random gradient errors result in similar effects.

Although a growth of projected emittances does not mean a blow-up of the beam emittance in the Liouville's sense, it is serious enough to impede smooth operation of the SLC:

1. The beam ellipse at the linac exit, even if it fulfills the design criteria, does not translate to the output beam ellipse at the Arc exit as designed. This causes a problem in the beam collimation within the FF section, since its arrangement of fixed and variable collimators works properly only for beams that are not seriously mismatched.[7]
2. A small steering change at the linac exit causes a large spatial variation of the beam centroid at the FF entrance.
3. A small fluctuation in the dispersion matching at the linac exit—beam switch yard region translates to a significant change of the beam dispersion into the FF.

Correcting the offset errors based on the construction data was a practically impossible task. Therefore, our approach has been either (i) to apply empirical corrections to particular symptoms, or (ii) to modify the system so that it becomes less vulnerable to mechanical errors. Several important ingredients in the effort are noted:

1. Techniques to measure the beam transport characteristics by generating and observing betatron oscillations through the system at a set of different initial phases. The first method was a simple sinusoidal fitting to the perturbed orbit[8]; eventually it evolved into a full reconstruction of 4 × 4 transfer matrices at every BPMs in the system.[9]
2. Various "fix" techniques to apply corrections. Some of them exploited the existing hardware (phasefix,[8] skewfix[9]), others were realized by hardware modifications (rollfix,[10] wirefix[11]).
3. A convenient formalism to characterize the magnitude of x-y coupling, in the form of "det$C$."[12] This helped to signify "where we are" at each stage of optical corrections.
4. Use of DIMAD simulation program[13] to predict effects of various "fixes" or perturbations applied to the system, for direct comparisons with experimental data.

A chronological description of the development is as follows:

In August 1987, a correction scheme for gradient errors (phasefix[8]) due to horizontal magnet alignment errors was developed. In the North Arc, it helped to achieve ~ 7 μm electron spot size at the interaction point (IP). A similar correction was applied to the South Arc in September 1987. During Winter 1987, modifications were made to the alignment of magnets in the rolled boundaries (rollfix[10]) to smooth the abrupt roll transitions. This was to make the optical behavior of the Arcs much less vulnerable to systematic gradient errors in the system.

In Spring 1988, a modification to the magnet excitation system was made (wirefix[11] or harmonic fix). A variable harmonic modulation of gradient (equivalent to either upright or skewed quads) across one-third of each Arc was introduced, so the effective beta functions of the system are quickly modified, without any realignment work. The Arcs then were functioning well enough to allow FF sections to routinely produce 5-10 μm spot sizes for both electrons and positrons at the IP.

During Fall and Winter 1988, significant progress[13] was made in understanding the x-y coupling, which, formerly, could not be entirely accounted for by the known rolled boundaries. It led to a concept of "skewfix" which corrects for the skew quad components of the magnets which are systematically misaligned in the y (vertical) direction.

See Table I for a list of "fix" actions and references. The net result of those efforts is as follows:

1. A 100% beam transmission through both Arcs is routine.
2. The dispersion has been matched by adjusting the beam steering through the beam switch yard region. See Fig. 3.

Table 1.

Action	Variable	Fight against -	Reference
Phasefix	Horizontal MOVs or x-alignment, and F-D imbalance, backleg excitation	Systematic grad. error / horizontal magnet offsets	8
Rollfix	Adiabatic smoothing of rolled junction	Big variation of x–y coupling	10
Skewfix	Vertical MOVs	Skew-quad fields / vertical BPM offsets	9
Wirefix	Harmonic modulations of gradients with 2× betatron osc. frequency	Remaining lattice imperfections	11

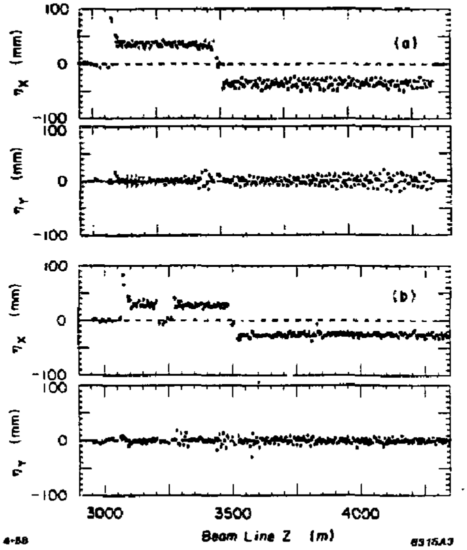

Fig. 3: Dispersion of the electron beam in the (a) North Arc and (b) South Arc, measured March 10, 1989.

