MODELING THE LOW-ALPHA MODE AT ANKA WITH THE ACCELERATOR TOOLBOX

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Abstract

The ANKA storage ring is operated frequently with low momentum compaction lattices to produce short bunches for the generation of coherent synchrotron radiation in the THz range. The bunch length can be varied in steps from one centimeter down to the sub-millimeter level. These low-alpha optics were modeled by using the Matlab based tools Accelerator Toolbox (AT) [1] and LOCO (Linear Optics from Closed Orbits) [2]. The calculations are compared with beam based measurements such as orbit response matrices, dispersion and chromaticity. This paper presents results and discusses the challenges with modeling beam optics in the low-alpha regime.

INTRODUCTION

The production of coherent synchrotron radiation (CSR) drastically increases the radiation power of frequencies in the far infrared / THz range. To enable CSR emission, the bunch length has to be shorter or equal to the requested radiation wavelength. In a storage ring a reduction of the linear momentum compaction factor α_0 is used to achieve this. Resulting from a low linear α_0, the higher order terms become more significant and cannot be neglected any more. The Accelerator Toolbox in combination with LOCO was used to obtain a low-alpha optics model in good agreement with measurements. Response matrix fits were applied to correct for quadrupole strength variations and beam position monitor (BPM) and corrector magnet (CM) imperfections. Furthermore beam parameters such as betatron tunes and chromaticities were compared to measurements to correct the models for multipole components in the magnets.

THE ANKA STORAGE RING

ANKA is a storage ring light source with a circumference of 110 m. It consists of 8 double bend achromat (DBA) cells containing 5 quadrupole and 2 sextupole families. Two DBAs together, separated by a short straight section, form one sector. The four RF-cavities are installed in pairs within these short straights. Presently three of the four long straights, dividing the sectors, contain insertion devices.

During ANKA commissioning, magnetic field measurements were made of one dipole, one quadrupole and one sextupole respectively for each family under various current settings. Resulting from these measurements, the magnet strength for a given current can be estimated by polynomial interpolation.

Low-Alpha Optics

In order to reduce the initial bunch length [3], short bunch operation is performed at a lowered beam energy of 1.3 GeV instead of 2.5 GeV, the energy during normal user operation. The electrons are injected with 0.5 GeV in standard optics and ramped up to 1.3 GeV. Then the optics is changed in steps to reduce the bunch length further.

Five different lattice configurations with decreasing momentum compaction were studied in detail:

Table 1: Investigated Optics

	measured f_s	**model α_0**
A	30.7 kHz	8.5×10^{-3}
B	29.2 kHz	7.8×10^{-3}
C	24.2 kHz	5.7×10^{-3}
D	8.5 kHz	0.74×10^{-3}
E	6.7 kHz	$0.46 \cdot 10^{-3}$

MEASUREMENTS

For all optics quoted in Tab. 1, a full set of measurements were done, consisting of:

- Tunes at the central frequency: Q_x, Q_y, Q_s
- Orbit response matrix at the central frequency
- Dispersion
- Chromaticity

Since measurements of the magnetic fields at a beam energy of 1.3 GeV are not available, multipole corrections of the magnets have to be determined by calculations, which will be discussed in the following sections.

MODELING

Beginning with the magnet strength calculated from the values of the current settings, a bare model for all of the five lattices was built in AT. Comparing model tunes and chormaticities with the measurements, a substantial difference was revealed and had to be improved by the following modifications in the model.

Response Matrix Fits

The measured orbit response matrix and dispersion was used as data input for LOCO and taken as basis for the model adjustment. Besides the quadrupole strength, the effective CM kick and coupling and the BPM gain were fitted.

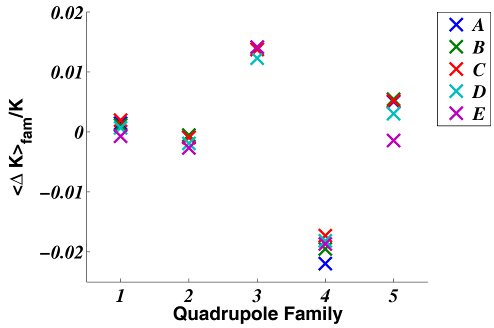

Figure 1: Average relative change in quadrupole strength from LOCO fit for model A-E (initial values: $K \approx \pm 2$)

Looking at the average change in quadrupole strength $\langle \Delta k \rangle$ per family (Fig. 1), quadrupole family 1, 2 and 5 seem to behave as expected. Whereas family 3 and 4 show a deviation of about 1.5% and 2% respectively w.r.t. the initial value.

