LINEAR AND NONLINEAR OPTICS STUDIES IN THE ANKA STORAGE RING

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Abstract

The ANKA electron storage ring operates in the energy range from 0.5 to 2.5 GeV. In order to improve machine performance a precise modelling of linear and nonlinear optics is mandatory. At the maximum energy, the dipole magnets show multipolar components due to saturation effects. A new optics model should take higher order fields of the installed magnets into account. In the framework of the model upgrade, extensive optics studies have been done, including a study of the beta function beating and a measurement of higher order chromaticity. Furthermore an energy calibration of the storage ring was done.

INTRODUCTION

ANKA is an electron storage ring for synchrotron radiation located at Forschungszentrum Karlsruhe, Germany (see for example [1]). It is operated in the energy range from 0.5 (injection) to 2.5 GeV (user operation). For a better understanding of the machine the linear and nonlinear optics model was revised. Information about the linear optics can be extracted from "classical" measurements of the β-function and from measurements of the orbit response matrix. At top energy the dipole magnets are close to saturation which causes nonlinear field components that should be accounted for in a model. Field maps of the higher orders do not exist for the exact beam energy, only for slightly lower excitation currents where the saturation is already 7% [2]. Beam based measurements must therefore be used to extract the effective multipolar fields acting on the beam.

β-FUNCTIONS, GRADIENTS AND THE ORBIT RESPONSE MATRIX

Optics Determination from the Response Matrix

The measured orbit response matrix (ORM), reflecting the change in orbit at beam position monitors (BPMs) with changes in the excitation of orbit corrector dipoles, contains a multitude of precise data points imprinted with the focusing structure of the storage ring. The LOCO program [3] provides an elegant way to extract information about the linear optics of the storage ring from the ORM.

Among the fit parameters in LOCO is the strength of the individual corrector kick. The individual strength for all horizontal and vertical corrector magnets resulting from the ORM analysis are shown in Fig. 1 for the same setting of the excitation current. Because of (geometrical) interferences with the ANKA storage ring vacuum chamber, eight

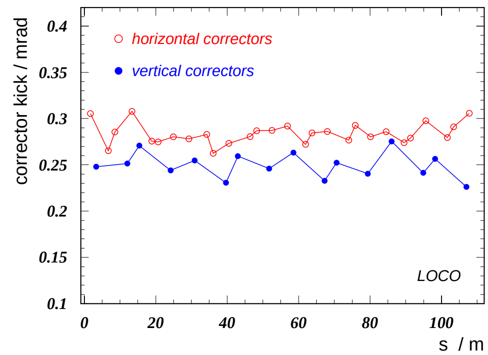

Figure 1: Strength of horizontal and vertical orbit corrector magnets for the individual correctors at the same excitation current. The alternating strength of the vertical correctors is clearly visible.

of the 16 vertical orbit correctors have a different layout. This results in a loss of about 10% of the steering capability for every second corrector. As can be seen in Fig. 1 this alternating structure is nicely reproduced by LOCO. Also the results showed slightly larger kicks for a given excitation than previously assumed. A new corrector calibration based on recent field measurements and the inclusion of fringe fields in the corrector dipoles explain this effect (see listing of average corrector kicks in Tab. 1). Including the new corrector calibration in the ANKA control system has improved the speed of convergence of the orbit correction.

The normalised quadrupole gradients averaged within each of the five families found by LOCO are displayed in Fig. 2. The error bar is a measure for the scatter of the individual gradients within a family. The gradients derived from magnetic measurements under the assumption of the nominal beam energy of 2.500 GeV and for a lower energy (2.477 GeV) are also shown. With respect to the nominal energy gradients, the values extracted from the ORM are systematically increased by about 1 %. This could be explained if the true beam energy was about 1 % lower than its nominal value: The gradients from magnetic measure-

corrector	old	new	meas.
horizontal	0.19	0.26	0.28
vertical	0.21	0.25	0.25

Table 1: Average corrector kicks for a given excitation current for old calibration, new calibration with inclusion of fringe field in the field integral and the effective kicks found by LOCO. All corrector kicks are given in mrad.

