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LINEAR COLLIDER TEST FACILITY: TWISS PARAMETER ANALYSIS AT THE IP/POST-IP LOCATION OF THE ATF2 BEAM LINE *

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Abstract

At the first stage of the ATF2 beam tuning, vertical beam size is usually bigger than 3µm at the IP. Beam waist measurements using wire scanners and a laser wire are usually performed to check the initial matching of the beam through to the IP. These measurements are described in this paper for the optics currently used (β_x=4cm and β_y=1mm). Software implemented in the control room to automate these measurements with integrated analysis is also described. Measurements showed that β functions and emittances were within errors of measurements when no rematching and coupling corrections were done. However, it was observed that the waist in the horizontal (X) and vertical (Y) plane was abnormally shifted and simulations were performed to try to understand these shifts. They also showed that multiknobs are needed in the current optics to correct simultaneously α_x, α_y and the horizontal dispersion (D_x). Such multiknobs were found and their linearity and orthogonality were successfully checked using MAD optics code. The software for these multiknobs was implemented in the control room and waist scan measurements using the α_y knob were successfully performed.

INTRODUCTION

ATF2 project proposes a test facility with a projected vertical beam size of 37nm. The optical configuration of ATF2 presently uses enlarged β functions at the IP (Interaction point) of 4cm and 1mm in X and Y respectively, which will be gradually reduced to their nominal values. For this optics, the nominal vertical beam size is of about 100nm.

At the first stage of the ATF2 beam line tuning, vertical beam size at the IP is usually large and wire scanners, located at the IP and Post-IP (PIP) (located 40cm downstream of the IP), as well as a laser wire located at the IP, are then used to measure horizontal and vertical beam sizes from around 3µm up to several hundred microns. During these last commissioning shifts, linear corrections were made at the extraction line and in the Final Focus System (FFS) so that vertical beam size could be reduced down to 3µm.

An interferometer located at the IP, the IPBSM "Shintake Monitor", is then used as the second stage of the ATF2 beam tuning to measure beam size from 3µm down to 37nm. At this level, multiknobs consisting of combinations of horizontal and vertical motions of the sextupoles used for chromaticity corrections become efficient correctors.

In order to check the initial matching of the beam through to the IP, the Twiss parameters need to be measured at the IP or PIP. Up to now, these parameters are measured by scanning QD0FF strength around its nominal value and measuring the corresponding beam size. This procedure is called beam waist measurements.

These measurements are described in this paper using wire scanners and the IP laser wire as the first stage of the beam tuning. The analysis of these measurements is shown using MAD optics code.

Software developed and implemented in the control room in order to perform an automation of these measurements is described here.

To finish, multiknobs enabling correcting simultaneously α_x, α_y and D_x at the IP are presented as well as the results of waist scan measurements performed with the α_y knob of these multiknobs.

BEAM WAIST MEASUREMENTS

Beam waist measurements consist of scanning the strength of QD0FF around its nominal value and measuring the corresponding beam size at the IP or PIP. From the response of the beam size which looks parabolic for small variations of QD0FF strength, it is possible to extract the Twiss parameters and the emittance thanks to the three coefficients of the fit of these measured parabolas [1].

Measurements presented in this paper were done at the IP and PIP with horizontal and vertical scanning tungsten wires of 10µm diameter and with the 10µm IP laser wire.

When performing these measurements in Y with 10µm tungsten wire scanners, the minimum of the parabola cannot be resolved since the vertical beam size is usually smaller than the wire scanner resolution (3µm). In this case, it is still possible to extract Twiss parameters by using two of the three coefficients of the parabola and assuming the emittance of the extraction line, which is usually measured just before doing measurements and corrections at the IP.

Measurements Done

Several beam waist measurements were done with the current optics since February 2010. In figure 1,

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measurements done the 22 April in X using the IP laser wire are shown. The nominal response calculated with MAD optics code is also plotted. During these measurements, the dispersion was also measured for each scan point. These are in fact very important measurements, in particularly in X, since the designed horizontal angular dispersion is not null at the IP (139mrad), which makes the spatial horizontal dispersion increase when varying QD0FF strength from its nominal value. The contribution of the measured dispersion to the beam size is then subtracted, which enables separating the dispersion error from other errors when analysing Twiss parameters. In figure 1, results are shown with and without subtraction.

