MEASUREMENT AND CORRECTION OF TRANSVERSE DISPERSION IN PETRA III

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Abstract

PETRA III is a 6GeV positron light source with a design horizontal beam emittance of 1nm.rad and 1% emittance coupling. This low emittance is achieved with proper correction of horizontal dispersion to its theoretical values in the arcs as well as dispersion free sections. The spurious vertical dispersion, arising due to misalignment and rotational errors of the magnets is also duly corrected as this contributes to the vertical beam size of the photon beam. Here we discuss the method taken to correct the horizontal dispersion using a combined orbit and dispersion correction scheme. In the vertical plane the same procedure can be used as that of horizontal plane or only the dispersion can be corrected using dedicated skew quadrupoles to millimeter level after orbit correction has been done. In this paper we present the methods used and results obtained in correction of dispersions in transverse planes.

INTRODUCTION

PETRA III[1] is a synchrotron light source recently commissioned with a positron beam energy of 6 GeV and 100mA stored current at betatron tune values (36.1272, 31.2888). This new light source which is a hybrid lattice with FODO and 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 coupling 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. Our goal is to reduce horizontal and vertical dispersion distortions as per the Table-1 as well as the betatron coupling in the ring so that the horizontal emittance is within 5% variation from its design value of 1nm.rad and vertical beam emittance can stay within an acceptable value ~10pm.rad. To obtain the aforesaid values PETRA III is equipped with 226 BPMs, 191 horizontal correctors, 187 vertical correctors and 12 skew quadrupoles. The correctors can impart a maximum of ±0.5mrad kicks where as the skew quadrupoles can impart maximum strength of $\pm 0.1\text{m}^{-2}$.

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

ORBIT & DISPERSION CORRECTION

The closed orbit and the dispersion are corrected [2] simultaneously using all beam position monitors (BPMs) and the correctors. This combined orbit and dispersion correction algorithm is given by the following system of linear equations:

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

With $\vec{u}$ being the closed orbit and $\vec{D}_u$ the dispersion measured at the BPMs, R the orbit response matrix, S the dispersion response matrix and $\vec{\theta}$ corrector kicks. α is a weighting factor used to shift from a pure orbit (α=1) to a pure dispersion correction (α=0). Singular Value Decomposition (SVD) has been proven to be a numerically robust method to solve such an equation.

The horizontal closed orbit and dispersion are corrected as per the above procedure and later vertical dispersion is corrected using 12 skew quadrupoles [3]. 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 DBA section. For the global vertical correction scheme, one can consider, a horizontal orbit offset through a skew quadrupole that 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,

$$\Delta y_i = \frac{\sqrt{\beta_{yi}\beta_{yj}}}{2\,Sin\left(\pi Q_y\right)}.Cos\left(\left|\varphi_{yi}-\varphi_{yj}\right|-\pi Q_y\right)\left(K_{1s}lx\right)_j$$

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

$$R_{ij} = \frac{D_{xi}\sqrt{\beta_{yi}\beta_{yj}}}{2\,Sin\left(\pi Q_y\right)}.Cos\left(\left|\varphi_{yi}-\varphi_{yj}\right|-\pi Q_y\right) \qquad [2]$$

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

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.

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The vertical dispersion in the 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.

GUI ORMDRM

A graphics user interface (GUI) ORMDRM as shown in Figure-1, is developed in MATLAB using the Middle Layer[4] as backbone under TINE[5] control interface utility to measure and correct transverse dispersion to its theoretical values. The ORMDRM performs correction of transverse dispersion using monitor to corrector theoretical response matrices. It displays results in graphics as well as in text form in three modes of operation. The modes are, 1. Combined Orbit and Dispersion Correction in Transverse Planes with All BPMs and Correctors, 2 Vertical Dispersion Correction with PKVSU Type Correctors Only and 3 Vertical Dispersion Correction with Skew Quadrupoles. In case of 1, one can correct the orbit and dispersion both in horizontal and vertical plane simultaneously or independently. In case of 3, one can correct only vertical dispersion in individual zones viz. west/north damping wiggler sections or DBA section or all-together.

The program starts with determination of theoretical orbit response matrix (ORM)/ dispersion response matrix (DRM) as desired by the mode of operation followed by measurements of orbits and dispersions using BPMs by varying RF frequency ~±1.5kHz in steps of 20Hz. The corrector strengths are determined for a pre-selected number of Eigen values. These correctors can be energised in a single step or in multiple steps. The cycle of measurement of dispersion and apply of corrector strengths to magnets iteratively continues to a number of times till the required convergence to theoretical values are achieved or a suitable tolerance is occurred before it corrects further with change in beam energy.

