Feedback Corrections for Ground Motion Effects at ATF2

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Abstract

Goals of ATF2 will be to provide beams with a few tens of nanometers and stability at the nanometer level. To achieve this, several corrections have to be applied as trajectory corrections and optics correction. Once the most critical effects are found, they must be canceled by trajectory correction and rematching of the optics quickly and efficiently. A method using SVD-determined knobs and how it can be implemented in ATF2 are here described.

INTRODUCTION

Beam position and optical mismatch, need to be corrected in the ATF2 line to satisfy the goals on size and position of the beam at the IP ($\beta_x = 4mm$ $\beta_y = 0.1mm$, $\gamma\epsilon_y = 3.10^{-6}$m.rad and $\gamma\epsilon_y = 3.10^{-8}$m.rad). Effects on the beam at the IP (Interaction Point) of initial misalignments of the magnets and of ground motion have been studied, and a general description of how to set up a correction is presented, illustrated by several correction algorithms which are proposed for ATF2. Magnet movers and variation of magnet strengths are used as correctors. Preliminary results and prospects will conclude this article.

DESCRIPTION OF EFFECTS ON THE BEAM AT THE IP

Displacements of the beam in quadrupoles and sextupoles produce mismatch of the trajectory, Twiss parameters, dispersion and high order aberrations. The effects depend on the type of the magnet, and increase with the displacement of the beam from the design trajectory. These displacements of the beam in a magnet can be due to a misalignment of the magnet itself or the propagation of a kick produced by a misalignment of an upstream magnet.

Steering

A quadrupole misalignment due to initial placement or ground motion kick the beam proportionally to the strength of the magnet and to the misalignment. A dipole strength error of a dipole can also kicks the beam. This kick is converted to displacement accordingly to the optical transfer matrix. The amplitude of this oscillation is proportional to the kick and to the focusing given by R_{12} and R_{34} coefficients. At ATF2 the y β functiona are very large just before the Final Doublet ($\simeq 10\,000$ m!), so it will be very affected by this effect.

Longitudinal Displacement of the Focal Point

An horizontal displacement of the beam in a sextupole focuses the beam proportionally to strength and displacement. The $< xx_p >$ correlation (α_x function), which should be 0 at IP, is then modified (displacement of the focal point) and the beam size increases quadratically. This horizontal displacement of the beam can be due to steering or quadrupoles displacements. Strength errors in quadrupoles produce waist displacement too.

$< x_p y >$ Coupling and Vertical Dispersion

A vertical displacement of the beam in a sextupole produces an y kick proportional to strength, displacement and the horizontal particle coordinate, resulting in a $< x_p y >$ correlation at the IP. If the sextupole is in a dispersive region (horizontal dispersion), this coupling will also produce vertical dispersion.
As in ATF2 the anomalous vertical dispersion from the ring is corrected with skew quadrupoles, an imperfect such correction can produce coupling too.

Other High Order Chromaticity Effect

To obtain a beam at the IP with a size close to that from linear optics (34 nm), the chromaticity from the focusing is corrected with sextupoles in dispersive regions and specific symmetry relations between the sextupoles are imposed to cancel the main other second-order aberrations while minimising the third-order ones. The above-mentioned errors can reduce the effectiveness of these cancellations.

METHOD OF CORRECTION

Obtain Response Matrix

The parameters of the accelerator which can be used to correct steering, coupling or chromaticity are :

- The strength of the magnets or correctors.
- The position of the magnets which are on movers.

To correct a displacement or a correlation of a beam at a given location, one needs to know which control variables are available and what change of this variable is needed to produce the opposite displacement or correlation. To obtain it one has to determine from the model of the line or experimentally what are the effects on correlations and displacement of an unitary change of each control variable. Once these effects for a unitary variation of a control variable are put in a vector, as it has been done for all the variables, the M matrix obtained will give (in a linear approximation) the correlations and the displacements of the beam (vector ΔE) for any combination of the chosen parameters (vector ΔP).

$$M \times \Delta P = \Delta E$$

Invert Response Matrix

SVD is a method that allows to "invert" a non-square matrix (see [2] [3] for more information). It is needed if the number of parameters used is different from the number of correlations and displacements to be corrected. If there are fewer correctors than variables to correct, SVD will give the correction that minimizes the RMS of the variables. If there are more correctors than variables to correct, SVD will give the correction that minimizes variations of the corrector parameters.