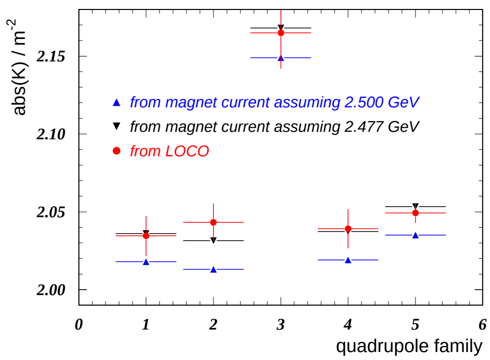

Figure 2: Normalised quadrupole gradients for the five families. Gradients derived from magnetic measurements are shown for a beam energy of 2.500 GeV, for the (true) beam energy of 2.477 GeV as well as those obtained with the LOCO program [3]. For the latter, the error bar is a measure for the scatter of the individual gradients within a family.

ments for the lower energy show a much better agreement with the ORM results. To verify this deviation in beam energy an energy calibration was done using resonant depolarisation (RDP) [4]. As a measure for polarisation change, the Touschek loss rate dependence on electron beam polarisation was used [5, 6]. For RDP, the beam energy is determined by slowly varying the frequency of the depolariser field with time over a given frequency range. If a depolarisation occurs during such a scan, the loss rate will increase suddenly and the beam energy can be determined from the corresponding frequency. The true beam energy could be confirmed to be (2.4774 ± 0.0001) GeV which is in good agreement with the findings from LOCO.
Figure 3 shows an example for depolarisation scans at different RF frequencies (and therefore energies). Using

$$\alpha_c \;=\; -\,\frac{f_{\rm RF}-f^c_{\rm RF}}{f^c_{\rm RF}}\,\frac{E_c}{E-E_c}$$

where $f_{\rm RF}$ is the RF frequency, E the beam energy and the index c stands for energy and frequency at the central orbit, allows to extract an estimate for the momentum compaction factor α_c from the measurements at different RF

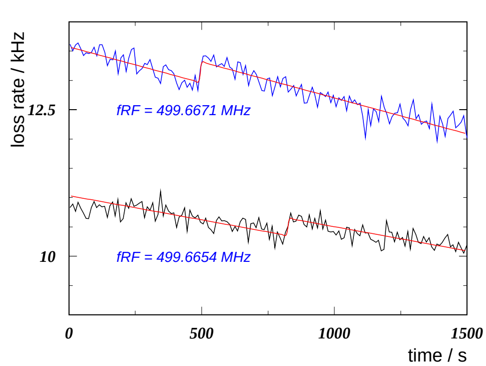

Figure 3: Loss monitor counting rate during two scans of the depolariser frequency at different RF frequencies. The shift in depolarising frequency and therefore in energy is clearly visible

frequencies: $\alpha_c \;=\; (7.1 \pm 0.1) \cdot 10^{-3}$. The quoted uncertainty is based on a frequency uncertainty of 10 Hz. This value is in good agreement with the theoretical value obtained from the MAD program [7] with the LOCO derived linear optics model of $7.2 \cdot 10^{-3}$.

Measurement of the β-Function

The β-function is measured by detecting the shift of the betatron tune, $\Delta Q_{x,y}$, resulting from a change in the strength of an individual quadrupole magnet, Δk. Alternatively to this *local* measurement, the β-function can also be derived from the change in the strength of an entire quadrupole family (*global* measurement). Far from half integer and integer resonances and for small changes in tune, the β-function can be estimated from the well known relation

$$\beta_{x,y} \approx \pm 4\pi \Delta Q_{x,y} / \Delta k$$

Figure 4 shows the horizontal and vertical β-function as a function of longitudinal coordinate in one sector. The symbols show local and global measurements, the curves represent the optics model. Global and local measurements are in reasonable agreement. Residual differences between the measurements and the theoretical model could arise from small tune shifts caused by not fully compensated changes in the closed orbit: if the change in quadrupole strength alters the orbit in sextupole magnets, a change in tune results.

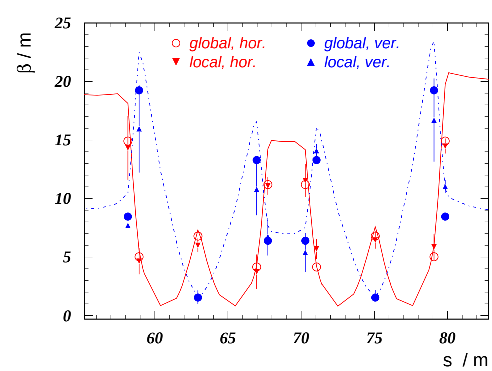

Figure 4: Horizontal and vertical β-function as a function of longitudinal coordinate in sector 3. The symbols show local (gradient variation of individual quadrupole) and global (gradient variation of quadrupole family) measurements. The curves represent the optics model derived from LOCO [3].

