MOMENTUM COMPACTION FACTOR AND NONLINEAR DISPERSION AT 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. Apart from higher order chromaticity also momentum compaction factor and dispersion have to be controlled. In this framework, the higher order momentum compaction factor has been determined exploiting the extraordinary precision of the resonant spin depolarisation method. Furthermore the nonlinear horizontal dispersion was measured as a function of the momentum deviation for different chromaticities. This paper discusses the experimental results and compares the findings to simulations.

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). At top energy the ANKA dipole magnets are close to saturation which causes nonlinear field components to appear. For a better understanding and eventual improvement of the machine performance, the linear and nonlinear optics has to be understood in detail. Figure 1 shows the regular ANKA optics in the first quadrant of the storage ring. Horizontal and vertical β functions are shown as well as the dispersion for $\Delta p/p = 0$. Beam based measurement methods have been employed to assess multipolar terms that show up e.g. in the higher order chromaticity. A parabolic fit to the measured horizontal and vertical tunes as a function of a momentum deviation produced by appropriate changes in the RF frequency yields the effective linear and nonlinear chromaticities according to

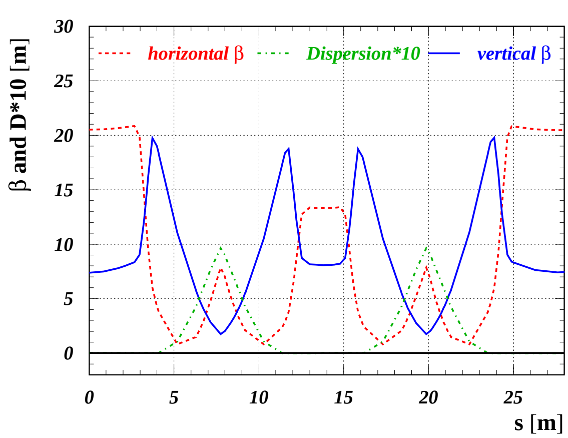

Figure 1: Horizontal and vertical β function and dispersion for $\Delta p/p = 0$ for one quarter of the ANKA storage ring. The dispersion has been scaled by a factor of 10 for better visibility.

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

The relative change in beam momentum, or rather in beam energy $\Delta p/p$ is given by

$$\frac{\Delta p}{p} = -\frac{1}{\alpha_c}\frac{(f_{\rm RF} - f^c_{\rm RF})}{f_{\rm RF}} \quad (2)$$

where f_{RF} is the frequency of the RF system, f^c_{RF} the central frequency and α_c the momentum compaction factor. Figure 2 shows an example of such a chromaticity measurement. The solid curves are fits of the previously mentioned parameterisation to the measurements. It is easily visible

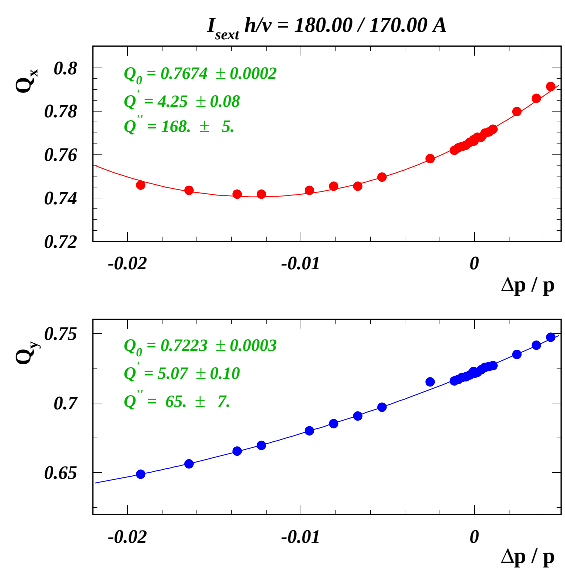

Figure 2: Measurement of the horizontal and vertical chromaticity. The points are measurements, the curves are fits to the measured data. The nonlinear shape clearly indicates the presence of higher order nonlinear terms like octupoles [2].

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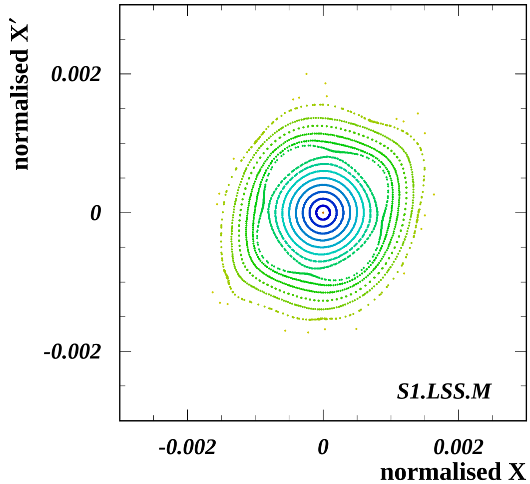

Figure 3: Horizontal phase space in the middle of the first long straight section generated with the MAD program [3] for the full nonlinear ANKA optics model.

