

SPURIOUS VERTICAL DISPERSION CORRECTION FOR PETRA III

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Abstract

The spurious vertical dispersion, arising due to the misalignment and rotational errors of the magnets in the storage rings dedicated for synchrotron radiation sources are highly undesirable in the low emittance machines, as this contributes to the vertical beam size of the photon beam. This is a matter of concern in PETRA III, a 6GeV positron storage ring with a horizontal beam emittance of 1nm.rad and 1% emittance coupling. In this paper the local and/or global vertical dispersion correction in the ring after getting a corrected orbit with combined horizontal dispersion correction of the perturbed lattice are discussed. The global vertical dispersion is corrected using the vertical corrector magnets used for orbit correction and 12 skew quadrupole magnets are used at three locations viz. two damping wiggler sections and the new octant with DBA cells, with a pair of skew quadrupoles on either side to correct locally without disturbing the dispersion out side. A SVD method can also be used considering the BPMs (Beam Position Monitors) on either side of insertion devices using skew quadrupoles to minimize the vertical dispersion in those locations so that the vertical emittance can be maintained at a desired value.

INTRODUCTION

PETRA III[1] is a new light source being reconstructed out of the existing storage ring PETRA II at a beam energy of 6 GeV and 100mA stored current with the betatron tune values (36.095, 31.345). The conversion of this 2.304km PETRA II storage ring will include the total rebuilding of one eighth of the storage ring to provide space for nine straight sections to install insertion devices. The new light source which is a hybrid lattice with FODO and DBA(Double Bend Achromat) cells, provides a horizontal beam emittance of 1nm.rad by enhancing the radiation damping in 2 sections of 40m long damping wigglers. The emittance ratio of 1% needs careful magnet alignments, orbit stabilization and closed orbit corrections. Side by side the small vertical emittance imposes tight tolerances on the spurious vertical dispersion that is created by misalignment and rotation of the magnets. The average vertical dispersion is a prominent parameter which can lead to significant increase in beam size and hence lower beam brightness. To maintain the emittance ratio and the vertical beam sizes thus enhanced by vertical dispersion at the crucial insertion sections the vertical dispersion has to be corrected [2-4]. Our goal is to reduce vertical dispersion as per the Table-1 and the betatron coupling in the ring so that the vertical beam size can stay within an acceptable value.

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Table 1: Dispersion limits at specific sectors to achieve design emittance.

	Horz. (mm)	Vert. (mm)
Wiggler section	18	5
Undulator's (ID's)	20	3
FODO arc		58
DBA	22	31

VERTICAL DISPERSION CORRECTION

For PETRA III orbit and dispersion correction has to be combined as the dispersion function in the wiggler and undulator sections has to be controlled. Three different schemes are chosen for orbit and dispersion correction in the aforesaid ring. They are discussed in the following paragraphs.

Case 1: The closed orbit and the dispersion are corrected simultaneously using all beam position monitors (BPMs) and the correctors. An algorithm [5] for the simultaneous optimization of the closed orbit and the dispersion is applied. This algorithm is given by the following system of linear equations:

$$\begin{pmatrix} \alpha \bar{u} \\ (1-\alpha)\bar{D}_u \end{pmatrix} + \begin{pmatrix} \alpha R \\ (1-\alpha)S \end{pmatrix} \bar{\theta} = 0 \quad [1]$$

With \bar{u} being the closed orbit and \bar{D}_u the dispersion measured at the BPMs, R the orbit response matrix, S the dispersion response matrix and $\bar{\theta}$ corrector kicks. α is a weighting factor used to shift from a pure orbit ($\alpha=1$) to a pure dispersion correction ($\alpha=0$). Singular Value Decomposition (SVD) [6] has been proven to be a numerically robust method to solve such an equation. Closed orbit and dispersion correction has been simulated to verify that the desired vertical and horizontal emittance can be achieved.

The major contribution to the remaining spurious vertical dispersion comes from the vertical orbit in the sextupoles. The contributions to the spurious vertical dispersion from other sources like tilted quadrupoles, the kick induced by the vertical closed orbit in the quadrupoles are comparatively small.

This has the disadvantage that the orbit and dispersion correction is coupled.

