OPERATION WITH A LOW EMITTANCE OPTICS AT ANKA

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Abstract

The electron storage ring at ANKA is designed as a variation of an eightfold DBA structure. Since its commissioning the facility has been operated with zero dispersion in the long straight sections resulting in an emittance of about 100 nmrad. Since mid 2004 ANKA is operated with dispersion distributed over the complete ring thus reducing the emittance to 50 nmrad. Optics calculations and measurements as well as operational experience will be discussed. In order to reduce the losses due to Touschek scattering, a lengthening of the bunches was done by modulation of the main frequency with twice the synchrotron frequency. An increase of the lifetime by 5 h could be achieved.

INTRODUCTION

The ANKA storage ring is in operation since 2000. Up to now, 10 beam lines are in operation, one further beam line at a bend and one at an insertion device are under commissioning. Since the commissioning of the storage ring, ANKA had been operated in the classical DBA optics with zero dispersion in the long straight sections. Since mid 2004 the ANKA optics has been changed to an optics with dispersion in all sections. Such optics are now used at nearly all storage rings with DBA structure and had been a design option at ANKA [1], too. Due to the installation of beam lines with insertion devices a lower beam size by reducing the emittance becomes more attractive, even at the expense of a reduced lifetime.

ANKA OPTICS

The ANKA lattice consists of eight DBA cells and has a fourfold symmetry. The DBA cells are formed by two quadrupole doublets (Q1,Q2), two bends and one focussing central quadrupole (Q3). The straight sections between the DBA cells have different lengths. The four medium long are used for the RF cavities (2) and for injection (1), the four longer ones are used (3), or foreseen (1) for insertion devices. The optics with zero dispersion in the long straight section is shown in Fig.1.

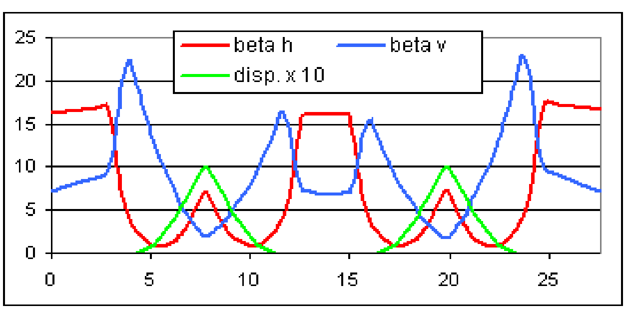

Figure 1: ANKA optics with zero dispersion.

The main optical parameters are given in Table1

Table 1: Main parameters of the ANKA storage ring.

Parameter			**Unit**
Energy	0.5 - 2.5		GeV
Circumference	110.4		m
Periodicity	4		2 * DBA
Energy loss	600		keV
Momentum spread	0.001		
RF Voltage	4 x 350		kV
RF acceptance	0.01		
Damping time	2.9, 3.0, 1.5		ms
Emittance	100	50	nmrad
Chromaticity h/v	-13.1 / -7.2	-12.2 / -6.8	
Mom. compaction	0.0075	0.0099	
Tune (h / v)	6.76 / 2.72	6.73 / 2.68	

For the optics with distributed dispersion the setting of Q3 is reduced and the ones of Q1,Q2 are modified to get about the same tune. For injection the old optics remains in use. The transition between the optics is done during the ramping to 2.5 GeV. The beta functions of the low emittance optics are shown in Figure 2.

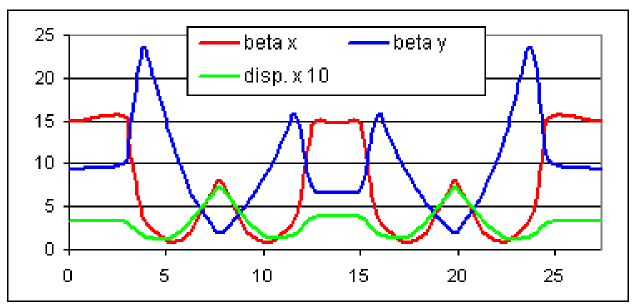

Figure 2: ANKA optics with distributed dispersion.

