FULLY COUPLED ANALYSIS OF ORBIT RESPONSE MATRICES AT THE ALS*

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Abstract

In order to understand the current limitations of the dynamic (momentum) aperture it is essential to have a good model representing the realistic lattice. Since some years an analysis of measured orbit response matrices is used to calibrate the lattice model at the ALS. Measurements of the response matrices are carried out weekly. Recently the orbit response matrix analysis has been expanded to a fully coupled analysis. In order to keep the computation time needed for the coupled analysis of a complete response matrix in resonable limits a new algorithm to calculate the model response matrix elements was written. The modified code was successfully used to determine localized coupling strengths. Predictions of the calibrated, coupled model are in good agreement with the results of independent measurements of several machine parameters.

1 INTRODUCTION

The Advanced Light Source (ALS) is a third generation synchrotron light source located at Lawrence Berkeley National Laboratory [1] (see Tab. 1). Similar to the situation at all other third generation synchrotron light sources the single particle dynamics is an important factor which contributes to several performance limitations, the most important ones are injection efficiency and lifetime.

Table 1: Nominal ALS parameters.

Parameter	Description	
E	Beam energy	1.5–1.9 GeV
C	Circumference	196.8 m
ν_x	hor. tune	14.25
ν_y	vert. tune	8.20
ζ_x	hor. nat. chromaticity	-24.6
ζ_y	vert. nat. chromaticity	-26.7

To understand the limitations, it is essential to have a good model representing the realistic lattice. To calibrate the linear model of the ALS an analysis of measured orbit response matrices [2] is used (with the computer codes LOCO and TRACY II) [3]. In this analysis, theoretical orbit response matrices for different settings of the fit parameters are calculated with TRACY II. Then LOCO is used to fit the model response matrix (C^{ij}) to the measured one ($\hat{C}^{ij}$):

$$C^{ij}_{12} = \left[R^{ij}(1-R^{jj})^{-1}\right]_{12} - \frac{\eta_i \eta_j}{(\alpha - \frac{1}{\gamma^2})C}, \qquad (1)$$

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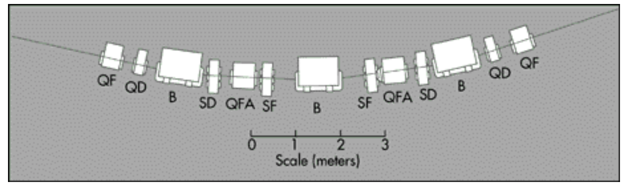

Figure 1: Schematics of one of the twelve triple bend achromats of the ALS.

where R^{ij} is the transfer matrix from corrector j to beam position monitor (BPM) i, R^{jj} is the one turn transfer matrix, η is the dispersion, α the momentum compaction factor, γ the Lorentz factor and C the circumference. The fit is performed using gradient errors (or other lattice parameters) δg_k and deviations in the BPM and corrector scaling factors from unity (Δx^i, Δy^j):

$$\hat{C}^{ij} = C^{ij} + \sum_k \frac{\partial C^{ij}}{\partial g_k} \delta g_k + C^{ij}\Delta x^i - C^{ij}\Delta y^j \qquad (2)$$

2 UNCOUPLED MODEL, LATTICE SYMMETRY

The measurement of a response matrix including all preparation times only takes about half an hour. Therefore it is carried out weekly to monitor long term changes of the lattice and to regulary restore the 12-fold symmetry of the lattice in order to keep a high injection efficiency and beam lifetime. In the analysis, the strength of all quadrupoles (Fig. 1 shows the schematics of the lattice magnets in one of the twelve ALS arcs) and a global strength of the quadrupole component of the gradient bends can be determined with a relative accuracy of about $1 \cdot 10^{-3}$. In addition the fit yields the relative gain factors of all correctors and all beam position monitors. So about 440 parameters are used to fit about 16,000 data points.

The results are well repeatable and independent measurements (e.g. beta functions, betatron tunes, momentum compaction factor, and dispersion) agree well with the same quantities deduced from the calibrated lattice model [4]. Fig. 2 compares the beta-beating before and after a symmetry correction. Prior to that correction the symmetry had not been corrected for about 4 months and due to swapping of power supplies (when repairing them after a failure), drifts in the lattice alignment and changes in the orbit, the beta beating had increased to a level where it reduces the lifetime at 1.5 GeV by about 10-15% and cuts the injection efficiency in half. The beta beating after a correction is small; about 2% in the horizontal and 3% in the vertical plane. A breaking of the lattice symmetry on this level does not have a significant influence on injection

