SLAC-PUB-15170

LOW EMITTANCE STUDIES FOR SUPERB *

S.M. Liuzzo, University of Pisa and INFN, M.E. Biagini, P. Raimondi, INFN/LNF, Frascati (Roma)
M. H. Donald, SLAC, Menlo Park, California

Abstract

SuperB[1] is an international project for an asymmetric 2 rings collider at the B mesons cm energy to be built in the Rome area in Italy. The two rings will have very small beam sizes at the Interaction Point and very small emittances, similar to the Linear Collider Damping Rings ones. In particular, the ultra low vertical emittances, 7 pm in the LER and 4 pm in the HER, need a careful study of the misalignment errors effects on the machine performances. Studies on the closed orbit, vertical dispersion and coupling corrections have been carried out in order to specify the maximum allowed errors and to provide a procedure for emittance tuning. A new tool which combines MADX and Matlab routines has been developed, allowing for both corrections and tuning. Results of these studies are presented.

INTRODUCTION

SuperB is a e^+e^- asymmetric collider, designed for $10^{36}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ luminosity. This is achieved with ultra low vertical emittance at the limit of present light sources, but with the difficulties brought by the presence of a Final Focus (FF). Magnet errors, like misalignments and tilts are always present in a ring and contribute to emittance growth. Low Emittance Tuning (LET) studies have been carried out at SuperB to understand the tolerated imperfections, the best correction scheme and the optimal BPM and correctors distribution. The work performed for the High Energy Ring lattice (V12) lattice [2] (6.7 GeV) is described in this paper.

SIMULATIONS

Tools

To implement the LET procedure we use MADX[3] and MATLAB[4]. MADX might be used alone, implementing misalignments, correction and iterations, but it does not allow complete freedom in plotting and correction may not be handled to include additional steering constraints. Moreover to change monitor or corrector pattern is slow and may lead to errors. Using Matlab a graphical interface was built that allows for:

- interactivity with MADX for input definition and elements installation
- analysis of any machine and/or error sequence
- definition of multiple errors in any element (including or excluding IR)
- showing and saving plots
- using user defined correction methods.

Orbit and Dispersion Free Steering

Using only the informations retrived from monitors it is possible to correct the orbit generated by machine imperfections using Singular Value Decomposition to calculate a pseudo-inverse of the Response Matrix(ces). Following [5], we use Dispersion Free Steering that allows to constrain at the same time orbit and dispersion. In this work dispersion is computed at monitors via

$$\eta_u = \frac{u_{+\frac{DE}{E}} - u_{-\frac{DE}{E}}}{2\frac{DE}{E}}.$$

The complete orbit-dispersion system is:

$$\begin{pmatrix} (1-\alpha)\,\vec{M} \\ \alpha\,\vec{\eta} \end{pmatrix} = \begin{pmatrix} (1-\alpha)\,ORM \\ \alpha\,DRM \end{pmatrix} \vec{K};$$

with ORM the Orbit Response Matrix, DRM the calculated Dispersion Response Matrix and α the relative weight between orbit and dispersion correction. Orbits are obtained by MADX with the input defined via the Matlab interface. Matlab then reads MADX output to build the matrices, and calculates the correction using the selected weights. All matrices are calculated without misalignments applied, so the correction needs to be reiterated including the effect of previously applied kicks. The kicks $\vec{K}_{n+1}$ applied at $n+1$ iteration will be:

$$\vec{K}_{n+1} = svd\,(M)^{-1}\left(\vec{R} + M\vec{K}_n\right)$$

where $\vec{K}_n$ are the previous kicks, $\vec{R}$ is the readings vector and M the Response Matrix used.

Coupling and β-beating Free Steering

The same procedure may be further specialized. Without introducing additional correctors or skew quadrupoles it is possible to measure two new response matrices for coupling (CRM) and β-beating (βRM). The columns of the response matrices are calculated as follows:

$$\forall\, Y kick\, K_y^j\; CRM^j = \begin{pmatrix} \frac{\vec{x}_{+\Delta Y} - \vec{x}_{-\Delta Y}}{2\Delta Y} \\ \\ \frac{\vec{y}_{+\Delta H} - \vec{y}_{-\Delta H}}{2\Delta H} \end{pmatrix} \qquad (1)$$

$$\forall\, X kick\, K_x^j\; \beta RM^j = \begin{pmatrix} \frac{\vec{x}_{+\Delta H} - \vec{x}_{-\Delta H}}{2\Delta H} \\ \\ \frac{\vec{y}_{+\Delta Y} - \vec{y}_{-\Delta Y}}{2\Delta Y} \end{pmatrix} \qquad (2)$$

where ΔH and ΔV are two fixed kicks applied in the horizontal or in the vertical plane while x and y are column

* Work supported by INFN

Work supported by US Department of Energy contract DE-AC02-76SF00515.

