CALCULATING IP TUNING KNOBS FOR THE PEP II HIGH ENERGY RING USING SINGULAR VALUE DECOMPOSITION, RESPONSE MATRICES AND AN ADAPTED MOORE PENROSE METHOD*

W. Wittmer†, SLAC, 2575 Sand Hill Road, Menlo Park, CA 94025, USA

Abstract

The PEP II lattices are unique in their detector solenoid field compensation scheme by utilizing a set of skew quadrupoles in the IR region and the adjacent arcs left and right of the IP. Additionally, the design orbit through this region is nonzero. This combined with the strong local coupling wave makes it very difficult to calculate IP tuning knobs which are orthogonal and closed. The usual approach results either in non-closure, not being orthogonal or the change in magnet strength being too big. To find a solution, the set of tuning quads had to be extended which resulted having more degrees of freedom than constraints. To find the optimal set of quadrupoles which creates a linear, orthogonal and closed knob and simultaneously minimizing the changes in magnet strength, the method using Singular Value Decomposition, Response Matrices and an Adapted Moore Penrose method had to be extended. The results of these simulations are discussed below and the results of first implementation in the machine are shown.

INTRODUCTION

Optimizing the interaction point(s) (IP) of colliders require tools that allow changes to lattice parameters (e.g. beta-, dispersion-functions) in this point. One approach is to create a set of tuning knobs. By design, these have to change one parameter only in one plane and introduce changes to all the lattice functions must be local. These are compiled of a set of interaction region (IR) magnets. In order to be applicable to practical tuning in the real machine, the magnet changes induced have to be free scalable and in addition, this scaling has to be linear. It is theoretically possible to calculate nonlinear scaled knobs, but in order to apply them successfully, in the real machine, the absolute value of the parameter to be changed has to be known. This information is in most cases not available.

Special efforts during the design phase of the lattice guarantee that these tuning knobs can be generated. Many lattices undergo several upgrades to increase the performance of the collider. During these upgrades, the induced changes result in reduced functionality or often the knobs seize to work. However, these knobs are essential for tuning so that new knobs can be generated. It has been demonstrated at RHIC [1] by applying Singular Value Decomposition to Response Matrix Analysis that a new set of tuning knobs can be calculated. The advantage of this method is that it is not bound to a specific code. In the case of RHIC the response matrix was extracted out of the model which is used to control the accelerator and was more precise than the MAD model. In this case, the number of constraints was equal to the number of available knob magnets.

To apply this method to the high and low energy ring (HER, LER) in PEP II the method described in [2] had to be extended. In this case, the number of available degrees of freedom is far larger than the number of constraints. The central task to calculate a set of tuning knobs was to identify the optimal set of knob magnets to be used.

LOCAL CORRECTION OF IP PARAMETERS

To locally correct any IP parameter there are at least two magnets necessary, one on each side of the IP. The first magnet creates a perturbation on the incoming beam resulting in the wanted change at the IP and the second correcting the outgoing beam by matching it to the unperturbed function. In most of the cases, this perturbation is not limited to one lattice function but effects all parameters. If this perturbation is larger than a tolerated error it must be corrected by adding magnets, one pair per parameter, to the original set. This determines the size of the knob.

The response matrix is calculated by varying the range of magnet strength individually and recording the response of the parameters of interest. During this procedure it is important to ensure that the response is measured in the linear regime since SVD breaks down when applied to nonlinear responses. This analysis also determines the magnet strength changes of the individual magnets. Theoretically, by inverting this matrix, one can simply calculate a knob for any of the parameters. In practice, this most likely fails. The main reason is that at least one of the magnets is changed beyond its linear range.

This can be overcome by analyzing the sensitivity matrix (s-matrix). It indicates the effect of the magnets on the parameter. A small s-value forces a bit change of the magnet and vice versa. If the values of the s-matrix show a too large spread, the particular set of magnets will not produce a working knob. This was the key issue to solve for the RHIC lattice. The s-values of the maximum magnets/constraint pair is 10^6 times larger than the final solution. This was accomplished by not constraining parameters. This approach can not always be successful. When the unconstrained parameters change is larger than the allowed range, the knobs range is reduced or will not work in practice at all.

* Supported by US DOE under Contract DE-AC03-76SF00515
† wittmer@slac.stanford.edu

EXTENDED METHOD

The basic idea of this method is to analyze the sensitivity matrix in a two dimensional parameter space. Originally only the spread of the s-values within one s-matrix was analyzed as described above. In practice, not all knobs calculated with this method were successfull although they all fulfilled the condition of minimal s-value spread. Detailed analysis showed that the absolute s-values were too small, which means that the knobs range will be too small. When using the knob beyond its range the nonlinearity will cause it to fail. This problem can be solved by also considering the absolute component of the s-values as well. It is sufficient to include only one absolute value into the optimization, generally the largest, as the others are determined through the spread. This leads to a two dimensional optimization problem. Both, absolute s-values and spread have to be maximized. In the case of LHC [2] and RHIC [1] the number of available magnets after the first part of the analysis (response analysis) was equal to the number needed. Therefore, only the s-matrix spread were analyzed. For HER and LER of PEP II the available magnets was larger than needed. First a set of magnets was analyzed according to the standard lattice design considerations. This set showed a very large spread and when applied to the model could not produce a solution.

