COUPLING CORRECTION IN ATF2 EXTRACTION LINE

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Abstract

The purpose of ATF2 is to deliver a beam with stable very small spotsizes as required for future linear colliders such as ILC or CLIC. To achieve that, precise controls of aberrations such as dispersion and coupling are necessary. Initially, coupling correction upstream of the final focus line of the ATF2 is performed with only two skew quadrupoles (SQ) in the extraction line (EXT). We thus first examine the feasability of coupling correction in the EXT with those SQ, considering several possible coupling error sources. The correction is first based on an algorithm of minimisation of vertical emittance with successive SQ scans, implemented in the Flight Simulator code. We will then investigate new methods to measure and extract the first order four coupling parameters of the beam matrix in order to perform a more direct and accurate coupling correction.

INTRODUCTION

The commissioning of ATF2, the final focus line of ATF installed at the exit of the ATF extraction line (EXT), started at the end of 2008. To deliver a stable beam of $\tilde{3}7$ nm vertical size at the interaction point, most of the aberrations such as coupling must be corrected at the upstream of the final focus line, in the EXT. Since 1998 several studies have underlined that the vertical emittance measured in the EXT is much larger (about a factor three) than the one measured in the damping ring (DR) [1]. Recent studies [2] suggested a large coupling of the beam in the EXT could be responsible for this. Several possible sources have been postulated, for example: shared DR/EXT quadrupoles where the beam passes with a large offset in the bores, potentially witnessing non-linear fields; non-linear fields in the extraction kickers and septum magnets; sextupolar fields in the EXT bend magnets. One of the quads in question was replaced for one with a larger aperture, the other sources are still under investigation. Coupling is corrected with skew quadrupoles installed in the dispersion free region of the EXT. We hope coupling can be minimised with careful control of the extracted orbit, other sources will still be present, such as roll of quadrupoles which will still need to be corrected however. We first briefly recap the basic formalism of beam optics and explain how to perform a complete measurement of the coupling components of a beam [3].
In the initial stages of the commissioning, two SQ only are available. We first estimated the potentiality of coupling correction with those two SQ only. Then we summarise the main results of the coupling correction performed until now during the commissioning of ATF2.

BASIC FORMALISM & BEAM MATRIX RECONSTRUCTION

The evolution of a beam matrix:

$$\sigma = \begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} & \sigma_{14} \\ \sigma_{12} & \sigma_{22} & \sigma_{23} & \sigma_{24} \\ \sigma_{13} & \sigma_{23} & \sigma_{33} & \sigma_{34} \\ \sigma_{14} & \sigma_{24} & \sigma_{34} & \sigma_{44} \end{pmatrix}$$

between two points, A and B, of an uncoupled transfer line is described by the following matrix equation:

$$\sigma^B = R\sigma^A R^T \ , \tag{1}$$

where

$$R = \begin{pmatrix} R_{11} & R_{12} & 0 & 0 \\ R_{21} & R_{22} & 0 & 0 \\ 0 & 0 & R_{33} & R_{34} \\ 0 & 0 & R_{43} & R_{44} \end{pmatrix} ,$$

is the uncoupled linear transfer matrix between the two points.

The elements $\sigma_{13} =< xy >$, $\sigma_{14} =< xy' >$, $\sigma_{23} =< x'y >$ and $\sigma_{24} =< x'y' >$ represent the coupling terms which should be minimised to provide optimal vertical projected emittance. Experimentally, only $\sigma_{11} =< xx >= \sigma_x^2$ and $\sigma_{33} =< yy >= \sigma_y^2$ are directly measurable from horizontal and vertical beam size measurements. On can also deduce $\sigma_{13} =< xy >$ measuring the beam along a u-axis, σ_u^2, tilted of an angle ϕ with respect to the x-axis, from the equation [4, 5]:

$$< xy >= \frac{\sigma_u^2}{2\cos\phi\sin\phi} - \frac{\sigma_x^2\cos\phi}{2\sin\phi} - \frac{\sigma_y^2\sin\phi}{2\cos\phi} \ . \tag{2}$$