Apply Correction

The inverted response matrix M^{-1} gives the variation of the parameters ΔP needed to obtain a variation of the correlations and displacements of the beam ΔE.

$$M^{-1} \times \Delta E = \Delta P$$

So to correct given ΔE correlations and displacements of the beam, one will have to vary the parameters of the accelerators by $-\Delta P$. The n^{th} column of M^{-1} is called a knob for the n^{th} correlation or displacement of the beam : it gives the variations of the parameters to be applied to make an unitary variation solely of this n^{th} displacement or correlation and this one only.
Even if the beam position can be easily measured with BPMs (Beam Position Monitors), there is no instrument to measure correlations in the particle distribution of the beam. The only way to measure it is to vary this correlation with the previously computed knob and measure the beam size variation : when the size is at the minimum of the parabola the correlation is canceled.

EXAMPLE OF ATF2 TRAJECTORY AND OPTICS CORRECTION

In ATF2, 2 steering correction methods and several correlations of the beam at the IP ($< x_p x >$, $< y y_p >$, $< x_p y >$, $< yE >$, $< x_p^2 y >$ and $< x_p y E >$) were simulated with $100n$m BPM reading errors, $100n$m rms displacements for magnets and ground motion. Horizontal and vertical kickers were used for steering correction, movers of 4 sextupoles in the Final Focus (FF) and the strengths of the 2 quadrupoles of the Final Doublet (FD) were used to correct correlations in the phase space of the beam at the IP.

"1 to 1" Steering Correction

It was the first studied, and it is exactly the application of the described method. This correction should give in a single step the strength of all kicker magnets to set the trajectory at the reference one in all BPMs.
Model-based response matrix determination was realized filling the response matrix M with the R_{12} and R_{34} coefficients of the transfer matrix between each kicker and BPM. For horizontal steering correction :

$$M_{i,j}^{model} = \begin{cases} R_{12}(j^{th}\ cor \rightarrow i^{th}\ BPM) & \text{if BPM downstream} \\ 0 & \text{else} \end{cases}$$

Experimental determination was simulated adding ΔC_i to the strength of a corrector i, measure the variation of all n BPMs readings $\Delta B = [\Delta B_1 \ \cdots \ \Delta B_j \ \cdots \ \Delta B_n]$, reset the corrector strength to the initial value. Once been done for all correctors (it is better to average BPMs readings to increase the precision), the M matrix is fully determined :

$$M_{i,j}^{exp} = \frac{\Delta B_j}{\Delta C_i}$$

Once the response matrix M is known, the variation of correctors strength ΔC is given by :

$$\Delta C = -M^{-1} \times \Delta B$$

where ΔB is the difference between the BPM readings and the desired values.

"1 on all" Correction

To avoid instabilities from errors in the response matrix, BPM readings and corrector strength, only 1 horizontal and vertical corrector strength can be changed after each reading of the BPMs. The same response matrix as for "1 to 1" correction has to be determined, but each vector V corresponding to each corrector is inverted individually using SVD.The strength of the corrector C to minimize the spread of downstream BPMs readings around the desired trajectory is obtained multiplying the corresponding inverted vector V^{-1} by the opposite of the vector of the difference between BPM readings and the reference trajectory $-\Delta B$:

$$C = -V^{-1} \times \Delta B$$

The used correctors can be chosen sequentially or taking the theoretically most efficient. The most efficient is the one which will minimize ΔB after the correction, and so minimize $V \times C + \Delta B = V \times (-V^{-1} \times \Delta B) + \Delta B$.