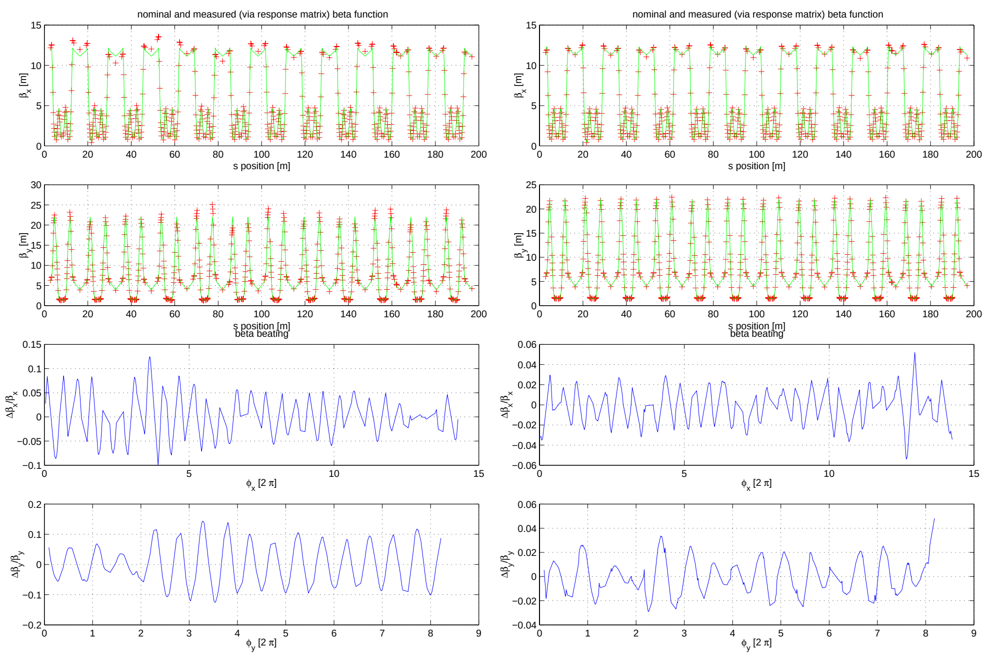

Figure 2: Comparison of beta beating after the lattice symmetry had not been corrected for about four months and the beating two weeks after a symmetry restoration (note the different vertical scales).

efficiency or beam lifetime.

3 COUPLED MODEL

The recent expansion of the response matrix analysis to a fully coupled analysis was mostly driven by two motivations. The first was to further refine our model for calculations of the single particle dynamics in the ALS. Later on this turned out to be not as important as we expected, since we could confirm with the simulation and measurement of frequency maps [5, 6], that the difference in the nonlinear dynamics for a lattice model with random coupling errors and a model with fitted coupling errors is small, as long as the one with random errors is adjusted to have the correct emittance coupling and the gradient errors are taken from a response matrix measurement. The second motivation is related to the upgrade of the ALS with the so called Superbends (C-shaped, superconducting, 5 T dipoles) [7]. In this upgrade, three normal conducting gradient dipoles will be replaced with Superbends in order to expand the capabilities of the ALS in the hard x-ray region. With the Superbends, the ALS will become more sensitive to coupling. Since the Superbends will increase the natural emittance, it is planned to operate with a lower coupling, in order to keep the brightness reduction for existing beamlines small.

3.1 Calculation Method

In order to keep the computation time needed for the coupled analysis of a complete response matrix using all 96 beam position monitors and 164 corrector magnets in reasonable limits a new algorithm to calculate the model response matrix elements was written. In the original approach to calculate coupled response matrizes LOCO used an external beam optics code (like MAD) to find a closed orbit for one corrector magnet at a time and repeat this for different settings of all lattice parameters to be adjusted. In the case of the ALS with 164 corrector magnets and about 155 coupled lattice parameters to be fitted simultaneously, this would require about 25,400 calculations of a closed orbit (in just one iteration). For a complete analysis of the ALS we need about two times six iterations. Including the singular value decomposition (SVD) this would sum up to several weeks of computation time.

Our approach to minimize the amount of tracking operations is to track particles at small transverse amplitudes to determine the transfer matrices and then calculate the theoretical response matrix using equation 1. This requires to calculate a closed orbit only once for every new setting of a lattice fit parameter, in our case 155 times in each iteration. In this way, we need about two days of computation time for all 12 iterations. The algorithm is not fully optimized yet, since it still calculates every transfer matrix for every setting of the fit parameters.

