WAIST CORRECTIONS AT THE INTERACTION POINT OF ATF2 IN THE PRESENCE OF IPBSM FRINGE ROTATIONS AND INPUT BEAM σ_{13}, σ_{24}*

Sha Bai, Jie Gao, IHEP, Beijing, China
Philip Bambade, LAL, Orsay, France

Abstract

The ATF2 project is the final focus system prototype for ILC and CLIC linear collider projects, with a purpose to reach a 37nm vertical beam size at the interaction point. In beam tuning towards the goal beam size, the presence of a tilt of the IP Shintake monitor fringe pattern with respect to the x-y coordinate system of the beam (or equivalently a σ_{13} correlation), as well as a σ_{24} correlation, can break the orthogonality in the main σ_{34} and σ_{32} waist corrections during the minimization and result in larger vertical beam sizes at IP. Both effects are studied, analytically and in simulation, and a practical procedure is suggested for diagnosing the presence of a residual fringe tilt, by measuring the influence of the horizontal waist correction on the minimum vertical beam size.

INTRODUCTION

ATF2 [1, 2] is the test facility with an ILC and CLIC type final focus line, to reach a final beam size of 37 nm. How to tune this small nanometer beam size in both simulation and experiment is a crucial point. The Shintake monitor (IPBSM) [3] has an important role in the measurement of the nanometer scale beam size. A tilt in the interference fringes or, equivalently, a finite σ_{13} correlation, increases the measured vertical beam size due to coupling from the horizontal dimension [4]:

$$\sigma_{\tilde{y}}{}^2 = \sigma_y{}^2 + \sigma_x{}^2 \sin^2\theta \tag{1}$$

Moreover, both such a fringe tilt and the presence of a residual σ_{24} can potentially break the orthogonality in the main σ_{34} and σ_{32} waist corrections, which are the main first order optical adjustments to reduce the vertical beam size in the presence of imperfections. In this paper, both these effects are investigated, at first analytically and secondly in simulation. A practical procedure to diagnose the presence of a residual fringe tilt is also described.

ANALYTIC DESCRIPTION OF WAIST CORRECTION IN PRESENCE OF IPBSM FRINGE TILT AND INPUT BEAM σ_{13}, σ_{24}

At the IP of ATF2, the vertical beam size can be significantly enlarged by normal and skew gradient errors in the magnets of the beam line. Once the optical demagnification has been set, using the QM11-16 matching quadrupoles upstream of the final focus section, inferring from measurements of the angular spread near the IP (directly with a screen or from waist scans), the main contributions originate from strength errors in the quadrupoles of the final focus section and from alignment errors in the five sextupoles (SF6FF, SF5FF, SD4FF, SF1FF, SD0FF). Being all close to $\pi/2$ betatron phase shift from the IP, such errors can only generate non-zero σ_{34} and σ_{32} correlations at the IP.

Correction of such non-zero σ_{34} and σ_{32} correlations is achieved using pre-calculated orthogonal combinations of sextupole movements in the horizontal and vertical directions, respectively. As a function of such correctors, labeled K and S (here, K can be taken as the horizontal sextupole multiknob and S the vertical sextupole multiknob), the combined effect of the two lenses on the beam can be expressed as [5]:

$$\sigma^{out} = R\sigma^{in}R^t \tag{2}$$

with
$$R = \begin{pmatrix} -K & 1 & -S & 0 \\ -1 & 0 & 0 & 0 \\ -S & 0 & K & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

where $\sigma_{in,out}$ are the beam matrices describing the four-dimensional phase-space at the waist and in the lenses, and R is the transfer matrix between the correctors, expressed in thin lens approximation. Computing the vertical beam size from (2), one obtains:

$$\begin{aligned}\sigma_{33}(K,S) = \sigma_{33}(0,0) + K^2\sigma_{44} + S^2\sigma_{22} \\ -2K\sigma_{34} - 2S\sigma_{32} + 2KS\sigma_{42}\end{aligned} \tag{3}$$

The correlation σ_{42} at the IP corresponds to a tilt of the beam shape (i.e. σ_{13}) at the final doublet. If this term is non-zero, the waist correctors K and S will not be orthogonal due to the mixed term in (3). Achieving a good coupling correction with the QK1-4 skew quadrupoles in the diagnostic section upstream of the final focus section should be enough to remove any significant σ_{42} at the IP, and no error within the final focus can generate it (as noted above). In practice, it can be checked by measuring the beam tilt on the screen at the entrance to the final doublet. It should not be tilted if the coupling correction with QK1-4 skew quadrupoles has worked properly. If a tilt is found, it must be corrected via an appropriate combination of QK1-4 adjustments. The K and S correctors can then be used orthogonally to cancel the residual σ_{34} and σ_{32} correlations at the IP.

