ANALYSIS AND CORRECTION OF OPTICAL ASYMMETRY AT THE ESRF *

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Abstract

Focusing errors in the ESRF machine are analysed and corrected with the orbit response matrix. To be able to cope with variation of errors due to different machine settings and beam conditions, an online use of the developed scheme is attempted. Beta functions deduced are compared with those derived independently with thousand turn BPMs. Internal consistency of the model is checked and correlation of the asymmetry correction to the width of nearest half-integer resonances is pursued. Numerical studies are also made to predict further gains in the correction by introducing more correctors into the machine.

1 INTRODUCTION

The correction of optical asymmetry and linear coupling is of great importance in achieving the designed performance of the ring. At the ESRF, it has conventionally been performed through empirical corrections of the nearest resonances with normal and skew quadrupolar correctors. An alternative was later developed for the coupling correction by modelling the skew quadrupole errors with the off-diagonal orbit response matrix [1]. Following its success, the corresponding alternative for the optical asymmetry correction is attempted by analysing the diagonal orbit response matrix. At the ESRF, the use of the diagonal orbit response matrix was initially made to calibrate the quadrupole families, by averaging out the asymmetry in the matrix [2].

As compared to the empirical resonance correction, the response matrix approach has clearly the advantage of being more systematic, providing simultaneously information on the source of errors. Its disadvantages, on the other hand, would be that it generally requires time consuming processing, as well as being indirect. The latter may be a critical drawback in view of the reality where focusing errors vary non-negligibly from one machine operation to another, due to insertion device gap changes, or different beam fillings and chromaticities. In developing the response matrix approach, therefore, an effort was made to make it work *on line*.

2 METHOD

As done with *LOCO* [3], focusing errors are deduced by fitting the diagonal response matrix of the model to the measured, which is started in principle from a symmetrical optics solution. It has been found important to use the steerer calibration found in the averaged response matrix analysis. A linearised equation

$$\begin{bmatrix} R_{ij}^{(H)} - A_{ij}^{(H)}(\boldsymbol{Q}) \\ R_{ij}^{(V)} - A_{ij}^{(V)}(\boldsymbol{Q}) \end{bmatrix} = \begin{bmatrix} \dfrac{\partial A_{ij}^{(H)}(\boldsymbol{Q})}{\partial Q_{\boldsymbol{k}}} \\ \dfrac{\partial A_{ij}^{(V)}(\boldsymbol{Q})}{\partial Q_{\boldsymbol{k}}} \end{bmatrix} \bullet [\Delta \boldsymbol{Q}], \qquad (1)$$

where

$R_{ij}^{(U)}$: Measured response matrix
$A_{ij}^{(U)}$: Model response matrix
$\boldsymbol{Q}$: Array of quadrupole strengths
ΔQ_k : Required increment on k^{th} quadrupole

is solved iteratively with the SVD method until saturation.

To be able to work online, only partial steerers are used to measure the response matrix. One steerer family is selected from each plane, using 32 steerers totally. The acquisition of the partial matrix then takes roughly 20 minutes. The solution of Eq. 1 is made for each pair of horizontal and vertical steerers, in parallel with the acquisition, to shorten the processing time. The solution for a pair is then averaged over all 16 pairs. Once the optics is computed with the obtained solution, a special thousand-turn BPM system developed at the ESRF, called *MTBPM*s, is used to measure the beta asymmetry [4]. The two results are compared. Minimisation of the asymmetry is then made on the computer with quadrupole correctors. Usually, the rms beta deviations at BPM positions are minimised. One may instead minimise any combination of beta deviations and calculated half-integer and integer resonance stopbands [5]

$$\delta Q = \frac{1}{2\pi} \left| \oint ds\, k(s)\, \beta(s) \exp\left\{ -i \frac{n}{Q_0} \int_0^s \frac{du}{\beta(u)} \right\} \right| \qquad (2)$$

where

$k(s)$: Deduced focusing error [m^{-2}]
$\beta(s)$: Beta of the average model
Q_0 : Tune of the average model
n : 72,73 (hor), 28,29 (ver) for the standard optics

Strengths found for the quadrupole correctors are applied

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to the machine and a new measurement is made. The whole process is iterated until saturation.

3 RESULTS

Quadrupole error flags were introduced at every quadrupole magnet locations, counting 320 totally. A matrix of the dimension (2×224)⊗320 is solved, the dimension being identical to that used in the coupling analysis. To get the best result for the focusing errors, a full matrix was initially measured with all correctors turned off. Equation 1 was solved iteratively from a symmetrical optics by increasing the number of eigenvectors in steps. The optimal number was finally ~70, again in accordance with that the coupling analysis. The degree of fit, of the model matrix to the measured, is shown in Figs. 1, in comparison with the initial values defined by the symmetrical model. The resultant error distribution is displayed in Fig. 2.

