ANALYSIS AND CORRECTION OF THE MEASURED COD IN INDUS-2

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Abstract

In Indus-2 there are 56 button type beam position monitors (BPMs), 48 horizontal and 40 vertical corrector magnets. The measured orbit has been fitted by effective quadrupole misalignments by using SVD of the response matrix generated between BPMs and the quadrupole misalignments in the model obtained by setting the magnet strengths as per the current set in the magnets. We present the global orbit correction algorithm developed for minimizing the orbit. The preliminary result for the orbit correction, at injection energy, in horizontal plane using best orbit correctors identified by an SVD of the response matrix is presented.

INTRODUCTION

The synchrotron light sources are characterized by low emittance of the electron beam and high brightness of the photon beams radiated from dipoles and insertion devices. Indus-2 is a 2.5GeV synchrotron radiation source with expanded Chasman Green lattice. The source consists of 8 unit cells; one unit cell contains 2 dipoles, 9 quadrupoles and four sextupoles. There are 7 beam position monitors (BPMs), 6 horizontal and 5 vertical corrector magnets in each cell for orbit measurement and its correction. One unit cell is shown in figure (1). The ring comprises of 72 quadrupoles divided into five families of quadrupole magnets. The closed orbit results from field errors and the errors arising from magnetic element positioning. The most severe effects come from misalignment of quadrupole magnets, where the resulting dipole field is proportional to both gradient and alignment errors. Indus-2 ring is being commissioned and measurement and correction of the beam dynamics parameters such as closed orbit distortion, tune, chromaticity etc. are being done. In this paper we describe the COD correction algorithms and its measurement and correction.

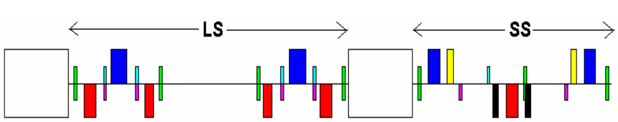

Figure 1: One unit cell of Indus-2 ring: Rectangles: empty-dipoles; blue-focusing quadrupoles; red-defocusing quadrupoles; yellow-focussing sextupoles; black-defocusing sextupoles; green-beam position monitors; magenta-horizontal corrector magnets and cyan-vertical corrector magnets. LS and SS stand for long straight section and short straight section.

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The measured orbit has been fitted by effective quadrupole misalignments by singular value decomposition (SVD) of the response matrix generated between BPMs and the quadrupole misalignments in the model obtained by setting the magnet strengths as per the current set in the magnets. We present the global orbit correction algorithm developed for minimizing and controlling the orbit. The preliminary result for the orbit correction, at injection energy, in horizontal plane using most effective correctors identified by SVD of the response matrix is presented.

ALGORITHM

Considering M BPMs and N correctors used for closed orbit correction in the storage ring, the response matrix Rij corresponding to the beam motion at the ith BPM per unit angle of kick by the jth corrector is given by

$$R_{ij} = \frac{\sqrt{\beta_i \beta_j}}{2\sin(\pi\upsilon)} \cos\left(\left|\varphi_i - \varphi_j\right| - \pi\upsilon\right) \quad (1)$$

where (β_i, φ_i), and (β_j, φ_j) are the beta function and phase advance at BPM and corrector locations, ν is the betatron tune.

The solution of the problem of the system of simultaneous linear equations between BPMs and the correctors is to effectively find out the inverse of the response matrix, R^{-1}. By SVD, the response matrix R can be decomposed into U, S, V [2]

$$R = U \times W \times V^T \quad (2)$$

Where U is an MxM unitary matrix ($UUT = UTU = 1$) and V is an NxN unitary matrix ($VT\ V = VTV = 1$), W is an MxN diagonal matrix with positive or zero. We call these diagonal elements $W_n(\geq 0, 1 \leq n \leq \min(M,N))$ the eigenvalues, which represent the coupling efficiency between the BPMs and correctors. The matrix R is singular if any of the eigen values are equal to zero. The R^{-1} can be calculated as

$$R^{-1} = V \times (W_{inv}) \times U^T \quad (3)$$

Here, W_{inv} is a diagonal matrix of dimension NxM and the elements are given by

$$W_{inv} = q_{\min(i,j)} \delta_{ij} \quad (4)$$

with

$$q_n = \begin{cases} 0, w_n \le \varepsilon w_{\max} \\ \dfrac{1}{w_n}, otherwise \end{cases} \qquad (1 \le n \le \min(M,N)) \qquad (5)$$

where ε is the singularity rejection parameter in the range [0,l]. This parameter is determined primarily by the orbit correction needs and the corrector strength limits. Zero q_n's correspond to decoupled channels which do not contribute to orbit correction.

