Modeling/debugging the ALS lattice

Christoph Steier
Accelerator and Fusion Research, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

In order to ensure reliable and consistent operation of the machine it is essential to have an accurate magnetic lattice model that represents the current of the accelerator. For the past several years we have been calibrating our magnetic model by analyzing measured orbit response matrices (using the computer codes LOCO and TRACY II). The response matrix relates the change in position of the beam orbit with a change in strength of a corrector magnet. The measurement of a response matrix including all preparation times only takes about one hour. Therefore it is carried out weekly to monitor long term changes of the lattice and to regularly restore the 12-fold symmetry of the lattice in order to keep a high injection efficiency and beam lifetime.

The response matrix has about 16,000 data points. To fit these data points usually the strength of all quadrupoles, a global strength of the quadrupole component of the gradient bends, and the gain factors of all correctors and all beam position monitors are adjusted (about 440 parameters in all). The results are very 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. Recently the orbit response matrix analysis has been expanded to a fully coupled analysis.

Figure 1 shows the beta functions as calculated from two calibrated machine models (derived from two orbit response matrix measurements) before and after a correction of the quadrupole strengths has been applied in order to restore the 12-fold symmetry of the ring. Before correction the beta beating (deviation of the beta function from its nominal value) before the correction was larger than 10 % in both transverse planes. At these values the injection efficiency of the ALS was already strongly reduced (by about one half) and the lifetime at 1.5 GeV was significantly reduced. In addition the source sizes at the user beamlines were distorted since both the beam size and the beam divergence depend on the beta function.

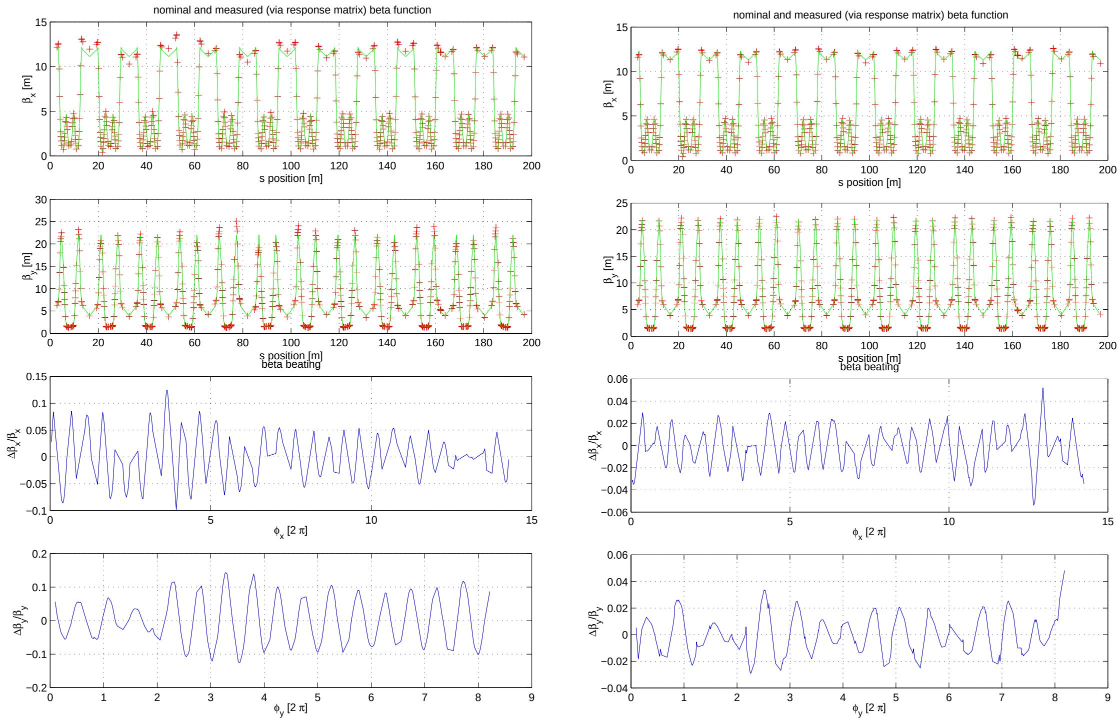

Figure 1. Beating (deviation from the ideal values) of the beta functions in the ALS before and after a correction based on the results from an orbit response matrix analysis.

After the correction the beta beating is reduced to 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 efficiency or beam lifetime.

To distinguish between the distortions coming from gradient bends and 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. It was possible to determine not only all gradient errors and horizontal orbit offsets in sextupoles, but also skew errors and vertical orbit offsets.