Chromaticity and Tune Fits

In order to improve chromaticity and tune matching, small multipole components were added:

- quadrupole components in the sextupoles
- quadrupole components in the dipoles
- octupole components in the dipoles

Higher pole effects - such as quadrupole components in dipoles - come about due to fringe fields, magnetic imperfections and also by the feed down effect caused by an off centered orbit. Their strengths were determined by a χ^2-fit taking all three tune values and the shape of the chromaticity functions into account. The identified effective quadrupole strength in the sextupoles are about 10% to 20% of those of the quadrupoles. The corrections in the dipoles were even smaller, about 1% for the quadrupole strength and no significant octupole component could be seen.
Finally the strength of the sextupoles themselves were adjusted to fit not only the curves' shape but also the magnitudes of the chormaticity. As Fig. 2 shows, the sextupole

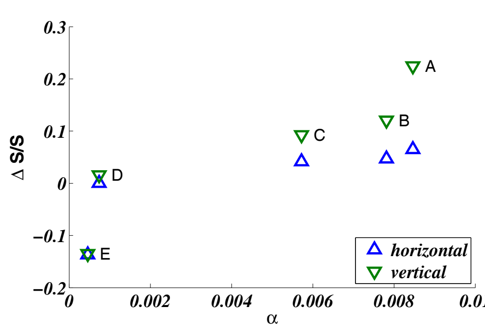

Figure 2: Relative change in sextupole strength to match chromaticity for models A-E (initial values: $S \approx \pm 25$)

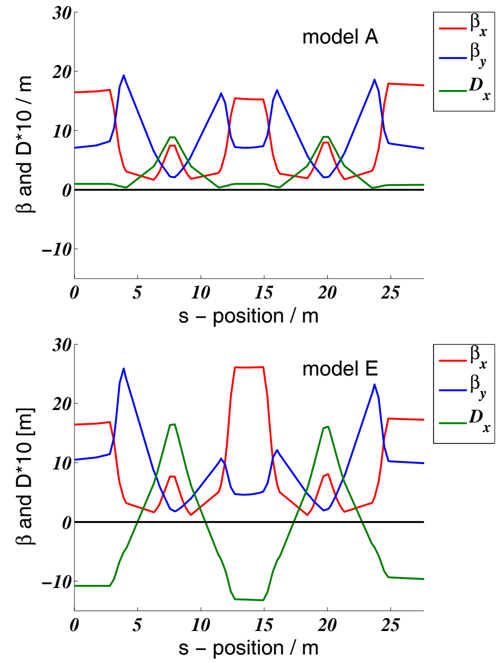

Figure 3: Beta functions and dispersion, model A and E

strengths had to be varied by about 10%.
As an example, the resulting optics functions for model A and E are shown in Fig. 3.

COMPARISON

After the adjustments discussed in the previous section, betatron and synchrotron tunes are closer to measured values (Fig. 4 and Fig. 5). The largest difference occurs in the horizontal betatron tune for the optics with higher α_0, but the model value could only be improved at the expense of the other tunes and the chromaticities. Since the synchrotron tune is connected directly to the momentum compaction the emphasis for modeling a low-alpha lattice was on improving this agreement. The best agreement is reached for the two optics with the lowest α, e.g. tunes and dispersion match nearly exactly.
In Fig. 5 measured and calculated synchrotron tunes are

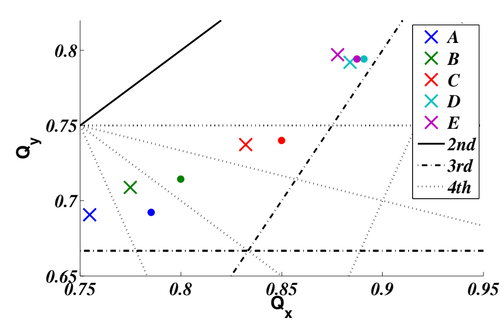

Figure 4: Tune space with resonance lines of different orders. ×: model, ●: measurement

