Corrector Ironing in the SLC Final Focus*

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Abstract

A method to minimize corrector excitations while maintaining a set of constraints on the orbit is described. This method, which is based on a singular value decomposition algorithm, was successfully applied in the final focus of the Stanford Linear Collider in order to remove "fighting correctors" and improve their tuning range.

I. INTRODUCTION

In beam lines with a large number of corrector magnets individual corrector excitations can acquire large values while the orbit remains bounded. In this case the effect of different correctors cancel. Having correctors at large values is operationally inconvenient, because it limits the range of correction. Here we describe an algorithm which minimizes the sum of squares of corrector excitations and, at the same time, maintains orbit constraints, such as position or angle at certain points in the beam line.

II. ALGORITHM

First we have to find out how each corrector affects each constraint. In linear beam lines the response of the orbit at one point to a corrector upstream is given by the transfer matrix elements R_{pq} between the corrector and the constraint point. In general the total effect of all correctors on the constraint is then

$$c_i = \sum_j R_{p(i),q(j)}\Theta_j = \sum_j A_{ij}\Theta_j \qquad (1)$$

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where $p(i) = 1, 3$ if we have a x/y-position constraint and $p(i) = 2, 4$ if we have a x/y-angle constraint. $q(j) = 2$ if corrector j is a x-corrector and $q(j) = 4$ if it is a y-corrector. Θ_j is the kick angle of corrector j. We will call the matrix A the *response matrix* and the vector c the *constraint vector*. Note that in the case where we have more correctors than constraints the matrix A has more columns than rows and we are dealing with an *under determined linear system.*

Assume now that we have a corrector configuration with corrector strengths $\bar{\Theta}_j$. The objective is to find new corrector strengths Θ_j such that the constraints are maintained and that $\sum_j \Theta_j^2$ is minimum. The first objective can be fulfilled by making Θ_j the solution of

$$\sum_j A_{ij}\bar{\Theta}_j = \sum_j A_{ij}\Theta_j \ . \qquad (2)$$

We require that the new corrector values Θ_j must produce the same constraint vector as the old corrector values $\bar{\Theta}_j$.

The second objective, namely to make $\sum_j \Theta_j^2$ minimum is automatically fulfilled by using a *Singular Value Decomposition* (SVD) Algorithm [1] to solve eq. 2. SVD finds a solution to eq. 2 and also explicitly constructs the null space of the under determined linear system. It then subtracts the projection of the solution onto the null space from the solution and thereby minimizes the norm of the solution [1], i.e. $\sum_j \Theta_j^2$.

Note that we can simply add an extra vector to the left hand side of eq. 2 to modify the orbit at one constraint point, e.g. to steer through the center of magnets with known misalignments.

III. APPLICATION

The algorithm described in the previous section is implemented in a computer code that reads the

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quadrupole and corrector values in the Final Focus of the Stanford Linear Collider (SLC). It then updates an offline model of the beam line and generates a table with the current corrector values and a few sample constraints. The user can then remove correctors he does not want to include in the ironing process and can also modify the constraints. This table is then used to set up the response matrix A and constraint vector c and subsequently performs the singular value decomposition using routines from ref. 1. Finally the new corrector values are printed, the old and new orbits are displayed and a file is generated that can be read by the SLC control system to linearly interpolate the corrector values from the old to the new configuration.

We have applied this algorithm successfully to the correctors near the interaction point (IP) which had acquired large values. Here we choose the constraint that the horizontal and vertical position and angle of the orbit at the IP and the position in two sextupoles are to remain fixed for a total of eight constraints. All ten included correctors were allowed to vary. The procedure brought the rms of the 10 included correctors down to 30 % of their initial value. Despite ing. Despite the rather large predicted orbit changes in the intermediate region beam position monitor readings downstream of the affected region showed very little changes. The newly found corrector configuration proved to be operationally more convenient, because the correctors' tuning range were increased considerably.

IV. Conclusion and Outlook

We have described an algorithm to minimize corrector strengths in beam lines which contain more correctors than orbit constraints. The method was implemented in a computer code and applied to correctors near the IP of the SLC. The rms of the involved correctors was successfully reduced to 30 % of their initial rms.

We need to note that the method relies on an accurate knowledge of the optics of the beam line as determined by the quadrupole lattice, because the trading off of corrector effects depends strongly on the transfer matrices between the correctors and the constraint points.

This method is directly applicable to circular accelerators. Either by constraining position and angles at one point the modification of the corrector configuration can be made transparent to the rest of the accelerator. In this way the corrector changes act similar to a local closed orbit bump. Alternatively, instead of using the transfer matrices R in eq. 1 one can use the closed orbit response coefficient matrix $C = R(1-S)^{-1}$ where S is the one turn transfer map starting at the corrector. In this case the bump is not closed but the constraints are still satisfied.

The described algorithm can easily be extended to incorporate other constraints such as fixed vertical position at the end of a synchrotron radiation (photon) beam line of length L. In this case the response matrix element A_{ij} between corrector j and the special constraint reads $R_{34} + L\,R_{44}$. The presented method was adapted for SPEAR and successfully used in the initial setup of SPEAR after a long shut down [2]. In general the response matrix element is the derivative of the constraint condition (the quantity to remain unaffected) with respect to the corrector strength. Following this prescription very general constraints can easily be included.

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References

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2. W. Corbett, et. al., Optimum Beam Steering of Photon Beam Lines in SPEAR, these proceedings.