vectors of the orbit at the BPMs. For example the notation $\vec{x}_{-\Delta H}$ represents the x orbit in presence of a fixed kick in the Horizontal plane of value $-\Delta H$ and the response matrix for this vector is the top quadrant of βRM. The first matrix (CRM) is studied only varying Y correctors, while the second one (βRM) only varying X correctors. Calling the coupling orbit and β-beating orbit to be corrected $\vec{C}$ and $\vec{\beta}$ (calculated as the columns of the response matrix) the complete systems of equations for the two planes are now:

$$\begin{pmatrix} (1-\alpha-\omega)\,\vec{M}_x \\ \alpha\,\vec{\eta}_x \\ \omega\,\vec{\beta} \\ \omega\,\vec{\beta}_{\pi/2} \end{pmatrix} = \begin{pmatrix} (1-\alpha-\omega)\,ORM \\ \alpha\,DRM \\ \omega\,\beta RM \\ \omega\,\beta RM_{\pi/2} \end{pmatrix} \vec{K}_x \tag{3}$$

$$\begin{pmatrix} (1-\alpha-\omega)\,\vec{M}_y \\ \alpha\,\vec{\eta}_y \\ \omega\,\vec{C} \\ \omega\,\vec{C}_{\pi/2} \end{pmatrix} = \begin{pmatrix} (1-\alpha-\omega)\,ORM \\ \alpha\,DRM \\ \omega\,CRM \\ \omega\,CRM_{\pi/2} \end{pmatrix} \vec{K}_y \tag{4}$$

where $\pi/2$ indicates the use of a different corrector at a phase advance of approximately 90 degrees for both planes. Solving this system is now like selecting among all the possible orbits, the one that has the minimum rms dispersion and coupling, hence the minimum vertical emittance.

Steering Parameters

In Figure 1 a simulation for SuperB HER lattice (excluding the FF) shows how vertical emittance and rms kick strength vary using an increasing number of eigenvectors (ordered by decreasing eigenvalue). It is clear that 65

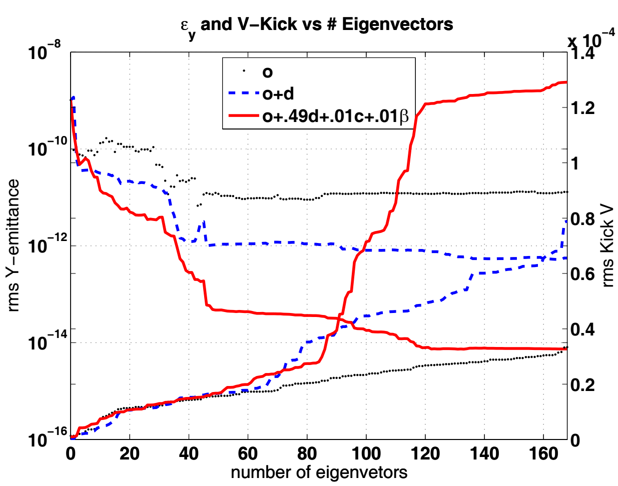

Figure 1: rms ϵ_y (m) and rms Kick applied (rad) vs number of eigenvectors used (ordered by decreasing eigenvalue), after vertical correction for machines with $100\mu m$ vertical misalignments in quadrupoles and sextupoles. Kick increases while emittance decreases.

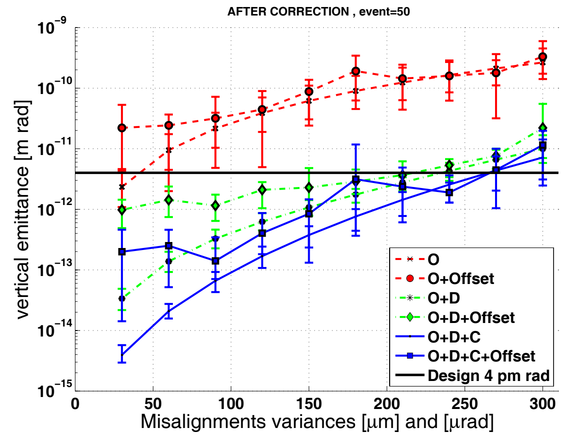

Figure 2: Vertical emittance (m) for machine misalignment from 30 to 300μm H and V for Sext and Quad and qudrupole Tilts of 30-300 μrad. Orbit (O), Dispersion (D) and Coupling and Beta-beating (C) Free Steering are compared

eigenvectors are a good guess to have optimal correction, maintaining at the same time small kick sizes. This value is also confirmed by the same plot for rms dispersion and rms orbit, not shown here. To determine the optimal values for α and ω, a scan for different values of this parameters is performed. The selected values are $\alpha = 0.5$ and $\omega = 0.01$, being at the center of the optimal correction region.

