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Chromaticity Corrections in the SLC Final Focus System*

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Abstract

To best minimize the beam spot sizes at the interaction region in a linear collider, it is important to reduce chromatic aberrations at the focal point among other optical errors. In this paper we describe the chromaticity correction techniques that have been developed and applied to the SLC final focus system. The resultant improvements and procedural issues are discussed.

I. INTRODUCTION

This paper presents our recent operational experience in conducting chromatic corrections at the SLC interaction point (IP) to minimize the spot size, thus to maximize the luminosity [1].

The first order transverse spot size σ_0 at the waist, in the absence of aberrations, can be written as -

$$\sigma_0 = \sqrt{\varepsilon\beta^*} = \varepsilon/\theta^* \quad (1)$$

where, ε is the un-normalized beam emittance, β^* is the beam beta at the waist, and θ^* is the beam angular divergence. In the SLC design, the beam emittance $\varepsilon = 3\times10^{-10}$ m.rad should yield $\sigma_0 = 1.5$ μm (i.e. $\theta^* = 200$ μrad) with normal conducting final triplets used with the Mark-II detector, and 1.1 μm (i.e. $\theta^* = 275$ μrad) with superconducting final triplets with the SLD detector. The typical energy spread ΔE is 140 MeV ($\Delta E/E = 0.3$ %, E = 45.5 GeV). Therefore, to limit the spot size growth due to optical aberrations to less than 0.5 μm, we need to maintain -

Residual IP dispersion:	$\eta < 0.15$ mm
Waist position error:	$\Delta W < 2.5$ mm
Chromaticity:	$\Delta W/\Delta E < 1.7$ mm / 100 MeV

Here we characterize the IP chromaticity as an energy dependence of the waist position. The contributions of those errors are to be added in quadrature. Obviously their relative importance varies, depending on the beam emittance delivered by the SLC linac through the ARCs. However, as the SLC performance approaches the design parameters, it is clear that careful attentions must be paid to detect those aberrations, remove them quickly, and maintain the corrected setup.

Figure 1 shows a schematic diagram of the SLC FFs [2]. The de-magnification is performed through the upper-transformer (UT), the final-transformer (FT) and the final triplet (Q3-2-1). The de-magnification control (i.e. control of IP β's) is made primarily with Q16 and Q17. The waist position (i.e. the focal depth of the final triplet; control of IP α's) is done by adjusting the strength of the final triplet quadrupole magnets.

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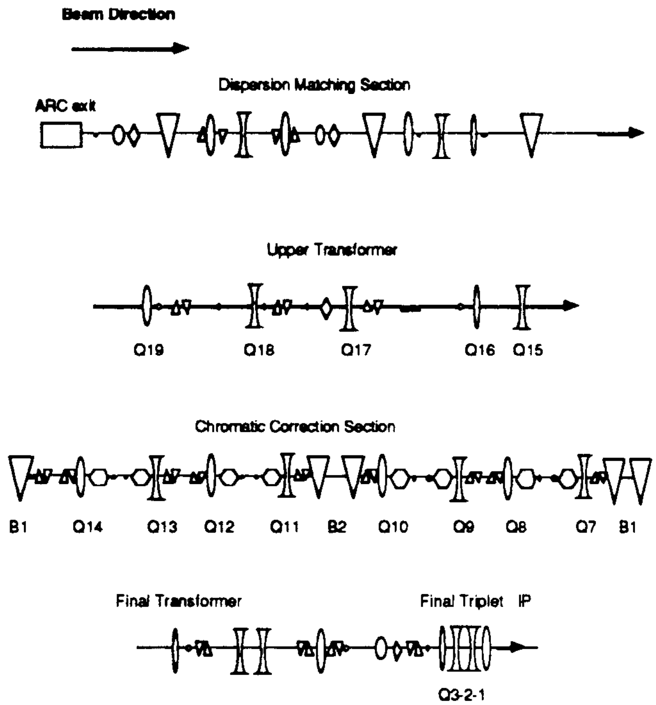

Fig. 1. Schematic diagram of the SLC Final Focus beam line.

Roughly two thirds of the IP chromaticities is created by the final triplet magnets. The Chromatic Correction section (CCS) is designed to compensate it through a 2-π achromat with a large horizontal dispersion ($\eta_{max} = 235$ mm) interlaced with two families of sextupole magnets. With zero field strengths of those sextupole magnets, the IP chromaticity would be $\Delta W / \Delta E \approx 4.0$ cm / 100 MeV (2.5 cm / 100 MeV) with the normal conducting (superconducting) final triplet. In the initial configuration we started with sextupole strengths calculated with TRANSPORT, assuming the "design" incoming beam. As the optics tuning proceeds, the strengths of UT and final triplet magnets would be varied in order to achieve the minimum spot size. This in turn calls for an iterated chromatic correction at the IP in situ.