Case 2: The closed orbits and horizontal dispersion are corrected as per the above procedure and later vertical dispersion is corrected using 12 skew quadrupoles. These skew quadrupoles are placed at three straight sections in the dispersive region of the FODO arcs. A pair of skew quadrupoles is placed around a phase difference of 72°

near high beta points on either side of damping wiggler section and the new DBA section. For the global vertical correction scheme, one can consider, a horizontal orbit offset through a skew quadrupole will generate a deflection in the vertical plane through an angle $\Delta\theta_y = k_{1s}lx$. This will generate a vertical orbit distortion of Δy such that,

$$\Delta y_i = \frac{\sqrt{\beta_{yi}\beta_{yj}}}{2\sin(\pi Q_y)} \cdot \cos(|\varphi_{yi} - \varphi_{yj}| - \pi Q_y) (K_{1s}lx)_j$$

With $x = D_x \Delta P/P$ and $y = D_y \Delta P/P$, one can write the skew quadrupole response matrix as

$$R_{ij} = \frac{D_{xi}\sqrt{\beta_{yi}\beta_{yj}}}{2\sin(\pi Q_y)} \cdot \cos(|\varphi_{yi} - \varphi_{yj}| - \pi Q_y) \quad [2]$$

$$\Delta D_{yi} = R_{ij}(K_{1s}l)_j$$

In this case, the vertical dispersion can be globally minimised at certain monitor locations using a SVD algorithm solving for a system of linear equations in Eq.2. The vertical dispersion in the new DBA section, where the insertion devices are placed is minimised using this algorithm.

An alternative is to correct vertical dispersion locally using 4 skew quadrupoles that form a local bump. It is performed by setting the dispersion and its derivative to zero at the second skew quadrupole in front, and closing the bump with the pair of skew quadrupole in back. These skew quadrupoles can be used to adjust the emittance ratio.

Case 3: In 3rd case, first the closed orbits and the horizontal dispersion are corrected as described in procedure of Case 1. Later, the vertical dispersion is globally corrected using a few numbers of selected beam position monitors and 21 vertical correctors in the old octants using SVD algorithm.

RESULTS AND DISCUSSIONS

The closed orbit is obtained using the MAD.x program [7] in the presence of damping wigglers and synchrotron radiation. The closed orbit and the dispersion corrections necessary as described above are carried out using a self developed program that solves a system of linear equations using SVD algorithm [8]. As described in the previous section, the vertical dispersion was corrected in three different procedures and the pros and cons are discussed below.

Case 1: The closed orbit is observed by 209 BPMs, mostly placed next to each horizontally defocusing quadrupoles in the old octants. Extra windings on 123 dipole magnets and 59 independent magnets are used as horizontal correctors while 189 independent magnets are used for vertical orbit correction. The simultaneous orbit and dispersion correction is carried out for different weighting factors (α in Eq.1) to maintain beam emittance ratio to a desired value viz. 1%. The results of vertical dispersion around the ring after correction for a specific case are shown in Fig.1.

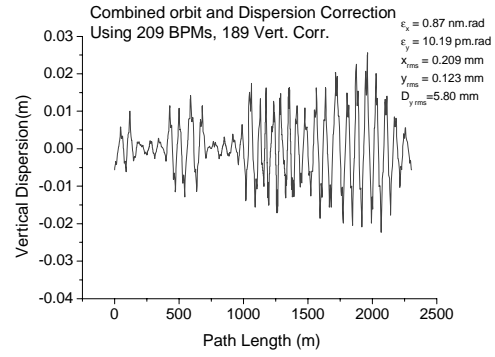


Figure 1: Vertical dispersion around the ring after combined orbit and dispersion correction.

Though the orbit and dispersions are corrected with desired emittance values, still it may not solve the dispersion problem completely in the damping wiggler sections.

Case 2: First the closed orbit and the horizontal dispersion are corrected using procedure of Case 1. Further, the local vertical dispersion and its derivatives are corrected using local bump method by means of 4 skew quadrupoles at the two damping wiggler section and the new DBA section. The results of vertical dispersion correction for a specific case are shown in Fig.2 at the damping wiggler section and the new DBA section.

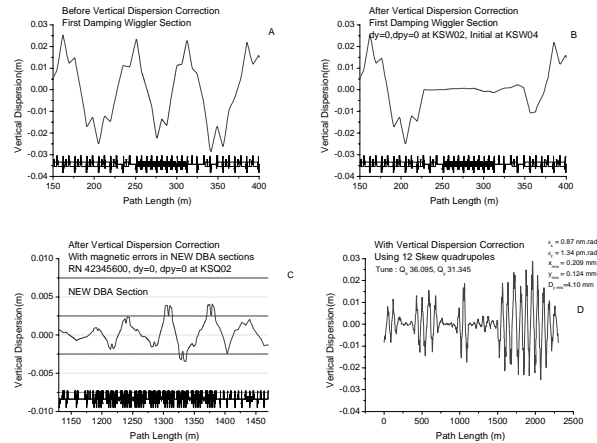


Figure 2: Vertical dispersion (A) 1st damping wiggler section before correction, (B) 1st damping wiggler section after correction, (C) at the new octant after correction and (D) around the ring after correction.