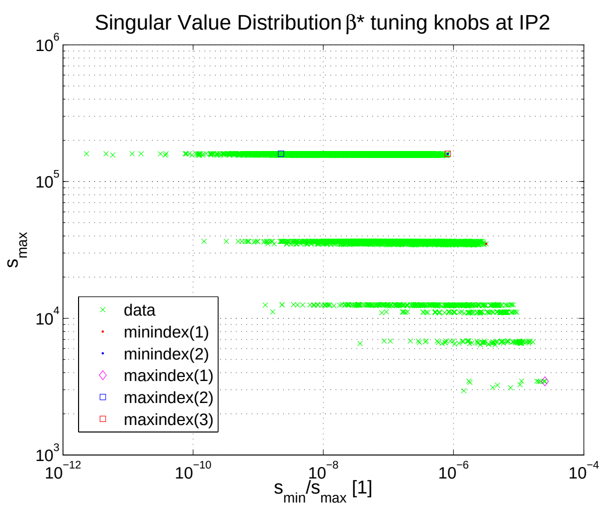

Figure 1: Double logarithmic representation of the s-matrix value pairs. The green points depict all possible solutions. The magenta diamond marks the set with the smallest spread, the blue square with the largest absolute s-value, the red square is an optimization of the spread in the vicinity of the largest absolute s-value. The red and blue dot are the result of optimizing both with different weights.

For the HER the number of needed magnets is 24. The available magnets are 34. This theoretical gives 1.311281e+08 possible solutions. Symmetry considerations reduce this number to 6188 which are based on the conditions described above. These conditions were verified on a reduced set to cope with time and memory limitations. This number is by far to large so that a manual analysis is not possible.

To visualize this problem each matrix is represented by a coordinate pair in the two dimensional plane. The abscissa represents the s-value spread as ratio of the smallest to largest value ${}^{s_{min}}/_{s_{max}}$. The ordinate depicts the largest s-value. When looking at this representation one finds that there is no obvious optimal solution. Either one coordinate moves fast away from its maximum as the other increases. By connecting local maxima a curve is formed. The optimum solution must lie on this line. Plotting the same data on a double logarithmic plot this line becomes a straight. Based on this information different conditions to find maxima have been derived. These are plotted in figure 1. Plotting the s-matrix values, with normalization such that the largest value equals one, of the solutions found by the maximization criteria, is shown in fig. 2.

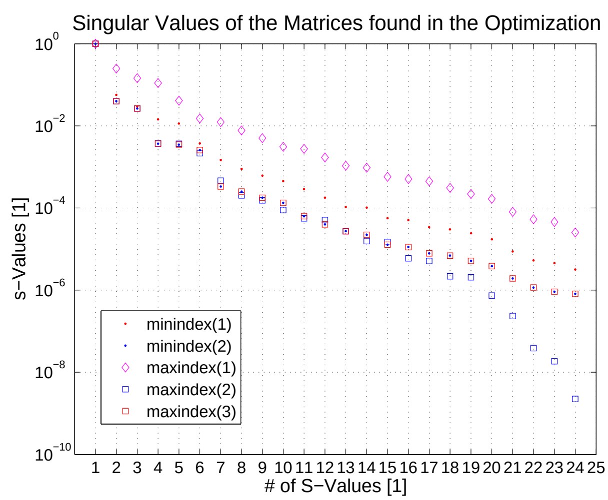

Figure 2: S-value spread of the five different solutions found with the optimization mechanism. The maximum spread difference is a factor of 10^4. The other solutions lie in between.

These two plots visualize the essence of this analysis. The first minimizes the solutions of interest by determining the local maxima. Out of this group a small set is derived, in this example five. The blue box in figure 1 represents the magnet combination with the largest absolute singular value. It has consistently been observed that this is not a local maximum for the pair. So as one condition the local maximum is calculated with emphasis on the absolute s-value. No case has been observed where a local maximum for the s-value spread had to be calculated. The second group of conditions minimizes the difference for both values of the pair, one with a linear condition the other with a logarithmic. A more detailed behavior of the s-matrix of these five solutions is depicted in figure 2.

This analysis does not guarantee that any of the found magnet combinations can be used to calculate a knob. The only way to test these is to use any optics code and calculate a solution by matching or to calculate them directly from the response matrix. It has been demonstrated, that the difference between a matched solution and the result by using the response matrix are smaller than the resolution of the hardware.

RESULTS OF IMPLEMENTATION IN THE HER

For the HER all five magnet combinations where used to try to calculate a vertical IP β knob. This was done with MADX. The combination which maximizes with emphasis on the s-value spread, represented by the magenta diamond in figure 1, was the only one being successful. This result is in particular very interesting as this magnet combination is only comprised of local skew quadrupoles and quadrupoles of the dispersion suppressor. None of the doublet magnets are part of this combination.