To evaluate the quality of the calibrated model including coupling terms several calculations and measurements were performed. The best test is to check predictions from the calibrated model against independent measurements (e.g. emittance coupling, closest tune approach, vertical dispersion, beam size changes when changing lattice parameters). Figure 2 shows such a comparison for beam size measurements conducted at Beamline 3.1 (the diagnostic beamline of the ALS) during a scan of the quadrupole strength of one family (QFA). Additional tests included the verification of the dynamic aperture calculated from this model and the comparison of a simulated frequency map with a measured one (see the section about frequency map measurements).

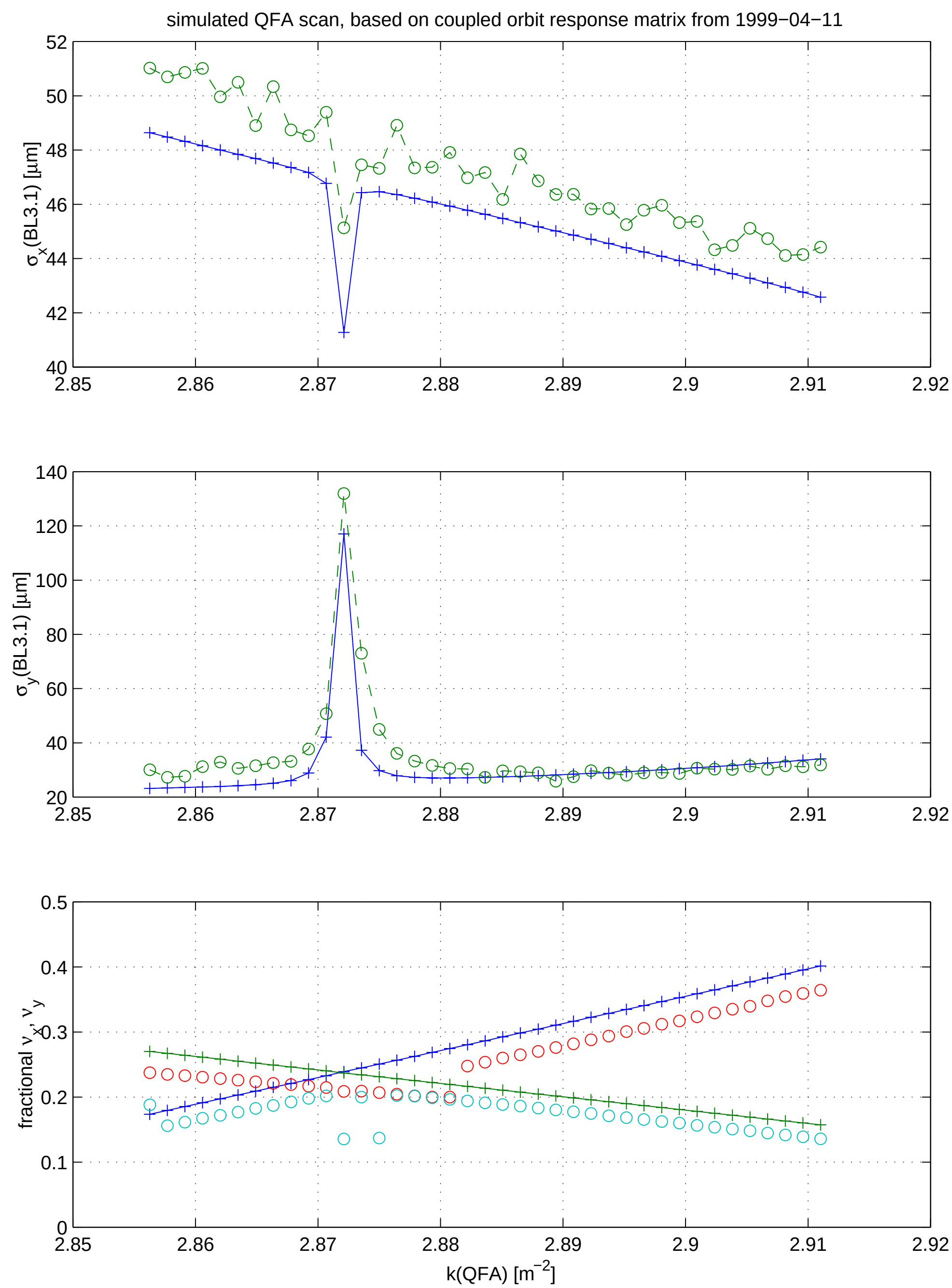

Figure 2. Comparison of the prediction of beam sizes and betatron tunes from a lattice model fit to the coupled orbit response matrix and a measurement at Beamline 3.1.

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Contact person: Christoph Steier, Accelerator and Fusion Research Division, Ernest Orlando Lawrence Berkeley National Laboratory. Email: CSteier@lbl.gov. Telephone: (510) 495-2992.