Simulation of beam size multiknobs correction at the Accelerator Test Facility 2 at KEK *

BAI Sha(白莎)[1] B. Bolzon[2] P. Bambade[3] GAO Jie(高杰)[1]

[1] Institute of High Energy Physics, CAS, Beijing 100049, China
[2] LAPP, CNRS/IN2P3, Annecy, France
[3] LAL, Univ Paris-Sud, CNRS/IN2P3, Orsay, France

Abstract: The ATF2 project is the final focus system prototype for the ILC and CLIC linear collider projects, with a purpose of reaching a 37 nm vertical beam size at the interaction point (IP). During the initial commissioning, we started with larger-than-nominal β-functions at the IP in order to reduce the effects from higher-order optical aberrations and thereby simplifying the optical corrections needed. We report on the 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 optic distortions at the IP. A vertical beam size which is very close to the nominal beam size is obtained based on the simulation study.

Key words: ATF2, beam size, multiknobs, simulation

PACS: 29.27.Eg, 29.20.Ej **DOI:** 10.1088/1674-1137/35/4/014

1 Introduction

The Accelerator Test Facility 2 (ATF2) [1, 2] is a test facility with an International Linear Collider (ILC) [3] type final focus line, to reach a final beam size of 37 nm at the optical focal point (hereafter referred to as IP, interaction point, by analogy to the linear collider collision point). How to tune this small nanometer beam size in both simulation and experiment is a crucial point. During the initial commissioning, from November 2008 to March 2009, we used large β optics with 20 times β_x (0.08 m) and 800 times β_y (0.08 m) at the IP and turned off all five sextupoles in the ATF2 line to reduce high-order optical aberrations [4]. In April 2009, we started using 20 times β_x (0.08 m) and 100 times β_y (0.01 m) (see Table 1). For the optical correction methods planned for the designed optics (β_y = 0.0001 m), sextupole multiknobs are used; while for the initial commissioning, we needed something different for rough adjustments in the large β optics mode. During the commissioning, a Shintake monitor based on colliding the beam with the interference pattern from lasers [5] is used to measure the beam size below 3 microns; while for larger beam sizes, wire scanners [6] with 10 and 5 micron diameters are used.

In this paper, the principle of waist scan, dispersion, coupling and β function multiknobs correction are first analyzed. Simulation studies at two different IP locations (IP and 40 centimetres downstream of IP, hereafter referred to as Post-IP, where the wire scanners are installed) developed based on multiknobs in the large β optics of ATF2 are then described. In the last section, the simulation results of the beam size

Table 1. Beam parameters with nominal and large β optics.

	large β optics		nominal β optics	
	nominal IP	wire scanner	nominal IP	wire scanner
β_x/cm	8.0	9.90	0.4	0.495
β_y/cm	1.0	1.84	0.01	0.0184
σ_x/μm	12.7	14.1	2.80	3.15
σ_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

Received 7 July 2010

* Supported by Agence Nationale de la Recherche of the French Ministry of Research (Programme Blanc, Project ATF2-IN2P3-KEK, contract ANR-06-BLAN-0027) and National Natural Science Foundation of China (10775154, 10525525)

correction and some further work needed for the practical implementation of these multiknobs during commissioning is outlined.

2 Multiknobs correction analysis

Since the beam line is not perfect, there are various kinds of magnet strength and alignment errors, rotation errors, etc. Thus, when the beam goes through the beam line with these imperfect magnets, the particle orbits will be different from the ideal ones, as a result, a larger-than-nominal beam size is obtained at the IP, which is beyond our expectation. In order to correct beam line imperfections or errors we chose 1mrad rotation errors and 1% strength errors at all quadruples in the ATF2 line to see the obvious effects and simulate the scanning of the minimum vertical beam size using the coupling and dispersion corrections with skew quadrupoles, the α waist scan knobs with a final doublet (QD0 and QF1 – a pair of quadrupoles which are at the end of the ATF2 beam line just before the IP) and the β_y knob with one matching quadrupole – QM12 which is located at the beginning of the final focus line.