A detrimental situation arises in case the Shintake monitor interference fringes are tilted with respect to the (x,y) coordinate system of the accelerator (as defined by the mid-plane axes of the magnets). The larger horizontal beam size at the IP will then feed in to the vertical beam size measurement. A relatively small tilt angle of typically

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$\theta \sim \sigma_y / \sigma_x = 10$ mrad in the present optical configuration with $\beta_{x,y} = 10$, 0.1 mm is enough to degrade the vertical beam size because of equation (1).

Besides it not being easy to know whether or not such a tilt is present, a further complication is that the corrections for the residual σ_{34} and σ_{32} correlations at the IP are then also no longer orthogonal. This can be seen introducing an additional coordinate rotation M in the calculation of (3).

$$M = \begin{pmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & \cos\theta & 0 & \sin\theta \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & -\sin\theta & 0 & \cos\theta \end{pmatrix} \quad (4)$$

Assuming a negligible σ_{42} residual correlation at the IP:

$$\sigma_{33}(K,S) = \sigma_{33}(0,0) + K^2\sigma_{44} + S^2\sigma_{22} - 2K\sigma_{34} - 2S\sigma_{32}$$
$$+\theta^2[\sigma_{11}(S=0) + S^2\sigma_{44} - 2S\sigma_{14}]$$
$$-2\theta[\sigma_{13} + K(\sigma_{14} - \sigma_{23}) - S(\sigma_{21} + \sigma_{43}) + SK(\sigma_{22} - \sigma_{44})] \quad (5)$$

Where, due to the mixed term in (5), the K and S correctors are no longer orthogonal.

SIMULATION OF WAIST CORRECTION IN PRESENCE OF IPBSM FRINGE TILT AND INPUT BEAM σ_{13}, σ_{24}

In order to check the obtained results without the simplifying assumptions in the analytic calculations presented above, the action of the different knobs in the optics of the full ATF2 beam line was simulated.

Waist Correction Multiknobs

Let's first describe the sextupole correction knobs. Two main aberrations which one must correct to bring the beam size down to the 100nm range are the two correlations between particle vertical positions and the vertical and horizontal angles. The former (latter) corresponds to a vertical waist offset (coupling effect). Correction is achieved combining horizontal (vertical) motions of several sextupoles, for example [6]:

X: 0 -0.6232 -1.0000 0.0216 0

Y: 0 0 0.0129 0 -0.0150

corresponding to the strengths of the ATF2 sextupoles SF6, SF5, SD4, SF1 and SD0, in arbitrary units.

Effect of a 30mrad Fringe Tilt on Waist Knobs

A finite tilt of the IPBSM fringes couples x and y beam sizes, generating the equivalent of σ_{13}. at the IP From Equation (5), K and S correctors are then also no longer fully orthogonal, due to the mixed term proportional to $\sigma_{x'}^2 - \sigma_{y'}^2$. The resulting shifts expected in the positions of the minima of the parabolas for different settings of the K and S correctors were studied in the simulation, to check the magnitude of such a possible loss in orthogonality.

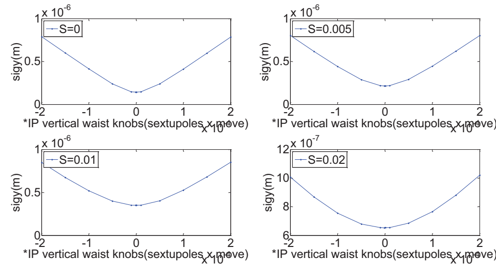

Figure 1: Vertical beam size change function of vertical waist knob K, for different settings of the coupling knob S.

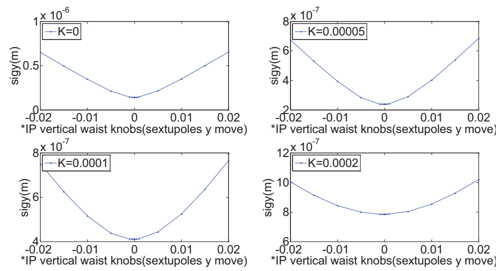

Figure 2: Vertical beam size change function of vertical waist knob S, for different settings of the coupling knob K.

The results of scanning the two knobs over reasonable ranges are shown in Figs. 1 and 2, using the present optical configuration with β_x* increased by a factor 2.5. Significant shifts in the positions of the minima are not observed. The fact that the angular divergences in this optics are rather close:

$$\sigma_{x'} = 0.000459 \quad \approx \quad \sigma_{y'} = 0.000404$$

helps to reduce the impact of the mixed term in (5). Computing directly from (5) for θ=30mrad and K=0.0001, the parabola minimum with respect to the coupling knob is near 410nm, and receives a ΔS=0.0003 shift. This just adds about 15nm to the 410nm beam size, which is tiny.

Effect of Input Correlation σ_{24} on Waist Knobs

Another case of non-orthogonality can be seen in Equation (5), via the mixed term in K and S which appears in case of a non-zero σ_{24} correlation. To check the corresponding magnitude, the QK1-4 skew quadrupole coupling knobs installed in the matching section upstream of the Final Focus were used to generate a σ_{24}=0.81 at the IP, keeping all other coupling terms at zero. The resulting phase space is shown in Fig. 3, where only the x′y′ is tilted, as expected. Similarly small effects were found in this case as in the previous one with tilted IPBSM fringes.