From Fig.2 (A-B) it is evident that by local correction the vertical dispersion is not disturbed outside the range of correction in the damping wiggler section. The vertical dispersion is nearly zero at damping wiggler sections while it is around 2 to 3mm at the insertion sections. It is due to the nonzero vertical orbit at the strong quadrupoles in that section. At the insertion section with a β function of 5m and beam emittance of 10pm.rad, we get a beam size of $7\mu\text{m}$ due to betatron contribution, while the dispersion part will be $\sim 2 - 3\mu\text{m}$ with a relative momentum spread of 0.001.

Further more, the vertical dispersion is minimized using 20 BPMs on either side of the 10 insertion devices and 4 skew quadrupoles on either side of the new octant using SVD algorithm. The results shown in Fig. 2C are further minimized by this algorithm, and are shown below.

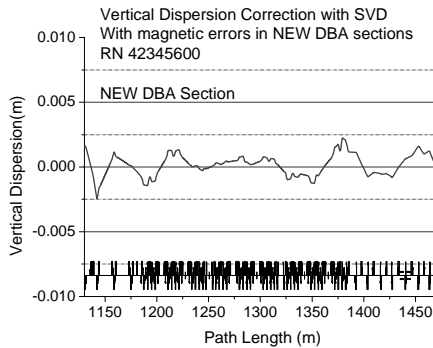


Figure 3: Vertical dispersion after further minimization with SVD algorithm in the new octant.

The results obtained from this are encouraging as the orbit differences before and after dispersion correction are below $30\mu\text{m}$ and the vertical emittance can be maintained with different weighting factors given to BPMs. The skew quadrupole strengths are small such that it can impart small betatron coupling. So, this procedure was repeated for many random cases. The results are shown in Fig. 4, where it is seen that the dispersion is well maintained with in desired 3mm limits on either side of 5m undulator sections.

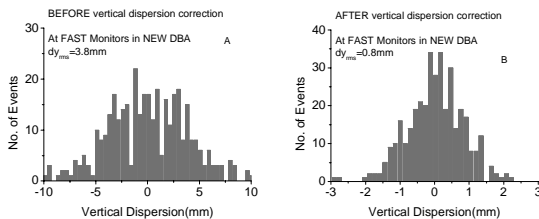


Figure 4: Vertical dispersion before (A) and after (B) correction at monitors on either side of 5m undulator in new DBA section.

Case 3: The vertical dispersion is corrected using 21 vertical corrector magnets placed on either side of 7 old FODO achromats, 20 BPMs in old octant, and using 20 BPMs on either side of the 10 insertion sections of the new Octant. The procedure is the same as described in Case 1, but here only the vertical dispersion is corrected.

The simulation results for dispersion correction using 40 BPMs and 21 vertical steering magnets are shown in Fig. 5. In these simulations, it is observed that the rms vertical dispersion is quite small, i.e. the vertical emittance is much smaller than desired $10\text{pm}\cdot\text{rad}$, which is the case of an over correction. The weighting factor on the degree of correction can be varied to get a moderate correction, which can be a key element to manage the vertical beam emittance. One can notice that on using the vertical correctors as the elements to correct the vertical spurious dispersion leads to larger change in vertical orbit before and after correction, which is $\sim 800\mu\text{m}$. This is not

desirable. In this case too one can not maintain the vertical dispersion at damping wiggler sections. This correction scheme may not be suitable.

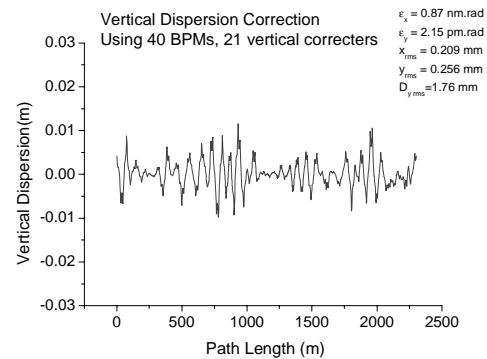


Figure 5: Vertical dispersion around the ring after correction with a few vertical correctors.

On comparison with the three different procedures to correct the spurious vertical dispersion in PETRA III, it is seen that 2nd case, where the vertical dispersion is corrected by use of 12 skew quadrupoles, with small change in vertical orbit before and after correction is most suitable. This provides more flexible control over the vertical dispersion in the damping wiggler sections.

CONCLUSION

For PETRA III, a scheme to correct the spurious vertical dispersion using a set of 12 skew quadrupoles is finalised. Keeping the betatron coupling coefficient low, it is shown that the vertical dispersion can be corrected to desired values at the two damping wiggler sections and in the new DBA section. The skew quadrupole magnets are designed and will be ordered in the second half of 2006.

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