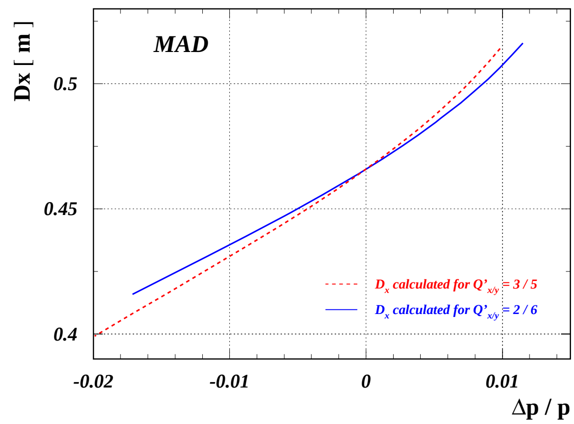

Figure 4: Horizontal dispersion as a function of momentum deviation as calculated by the MAD program for two different sets of horizontal and vertical chromaticities. The calculation was done for a beam position monitor located in a dispersive region in the storage ring. The nonlinearity of the dispersion in momentum deviation is clearly visible. There seems to be a divergence of the the dispersion for large positive $\Delta p/p$.

that a modelling up to the second order is sufficient to describe the data. The results for this particular measurement are quoted in Fig. 2.

Figure 3 shows a phase space portrait in normalised coordinates of the regular ANKA storage ring optics generated with the MAD program [3]. The phase space map indicates the presence of fourth order resonance regions for horizontal displacements corresponding to about 4 mm in physical phase space. This seems to agree with the observations during scans of the beam lifetime as a function of momentum deviation where the lifetime decreases suddenly for relative momentum deviations larger than $+1\%$.

NONLINEAR DISPERSION

In the framework of the storage ring optics modelling, the momentum dependence of the dispersion function has been investigated. Figure 4 shows the horizontal dispersion as a function of momentum deviation calculated with MAD for two different sets of horizontal and vertical chromaticities at a beam position monitor located in a dispersive region in the storage ring. The calculations for a beam position monitor in a non-dispersive region are displayed in Fig. 5. The nonlinearity of the dispersion in momentum deviation is clearly visible for both cases. It is interesting to note that the dispersion seems to diverge for values of $\Delta p/p > 1\%$ which corresponds to the observations during the lifetime scans. It is also clear from Figures 4 and 5 that a change in chromaticity influences the nonlinearity of the dispersion.

The MAD computations have been compared to measurements for the same sets of chromaticities. To improve the significance of the curvature terms, the averages over all beam position monitors in either dispersive or non-dispersive regions are considered. Figure 6 and Fig. 7 show the measured dependencies of the dispersion on momentum deviation. The MAD calculations are also shown.

Although the MAD calculations seem to reproduce the general behaviour of the measurements, there are clear differences in the higher order terms that need to be understood. A detailed study of this phenomenom is still pending.

MOMENTUM COMPACTION FACTOR

As the momentum compaction factor α_c describes the relation between relative change in RF frequency (or orbit length) and energy change (Eq.(2)) it enters in most studies of momentum dependent behaviour. To ascertain that observed nonlinear effect really are caused by the phenomenom being studied, it is imperative to understand the

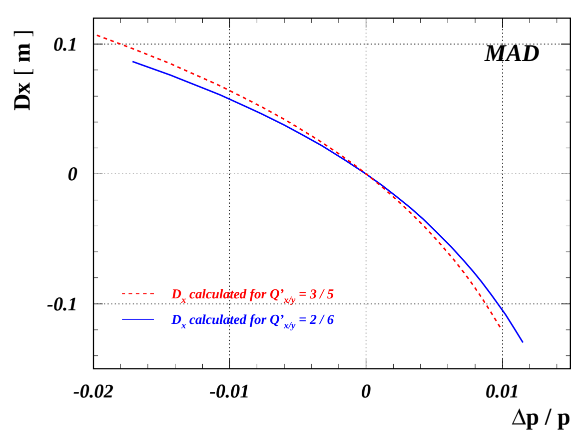

Figure 5: Horizontal dispersion as a function of momentum deviation as calculated by the MAD program for two different sets of horizontal and vertical chromaticities. The calculation was done for a beam position monitor located in a non-dispersive region in the storage ring. Again the divergence of the the dispersion for large positive $\Delta p/p$ is pronounced.

