SIMULATION ON THE BREAKING OF α_x MULTIKNOB ORTHOGONALITY IN THE PRESENCE OF GRADIENT AND COUPLING ERRORS AND EXPERIMENTAL INVESTIGATION*

S. Bai, J. Gao, IHEP, Beijing, China
P. Bambade, LAL, Orsay, France
G. White, SLAC, USA

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 can break the orthogonality in the main σ_{34} and σ_{32} waist corrections required to reduce the vertical beam size at IP. Concerning the method of doing α_x scan and measuring the vertical beam size to diagnose the IPBSM fringe tilt or residual σ_{13}, one thing should be studied is to check what could break the orthogonality of the α_x knob other than σ_{13} and the IPBSM fringe tilt. In this paper, we report on the simulation study that check for the breaking of orthogonality of the α_x knob in the presence of gradient and coupling errors; to what extent this breaking of orthogonality can go; and also calculate the IPBSM fringe tilt angle from experiment results.

INTRODUCTION

The ATF2 project is the final focus system prototype for ILC and CLIC linear collider projects, with a purpose to reach 37 nm vertical beam size at the interaction point (IP) [1]. How to tune this small nanometer beam size in both simulation and experiment is a crucial point. The Shintake monitor takes an important role in the measurement of the nanometer scale beam size. 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. It is essential to diagnose if the IPBSM fringe rotation or a residual σ_{13} exist in experiment. The method is to do α_x scan and measure the vertical beam size [2]. However, in an imperfect system which is with errors, the orthogonality of the α_x multiknob can be broken. Even if there is not a residual σ_{13} or a non-zero IPBSM fringe tilt, when we measure the vertical beam size using the IP Shintake Monitor, it can still change because of the errors in the beam line. One has to check what could break the orthogonality of the α_x knob other than σ_{13} and the IPBSM [3] fringe tilt and to what extent the breaking happens.

In this paper, the breaking of orthogonality of the α_x knob in the presence of gradient errors is first analyzed and the magnitudes of gradient errors are increased until the orthogonality can be seen to break. The breaking of orthogonality of the α_x knob in the presence of roll errors is then reported. In the next step, it is considered introducing both the gradient and roll errors to all quads simultaneously. Finally, an experimental procedure is suggested and results from a first trial of an α_x waist scan are reported.

CHECK FOR THE BREAKING OF THE α_x KNOB ORTHOGONALITY IN THE PRESENCE OF GRADIENT ERRORS

The linear knobs for α_x (x waist), α_y (y waist), <y x'> (main coupling term from sextupole vertical misalignment or quadrupole tilts), <y dE/E> (vertical dispersion) are all designed to be orthogonal. One can expect that in a perfect system, they will indeed be very close to orthogonal, and also linear, at least in some range. However in an imperfect system, that is, in a system with errors, the transfer matrices between sextupoles will be slightly different from the ideal values, and this will break both the orthogonality and linearity between all these knobs, at least at some level.

The question to find out is how fast this breaking occurs, and whether or not orthogonality of some particular knobs can be broken sooner than others. In the case of the α_x knob, in addition to the general breaking of orthogonality due to errors in the transfer matrices, there is also this possibility which we have studied of fringe tilting or σ_{13}. For the method of finding out about the existence of σ_{13} or IPBSM fringe tilt (based on scanning α_x and measuring σ_y) to be efficient, the potential additional breaking of orthogonality due to errors in the transfer matrices must remain small.

The only way is to check quantitatively. First, let's see how σ_x and σ_y depend on the α_x knob. That is in the nominal BX2p5BY1 optics [4], with and without random gradient errors in the quadrupoles, no roll errors for the moment, do the α_x scan (using the combination of the horizontal sextupole movements) to change σ_x by a factor 2 or 3 and see how much the σ_y changes.

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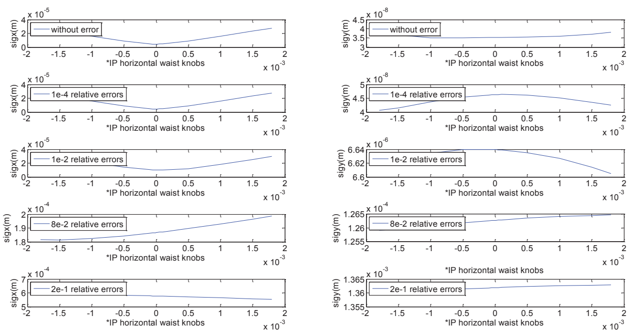

Figure 1: σ_x and σ_y dependence on the α_x knob with and without gradient errors.