In this paper we review our present method of detecting and correcting IP chromaticities at the SLC. A couple of operational issues are outlined for further investigation.

II. DETECTION OF IP CHROMATICITIES

If the accurate values were known for the beam spot size, emittance, β^*, and IP dispersions, then the contributions from the IP chromaticities may be deduced from them. However, this is impractical, because those beam parameters are usually unknowns, and they have to be experimentally determined collectively. Instead, in a more direct approach, the shift of

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beam waist position as function of beam energy is measured. Techniques involved in this measurement are as follows.

First we define the convoluted IP spot sizes Σ's as:

$$\Sigma_x = \sqrt{\sigma(e^-)_x^2 + \sigma(e^+)_x^2} \qquad (2)$$

$$\Sigma_y = \sqrt{\sigma(e^-)_y^2 + \sigma(e^+)_y^2}$$

The Σ's can be measured by performing a beam-beam scan and by fitting the observed beam-beam deflection angle as function of relative beam offsets [3].

A set of orthogonalized multi-device knobs have been developed, and are used to control the x and y waist positions across the IP. This is done by varying the field strength of final triplet magnets [4]. The waist position, beam angular divergence and the minimum Σ are determined by repeating the beam-beam scans at several varied settings of the waist knob. At the SLC this procedure is called a "waist scan". An example of the result of a waist scan is shown in Figure 2. The fitting error of waist position in a typical scan is ≈ 1 mm.

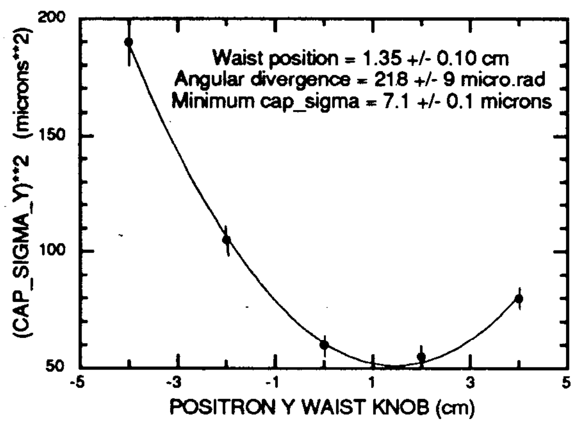

Fig. 2. Example of the result of a waist scan (positron Y waist).

The IP chromaticity can be measured by repeating such waist scans at several different beam energies, and by observing the linear dependence of the waist position on the average beam energy. The beam energy can be changed in the range ± 300 MeV without difficulties by varying the setpoint of the energy feedback system operating at the SLC beam switch yard (i.e. entrance to the ARCs). The beam energy can be monitored with the same feedback software or with the energy spectrometer at the Final Focus extraction line right upstream of the main beam dump with an accuracy better than 30 MeV. An example of an IP chromaticity measurement using this technique is shown in Figure 3.

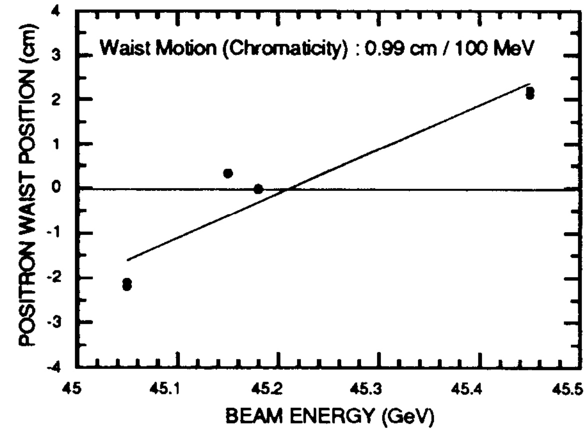

Fig. 3. Example of an IP chromaticity measurement before a correction was applied.

III. CHROMATIC CORRECTIONS

The IP chromaticity can be adjusted, without significantly affecting the β*, by modifying the strength of sextupole magnets in the CCS. In the SLC FFs the CCS has two families (four focussing and four defocussing) of sextupole magnets. Each family of sextupole magnets are driven in series by a single large-current power supply. For an assumed characteristics of the incoming beam, it is possible to create two combinations of power supply perturbations which affect either the x or y IP chromaticity without affecting the other. This calculation has been done for the design beam line.