2.1 Simulation studies of the waist scan multiknobs at post-IP

Simulations on the large β optics were done to test the adjustment of the beam waists at the Post-IP in the presence of independent errors in the horizontal and vertical planes. The final doublet is used to adjust the waist ($\alpha_{x,y}$) at the Post-IP. From fitting with the MAD (Methodical Accelerator Design) code [7], which is a program widely used to design and calculate the properties of particle accelerators, we get orthogonal waist scan multiknobs at the Post-IP:

1) $\alpha_x = 0.1$, $\alpha_y = 0.0$, $\delta_{\mathrm{QD0/QD0}} = -8.99\times10^{-4}$, $\delta_{\mathrm{QF1/QF1}} = -5.37\times10^{-4}$.

2) $\alpha_x = 0.0$, $\alpha_y = 0.1$, $\delta_{\mathrm{QD0/QD0}} = -7.72\times10^{-3}$, $\delta_{\mathrm{QF1/QF1}} = -1.36\times10^{-3}$.

For waist errors of reasonable magnitudes, adjustments can be computed by efficiently scaling these coefficients linearly. A first application study was done with random relative field errors in all ATF2 quadrupoles, with RMS errors of 1%. Fig. 1 shows the effect of correcting 100 seeds using the defined $\alpha_{x,y}$ multiknobs. The white and gray histograms show the beam sizes before and after scans to find the minimum values, while the black line shows the ideal beam size that we want to reach. Residual horizontal dispersion is generated by the above procedure for quadrupole errors in the non-dispersive parts of ATF2. However, the corresponding contribution to the horizontal beam size was found to be 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 gray histogram, that is because the β function changes at Post-IP for this set of errors. Thus, a more complete simulation study on multiknobs correction is needed and is described in the following section.

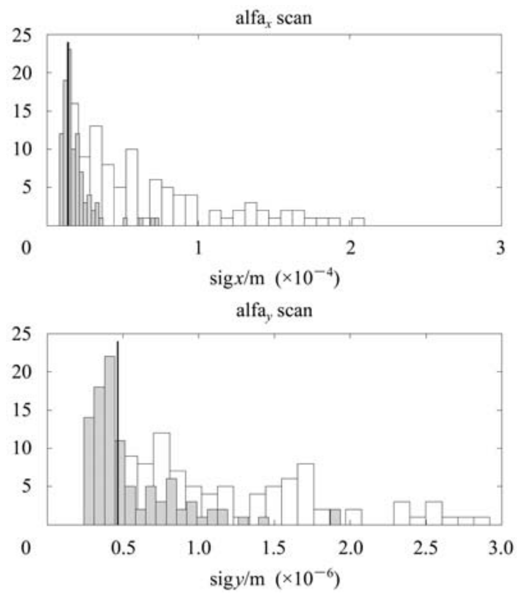

Fig. 1. $\alpha_{x,y}$ multiknob orthogonal waist scan with large β optics at Post-IP.

2.2 Dispersion correction multiknob at post-IP

QS1X and QS2X – two skew quadrupoles of the same kind in the ATF2 beam line are used for dispersion corrections, both on spatial and angular, since they introduce sufficiently spatial and angular dispersion. We choose sum knob (QS1X+QS2X) for which QS1X and QS2X have the same currents. That is because the phase advance between QS1X and QS2X is close to π, as one can see from the twiss parameters of the ATF2 line in Fig. 2, and they should not introduce significant coupling if they are in a sum knob since the effects are subtracted.

As dispersion may also increase effective emittance, to check this effect, the strength of QS2X varies around that of QS1X (fixed) to find the minimal emittance, and the result shows that minimal emittance exists at 13.4 pm with a quasi sum knob (QS1X+70%QS2X)[@]. However, after comparing the minimum vertical beam size corrected with a quasi sum knob (QS1X+70%QS2X) and the sum knob (QS1X+QS2X), there is almost no difference.

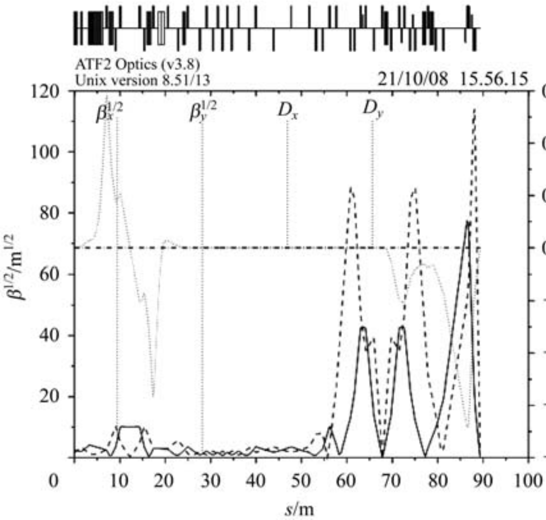

Fig. 2. Twiss parameter of the ATF2 line.