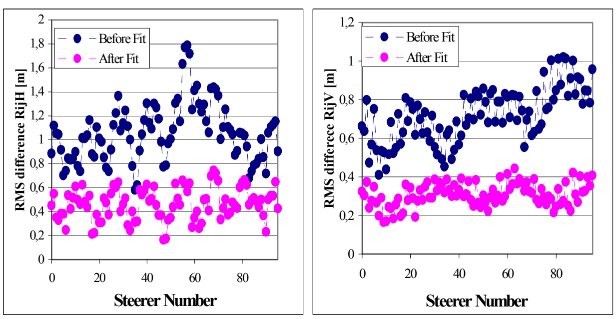

Figure 1: Difference of response matrix between the model and the measured. For a given steerer pair, rms is taken over all BPMs. Left: horizontal. Right: vertical.

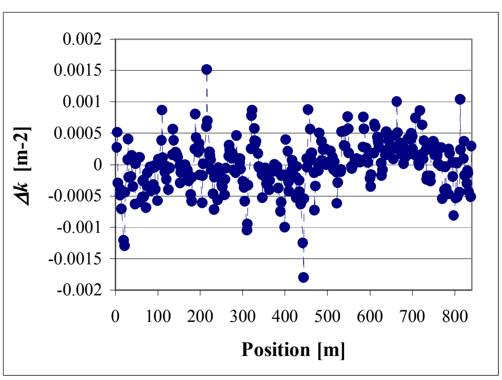

Figure 2: Obtained quadrupolar errors with the full response matrix. All correctors turned off.

The deduced errors have no distinction whether they come from the quadrupoles or displacement errors at the sextupoles. Taking nonetheless ratios of the errors to the quadrupole strengths at the same location, the majority is found to lie within 10^{-3}, though there are many peaks extending beyond 2×10^{-3} level. The corresponding beta asymmetry agrees well with that measured by *MTBPMs* (Figs. 3). The rms values of $\Delta\beta/\beta$ calculated at BPM positions are listed in Table 1. The same result could be obtained with the partial matrix described earlier. In the error distribution, however, there were some differences in the medium amplitude range, which suggest the limit of precision of the model. In fact, one confirms the importance, as in the coupling case, of averaging over different steerer pairs to eliminate singularities that may exist in individual pair solutions. Further numerical studies are needed to optimise the number of pairs used.

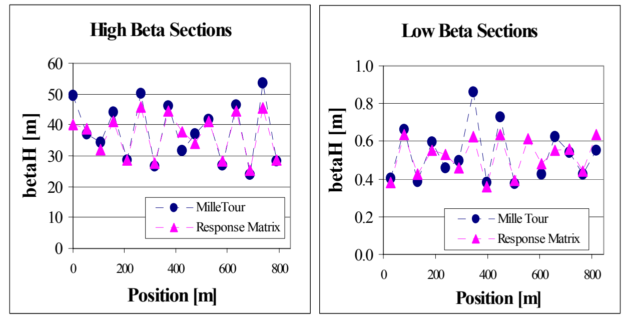

Figure 3: Beta asymmetry deduced with the response matrix and *MTBPMs*. All quad correctors are turned off.

As in the coupling correction, a large reduction on $\Delta\beta/\beta$ could be achieved on the first correction, especially in the horizontal plane, but after 2 iterations, the correction saturated (Fig. 4). The reason of saturation needs be clarified along with the fact that not much reduction was made in the vertical plane. Another undesirable feature met was the discrepancy between the two beta measurement, which started to appear after the first correction. As the resulting corrector strengths resembled those obtained by the resonance correction, one could also think that the best solution was obtained with the given corrector configuration. The best symmetry measured with *MTBPMs* are is listed in Table 1. Those calculated by the model were smaller and around 5% range. There was not much improvement vertically. The final rms values were only slightly lower than those achieved by the resonance correction.

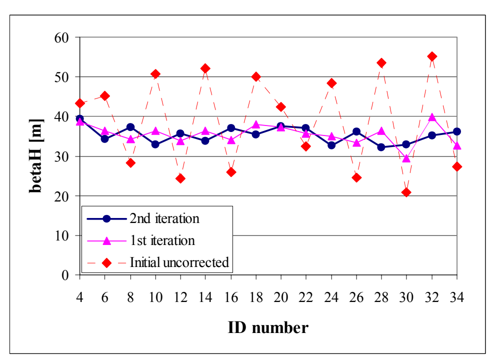

Figure 4: Horizontal beta at high β sections.