From these measurements one can theoretically reconstruct the full beam matrix using both quad and skew quadrupole scans. The transfer matrices, expressed in the thin lens approximation, are respectively:

$$R_Q = \begin{pmatrix} 1 & 0 & 0 & 0 \\ k & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -k & 1 \end{pmatrix} ,$$

and

$$R_{SQ} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & k & 0 \\ 0 & 0 & 1 & 0 \\ k & 0 & 0 & 1 \end{pmatrix} .$$

The square of the measured beam sizes, σ_{11}^M, σ_{33}^M and σ_{13}^M, can be expressed as parabolic functions of the quadrupole and skew quadrupole strength, described by the 3 fit parameters in the equation: $\sigma^2 = A(k-B)^2+C$. Developing the equation 1, one obtains the following two systems respectively for the quadrupole and the skew quadrupole scan:

$$\begin{aligned}
\sigma_{11}^M =& (R_{11}+kR_{12})^2\sigma_{11}^Q + 2R_{12}(R_{11}+kR_{12})\sigma_{12}^Q \\
&+ R_{12}^2\sigma_{22}^Q\ , \\
\sigma_{33}^M =& (R_{33}+kR_{34})^2\sigma_{33}^Q + 2R_{34}(R_{33}+kR_{34})\sigma_{34}^Q \\
&+ R_{34}^2\sigma_{44}^Q\ , \\
\sigma_{13}^M =& (R_{11}+kR_{12})(R_{33}-kR_{34})\sigma_{13}^Q \\
&+ R_{12}(R_{33}-kR_{34})\sigma_{23}^Q + (R_{11}+kR_{12})R_{34}\sigma_{14}^Q \\
&+ R_{12}R_{34}\sigma_{24}^Q\ ,
\end{aligned}$$

and

$$\begin{aligned}
\sigma_{11}^M =& R_{11}^2\sigma_{11}^{SQ} + 2R_{11}R_{12}\sigma_{12}^{SQ} + R_{12}^2\sigma_{22}^{SQ} \\
&+ 2kR_{11}R_{12}\sigma_{13}^{SQ} + 2kR_{12}^2\sigma_{23}^{SQ} + k^2R_{12}^2\sigma_{33}^{SQ}\ , \\
\sigma_{33}^M =& R_{33}^2\sigma_{33}^{SQ} + 2R_{33}R_{34}\sigma_{34}^{SQ} + R_{34}^2\sigma_{44}^{SQ} \\
&+ 2kR_{33}R_{34}\sigma_{13}^{SQ} + 2kR_{34}^2\sigma_{14}^{SQ} + k^2R_{34}^2\sigma_{11}^{SQ}\ , \\
\sigma_{13}^M =& k[R_{11}R_{34}\sigma_{11}^{SQ} + R_{12}R_{34}(\sigma_{12}^{SQ}+\sigma_{34}^{SQ}) \\
&+ R_{12}R_{33}\sigma_{33}^{SQ}] + (k^2R_{12}R_{34} + R_{11}R_{33})\sigma_{13}^{SQ} \\
&+ R_{33}R_{12}\sigma_{23}^{SQ} + R_{11}R_{34}\sigma_{14}^{SQ} + R_{12}R_{34}\sigma_{24}^{SQ}\ .
\end{aligned}$$

This enables one to reconstruct respectively the following combinations of the ten beam matrix elements:

$$\begin{aligned}
&\sigma_{11}^M \rightarrow \sigma_{11}^Q, \quad \sigma_{12}^Q, \quad \sigma_{22}^Q\ , \\
&\sigma_{33}^M \rightarrow \sigma_{33}^Q, \quad \sigma_{34}^Q, \quad \sigma_{44}^Q\ , \\
&\sigma_{13}^M \rightarrow \sigma_{13}^Q, \quad [\sigma_{14}^Q - \sigma_{23}^Q], \\
&\qquad [R_{12}R_{33}\sigma_{23}^Q + R_{11}R_{34}\sigma_{14}^Q + R_{12}R_{34}\sigma_{24}^Q]\ ,
\end{aligned}$$