When ε = 0, all the non-zero eigen values are retained and the most accurate correction will result. However, this will require very robust power supplies for the correctors. On the other hand, if ε = 1, R^{-1} is a null matrix and there will be no orbit correction. Usually, ε is set to the smallest value such that none of the power supplies saturates.

SIMULATION

The singular values in descending order of the model response matrix obtained with all 56 BPMs and 48 correctors in horizontal plane are shown in figure (2). The large decrease at # 32 indicates that 16 of the correctors are redundant and therefore do not contribute much to orbit correction. These correctors have the smallest values of the function

$$E(j) = \sum_n w_n V_{jn}, \qquad (1 \le j \le 48) \qquad (6)$$

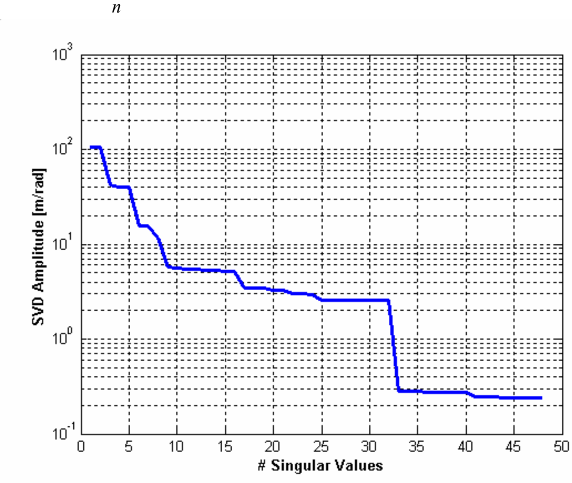

Figure 2: Singular value decomposition in horizontal plane of the model response matrix [9.3, 6.2].

In figure (3), the function E is plotted with number of correctors. It can be seen that 16 correctors having larger amplitude of E are most effective in correcting the COD. We simulate the closed orbit in the ring at presently working tune (9.3, 6.2) assuming rms misalignments of all quadrupole magnets by 0.2mm terminated at 3σ. The effect of singular values on orbit correction is shown in figure (4). The COD correction with 8, 16, 32 most effective correctors and all 48 correctors is shown in figure (5). It can be inferred that there is not much gain in orbit correction by all 48 corrector magnets as compared to the correction by 32 magnets.

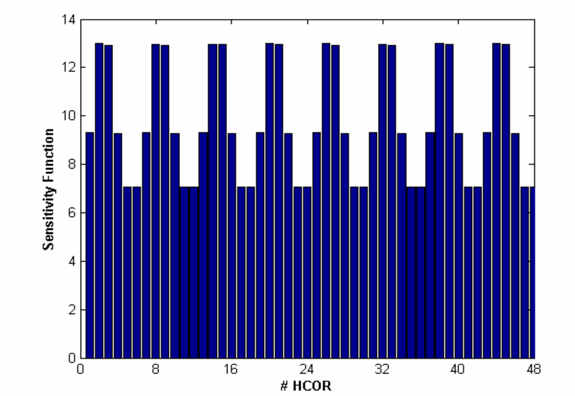

Figure 3: Sensitivity function for the horizontal corrector magnets for model response matrix [9.3, 6.2].

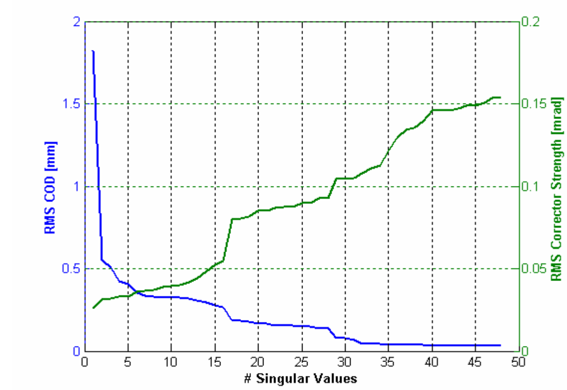

Figure 4: Effect of singular values on closed orbit correction in horizontal plane generated with 0.2mm rms random (seed-123456) misalignment of all Quadrupoles terminated at 3σ.

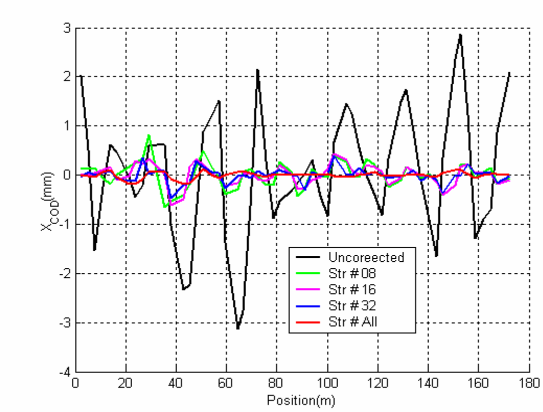

Figure 5: Orbit correction with the ideal lattice response matrix in horizontal plane.