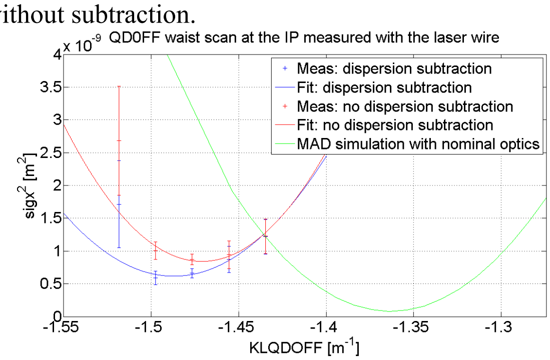

Figure 1: Beam waist measured the 22 April 2010 at the IP laser wire in X and simulation of design optics

Results of some beam waist measurements performed when no rematching and coupling correction at the IP/PIP were done are presented in table 1. For the measurements of the 24 February 2010 and of the 22 April 2010 at the PIP in X, dispersions were not measured for lack of time. However, the nominal spatial horizontal dispersion was subtracted to the beam size. For the other measurements, the dispersion was measured at each scan point and subtracted from the beam size.

Note that for the current optics, the nominal parameters are β_x=0.04m, β_y=0.001m, ε_x= 2.0nm and ε_y=0.012nm.

Table 1: Example of Twiss parameters and emittance measured since February 2010 at the IP and PIP before performing rematching and coupling correction

	24/02/2010 (IP:X; PIP:Y)	22/04/2010 (PIP)	22/04/2010 (IP LW)
α_x [1]	1.05±0.08	2.95±0.36	2.43±0.72
α_y [1]	60.44±3.59	73.54±8.39	/
β_x [m]	0.089±0.007	0.096±0.006	0.093±0.028
β_y [m]	1.5e-3±8.9e-5	1.0±0.1e-3	/
ε_{xext} [nm]	1.867	1.3	1.3
ε_{xip} [nm]	2.39±0.18	2.69±0.18	6.59±1.95
ε_{yext}[nm]	0.019	0.017	/
ΔKLQD0 in X (%)	3.70	8.11	10.77
ΔKLQD0 in Y (%)	-3.48	-2.46	/

The β mismatch was slightly bigger than a factor 2 in X for these measurements and well matched in Y when the dispersion contribution was subtracted. These are usually the results obtained since the beginning of the commissioning before performing rematching at the IP/PIP, which is within tolerable errors and can be thus easily rematched.

The horizontal emittance at the IP was little higher than the design except at the IPLW where strange values where found for the first time.

But the critical point observed during these waist scan measurements was about the longitudinal waist positions.

First, the QD0FF strengths needed to put the beam waists at the common desired location (at the IP or PIP) are very different in X and Y. The first conclusion is thus that multiknobs are needed in this current optics to correct simultaneously α_x and α_y. A proposition of multiknobs will be described later in this paper.

Then, the experimental waist obtained in both X and Y is much different from the nominal one, which can be also clearly seen in figure 1 (for X). The parameter α_x was measured to be between 1.0 and 2.9 and α_y at around 60-70. The strength of QD0FF was thus increased of up to 11% and decreased of up to 3.5% from their nominal value in order to be at the waist in X and Y respectively. These huge variations should be understood as a priority. Simulations were then performed and are described in the section “Waist shift analysis”.

Software Implementation in the Control Room

Software performing an automation of beam waist measurements has been developed recently since this task was done manually before.

This software has been implemented in the control room via the “Flight Simulator” interface [2], application allowing international collaborators to develop tuning software even remotely.

From a user interface, the wire scanner scan can be controlled as well as the QD0FF strength. The data of the wire scanner detector is then read and the beam size can be then extracted. This step already exists in the V-system but the new Flight Simulator based software integrates in addition a complete analysis of Twiss parameters and emittance. It is also planned to add the automation of the task which consists in finding the beam with the wire scanners before performing measurements. This can be done by searching automatically the beam thanks to BPM-based modelling which is currently very accurate. Another plan is to incorporate multiknobs in this software instead of performing the scan only with QD0FF. These multiknobs are presented later in this paper.

WAIST SHIFT ANALYSIS

Error on the Global Energy

Since α_x and α_y were observed to be of the same positive sign during all measurements, one hypothesis to explain these waist shifts is that the global energy of quadrupoles is higher than expected.

Simulations were then performed with MAD optics code where all the quadrupole strengths were changed by a common factor from -2% to 2% and where α_x and α_y

were fitted independently with QD0FF to be null. These fits are equivalent to the beam waist measurements done with QD0FF. The QD0FF strengths needed for these fits were then recorded versus the energy variation and compared to the measured ones (see figure 2).