In figure 1, it shows just the beam size dependence for a particular seed and increasing error magnitude. As can be seen, σ_y almost does not change at all without any errors, while with random gradient errors in the quadrupoles, the y beam size are strongly enlarged by the errors, since gradient errors will move the waists, and also modify the β functions at the waists. So, one has to first do α_x and α_y scans to find the minima for each beam size before we test the orthogonality of the α_x scan with respect to vertical beam size.

To do this, we can use the α_y and α_x scan and find the settings needed to minimise the y beam size. Starting from the corresponding α_y and α_x values. For different seeds the required α_x and α_y values will be different.

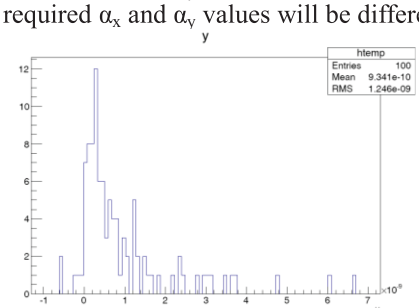

Figure 2: Orthogonality check of α_x knob when introducing gradient errors 1e-3.

The distribution in figure 2 shows the difference between the minimum vertical beam size at the IP obtained implementing after the α_x and α_y correction in a beam line with 1e-3 gradient errors and that obtained after changing σ_x by a factor 2 or 3. As can be seen, the RMS of this histogram is around 1nm. In this case, the orthogonality is not much broken.

Without necessarily keeping the multiknob correctors within their practical limits, we increase the gradient errors until the α_x knob becomes non-orthogonal. It happened when the gradient errors increased to 4e-3, and the typical difference of the two beam sizes becomes much larger to ~14nm.

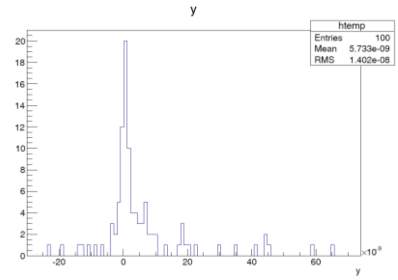

Figure 3: Orthogonality check of α_x knob when introducing gradient errors 4e-3.

CHECK FOR THE BREAKING OF THE α_x KNOB ORTHOGONALITY IN THE PRESENCE OF COUPLING ERRORS

There are also the coupling errors existing in the ATF2 beam line, which is from the quadrupoles roll errors. We also have to check for the breaking of the α_x knob orthogonality in the presence of the coupling errors. For each seed of rolls, before checking the α_x knob orthogonality, one should first check for the presence of a σ_{13} at the IP, if needed, use the appropriate QK1-4 skew quadrupole multiknob to minimise it.

While the σ_{23} is the dominant term from FFS errors, and also there are some vertical dispersion generated at IP. In this case, before checking for the α_x knob orthogonality, we have to first do σ_{23} correction and then correct the vertical dispersion. For the roll error magnitude 300μrad which is from the standard simulation error parameters in ATF2 beam line, the orthogonality of α_x knob is kept.

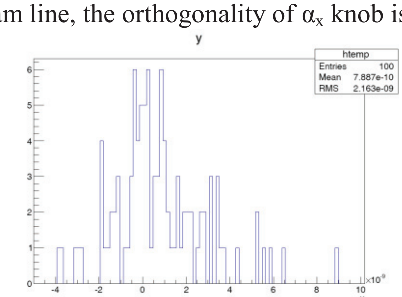

Figure 4: Orthogonality check of α_x knob when introducing roll errors 300 urad.

We find that the orthogonality breaks down when the roll errors are increased to 800 urad.

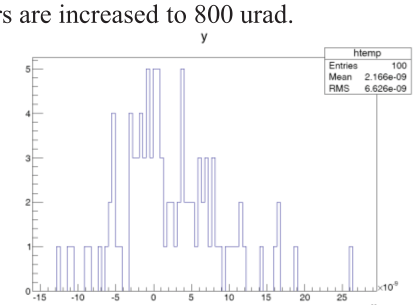

Figure 5: Orthogonality check of α_x knob when introducing roll errors 800 urad.

