ATF2 SPOT SIZE TUNING USING THE ROTATION MATRIX METHOD*

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Abstract

The Accelerator Test Facility (ATF2) at KEK aims to experimentally verify the local chromaticity correction scheme to achieve a vertical beam size of 37nm. The facility is a scaled down version of the final focus design proposed for the future linear colliders. In order to achieve this goal, high precision tuning methods are being developed. One of the methods proposed for ATF2 is a novel method known as the 'rotation matrix' method. Details of the development and testing of this method, including orthogonality optimisation and simulation methods, are presented.

INTRODUCTION

ATF2 is currently being commissioned at KEK, Japan [1]. The development and implementation of the software is underway to reach the goal of achieving vertical beam size of 37 nm at the interaction point (IP). One of the required tools is a set of 'tuning knob' algorithms that will autonomously optimise the parameters of a set of five sextupoles within the 'final focus' of ATF2 in order to minimise the IP beam size. The variable parameters of the sextupoles are the horizontal and vertical position, along with the roll angle and sextupole strength of each sextupole magnet. Traditional methods for the development of the sextupole-based tuning knobs have been developed [2], along with a novel approach. The novel sextupole-based tuning knob method presented in this paper is known as the 'rotation matrix' method. The theory, optimisation and testing of the rotation matrix method is presented.

ROTATION MATRIX METHOD

The rotation matrix method relies upon the use of a so called 'beam response matrix', R, which is conceptually visualised as rotating/compressing a disturbed beam, $beam_{err}$, into the ideal beam, $beam_0$. The response matrix is defined as

$$R = beam_0^{-1}.beam_{err} - I \qquad (1)$$

where I is the 6x6 identity matrix and $beam_0$ & $beam_{err}$ are matrices containing the 6-dimensional coordinates (x, x', y, y', l, δ) of the same initial set of particles with and without errors respectively. This results in a 6x6 R matrix. Response matrices are calculated when all 4 parameter changes for all 5 sextupoles are independently set to predetermined values when no other errors are present. This generates 20 unique response matrices, which are normalised with respect to one of the response matrices. The matrix to be used for the normalisation process was arbitrarily chosen to be the horizontal motion-based response matrix that contains the largest numerical value. Following the normalisation, Singular Value Decomposition (SVD) is used to invert the combined response matrix. This results in 36 tuning knobs, which contain the normalised values for all available sextupole parameters.

The knobs are applied 'one at a time' in a predetermined sequence. By repeating this process several times for all of the tuning knobs, the beam size at the IP can theoretically be reduced to the design value. A Nelder-Mead simplex minimiser is used in order to determine the strength of the knob applied [3]. The 'figure of merit' which is minimised is a combination of the horizontal and vertical beam sizes measured at the 'beam size monitor' [4], which is expected to have a resolution of 2nm. The relative weighting applied to the horizontal and vertical beam sizes in order to calculate the figure of merit is a parameter which must be optimised in order to increase the efficiency of the minimiser.

Due to the under-constrained nature of the rotation matrix method, the orthogonality of all 36 tuning knobs is very poor. As a result a sub-set of tuning knobs must be chosen and optimisation must be performed on the orthogonality of the chosen tuning knobs.

TUNING KNOB OPTIMISATION

The ATF2 extraction line and final focus were simulated using DIMAD. A range of magnet misalignments [5] were applied and the orbit was corrected. Each theoretically optimal tuning knob was analytically applied to the resultant $beam_{err}$ and the change in the horizontal and vertical beam sizes were calculated by fitting a Gaussian to the beam distribution. It was determined that 5 tuning knobs had a significant effect on the horizontal beam size and 5 tuning knobs had a significant effect on the vertical beam size. The 10 chosen tuning knobs were (xx, xy, x'x, x'y, yx, yy, y'x, y'y, δx, δy). These 10 tuning knobs had very poor orthogonality to each other initially. A systematic approach was taken to improve the orthogonality of these tuning knobs. The order of magnitude of the 4 magnet parameter values used during the initial response matrix generation phase were optimised by comparing all possible combinations within a predetermined range. The magnet parameter values were fine-tuned using a simplex minimiser. The number of eigenvalues retained during the SVD process was also optimised with respect to the orthog-

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onality of the tuning knobs. Finally the weightings applied to each of the 4 magnet parameters when applying the tuning knobs were optimised following the same routine used during the response matrix generation phase. After the optimisation was completed, 2 of the tuning knobs were considered fully orthogonal, with the rest of the tuning knobs showing a wide range of orthogonality levels.