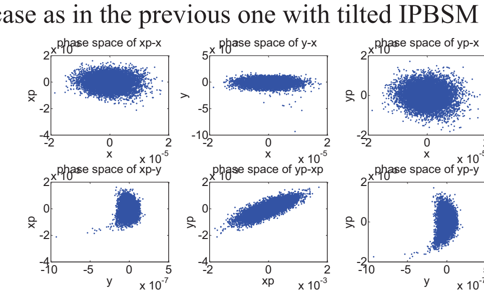

Figure 3: Phase space at IP with non zero σ_{24} correlation.

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INFLUENCE OF HORIZONTAL WAIST CORRECTION ON THE VERTICAL BEAM SIZE IN PRESENCE OF IPBSM FRINGE TILT AND INPUT BEAM σ_{13}

While the loss in orthogonality does not appear to be a problem quantitatively, the presence of an IPBSM fringe tilt or residual σ_{13} (due, respectively, to imperfect alignment of the laser paths and imperfect coupling measurements and correction using the OTR system and QK1-4 skew quadrupoles upstream of the final focus) remains an issue. This is because the horizontal beam size is much larger than the vertical one, resulting is possibly significant increases in minimum vertical beam size, even for modest tilt angles and / or residual σ_{13} correlation. A diagnostic is thus essential. Since the horizontal beam size then couples strongly into the vertical one (see Equation (1)), a way to find out is by varying it systematically using horizontal waist knobs (computed similarly to the vertical waist knobs by combining horizontal sextupole motions) and checking for a possible impact on the vertical beam size. If the horizontal waist knob is orthogonal to all other knobs, and if the scan is done in the linear domain, a variation should not be observed unless the fringes are tilted or σ_{13} is non zero. An upper bound can be determined experimentally to assess the possible impact of a residual IPBSM fringe tilt or σ_{13} correlation in the vertical spot size minimization.

The above procedure is illustrated in simulation below.

Choose a Suitable Input σ_{13}

The QK1-4 coupling knobs were used to generate σ_{13} at the IP while keeping $\sigma_{24}=\sigma_{14}=\sigma_{23}=0$. The impact on the vertical beam size is shown in Fig. 4.

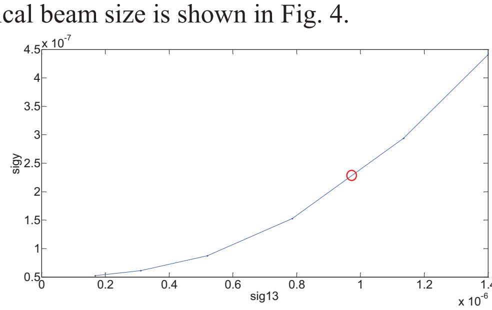

Figure 4: Vertical beam size as function of the input σ_{13}.

Impact of Non-zero σ_{13} on σ_y Dependence wrt σ_x

Choosing σ_{13}=0.98, the vertical beam size was computed as function of horizontal waist scan knob. As shown in Fig. 5, the vertical beam size changes a lot.

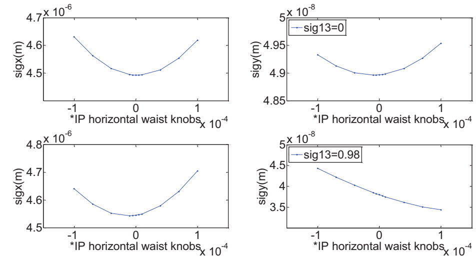

Figure 5: Vertical beam size function of horizontal waist knob for the case of σ_{13} = 0.98.

Impact of Fringe Tilt on σ_y Dependence wrt σ_x

A similar behaviour is shown in Fig. 6 for the case of σ_{13}=0 but IPBSM fringes rotated by 30mrad.

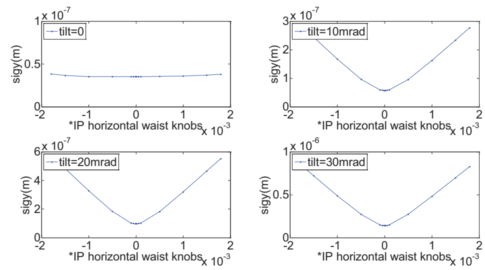

Figure 6: Vertical beam size function of horizontal waist knob for the case of IPBPSM fringes tilted by 30 mrad.

Summary and Prospects

Horizontal and vertical sextupole multiknob orthogonality is not significantly broken by the presence of a fringe tilt in the Shintake. However, a residual tilt remains a severe problem due the flatness of the beams. An upper bound on the fringe tilt can be determined simulating and measuring the vertical beam size as function of the horizontal waist knob.

The quasi orthogonality of these main waist and coupling corrections will also be checked in simulations with more complete sets of imperfections.

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