Simulations

All simulations presented are made for HER at 6.7 GeVwith 168 H and V correctors, and 168 H and V monitors, installed at every quadrupole, sextupole and octupole. Misalignments are applied with a gaussian distribution truncated at 2.5 σ. To determine the maximum tolerated misalignment, plots as that in Figure 2 are considered [6]. For 10 different values of error variance a summary of the distribution obtained is given. The central mark shows the average, while the error bars include the distribution from the 5th to the 95th percentile. The effect of BPM offsets of 300 μm, is also taken into account. A comparison of different correction scheme is also presented to give evidence of the improvement given by dispersion (D) and coupling and β-beating (C) free steering respect to pure orbit (O) correction.

Tolerance Table

To summarize the result of LET a table (Table 1) of tolerated imperfections is built. To determine the tolerated value the following procedure is used:

1. misalignments of sextupoles and misalignments and tilts of quadrupoles are analyzed separately for increasing variance.
2. an interval of variances that leads to emittances under 1pm is selected in both cases

3. these intervals of variances are applied together and the tolerated values are selected as those giving a 0.5 pm threshold
4. once fixed the values of the previous step the monitor offset variance is studied.

As a result of this analysis the combination of all the imperfections gives a vertical emittance of less than 1pm for the tolerated values. This low threshold is necessary to allow the subsequent introduction of errors in solenoids and FF magnets.
Correction is performed for every simulation in three steps: the first with sextupoles off and only orbit correction, the second and third using dispersion, coupling and β-beating free steering parameters mentioned above.
Figure 3 shows the effect of quadrupole displacements and tilts (red), sextupole displacements (blue) and monitor offsets (green). Using the new correction scheme errors like monitor offsets and quadrupole displacements influence less the final emittance and the tolerated values may be higher.

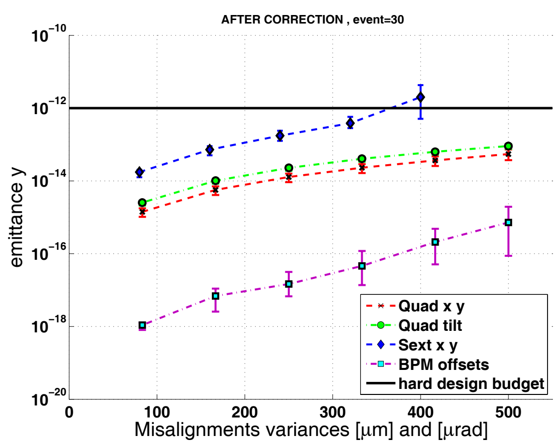

Figure 3: Misalignments tilt and BPM offset errors. Every point is the average of 5 simulations.

In Figure 4 is shown a histogram of the vertical emittance before and after correction for 50 different machine misalignments sets with the imperfections variances listed in table 1.

Final Focus

The same analysis can be applied to the ring with FF. A preliminary study was performed including 230 correctors and 250 monitors. The same weights and correction scheme are applied using 90 eigenvectors. In all the simulations the errors in the arcs are fixed to the values determined for the machine without final focus. However, for these values, the errors tolerated in the final focus are very little ($< 30\,\mu$m). This work is preliminary and needs to be completed with a more realistic simulation of common errors for elements installed on the same support.

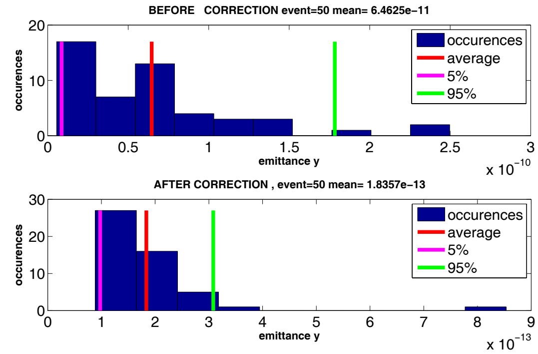

Figure 4: Vertical emittance for 50 simulation with misalignment and tilts from Table 1.

Table 1: Tolerances; values of the combined tolerated displacements, tilts and monitor offsets.

error	tolerance
quadrupole Y	300 μm
quadrupole X	300 μm
quadrupole tilt	300 μrad
sextupole Y	150 μm
sextupole X	150 μm
BPM OFFSET	400 μm
vertical emittance	$< 1\,\mathrm{pmrad}$

CONCLUSIONS

Low Emittance Tuning procedures were applied to SuperB HER without Final Focus. To correct the orbit due to misalignments and tilts, Dispersion, Coupling and β-beating free steering are applied, improving significantly the correction obtained using only Orbit Steering, and suppress the effect of monitor offsets. From simulations a tolerance table for various machine imperfections is obtained, including a first analysis for the Final Focus. Future results will be improved by the introduction of other imperfections and by the ability of dealing with more realistic common misalignments for elements installed on the same support. A Matlab and MADX tool, very fast and flexible, has been developed for the analysis of imperfections.

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