In addition provision is made to assign different weight factors to the BPMs, choose different number of BPMs and correctors depending on their availability, and editing of initial orbits and dispersion values. As it uses the theoretical optics of the lattice created in Middle Layer, it prints the betatron tune values which can be edited. The weight factor that decides the degree of orbit to dispersion correction in combined correction scheme can be chosen along with the Eigen values cut off factor which is the ratio of n^{th} Eigen value to most dominant Eigen value. Left click in graphs of dispersion pops up a separate figure with enlarged view. Similarly left click on the list boxes of BPMs or correctors pop up the data in more details in a tabular form. The data can be used to compare readouts of different measurements.

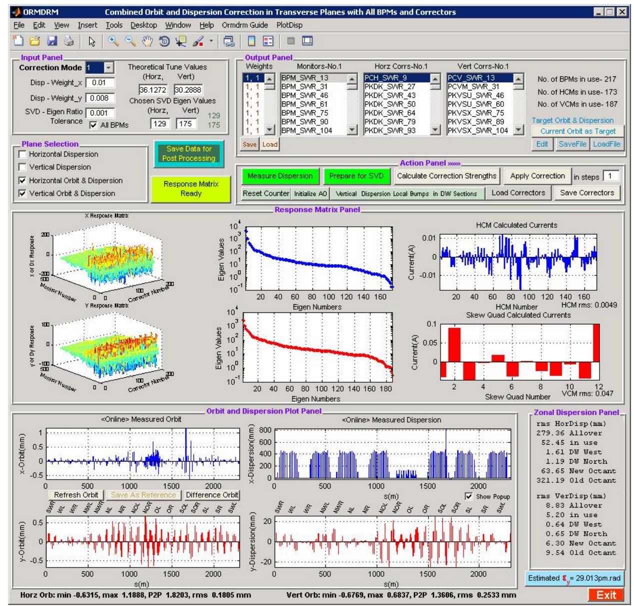

Figure 1: The graphics user interface ORMDRM used for measurement and correction of transverse dispersion for PETRA III.

RESULTS AND DISCUSSIONS

The closed orbit is corrected after the beam based alignments in both horizontal and vertical plane using the orbit response matrix. The orbit so obtained is set as the target orbit for combined orbit and dispersion correction in horizontal plane. The horizontal dispersion is corrected using this procedure with a SVD algorithm in a few iterations till the required tolerance limits are reached. In this case all the available BPMs (217 out of 226) are used with 173 horizontal correctors. The slow corrector magnets embedded in the dipole magnets in the DBA section are not used for horizontal dispersion correction for some specific reasons. The spurious vertical dispersion is reduced to certain values due to vertical orbit correction and the combined orbit and vertical dispersion correction is not required. As mentioned earlier the dispersion is critical at two damping wiggler sections on west/north and at IDs. So, it is not so important to worry about the spurious vertical dispersion at other FODO octants. Importance is given to minimise the distortions at insertion sections. As a result, the vertical dispersion is corrected using a selected number of 49 BPMs and 12 skew quadrupoles using a SVD algorithm in global correction scheme. The measured dispersion values obtained after a dispersion correction with ORMDRM GUI in few iterative steps is plotted in Figure-3, where the uncorrected dispersions are plotted in Figure-2 for comparison. One can observe that the theoretical and measured horizontal dispersion values are almost matching and within our tolerable limits. Looking into the difference plot (difference of dispersion in horizontal plane between the theoretical and measured corrected dispersion) one can see that the rms value is ~5mm which is quite small.

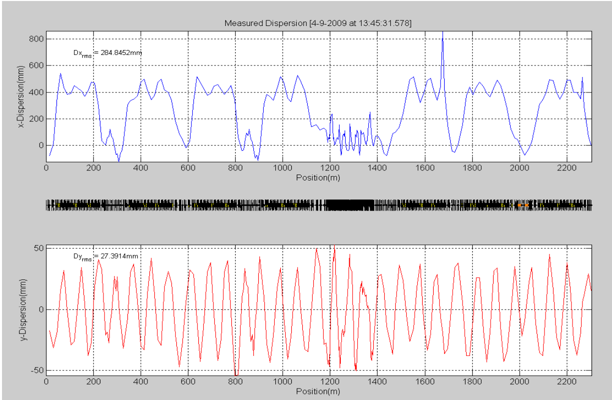

Figure 2: The uncorrected horizontal and vertical dispersion as measured during sometime after BBA and optics correction.