OPERATION EXPERIENCE

The transition between the two optics is done during ramping without any particle losses. The low emittance causes a smaller lifetime, due to larger Touschek scattering. To compensate the higher losses two injections are done presently per day. Concerning the user experiences, especially one beam line (PX) with focussing optics reported a gain in efficiency.

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Figure 3 shows current and lifetime of a typical day at ANKA with the low emittance optics. The regular beam dump before injection is done by reducing slowly the RF power. The losses can be monitored by 24 PIN diode loss monitors distributed around the ring. The losses showed a peculiar maximum at one dispersive section for the old optics. The losses for the new optics with distributed dispersion are now more localised next to the septum, where a finite dispersion and reduced aperture make the acceptance smaller.

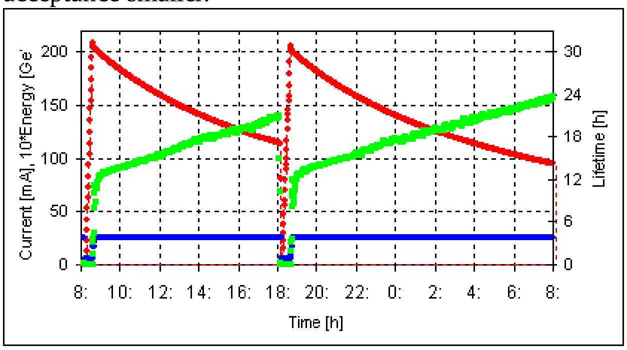

Figure 3: Typical current and lifetime at ANKA.

FILLING PATTERN

Injection at ANKA is done at 0.5 GeV. Due to the short damping time (370ms) instabilities are dominant and limit the maximum accumulated current to 200 mA, where vertical oscillations are coming up. Also this value could only be achieved by optimized temperature settings for the cavities and a special filling pattern. The ANKA injector has a harmonic number of 44. Due to beam losses during extraction about 35 bunches (70 ns) (called a train) are transferred into the storage ring. Standard filling is done by injecting two trains with a small gap of 50 ns and a large gap of 178 ns. This filling pattern is shown in Figure 4. An alternative filling pattern with three trains separated by 30, 30 and 98 ns results in higher lifetime, but less maximum injected current. We believe that the large gap is needed to prevent the trapping of ions and that the smaller gap prevents instabilities due to fast ions. Comparable experiences are reported elsewhere [2].

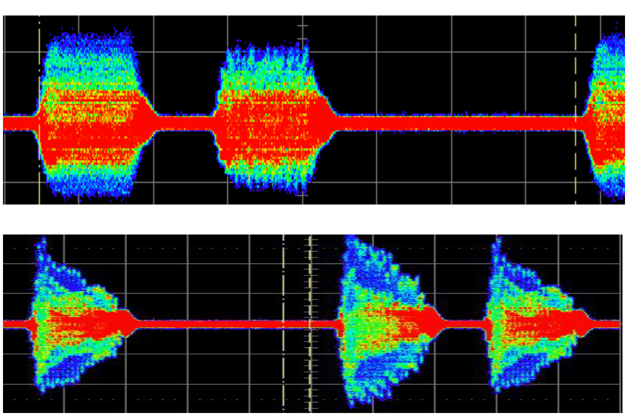

Figure 4: Bunch distribution in the storage ring. Top: Stable injection. Bottom: After a vertical instability at injection.

TOUSCHEK LIFETIME

The reduced emittance results in higher losses due to Touschek scattering. This could be clearly demonstrated by the different lifetimes, while injecting the same current but distributed in 1, 2 or 3 trains, corresponding to 1.8, 0.9, 0.45 nC/bunch. If the inverse lifetime is plotted as a function of the current per bunch the Touschek lifetime can be separated. Figure 5 shows this dependence. While the extrapolated lifetime is 25 h without Touschek effects for 180 mA, the measured lifetimes is 10 h for 2 trains.