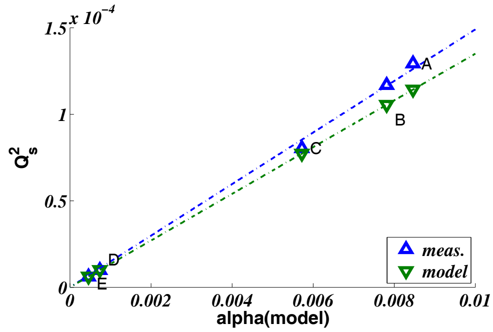

Figure 5: Squared synchrotron tune for models A-E as function of model α

displayed as function of the model momentum compaction factor. For linear approximation the square of the synchrotron tune and the momentum compaction factor should be proportional: $Q_s^2 \propto \alpha$, which is reproduced by the model. However, the measured synchrotron tunes for models A to C lie above the predicted values. That suggests, that the calculated alpha is lower than it was during the measurements, which can be explained by the uncertainty of the effective RF-voltage. The model tunes for different α follow the power law mentioned above with a high precision. Hence an impact from higher order terms does not seem to be described by the AT calculations.

The choice of alpha also effects the comparison of the dispersion (Fig. 6) since we can only estimate the change in beam energy from the change of RF-frequency. Here again, models D and E resemble the measurements best. An underestimated alpha could explain the difference between measurement and calculation for model A.

Fig. 7 shows comparison between measured and fitted chromaticity Q'. The vertical chromaticity is nearly linear which is well reproduced by the models. The largest differences in horizontal chromaticity occur in models C and D. For model D and E a wide variation of RF-frequency was not possible since a small frequency change results in a large energy change for low momentum compaction factors. This reduces the sensitivity of the fits and hence the possibility to distinguish exactly the higher multipoles in the magnets.

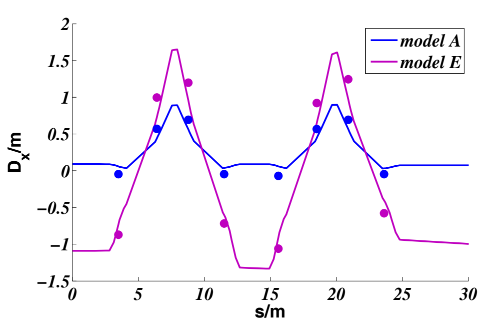

Figure 6: Comparison of measured and model dispersion of one sector for models A and E

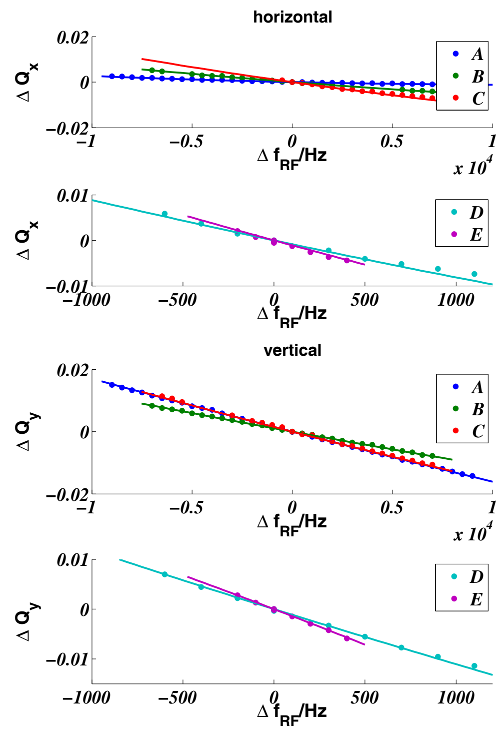

Figure 7: Comparison of measurend and model chromaticity

SUMMARY

Measurements and lattice calculations for five different optics with decreasing momentum compaction factor were studied. After the adoption of additional multipole components in the sextupoles and dipoles, measured and model tunes, dispersions and chromaticities agree reasonable within the uncertainties. Since detailed measurements of the magnetic field of the different magnets at a beam energy of 1.3 GeV do not exist, these calculations are the only way to get insight and provide the basis for further detailed investigations.

Especially the determination of α_0 by these models has a big importance since it is the key parameter for understanding and simulating CSR emission.

An influence on the synchrotron tune value from the higher order alpha terms can not be seen within AT. This raises the question if other calculation tools could exceed this or if the linear part is still dominant.

REFERENCES

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[3] A.-S. Müller et al. "Far Infrared Coherent Synchrotron Edge Radiation at ANKA", PAC 2005