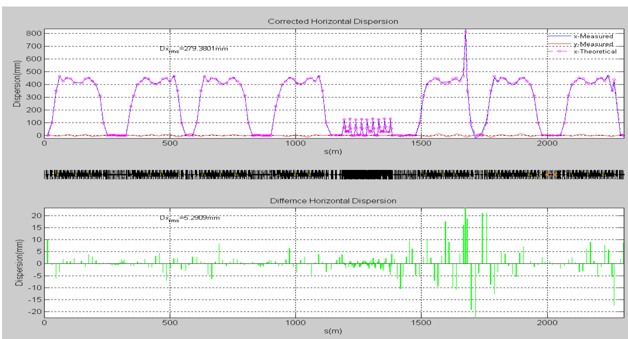

Figure 3: (a) The horizontal dispersion measured (blue) and theoretical (magenta) are plotted along with measured vertical dispersion (red) for PETRA III for comparison. (b) Shows the difference horizontal dispersion between the theoretical and the measured data.

In Figure-4, the measured horizontal and vertical dispersion are plotted after the corrections are made as a function of position to visualise their magnitudes at the damping wiggler sections of west and north as well as at DBA sections.

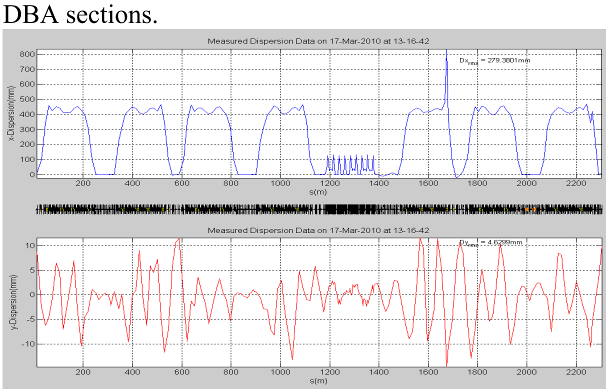

Figure 4: (a) The measured horizontal dispersion (blue) and (b) the measured vertical dispersion (red) are plotted as a function of position to visualise at the damping wiggler west/north and DBA sections.

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 sections to flatten it to zero.

As the damping wiggler sections are crucial, the dispersion plot is zoomed and highlighted in these sections west/north so that to ensure the corrected values are within our tolerance limits of present correction scheme, and shown in Figure-5. We vary ±1.5kHz RF frequency that corresponds to $\Delta P/P = \pm 2.5‰$ at 6GeV. So 10mm dispersion will give rise to a ±25µm orbit shift. Without fast orbit feedback system the stability of orbit is observed to be ~1µm rms. So looking to the measured data at west/north damping wiggler section a resolution ±5mm is tolerable.

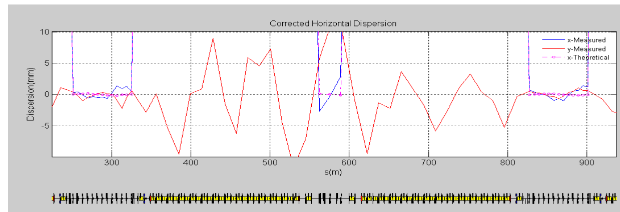

Figure 5: The measured horizontal dispersion (blue) and vertical dispersion (red) are zoomed up at the damping wiggler section in west/north to show that they are within ±5mm.

CONCLUSION

For PETRA III, the scheme to correct the spurious vertical dispersion using a set of 12 skew quadrupoles is implemented. Keeping the betatron coupling coefficient low (as the required skew quadrupole strengths are low $K_{1s\ max}$=~$0.011m^{-2}$), it is shown that the vertical dispersion is corrected to millimetre level at the two damping wiggler sections and in the DBA sections with insertion devices. As the lowest emittance light source in the world, this goal is achieved with proper correction of horizontal dispersion in the achromats side by side in the dispersion free long straight sections incorporating 80m of damping wigglers. The results achieved are satisfactory and limited to currently used measurement accuracies.

REFERENCES

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