Although the tuning knobs must be built using simulations, the tuning knobs can be generated with or without error contributions. As a result, the tuning knobs were built with and without initial beam jitter and static errors. Since Lucretia [6] is the 'code of choice' for ATF2 software development, a decision was made to switch to Lucretia. When initial beam jitter was simulated, the resultant tuning knobs were averaged over 10 bunches. It was found that after all 10 tuning knobs had been set that using the ideal lattice with the inclusion of initial beam jitter was the most efficient correction technique (see Table 1). This is due to the fact that the initial beam parameters have a large effect on the effects of the tuning knobs, which is cancelled by using a statistically large group of initial conditions. Machine time (Time) is a summation of the time taken for each set of averaged BPM readings and the maximum time taken for mover moves during each application of a tuning knob.

Table 1: A comparison of the effects of error sources (static and dynamic) on the efficiency of the tuning knob generation procedure

Static	Dynamic	Vertical Beam size (nm)
No	No	652.6
No	Yes	145.0
Yes	No	216.9
Yes	Yes	223.2

The figure of merit used by the minimiser in order to determine the strength of each tuning knob is given by

$$\sqrt{(\frac{\sigma_x}{\sigma_{x0}})^2 + \alpha(\frac{\sigma_y}{\sigma_{y0}})^2} \tag{2}$$

where σ_x and σ_y are the horizontal and vertical beam sizes respectively, σ_{x0} and σ_{y0} are the design horizontal and design vertical beam sizes respectively and α is the weighting factor. A range of weighting factors were tested in Lucretia using the same error seed (Fig. 1). A resolution of 2nm at the beam size readings was applied. A 10,000 particle beam was used during simulations, which results in beam size jitter of the order of 1nm. For all weighting factors, the first tuning knob decreases the beam size by 90% before the resolution of the beam size monitor and the beam size jitter begin to dominate the effects of the tuning knobs. In order to correct the horizontal beam size while never allowing it to dominate the figure of merit, a weighting factor of 500 was chosen for future simulations.

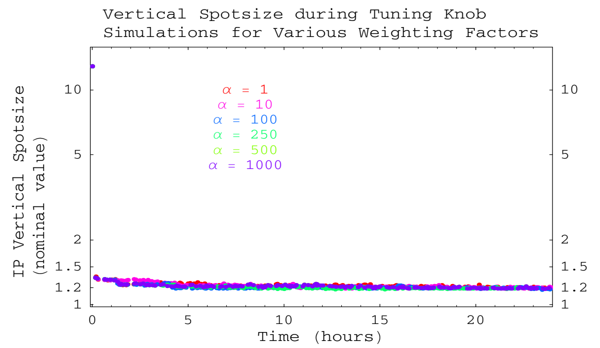

Figure 1: The vertical spotsize of ATF2 as a function of machine time during tuning knob simulations using a range of weighting factors

SIMULATION RESULTS

The tuning knobs were tested in the presence of individual errors on the final sextupole (SD0FF) and final quadrupole (QD0FF). No beam jitter was included and the beam size monitor was assumed to have perfect measuring ability.

A sextupole strength error of $\frac{\Delta B}{B} = 10^{-2}$ was applied to SD0FF. The orthogonally optimised tuning knobs were tested along with a range of other scenarios (Fig. 2). The tested scenarios were:

- Tuning knobs without orthogonality optimisation
- Tuning knobs generated with a reduced contribution from roll effects
- Tuning knobs generated with a stronger contribution from sextupole strength effects

The tuning knobs that had reduced orthogonality had larger starting tuning knob strengths than the orthogonally optimised tuning knobs, so each tuning knob took more machine time to optimise its strength. An increased contribution from sextupole strength effects quickly compensates for the original error and reaches the design vertical beam size in roughly 1 hour. The orthogonally optimum tuning knobs quickly reach a state where any application of the tuning knobs creates beam size growth effects.

A quadrupole strength error of $\frac{\Delta B}{B} = 10^{-3}$ was applied to QD0FF. The orthogonally optimised tuning knobs were tested along with the most successful scenario from the previous test and a set of unoptimised tuning knobs (Fig. 3). As with the previous test, an increased contribution from sextupole strength effects quickly compensated for the original error. The orthogonally optimum tuning knobs quickly reach a state where any application of the tuning knobs creates beam size growth effects, which indicates that the orthogonality of the optimised tuning knobs is not ideal. The unoptimised tuning knobs slowly

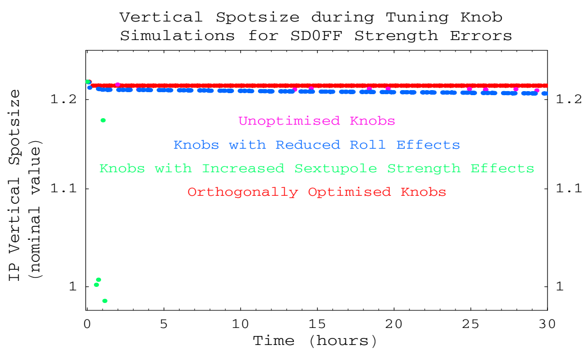

Figure 2: The vertical spotsize of ATF2 as a function of machine time during tuning knob simulations when a sextupole strength error is applied to SD0FF

correct for the original error due to coincidence rather than design.

