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# SIMULATION OF MULTIKNOBS CORRECTION AT ATF2*

Sha Bai, Jie Gao (IHEP Beijing, Beijing), Philip Bambade (LAL, Orsay; KEK, Ibaraki), Benoit Bolzon (LAPP, Annecy, 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. During initial commissioning, we started with larger than nominal β-functions at the IP, to reduce the effects from higher-order optical aberrations and thereby simplify the optical corrections needed. We report on simulation studies at two different IP locations developed based on waist scan, dispersion, coupling and β function multiknobs correction in the large β optics of ATF2, in the presence of two kinds of magnet inaccuracies (quadrupole gradient and roll errors) to generate all possible linear optics distortions at the IP. A vertical beam size which is very close to the nominal beam size is obtained based on the simulation study.

## INTRODUCTION

ATF2 [1,2] is the test facility with an ILC 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. During the initial commissioning, until March 2009, we used a large β optics with 20 times $\beta_x$ (0.08m) and 800 times $\beta_y$ (0.08m) at the IP and turned off all the five sextupoles in ATF2 line to reduce the high-order optical aberrations [3]. In April 2009, we started using 20 times $\beta_x$ (0.08m) and 100 times $\beta_y$ (0.01m) (see Table 1). For the normal optical correction methods which are planned for the designed optics ($\beta_y$=0.0001m) are based on sextupoles, while for the initial commissioning, we needed something different for rough adjustments in the large β optics mode. During the commissioning, BSM [4] is used to measure beam size below 3 microns, in correcting while for larger beam sizes, wire scanners [5] with 10 and 5 micron diameter are used.

Table 1: Beam Parameters with Nominal and Large Β Optics

| | Large β optics | | Nominal β optics | |
|---|---|---|---|---|
| | Nominal IP | Wire scanner | Nominal IP | Wire scanner |
| $\beta_x$(cm) | 8.0 | 9.90 | 0.4 | 0.495 |
| $\beta_y$(cm) | 1.0 | 1.84 | 0.01 | 0.0184 |
| $\sigma_x$(μm) | 12.7 | 14.1 | 2.80 | 3.15 |
| $\sigma_y$(μm) | 0.343 | 0.466 | 0.0343 | 0.0466 |
| QD0 current(A) | 130.34 | 105.24 | 130.34 | 105.24 |
| QF1 current(A) | 70.84 | 66.87 | 70.84 | 66.87 |

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## MULTIKNOBS CORRECTION ANALYSIS

Since the beam line is not perfect, but with every kinds of strength errors of the magnets and also alignments, rotation errors, etc… Thus, when the beam went through the beam line with these imperfect magnets, particle orbits will be different from the ideal ones, in result that a larger than nominal beam size was got at the IP, which is beyond our expectation. In order to train correcting those imperfections or errors of the beam line, we choose 1mrad rotation errors and 1% strength errors at all quadruples in ATF2 line to see obvious effect and simulated the scanning of the minimum vertical beam size using the coupling and dispersion corrections with skew quadrupoles, the α waist scan knobs with final doublet and the $\beta_y$ knob with QM12.

### *Simulation Studies on Waist Scan Multiknob at Post-IP (IP+40cm)*

Simulations using the large β optics with $\beta_x$ = 0.08 m and $\beta_y$ = 0.01 m were done to test adjusting the beam waists at the IP in the presence of errors independently in horizontal and vertical planes. QD0 and QF1 strengths were found fitting with the MAD program to get:

1) $\alpha_x$= 0.1,$\alpha_y$=0.0 $\delta_{QD0/QD0}$ = -8.99e-4, $\delta_{QF1/QF1}$ = -5.37e-4
2) $\alpha_x$= 0.0,$\alpha_y$=0.1 $\delta_{QD0/QD0}$ = -7.72e-3, $\delta_{QF1/QF1}$ = -1.36e-3

For waist errors of reasonable magnitudes, adjustments can be computed efficiently scaling these coefficients linearly. A first application study was done with random relative field errors in all ATF2 quadrupoles, with RMS of 0.01. Fig. 1 and 2 show the effect of correcting 100 seeds using the defined $\alpha_{x,y}$ multiknobs. The red and blue histograms show the beam sizes before and after scans to find the minimum values. Residual horizontal dispersion is generated by the above procedure for quadrupole errors in the non-dispersive parts of ATF2. The corresponding contribution to the horizontal beam size was however found small enough to be neglected for this set of errors, so the waist scan on the horizontal plane seems perfect. While for the vertical plane, the correction is not so good due to a large tail in the blue histogram, that's because the β function change at IP for this set of errors, so a more complete simulation study on multiknobs correction was needed and is described in the following section.