and

$$\begin{aligned}
&\sigma_{11}^M \rightarrow \sigma_{33}^{SQ},\ [R_{11}\sigma_{13}^{SQ} + R_{12}\sigma_{23}^{SQ}], \\
&\quad [R_{11}^2\sigma_{11}^{SQ} + 2R_{11}R_{12}\sigma_{12}^{SQ} + R_{12}^2\sigma_{22}^{SQ}]\ , \\
&\sigma_{33}^M \rightarrow \sigma_{11}^{SQ},\ [R_{33}\sigma_{13}^{SQ} + R_{34}\sigma_{14}^{SQ}], \\
&\quad [R_{33}^2\sigma_{33}^{SQ} + 2R_{33}R_{34}\sigma_{34}^{SQ} + R_{34}^2\sigma_{44}^{SQ}]\ , \\
&\sigma_{13}^M \rightarrow \sigma_{13}^{SQ}, \\
&\quad [R_{12}R_{34}(\sigma_{12}^{SQ}+\sigma_{34}^{SQ}) + R_{11}R_{34}\sigma_{11}^{SQ} + R_{12}R_{33}\sigma_{33}^{SQ}], \\
&\quad [R_{12}R_{33}\sigma_{23}^{SQ} + R_{11}R_{34}\sigma_{14}^{SQ} + R_{12}R_{34}\sigma_{24}^{SQ}]
\end{aligned}$$

Determining the ten elements of the beam matrix with this method requires a quadrupole and a skew quadrupole element at the same lattice location. Nevertheless, from a complete set of parabolic reconstructions with a SQ scan, one can deduce all the coupling elements, σ_{13}^{SQ}, σ_{13}^{SQ}, σ_{14}^{SQ} and σ_{24}^{SQ}, if perfect knowledge of the optics is assumed.

EVALUATION OF COUPLING CORRECTION WITH TWO SQ

The Flight Simulator (FS) [6] code is a Matlab developed interface between Lucretia, a single-pass electron beam tracking code, and the EPICS control system of ATF2. It can be used both as a simulation and as a command tool for ATF2. The FS code has been used to evaluate the feasability of correcting coupling with the two SQ, QK1X and QK4X, initially available for coupling correction in the EXT. Agreed standard errors coming from the damping ring, the magnet alignments in EXT, the magnetic fields, etc were used. Moreover, we considered as well some possible additional sources of coupling arising from shared magnets (QM7) between the DR and the EXT.

The coupling correction implemented in the FS is based on an algorithm of minimisation of vertical emittance with successive SQ scans. The vertical emittance, $\epsilon_y = \sqrt{\sigma_{33}\sigma_{44} - \sigma_{34}^2}$, can be reconstructed using beam size measurements at the five wirescanner positions available, and deducing the emittance using a least-squares method. The top plots of the figure 1 shows the comparison of the vertical emittance (mean value on left hand side and r.m.s on right hand side obtained for one hundred simulated measurements) before coupling correction, in pink, after coupling correction using two SQ, in orange, and using four SQ, in yellow, for different sets of errors. The first set correspond to EXT errors only and the second also includes coupling from QM7. The third set combines EXT errors and DR errors, the fourth includes also coupling from QM7, and the last one has double coupling from QM7. The bottom plots of Figure 1 shows the same as previously described for the vertical beam size. The efficiency of the coupling correction seems to be improved by a modest 15% to 20% using four SQ compared to two SQ. We thus concluded that in the initial stages of ATF2 commissioning the two SQ are sufficient.