Optic Correction

Once the trajectory has been corrected, some correlations remain mainly due to displacements of sextupoles against BPMs. Simulation of $100n$m magnet displacements show that the main relevant correlations of the beam are $< y_p y >$ (y focusing error), $< x_p y >$ (coupling), $< Ey >$ (y dispersion), $< x_p x_p y >$ (geometric aberration) and $< x_p E y >$ (chromo-geometric aberation). Computing a y focusing correction also bring a way to correct $< x_p x >$ (x focusing), so it will be corrected too. One can

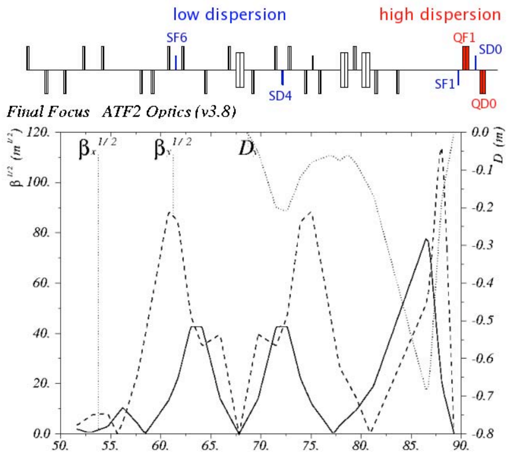

Figure 1: Twiss parameters of ATF2 FF section and magnet position used to correct optic.

see that coupling and the 2 main aberrations depend on x_p (not x), that's because this effect is due to the misaligned sextupoles in the FF, which are at $\frac{\pi}{2}$ phase advance from the IP.
It was found that changing the strength of FD quadrupoles changed efficiently x and y focusing with negligible other effects and moving vertically the 4 strongest FF sextupoles changed efficiently the 4 other correlations. Moving sextupoles in dispersive region changes all the correlations whereas in dispersion-free region, there is a negligible effect on y dispersion (see figure 1). Such a choice avoids a degenerated response matrix (with $\simeq 0$ determinant) and gives assurance that a correction can be applied with reasonable changes in positions and strengths of the magnets. Once the parameters are chosen, the response matrix between these parameters and the correlations can be simulated, the matrix inverted, and knobs extracted as described above. Then the correlations can be scanned and corrected one after one, experimentally modifying the parameters proportionally to the knob values and measuring the beam size at each step. A parabola has to be fitted as function of the knob-factor to find the minimum in size, and the correction is applied just setting the parameters according to this point. First results of simulating steering correction followed by optics correction are shown in figure 2 with initial magnet misalignment of $100n$m, BPM reading errors of $100n$m, using a ground motion model[4] fitted on measurements made at KEK by R.Sugahara et al. [5][6]. The correction was made after 5 size measurements for each of the 6 correlation knobs.

CONCLUSION AND PROSPECTS

The steering and optics corrections based on SVD are powerful and easy to implement. It is a very general way, so it can compute whatever correction from whatever parameters of the accelerators. One has to be careful and look for efficient and non-degenerate parameters. Simulation of the described algorithm shown that the beam can be corrected to approach the nominal beam size by sequential application of steering and 6 perpendicular optics knobs. For 20 seeds which were tried 95% ended up below $60n$m in vertical size). To achieve this, a total of 6×5 size measurements are needed, expected to take about 30×90s $= 45$min with the Shintake monitor [7]. Further optimisation can be done using more complex algorithms [8].
Some effects are not yet simulated, and could make some other correlations appear, requiring some other knobs , and more complex corrections. These effects are the beam jitter at the injection of the extraction line and roll of the magnets. About the steering correction, understanding if it has to be done as a feedback or just sometimes should be determined, and in the case of a feedback, the interference with other feedbacks should be studied, especially with the IP position feedback. In that case, one can think to include the IP position feedback in the steering correction feedback, using scaling in response matrix determination. The effect of limits in corrector strengths and mover ranges, and how to deal with that, should also be pursued.

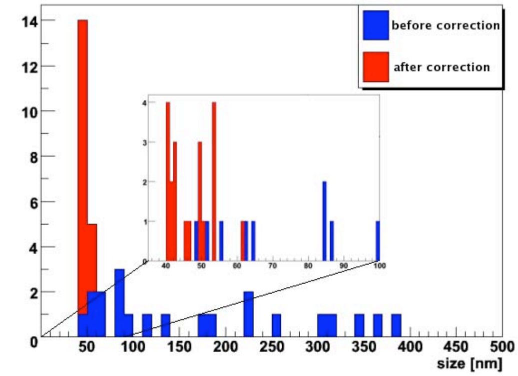

Figure 2: Beam size at ATF2 IP before and after "1 on all" steering and optic corrections.

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