Chromatic corrections can be applied based on the IP chromaticity measurements outlined in section II and those chromaticity knobs. Figure 4 displays the result of chromaticity measurements after a correction was applied for the initial case shown in Figure 3. It indicates that the original IP y chromaticity for positrons of ΔW / ΔE ≈ 1.0 cm / 100 MeV was reduced to ΔW / ΔE ≈ 0.4 cm / 100 MeV.

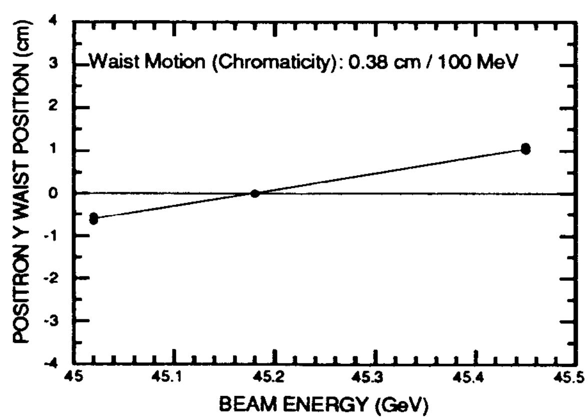

Figure 4. Example of an IP chromaticity measurement after a correction was applied.

IV. Remaining Issues

So far we have been able to correct IP chromaticities to the level of $\Delta W / \Delta E < 0.5$ cm / 100 MeV. Hence its contribution to an IP spot size increase is 1.5 - 2.0 µm. While this is reasonably small for the actual beam emittance of (5 - 6) $\times 10^{-10}$ m.rad in the past year, an improved corrections will be required in the near future.

A need for IP chromaticity corrections, aside from the one for the initial setup, arises through the following mechanism.

a) First, for some difficult-to-identify reasons, from time to time the incoming beam characteristics change so that the IP de-magnification is significantly affected. This calls for an adjustment with Q16 or Q17 in the UT [5]. (The IP waist adjustments using Q1-2-3 can hardly change the IP de-magnification.)

b) However, because of the design, the Q16/17 adjustments also significantly move the IP waist. In the present beam line design there is no clean way to control the IP de-magnification with UT quadrupole magnets without affecting the waist position.

c) The IP waist motion introduced with the UT quadrupole magnet changes now need to be compensated by adjusting the strength of Q1-2-3. This leads the IP chromaticity to change.

Regarding the issue a): The source of variations of the incoming beam characteristics should be identified and stabilized. An effort is being initiated to measure the beam parameters at the end of the SLC linac and simulate its propagation through the ARCs using the experimentally determined beam transfer matrices across them [6]. Attempts will be made to determine whether the measured IP spot characteristics changes are consistent with beam parameter changes from the linac.

Regarding the issue b): Due to geometrical constraints, it is difficult to redesign the FFs UT as a true zoom lens system, although investigations are ongoing. It may be possible to improve the beta-matching procedure by exploiting the data available from new wire scanners installed in the FFs [7]. This should eventually allow to stream-line the beta-matching and chromaticity corrections.

Regarding the issue c): Since the bulk of IP chromaticities is due to Q1-2-3, the chromaticity corrections, in principle, can be determined solely based on the knowledge of final triplet magnet strength and the geometry. This has not been completely successful possibly due to the ambiguities in the beam transfer across the CCS and FT. Detailed work of second-order beam transport simulation in this area is being prepared.

Large IP chromaticity corrections naturally require large changes of CCS sextupole magnet strengths. Transverse misalignments of sextupoles, during those corrections, introduce spurious IP dispersions, waist shifts or de-magnification changes. They then lead to another round of IP spot optimization work. It means a long turn-around time (at least an hour or two) needed before the success or failure of the correction can be confirmed. A good CCS sextupole alignment at most within 0.2 mm is required to alleviate the problem. Sighting through the tunnel for precision mechanical alignment of those magnets is difficult. This is because of the presence of large toroidal magnets placed in the CCS to reduce detector backgrounds from muons, which are produced at upstream collimators. A technique to measure sextupole alignments using the beam has been developed [8]. We plan to test it and apply corrections during the Spring '91 run cycle.

V. Conclusions

The current technique of measuring the IP chromaticities in the SLC FFs has been presented. A semi-empirical correction scheme has been successfully implemented to control the IP chromaticities, as characterized by the waist position dependence on the beam energy to better than 0.5 cm / 100 MeV. Several outstanding issues for further improvements have been identified, and possible courses of efforts in the near future are presented.

Acknowledgements

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