2.3 Coupling correction multiknobs at post-IP

As stated in Section 2.2, the dispersion correction knob should not introduce significant coupling, but it is in fact not so perfect and will introduce a little coupling. Meanwhile, because of the roll errors of the quadrupoles, a coupling correction multiknob[1)] with skew quadrupoles QK1X, QK2X, QK3X, QK4X is introduced in the non-dispersion region so as to have no influence on the dispersion correction. We first choose a $\langle xy\rangle$ knob and then a $\langle x'y\rangle$ knob to correct the coupling in order to minimize the vertical beam size at the Post IP, since the $\langle x'y\rangle$ is particularly dominant in the designed optics ($\beta_y = 0.0001$ m). From calculations to correct $\langle xy\rangle$, $\langle xy'\rangle$, $\langle x'y\rangle$ and $\langle x'y'\rangle$ independently, we can obtain the matricial normalized multiknobs efficiently, as shown in Table 2. The correlations obtained with the calculated multiknobs are shown in Table 3, from which one can see that the multiknobs are well orthogonal.

Table 2. Coupling correction multiknobs with QK1–4X.

Knob (normalized)	QK1X	QK2X	QK3X	QK4X
$\langle xy\rangle$ (1st knob)	1	−0.4667	−0.5500	−0.8722
$\langle xy'\rangle$ (2nd knob)	−0.8722	−0.5500	0.4667	−1
$\langle x'y\rangle$ (3rd knob)	0.5500	0.8722	1	−0.4667
$\langle x'y'\rangle$(4th knob)	−0.4667	1	−0.8722	−0.5500

Table 3. Coupling correction orthogonal multiknobs.

correlations	1st knob	2nd knob	3rd knob	4th knob
$\langle xy\rangle$	**0.83**	−0.12	0	0
$\langle xy'\rangle$	0.12	**0.83**	0	0
$\langle x'y\rangle$	0	0	**0.83**	−0.12
$\langle x'y'\rangle$	0	−0.01	0.12	**0.83**

2.4 β function correction multiknob at post-IP

The matching quadrupoles QM12, QM13, QM14, QM15 and QM16, which are in the beginning of the ATF2 final focus line, are used to correct α_x, β_x, α_y and β_y at IP or Post-IP. When introducing 1% strength errors to all the ATF2 quadrupoles, it may change the β function at Post-IP, as mentioned in

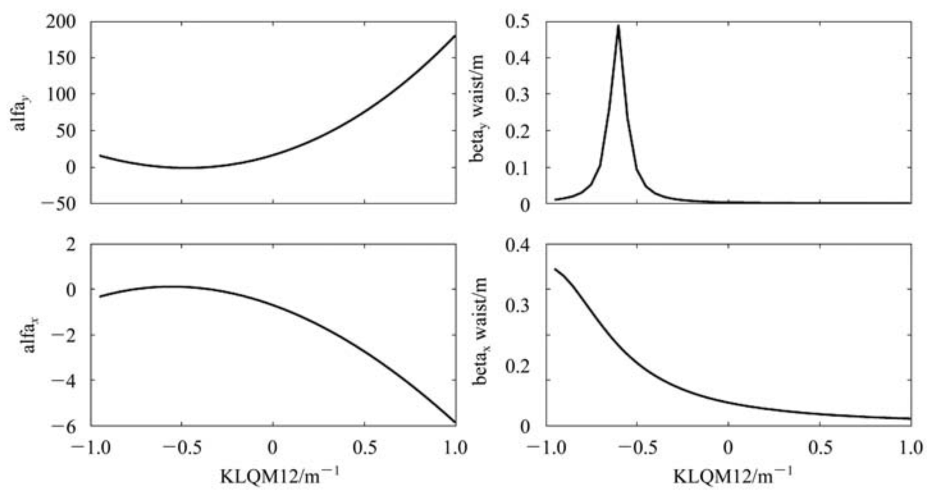

Fig. 3. Strength change of QM12 influence on α_x, β_x, α_y and β_y.

1) Bolzon B, Bambade P. Effect of skew quadrupoles corrections at post-IP wire-scanner, presentation in 8th ATF2 project meeting, 2009-06-10.