This knob was based on the HER design model and tested in August 2006. The results were encouraging. The vertical $\beta^\star$ was reduced but only by half of what the simulations predicted. The biggest problem were that the knob was not orthogonal to the coupling parameters. The measured $\bar{C}_{12}$ deteriorated while dialing in the knob. A more detailed analysis revealed that the problem was most likely caused by the fact that the design model differs significant from the real machine.

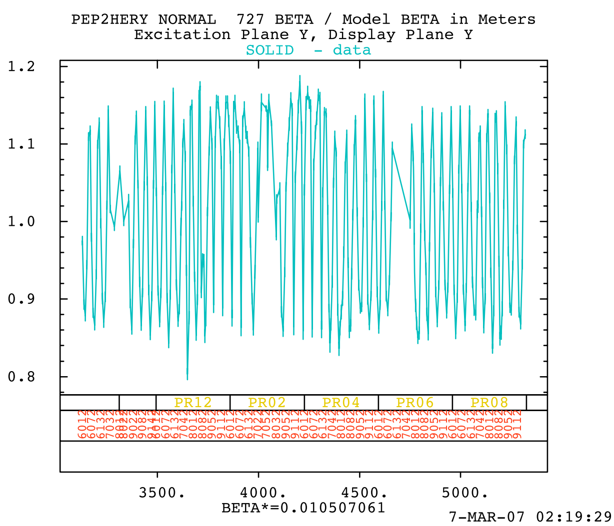

Figure 3: HER vertical β-beat with respect to the design lattice measured before the implementation of the $\beta_y^\star$ knob.

The Model Independent Analysis (MIA) mechanism provides a model which describes the physical machine was far better. Based on this information and the results from the first test a mechanism was developed which automatically generates a MADX model based on the model calculated by MIA.

This model was used to recalculate the knob values and the knob was successfully tested. The vertical IP β-function changed from 10.5 mm to 9.15, with 9.0 predicted by the simulation, and the coupling did not change significantly. The changes of other parameters were all smaller than the allowed range. No β wave developed around the ring in both planes. Figures 3 and 4 show the effect of the knob for the β-function in the vertical plane. In the IR2 area where the knob magnets are located, a symmetric wave develops. This wave is local and changes the $\beta_y^\star$ as desired.

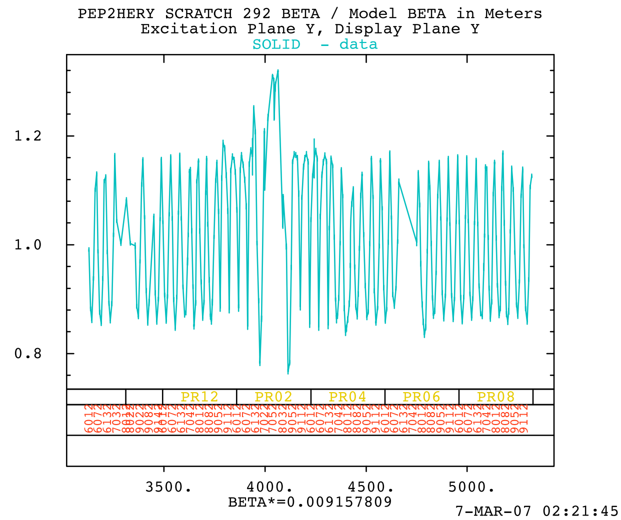

Figure 4: HER vertical β-beat with respect to the design lattice measured after the implementation of the $\beta_y^\star$ knob.

This magnet combination also allows to calculate knobs for the four coupling parameters. As this knob is comprised partially of normal quadrupoles, its application to normal operator tuning is problematic as the magnet standardization will be lost. To avoid this problem, the analysis was repeated with only skew quadrupoles. A solution was found which corrects C_{11} and C_{12} at the IP. This knob was successfully implemented.

SUMMARY

To calculate IP parameter knobs a set of suitable magnets had to be determined out of a larger group. The method based on singular value decomposition was extended to analytically find this set. This method has been used to generate a vertical $\beta^\star$ knob for the HER which was tested successfully. To better describe the physical machine a mechanism was generated which ports the MIA generated model to MADX.

REFERENCES

[1] W. Wittmer, F. Zimmermann, F. Pilat, V. Ptitsyn, J. Van Zeijts, ‘Adjusting the IP β functions in RHIC.’, *Presented at 9th European Particle Accelerator Conference (EPAC 2004), Lucerne, Switzerland, 5-9 Jul 2004.*

[2] W. Wittmer, D. Schulte, F. Zimmermann, ‘Calculating LHC Tuning Knobs Using Various Methods.’, *Presented at 9th European Particle Accelerator Conference (EPAC 2004), Lucerne, Switzerland, 5-9 Jul 2004.*

 1-4244-0917-9/07/$25.00