To distinguish between the distortions coming from quadrupoles and the ones caused by orbit offsets in sextupoles for each model fit two orbit response matrices are analyzed. One is measured with all sextupoles switched off and the other one with nominal lattice settings. Using some care in the decision which singular values to use and which ones to discard in the SVD it was possible to determine not only all gradient errors and horizontal orbit offsets in sextupoles, but also localized skew errors and vertical orbit offsets. However, the error of the values for the individual skew strengths is difficult to determine. Qualitatively, it is at least significantly larger than the error in the determina-

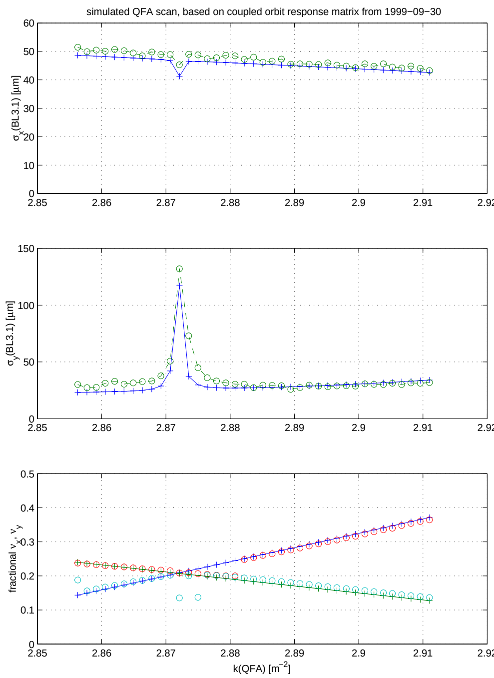

Figure 3: Comparison of predicted (crosses) and measured (circles) beamsizes for a scan of one quadrupole family.

tion of the normal gradient errors.

3.2 *Model Predictions and Measurements*

The best test to evaluate the quality of the calibrated model is to check its predictions against independent measurements (e.g. emittance coupling, closest tune approach, vertical dispersion, beam size changes when changing lattice parameters). Fig. 3 shows a comparison of beam size measurements with calculations based on the calibrated machine model during a scan of the quadrupole strength of one family (QFA). The agreement is very good. In fact, the beamsizes at the nominal settings of the lattice (the center of the plot) differ by only 3%.

In Fig. 4, measured and calculated horizontal and vertical dispersion functions are compared. The qualitative agreement is good and the rms values are fairly close to each other. Additional tests included the verification of the dynamic aperture calculated from the calibrated model and the comparison of a simulated frequency map with a measured one [5, 6].

4 SUMMARY

The uncoupled analysis of orbit response matrices is used as a routine tool at the ALS to calibrate the machine model for simulations, to monitor long term drifts of the lattice and to periodically restore the 12-fold symmetry in order to keep a high injection efficiency and good lifetimes. The codes used for this analysis have been modified in order to reduce the computation time needed for a coupled analysis. This allowed the analysis of complete, fully coupled response matrices with a reasonable computation time. The

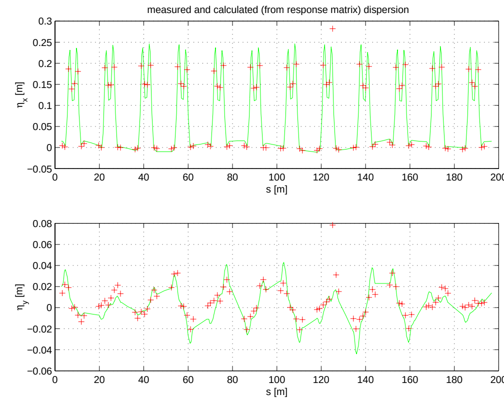

Figure 4: Comparison of the predicted (solid lines) and measured (crosses) horizontal and vertical dispersion function.

results show, that local coupling errors can be determined and the predictions of the calibrated, coupled model agree well with measurements. After the installation of the Superbends, this method will be applied to locally correct for coupling and vertical dispersion.

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REFERENCES

[1] 1-2 GeV Synchrotron Radiation Source Conceptual Design Report, LBNL publication *PUB-5172 Rev.* (1986)

[2] J. Safranek, "Experimental Determination of Storage Ring Optics using Orbit Response Measurements", BNL note 63382 (1996)

[3] Robin, D., Safranek, J., Decking, W., "Realizing the benefits of restored periodicity in the advanced light source", Phys. Rev. ST Accel. Beams 2 044001 (1999)

[4] D. Robin, C. Steier, J. Safranek, W. Decking, "Enhanced Performance of the Advanced Light Source through Periodicity Restoration of the Linear Lattice", these proceedings

[5] Robin, D., Steier, C., Laskar, J., Nadolski, L., "Global Dynamics of the Advanced Light Source Revealed through Experimental Frequency Map Analysis", accepted to *Phys. Rev. Let.*, (2000)

[6] C. Steier et al., "Lattice Model Calibration and Frequency Map Measurements at the ALS", these proceedings

[7] D. Robin, et al., "Status of the Superbend Project at the Advanced Light Source", these proceedings