Table 1: $(\Delta\beta/\beta)_{rms}$ measured with *MTBPMs*:

	Uncorrected	After 3 iterations
Horizontal	29.4%	8.7%
Vertical	10.8%	9.7%

In the applied case, it was found that combining the resonance stopbands in the minimisation does not produce better results for the asymmetry correction. On the contrary, it was observed that the correction of $(\Delta\beta/\beta)_{rms}$ is directly correlated to minimising the stopband (Fig. 5). This is consistent with the fact that the two methods give similar solutions. The use of stopbands in the minimisation, of particularly higher orders, may be useful at a furthermore reduced level of asymmetry.

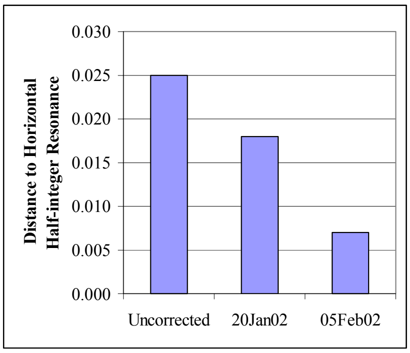

Figure 5: Measured horizontal half-integer resonance stopband versus the correction level.

4 EXTENSION

As it was done in the coupling correction with the response matrix and enabled a marked reduction in the coupling [1], we can make use the obtained knowledge on the focusing errors to study the gain in the asymmetry correction by introducing more correctors. In the present case, out of 36 available corrector positions in the machine, 16 were chosen uniformly without optimisation with respect to the error distribution.

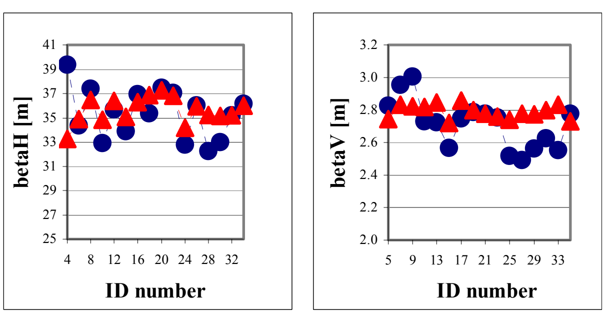

Figure 6: Predicted $\Delta\beta/\beta$. Circles: with the existing 16 correctors. Triangles: with 16 additional correctors.

The result of the correction indicated a reduction on $(\Delta\beta/\beta)_{\rm rms}$ by nearly a factor by two, namely from 4.6 to 2.6% horizontally, and from 4.5 to 2.1% vertically (Figs. 6). Better behaviour is found for the resulting corrector strengths as well, being weaker and more uniformly distributed (Fig. 7). A further investigation by optimising the number and the position of the correctors would be worthwhile.

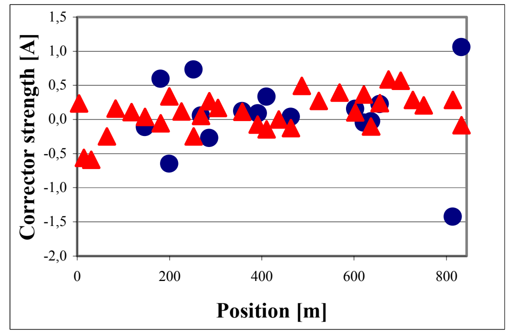

Figure 7: Distribution of corrector strengths. Circles: with the existing 16 correctors . Triangles: with 16 additional.

5 CONCLUSION

An online correction of the optical asymmetry was developed using the orbit response. Applying it to the ESRF machine, it managed to correct the asymmetry, within an acceptable time (a couple of hours) from scratch. Starting from the uncorrected values of 30% horizontally and 11% vertically, the final beta asymmetry of the model was nearly 5% in both planes. However, the correction saturated already after 2 iterations. Although it may as well be that we have reached the limit of correction with the present corrector configuration, the fast saturation resembles that encountered in the coupling correction with the response matrix. In the latter case, the saturation was due to the lack of precision and the correction had to be continued by an empirical minimisation. As an advantage of the present scheme, on the other hand, a numerical study could be performed, on the basis of the obtained focusing errors, to predict that the asymmetry could be further reduced by a factor of two by introducing more correctors.

6 ACKNOWLEDGEMENT

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7 REFERENCES

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