MEASUREMENTS

Several measurements have been performed in the ATF2 EXT during ATF2 commissioning shifts to date showing a significantly coupled beam as experienced in ATF. The procedure used to correct it was the same as the one just described aboved for the simulation. To correct the coupling, a large strength was required for one of the two available SQ, while the other had no effect on the correction. The Figure 2 shows the emittance reconstruction as a function of QK1X strength. An emittance of $\simeq$ 25 pm was reached. This compares to a measured value in the DR of about 12pm. Other shifts show corrected vertical emittances ranging from this up to above 100pm for similar DR emittance values. Initial studies indicate the vertical beam size in the EXT region is very sensitive to the horizontal orbit here. Further studies are in progress to uncover the source of this.

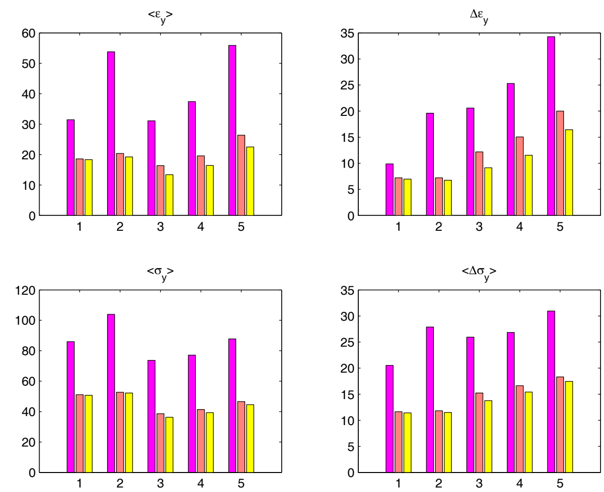

Figure 1: Vertical emittance (upper figures) and vertical beam size (lower figures) comparison with different sets of input errors.

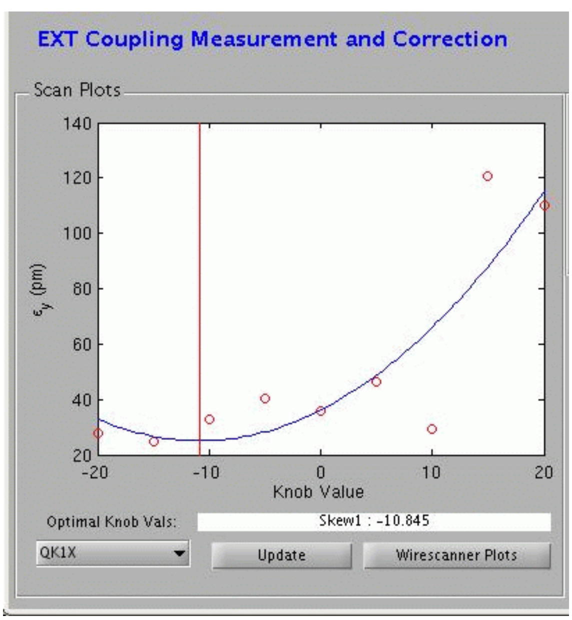

Figure 2: Vertical emittance reconstructed from multi-wire beam size measurements as a function of QK1X strength.

CONCLUSIONS

In the coming months, the two other skew quadrupoles will be installed in the EXT and enable a more complete coupling correction as designed. Experimental measurements of the coupling parameters is currently hindered by the accuracy and speed of the wirescanner system. It takes upwards of an entire 8-hour shift to perform the emittance minimisation described above with a maximum beam repetition rate of the ATF2 machine at 3Hz for this measurement. This program will greatly benefit from faster measurement instrumentation. It has not been possible to scan a skew quadrupole for the three beam sizes, σ_{11}, σ_{33} and σ_{13} within the available time so far. Moreover, the parabola reconstruction from the horizontal beam size, a hundred times larger than the vertical one, is only possible if the precision is enough to measure beam size variations. The precision of wirescanners used to measure the horizontal beam size is limited to $12\mu m$. One alternative solution currently under investigation involves supplementing the wirescanner system with a set of OTR's. This would greatly increase the speed of the scanning system. Research is under way to understand if a suitable target and optics arrangement can be achieved to measure the sub $10\mu m$ vertical beam size at the waist locations in the EXT diagnostics section.

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