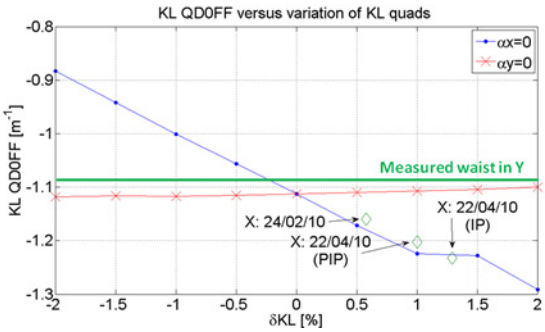

Figure 2: Hypothesis test of an error on global energy to explain waist shifts measured in X and Y

Figure 2 clearly shows that the waist shifts measured in X can be explained by an energy higher of 0.5-1.3% compared to what was expected. This error on the trusted energy is reasonable. However, the simulated variations of QD0FF strength needed to fit the waist in Y when the energy changes are much lower than for X, and the waist shifts measured in Y can be explained by an energy higher of around 8%. Since the change of energy is really different to explain measurements in X and Y, waist shifts cannot be only explained by an error in the energy.

Horizontal Dispersion Induced by Waist Shift

Measurements done the 22 April 2010 at the PIP showed a large horizontal dispersion of -18mm since α_x was of 2.95 and α_y of 73.54.

With MAD optics code, α_x and α_y were fitted to the measured values with QD0FF and QF1FF. At the PIP, horizontal dispersion was then of -19mm, which corresponds to measurements. Note that this dispersion did not change when changing α_y values.

The large measured dispersion can be only due to the waist shift in X, which confirm the importance of resolving this problem and the need of multiknobs.

MULTIKNOBS

It was shown previously that multiknobs are needed to correct simultaneously α_x and α_y at the IP or PIP. Moreover, D_x should be also corrected for errors generated in the FFS. The QD0FF, QF1FF and QF9BFF multiknobs were found to be the best ones and linear coefficients of these multiknobs were calculated with the MAD optics code. Tests of linearity and orthogonality were also performed with this code for the α_x, the α_y (see figure 3) and the D_x knobs. These knobs were found to be well linear and orthogonal within the highest errors of α_x, α_y and D_x usually seen in measurements.

These multiknobs have been then implemented in the Flight Simulator and the α_y knob was tested during the continuous run of the ATF2 beam tuning in May. Just before the α_y knob test, the vertical beam size was around 5μm and had to be lowered down to 3μm in order that the Shintake Monitor takes over the measurements. The α_y knob was successfully tested since D_x stays within mm range and the horizontal beam size did not increase at each scan point. This last one was of 15μm, which is close to the nominal value. The experimental waist was found at α_y=20 with a vertical beam size of 3.5μm (figure 4). The β function was extracted from the coefficients of the parabola and was found to be well matched.

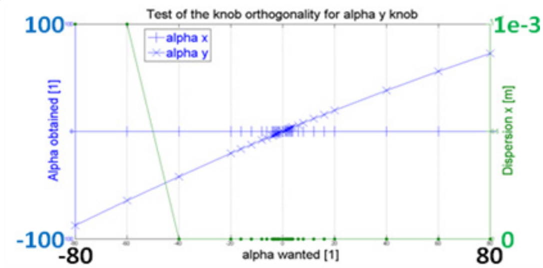

Figure 3: Linearity and orthogonality test (with MAD) of the α_y multiknob based on QD0FF, QF1FF and QF9BFF

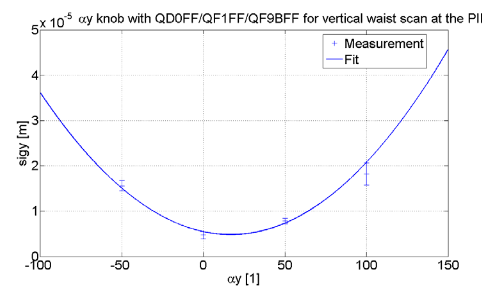

Figure 4: Waist scan measurements at the PIP with the α_y multiknob based on QD0FF, QF1FF and QF9BFF

CONCLUSION

Beam waist measurements done with QD0FF at the IP and PIP showed abnormal waist shifts in both X and Y which are not yet been understood. However, it was proven that they cannot be only due to an error on the energy of quadrupoles. They showed also that multiknobs are needed to correct α_x, α_y and D_x at the IP (or PIP) in the current optics (and future ones with lower β functions).

Such multiknobs were found and their orthogonality and linearity were successfully tested in simulation. Moreover, α_y knob was experimentally tested when performing beam waist measurements and results confirm that this knob is really orthogonal. The α_x and D_x knobs need also to be tested experimentally. Software performing the automation of beam waist measurements with such multiknobs is under development, in addition to the one which was recently implemented for QD0FF scan.

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