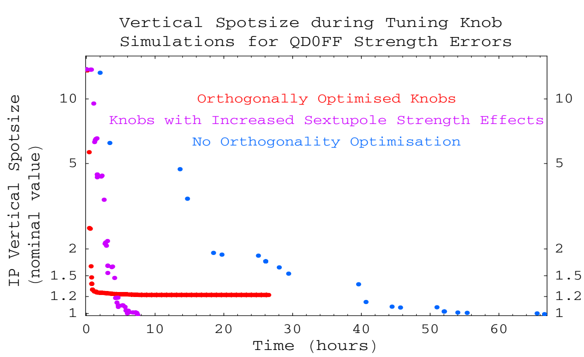

Figure 3: The vertical spotsize of ATF2 as a function of machine time during tuning knob simulations when a quadrupole strength error is applied to QD0FF

A quadrupole roll error of 1mrad was applied to QD0FF. The orthogonally optimised tuning knobs were tested along with the scenarios from the previous test (Fig. 4). An increased contribution from sextupole strength effects results in a decrease of the vertical beam size followed by an increase of the vertical beam size, this is due to a strong inverse coupling between the horizontal and vertical beam size. As the vertical beam size decreases, the horizontal beam size increases until the horizontal beam size dominates the figure of merit, at which point the process is reversed. The orthogonally optimum tuning knobs slowly decrease the vertical beam size, however after 24 hours of machine time the vertical beam size is still around 10 times larger than the design value. The unoptimised tuning knobs slowly decrease the beam size down to twice the nominal value within 3 days of machine time.

A full range of static and dynamic errors were applied to a simulation of ATF2. The same scenarios used in the previous tests were used along with a special case (Fig. 5). If

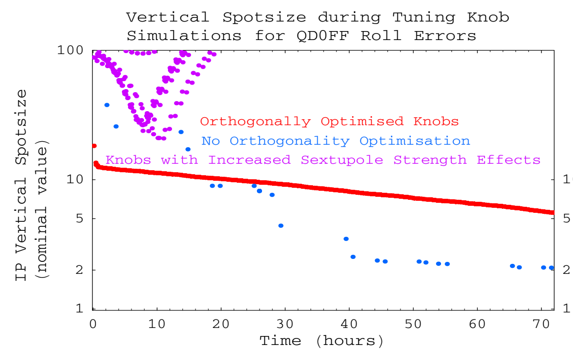

Figure 4: The vertical spotsize of ATF2 as a function of machine time during tuning knob simulations when a 1mrad roll error is applied to QD0FF

the beam size did not decrease by 2nm over a full set of 10 tuning knobs, the tuning knobs would be re-generated using the current simulated beamline, complete with errors. This should be tested to see if the machine has changed so much as to make the tuning knobs no longer applicable. The results indicate that the tuning knobs are always applicable and that the lack of change in the vertical beam size is due to the beam size monitor resolution and the beam size jitter due to dynamic errors. The unoptimised tuning knobs fail to converge quickly, as such they are not suitable for use on the real machine. Preliminary results from the use of tuning knobs with increased sextupole strength effects show no improvement over the orthogonally optimised tuning knobs.

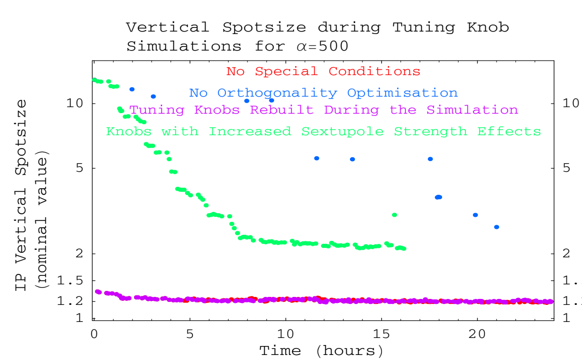

Figure 5: The vertical spotsize of ATF2 as a function of machine time during tuning knob simulations when a weighting factor of 500 is used

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