Section 2.1. Thus, we have to readjust the matching quadruples to correct α_x, β_x, α_y and β_y at Post-IP. In all five matching quadrupoles, QM12 has a good performance that will correct β_y with only small changes to α_y, which can be seen from Fig. 3. Instead of fitting all the matching quadrupoles QM12, QM13, QM14, QM15, QM16, we choose only QM12 to correct β_y to simplify the procedure.

3 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, α waist scan knobs with a final doublet and the β_y knob with QM12 were done at the Post-IP. We choose first to scan in only a single iteration step by step within the strength limits of all the magnets. Fig. 4 shows the results after the multiknobs correction. The histograms show the vertical beam size distribution after successive multiknobs scans to find the minimum values, while the left dashed and right solid lines show the ideal beam size and average beam size after correction, respectively.

The vertical beam size goes down to 6.7×10^{-7} m

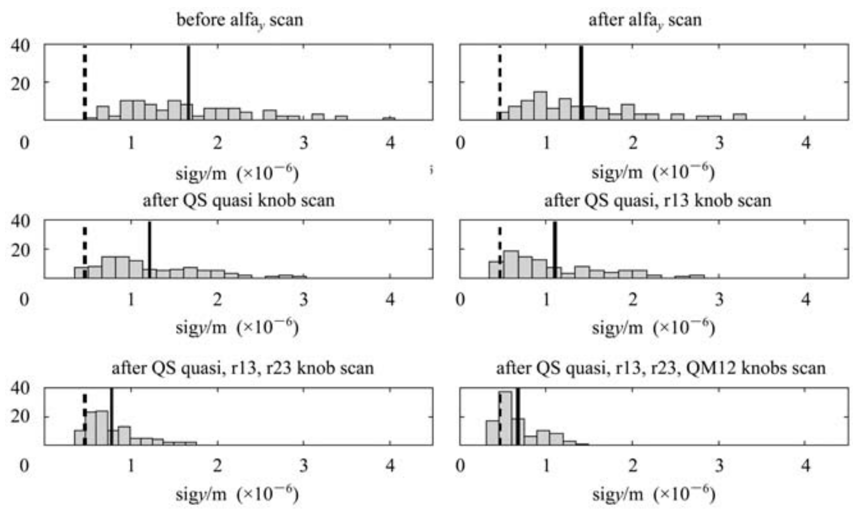

Fig. 4. After multiknobs correction to find the minimum vertical beam size at Post-IP.

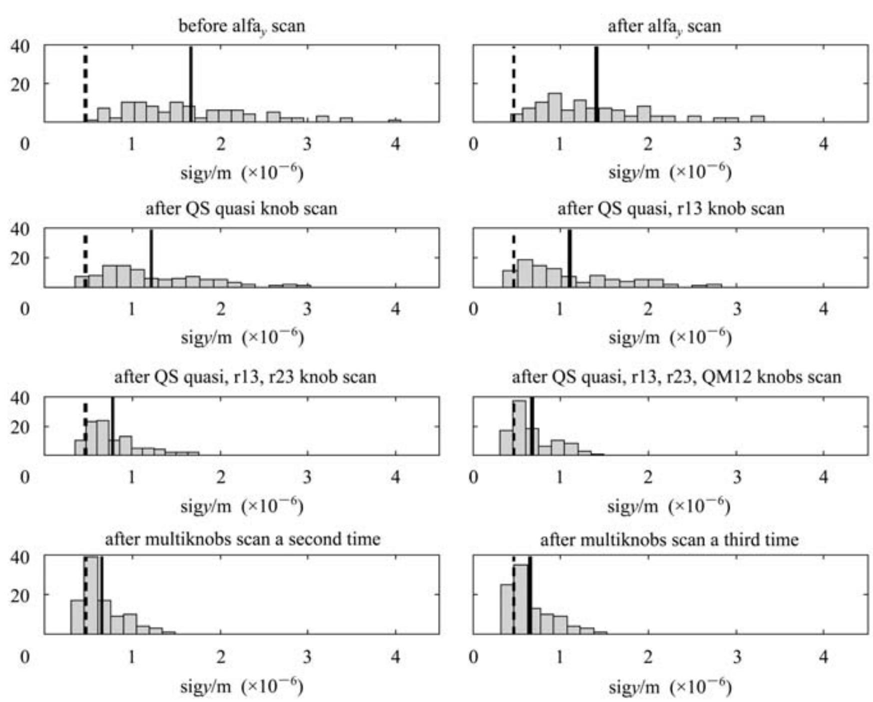

Fig. 5. After multiknobs scan correction another two times to find the minimum vertical beam size at Post-IP.