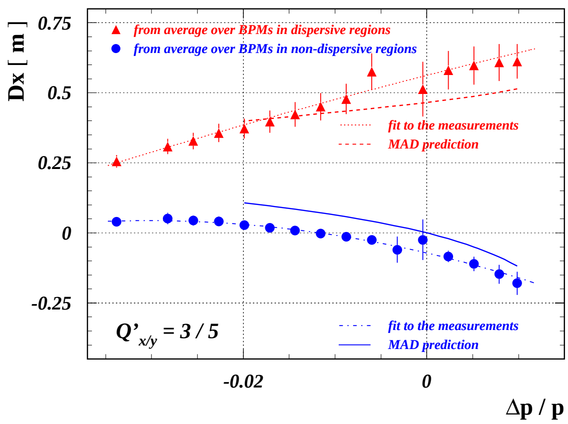

Figure 6: Horizontal dispersion as a function of momentum deviation obtained by changing the RF frequency for a horizontal chromaticity of 3 and a vertical chromaticity of 5. Measurements derived on the observation of the average horizontal closed orbit shift for beam position monitors in dispersive (triangles) and "non-dispersive" sections are shown as well as calculations with the MAD program are shown. The error bars reflect the scatter of the beam position measurements at different locations in the storage ring for a given momentum deviation.

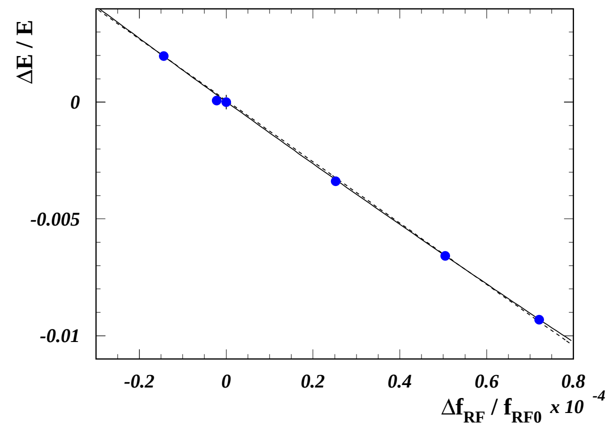

Figure 8: Relative energy change determined with resonant electron spin depolarisation [4] as a function of relative change in RF frequency. The dashed line is a straight line fit to the measurements, the solid curve a parabolic fit.

momentum dependence of α_c itself. This dependence can be quantified by direct measurements of the beam energy for different RF frequencies. The method of choice for the energy determinations is the resonant electron spin depolarisation [4] which allows absolute measurements of the beam energy with an intrinsic precision of the order of $2 \cdot 10^{-5}$. Figure 8 shows such a set of measurements. The dashed line is a straight line fit to the measurements, the solid curve a parabolic fit. The χ^2 per degree of freedom for the two fits clearly confirms the existence of a quadratic term in the momentum compaction factor such that

$$\frac{\Delta f_{\rm RF}}{f_{\rm RF}} = \alpha_c^0 \frac{\Delta E}{E} + \alpha_c^1 \left(\frac{\Delta E}{E}\right)^2 \qquad (3)$$

The linear term of the momentum compaction factor is determined as $\alpha_c^0 = (7.39 \pm 0.01) \cdot 10^{-3}$. This is in reasonable agreement with the theoretical expectation of $7.2 \cdot 10^{-3}$. The quadratic term is found to be $\alpha_c^1 = (4.1 \pm 0.2) \cdot 10^{-2}$. This result is highly significant but amounts to rather small corrections on the momentum compaction factor for the energy ranges relevant to the studies presented in this paper.

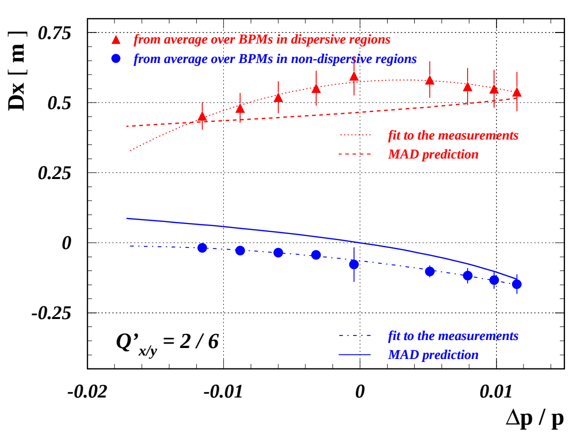

Figure 7: Horizontal dispersion as a function of momentum deviation obtained by changing the RF frequency for a horizontal chromaticity of 2 and a vertical chromaticity of 6. Measurements derived on the observation of the average horizontal closed orbit shift for beam position monitors in dispersive (triangles) and "non-dispersive" sections are shown as well as calculations with the MAD program are shown. The error bars reflect the scatter of the beam position measurements at different locations in the storage ring for a given momentum deviation.

SUMMARY

In the framework of a modelling of the nonlinear optics of the ANKA storage ring, the dependence of the dispersion on momentum deviation has been studied for different chromaticities. Calculations of the effect seem to reproduce the general behaviour but there are clear differences in the higher order terms visible at first sight that need to be understood. The nonlinearity of the momentum compaction factor has been measured using the method of resonant depolarisation. The deviation from a linear behaviour is found to be highly significant but small.

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