CHECK FOR THE BREAKING OF THE α_x KNOB ORTHOGONALITY IN THE PRESENCE OF GRADIENT AND COUPLING ERRORS

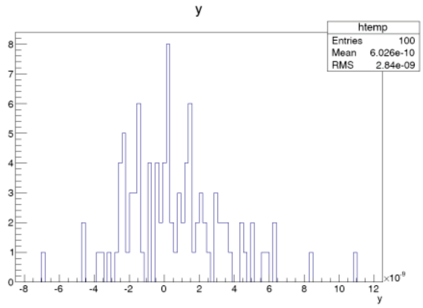

Figure 6: Orthogonality check of α_x knob when introducing both gradient and roll errors.

If gradient and roll errors are at the level of 1e-3 and 300 urad which are from the standard ATF2 error parameters, the impact of the α_x knob on vertical beam size (due to breaking of the orthogonality) is less than 3 nm as can be seen from figure 6.

Since 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 according to [5]:

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

one can compute the fringe tilt which corresponds to a 3 nm increase from the minimum beam size. It is $\theta \approx 3.3$mrad. Thus, the proposed method of scanning α_x and measuring σ_y can allow a fringe tilt larger than 3.3mrad to be diagnosed safely in experiment.

EXPERIMENTAL INVESTIGATION OF THE PRESENCE OF IPBSM FRINGE TILT

According to the simulation analysis above, the proposed experimental procedure is illustrated below:

1) Check for the presence of σ_{24} (essentially a tilt on the screen in front of the FD), if there is one, correct with appropriate skew quad multiknob.

2) Check for the presence of σ_{13} with the proposed method of scanning the α_x knob and measuring σ_y (if needed, a correction can be done with the appropriate skew quad multiknob, or one should consider realigning the laser beams, to reduce the fringe tilt…).

3) After (1) and (2), the α_y and σ_{23} should be orthogonal and the minimum beam size should not be dominated by σ_{13} or an IPBSM fringe tilt.

From the α_x scan in December 2012, we can see some obvious σ_y dependence, which may come from the IPBSM fringe tilt.

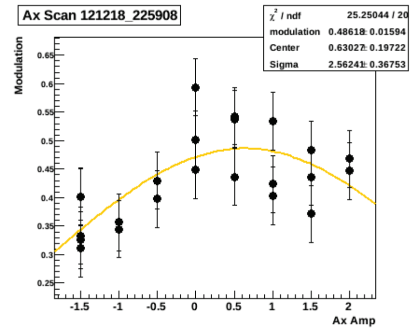

Figure 7: α_x scan in December 2012.

We can estimate the spot size from the measured modulation:

$$\sigma_y = \frac{d}{2\pi}\sqrt{2\ln\left(\frac{|\cos\theta|}{M}\right)} \tag{2}$$

For the Shintake monitor 174 degree mode, the laser with a crossing angle 174 degree, d=533nm.

$$\sigma_y = \frac{533nm}{2\pi}\sqrt{2\ln\left(\frac{|\cos 174^0|}{0.48618}\right)} = 101nm \tag{3}$$

The IPBSM fringe tilt θ can be extracted from the equation (1):

$$\theta = \arcsin\left(\frac{\sqrt{101nm^2 - 37nm^2}}{9um}\right) \approx 10mrad \tag{4}$$

The vertical beam size will be reduced to 65nm if the 10 mrad tilt would be removed or corrected.

Summary and Prospects

Reliability is checked in the presence of other imperfections and orthogonality is still kept for the standard simulation error parameters in ATF2 beam line. This method to diagnose the IPBSM fringe tilt, doing α_x scan and measuring the vertical beam size, can allow a fringe tilt larger than 3.3mrad to be diagnosed safely. An experimental method for diagnosis is proposed. The possible IPBSM fringe tilt implied by the observed σ_y dependence is about 10mrad, after analyzing the α_x scan already done in December 2012.

REFERENCES

[1] B.I. Grishanov, et al., ATF2 proposal, KEK-Report-2005-2, SLAC-R-771.

[2] S. Bai, et al., "Waist corrections at the interaction point of ATF2 in the presence of IPBSM fringe rotations and input beam σ_{13}, σ_{24}", IPAC2012 TUPPC023.

[3] T. Shintake, Nucl. Instr. Meth. A311, 453 (1992).

[4] S. Bai, et al., "Mitigating the effects of higher order multipole fields in the magnets of ATF2 at KEK", Chinese Physics C. 2012-08, Accelerator.

[5] P. Tenenbaum and T. Shintake, Annu. Rev. Nucl. Part. Sci. 1999. 49:125-62.

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