which is close to the ideal vertical beam size 4.67×10^{-7} m, but at around 1 micron, there are some badly corrected seeds, amounting to about 15% of the total. After analysis of the phase space of these abnormal seeds, obvious correlation can be seen and some coupling still remained. It means that another iteration of the multiknobs scan is needed. A simulation study with the multiknobs scan correction another two times is shown in Fig. 5, which indicates that after the two another iterations, the vertical beam size goes down to very close to the ideal beam size.

When shifting back from the Post-IP to the IP, the vertical beam size simulated is preserved, which can be seen from Fig. 6. Thus, since the Shintake monitor that is installed at the IP is still under preparation for nanometer measurement resolution, the simulation study of beam size multiknobs correction in this paper makes tuning at the Post-IP feasible to prepare the beam for the Shintake monitor.

As stated before, the simulation is scanned in all the magnet strength limits, but there is an exception. The QK2X, QK3X which have the strength limit 5 amperes before were found to be not large enough for the scan. So the power supplies of the skew quadrupoles QK1X, QK2X, QK3X, and QK4X were changed to 20 amperes at KEK to match the requirements[1)].

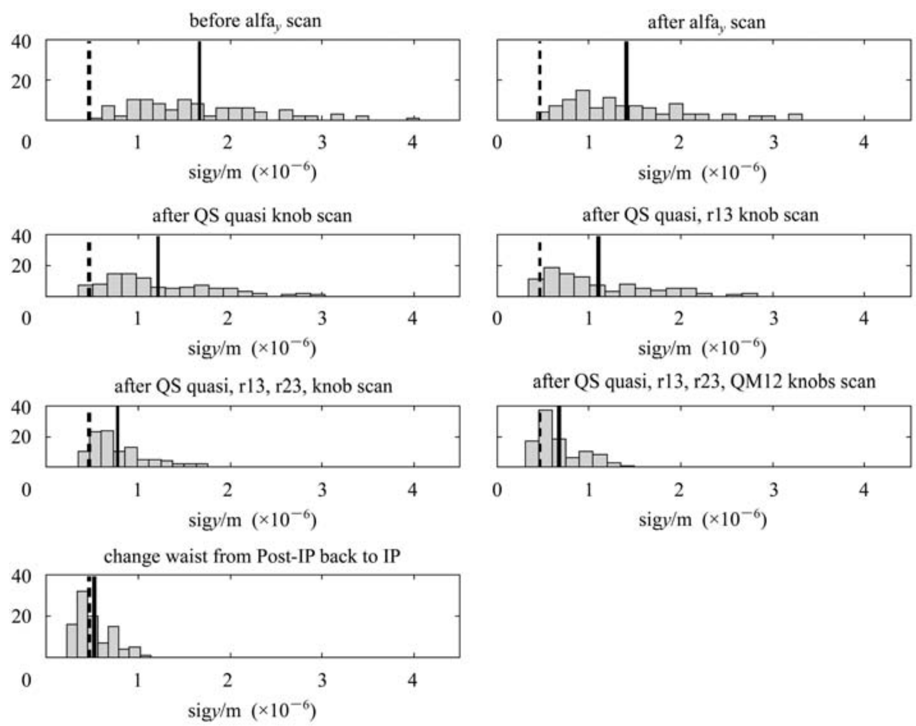

Fig. 6. Results after shifting back to IP.

4 Summary and prospects

A 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 ideal 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 and can be improved in several iterations.

References

1 Grishanov B I et al. 2005, Report No. SLAC-R-771
2 Bambade P et al. Phys. Rev. ST Accel. Beams, 2010, **13**: 042801
3 ILC RDR, ILC-Report-2007-001
4 BAI Sha et al. 2008, ATF-Report No. 08-05
5 Shintake T. Nucl. Instrum. Methods A, 1992, **311**: 453
6 Field C. 1994, Report No. SLAC-PUB-6717
7 The MAD Program. http://hansg.web.cern.ch/hansg/mad/mad8

1) Terunuma N. private communication.