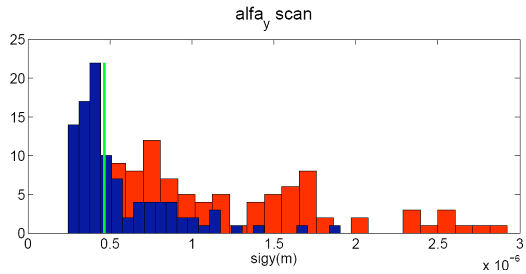


Figure 1: $\alpha_y$ multiknob orthogonal waist scan with large β optics at IP

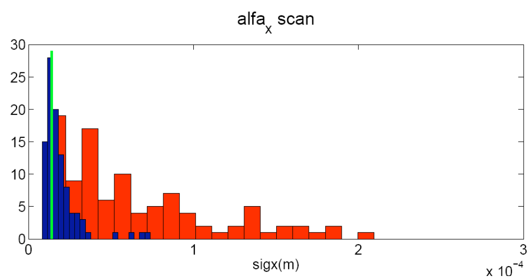


Figure 2: $\alpha_x$ multiknob orthogonal waist scan with large β optics at IP

## *Dispersion Correction Multiknob at Post-IP.*

Dispersion correction use the QS1X/QS2X sum knob (QS1X+QS2X) for which QS1 and QS2 have the same currents. The phase advance between QS1 and QS2 is close to π, designed not to introduce significant coupling with sum knob (QS1X+QS2X).

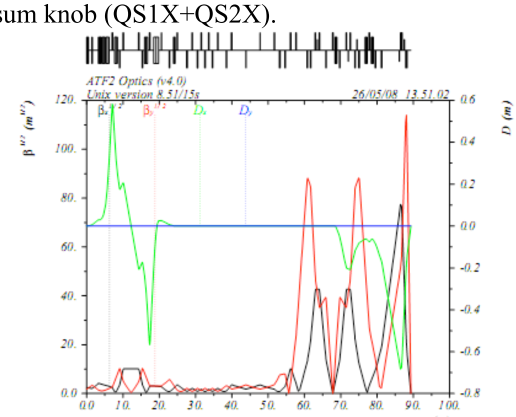


Figure 3: Twiss parameter of the ATF2 line

To check the residual coupling effects from the sum knob, the strength of QS2 was varied around the one of QS1 (fixed) to find the minimal emittance, and the result shows that minimal emittance exists at 13.4pm with quasi sum knob (QS1+70%QS2) [6]. However after check to compare the minimum vertical beam size corrected with quasi knob (KLQS2X=70%KLQS1X) and using the original definition (KLQS1X=KLQS2X), there is almost no difference in the minimum vertical beam size which can be obtained.

## *Coupling Correction Multiknobs at Post-IP*

Since the dispersion correction designed not to introduce coupling but not so perfect and will introduce a little coupling, meanwhile because of the roll errors of the quadrupoles, a coupling correction multiknob with skew quadrupoles QK1, QK2, QK3, QK4 [6] is introduced in non-dispersion region so as to have no influence on the dispersion correction. We choose first <xy> knob and then <x'y> knob to correct coupling to minimize the vertical beam size at Post IP wire scanner.

Table 2: Coupling Correction Multiknobs with QK1~4

| Knob (Normalized) | QK1X | QK2X | QK3X | QK4X |
|---|---|---|---|---|
| <xy> | 1 | -0.4667 | -0.5500 | -0.8722 |
| <xy'> | -0.8722 | -0.5500 | 0.4667 | -1 |
| <x'y> | 0.5500 | 0.8722 | 1 | -0.4667 |
| <x'y'> | -0.4667 | 1 | -0.8722 | -0.5500 |

Table 3: Coupling Correction Multiknobs Orthogonal

| Correlations | 1st knob | 2nd knob | 3rd knob | 4th knob |
|---|---|---|---|---|
| <xy> | **0.83** | -0.12 | 0.00 | 0.00 |
| <xy'> | 0.12 | **0.83** | -0.00 | 0.00 |
| <x'y> | 0.00 | -0.00 | **0.83** | -0.12 |
| <x'y'> | 0.00 | -0.01 | 0.12 | **0.83** |

## *β function Correction Multiknob at Post-IP*

When introducing 1% strength errors, the matching quads may change the β function at Post-IP wire scanner. That's why to use matching quad to correct $\alpha_x$, $\beta_x$, $\alpha_y$ and $\beta_y$. Choose QM12 that has a good performance which will be to correct $\beta_y$ with only small changes to $\alpha_y$ instead of fitting all the matching quadrupoles QM12, QM13, QM14, QM15, QM16.