3. The "blow-up" factor of the betatron oscillations sent from the Arc entrance is less than 1.2 (ideally 1.0).
4. The det$C$ parameter, characterizing the magnitude or remnant x–y coupling, is measured to be 0.006 at the exit of the North Arc (electron side, see Fig. 4), 0.13 for the South Arc (positron side). The det$C$, ideally, should be zero at the Arc exit.
5. With beam steering/energy feedback systems operating at the Arc entrance, the orbit (beam centroid) reproduces within 100 μm over weeks.

6. REMAINING ISSUES

One outstanding issue in the physics runs at the SLC is beam-related backgrounds in the detector.[7] All of the evidence indicates that the beam transfer across the Arcs is very stable once a configuration is set up. However, the delicate intershadowing of beam collimators in the Arcs and FFs is quickly broken as the incoming beam condition changes.

As noted in the previous section the Arcs have been "tuned" to have a small net det$C$ (*i.e.*, very small remaining x–y coupling). However, this does not mean that the total "phase length" of the Arcs agrees exactly with the design. Therefore, frequently, wirefix must be applied to introduce extra x–y coupling or to modify the beam transfer, so that the beam at the Arcs exit is nearly matched to the FF. Using wirefix in this way is very practical and a rather quick solution to the problem at this moment of initial physics runs. However, a complete tune-up of the whole Arcs is being prepared with all the developed "fix" techniques to bring the system even closer to the ideal design. We hope that it will make the detector background less sensitive to the changes in the incoming beam conditions.

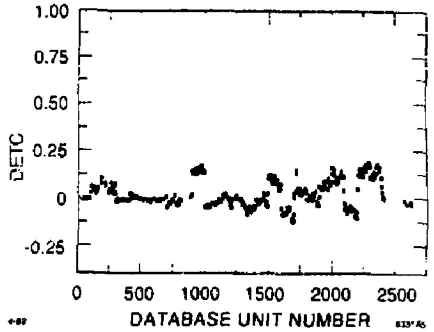

Fig. 4: Measured values for detC in North Arc, February 28, 1989.

7. CONCLUSIONS

In the operation of the SLC Arcs we are equipped with powerful tools to (i) correct systematic gradient errors due mainly to horizontal placement errors (phasefix), (ii) correct systematic skew-field errors due mainly to vertical placement errors (skewfix), and (iii) can semi-empirically modify the effective beta functions at the Arc exit (wirefix). The Arcs are able to interface between the SLC linac and the SLC FF in a well-controlled fashion, so that electron and positron beams are delivered with sufficiently high quality for the first-round SLC runs.

REFERENCES

1. G. Fischer *et al.*, "Some Experiences on the Commissioning Program of the SLC Arcs," SLAC-PUB-4206 (1987).
2. T. Fieguth *et al.*, "Tuning the Arcs of the SLC Linear Collider," *SLAC-PUB-4628 (1988).*
3. S. Kheifets *et al.*, "Beam Optical Design and Studies of the SLC Arcs," SLAC-PUB-4013 (1987).
4. T. Fieguth *et al.*, "Studies of Anomalous Dispersion in the SLC Second Order Achromat," SLAC-PUB-4096 (1987).
5. W.T. Weng, "Studies of the SLC Arc Magnets," SLAC-CN-352 (1987).
6. M. Sands, "Betatron Oscillations and Rolled Achromats," SLAC-CN-355 (1987).
7. D. Burke *et al.*, "Beam Collimation and Detector Backgrounds at e^+e^- Colliders," these proceedings.
8. J. Haïssinski, *et al.*, "PHASEFIX," these proceedings.
9. T. Barklow, "A Technique for Measuring the 4 ×4 Transfer Matrix for Beamline Section with Cross-Plane Coupling," SLAC-PUB-4969 (April 1989).
10. P. Bambade *et al.*, "ROLLFIX - An Adiabatic Roll Transition for the SLC Arcs," SLAC-PUB-4835 (February 1989).
11. P. Bambade and A. Hutton, "Specification of Harmonic Corrections (Wirefix) for the SLC Arcs," SLAC-CN-370 (1989).
12. K. Brown and R. Servranckx, "Cross-Plane Coupling and its Effects on Projected Emittances," SLAC-PUB-4679 (1988).
13. R. Servranckx and K. Brown, "DIMAD program," SLAC 285 (1985).