CHROMATICITY MEASUREMENTS AND MODELLING

To gain information about nonlinear magnetic field components, the horizontal and vertical tunes are measured as a function of a momentum deviation produced by appropriate changes in the RF frequency. A parabolic fit yields the effective linear and nonlinear chromaticities according to

$$Q_{x,y} = Q_{0\ x,y} + Q'_{x,y}\left(\frac{\Delta p}{p}\right) + \frac{1}{2}\,Q''_{x,y}\left(\frac{\Delta p}{p}\right)^2 .$$

Figures 5 and 6 show examples of such measurements for different sextupole currents. The solid curves are fits of the previously mentioned parameterisation to the measurements. It is easily visible that a modelling up to the second order is sufficient to describe the data. As a first approach the strengths of the existing sextupole magnets are fitted to reproduce the measured parameters. For this the STATIC command of the MAD program [7] is used. The results of these fits can be seen as dashed curves in Fig. 5. Obviously the behaviour cannot be understood from sextupolar fields only. The measurements seem to suggest the presence of octupolar fields. Those octupolar components could for example be generated by a decapole component in the bending dipole field with an offset. To test the assumption of the presence of octupoles, virtual nonlinear elements were inserted in the machine model in the form of thin multipoles at entry and exit of each dipole magnet. The strength of those virtual octupoles was than adapted to fit the measured data. The results are displayed as dash-dotted curves in Fig. 5 which fit the measurements nicely. The virtual octupoles at both ends of a dipole were found to be of approximately equal size and opposite sign.

For a change in sextupole strength (Figures 5 and 6) the first order chromaticity is changed whereas the second order chromaticity stays almost the same. This is a further confirmation of the presence of higher order nonlinear components.

SUMMARY

Detailed studies have shown that at the highest magnet currents the beam energy is lower by about 1% than expected. This was diagnosed indirectly by extracting the normalised quadrupole gradient using LOCO to analyse measurements of the orbit response matrix, and confirmed independently by resonant depolarisation. A closer investigation of the chromaticities indicates that higher order multipole components, possibly related to saturation effects in the dipole magnets, may be the reason.

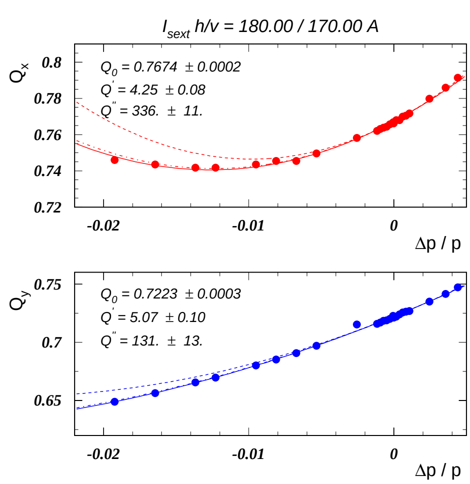

Figure 5: Tune as a function of momentum deviation. The upper plot shows the horizontal, the lower plot the vertical tune. The solid curves are parabolic fits whose parameters are quoted. The dashed curves are best fits with sextupoles only, the dash-dotted curves that almost coincide with the parameterisations are best fits with sextupoles and assumed octupolar components.

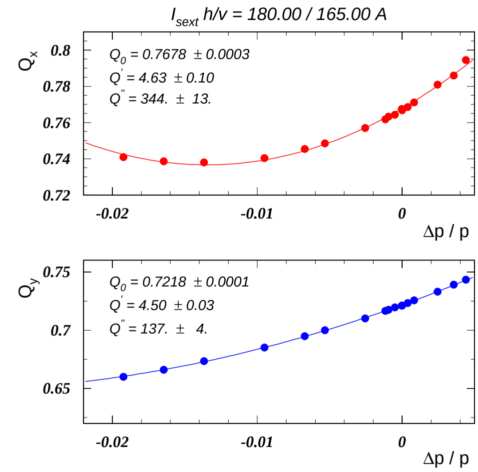

Figure 6: Tune as a function of momentum deviation. The upper plot shows the horizontal, the lower plot the vertical tune. The solid curves are parabolic fits whose parameters are quoted. In contrast to Fig. 5 the vertical sextupole strength was modified. It is clearly visible, that whereas the first order chromaticity changes, the second order stays almost constant.

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