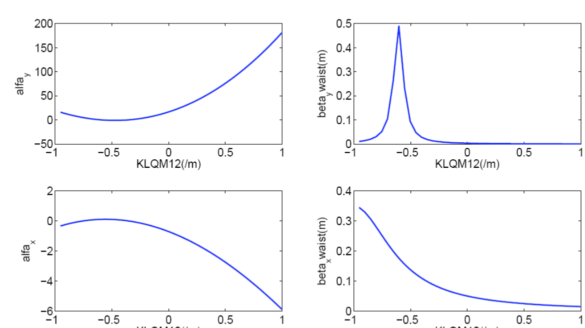


Figure 4: Strength change of QM12 influence on $\alpha_x$, $\beta_x$, $\alpha_y$ and $\beta_y$.

## SIMULATION ON MULTIKNOBS CORRECTION

Simulation to scan the minimum vertical beam size (tracking in MAD with energy spread 0.0008) using the coupling and dispersion corrections with skew quadrupoles, the α waist scan knobs with final doublet and the $\beta_y$ knob with QM12 were done at the Post-IP wire scanner. Scan in several steps in the strength limits of all the magnets in only a single iteration. Fig. 5 shows the results after the multiknobs correction. The blue histograms show the beam sizes after successive multiknobs scans to find the minimum values, while the green and blue line show the nominal beam size and average beam size after correction.

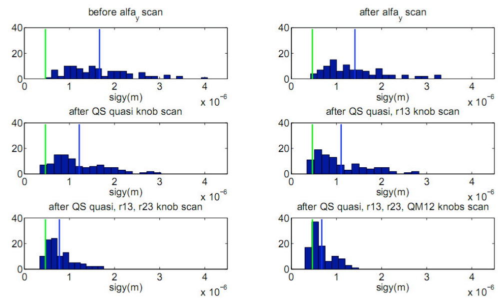


Figure 5: After multiknobs correction to find the minimum vertical beam size at Post-IP

The vertical beam size goes down to 6.7e-7m which is close to the nominal vertical beam size 4.67e-7m, but at around 1 micron, there are some badly corrected seeds, amounting to about 15% of the total. And this is caused by the rotation errors of final doublet. A simulation study of the multiknobs correction without the rotation errors on the final doublet is shown in Figure 6.

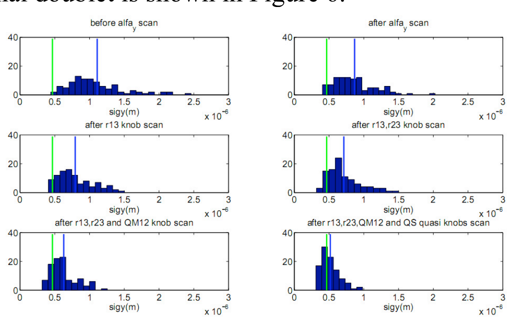


Figure 6: After multiknobs correction to find the minimum vertical beam size at Post-IP without rotation errors on QD0&QF1

When shifting back from the Post-IP to IP, the vertical beam size simulated is preserved that it makes tuning at the post-IP feasible to prepare the beam for the BSM.

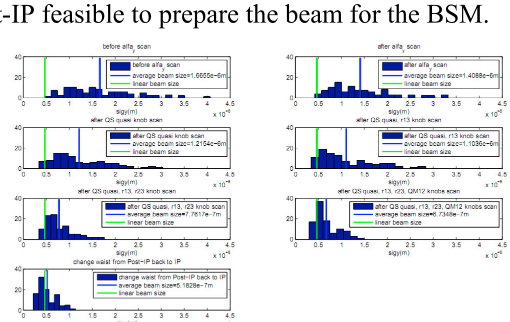

Figure 7: Results after shifting back to IP

As stated before, the simulation is scanned in all the magnet strength limits, but there is an exception. The QK2, QK3 which have the strength limit 5A before were found not big enough for the scan. The power supplies were changed to match the requirements defined by this study[7].

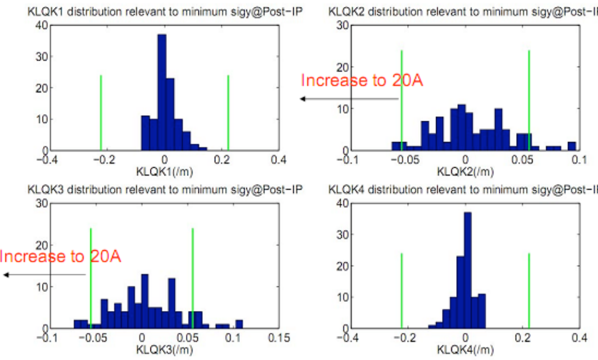


Figure 8: QK1~4X strength distribution relevant to minimum $\sigma_y$ at PIP

## *Summary and Prospects*

Large β optics mode has been chosen for the initial commissioning, and in this optics mode, a simulation of coupling, dispersion, waist scans and β function correction multiknobs was done in the presence of magnet strength and roll errors. A vertical beam size which is very close to the nominal beam size was obtained. In the ATF2 commissioning, a reasonable initial correction of the beam size could be realized by setting these knobs in a single iteration according to this procedure.

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