MEASUREMENT AND ANALYSIS

The theoretical betatron tunes estimated by considering magnetic field as per the set current in the magnets are (9.31, 6.14). The response matrix was generated with this model and compared with the measured response. The result for one of measured changes in COD due to 1A current in the corrector magnet is shown in figure (6). This show an agreement between model and measured response in horizontal plane while there is a small deviation in vertical plane. This effect may be attributed to the change in tune in vertical plane or due to the calibration error of the integrated magnetic field data of vertical corrector magnet. The FFT analysis of the measured COD in horizontal and vertical planes show the peak at 9^{th} and 6^{th} harmonics which confirm the integer part of the set betatron tune [3,4].

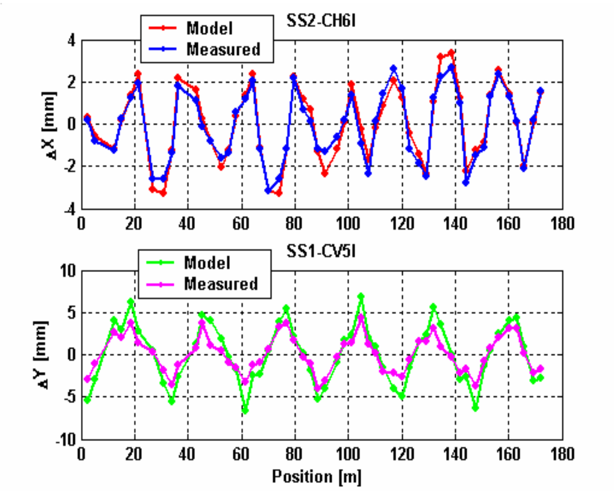

Figure 6: The measured and model response with 1.0A current in corrector magnets in both the planes.

The measured COD has been fitted, as shown in figure (7), with the quadrupole misalignments by SVD of the response matrix constructed by the COD change at BPMs per unit change of misalignments. The effective misalignments so obtained may not be the actual misalignments but give information about the magnitude of the misalignments. To get actual misalignments one should change the tune and recalculate the misalignments.

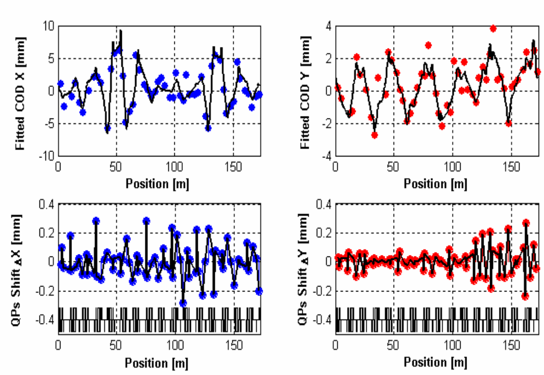

Figure 7: The COD fit with the effective misalignments of the quadrupoles.

The measured COD has been corrected in horizontal plane at the injection energy 550MeV. In the first trial of orbit correction, out of 48 correctors 16 were identified as the most effective correctors by SVD of the model response matrix. The measured and corrected closed orbit with these 16 correctors is shown in figure (8) together with the measured COD in vertical plane. In the first iteration of orbit correction, the maximum and rms COD has been reduced to 2.5mm and 1.3mm from 6.7mm and 2.9mm respectively [3]. Further improvement in orbit correction will be tried. The correction in vertical plane is yet to be attempted.

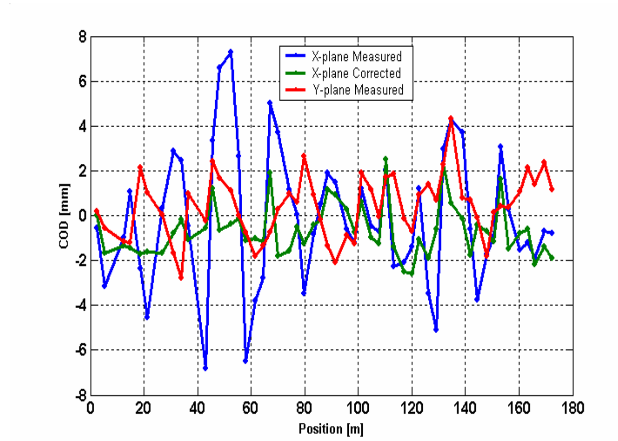

Figure 8: Measured COD in horizontal and vertical plane and corrected orbit in horizontal plane at 550MeV.

CONCLUSION

The closed orbit response matrix has been measured and found to be in agreement with the model response matrix in horizontal plane. The COD correction in horizontal plane has been done using 16 corrector magnets and further improvement in correction will be tried.

ACKNOWLEDGEMENT

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