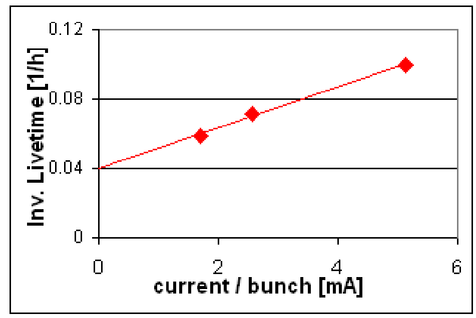

Figure 5: Inverse Lifetime as a function of the bunch current.

MOMENTUM ACCEPTANCE

The dynamic Momentum Acceptance as a function of the momentum deviation has been determined by measuring lifetime and tune for different RF frequencies. The results for the low emittance optics are given in Figure 6. Note that ANKA is normally operated with a RF voltage of 1.4 MV, giving an RF acceptance of ± 1 %. No increase of lifetime is observed for higher voltages. The fractional tune values for the performed measurement are given in Fig.6 (right). The graph indicates that the dynamic acceptance is limited by the 4th order resonance line, although this line is crossed during the ramping process.

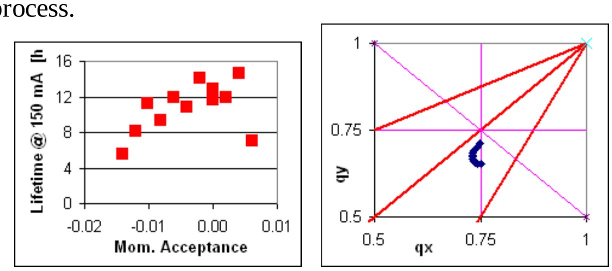

Figure 6: Lifetime and tune range as a function of momentum deviation.

COUPLING

ANKA is operated close to the difference resonance given by qx-qy = 4. By increasing the strength of the vertical focussing quadrupole Q2 the resonance line is crossed without beam loss. However, at the same time the coupling between the horizontal and vertical emittance is increased. In Figure 7 the measured tunes are shown during the resonance crossing process.

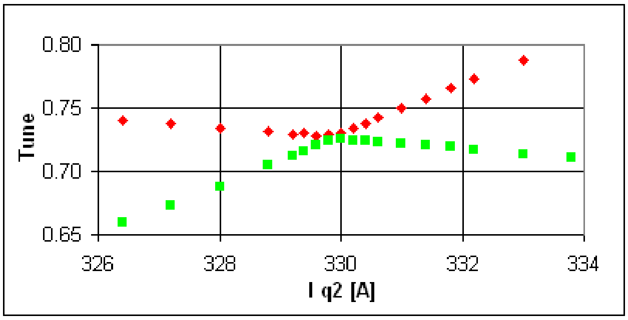

Figure 7: Horizontal (red) and vertical tune (green) during resonance crossing.

The difference in the tune can be approximated by the following formula [3]:

$$\left|q_x - q_y\right| = \sqrt{\Delta^2 + C^2} \tag{1}$$

where qx, qy are the horizontal and vertical tune respectively,
Δ is the tune difference for unperturbed tunes and
C is the minimum tune approach.

From the tune measurement a value of C = 0.006 ± 0.002 could be determined.
The emittance coupling is than given by:

$$\frac{\varepsilon_y}{\varepsilon_x} = \frac{C^2}{2\Delta^2 + C^2} \tag{2}$$

The beam sizes calculated from the tune crossing and the measured beam sizes from a visible light Synchrotron Radiation monitor are given in Figure 8. The beam sizes from the monitor are corrected for diffraction effects by a σ of 0.12 mm. For the standard operation (Q2 = 328 A) the coupling is 0.7 %.

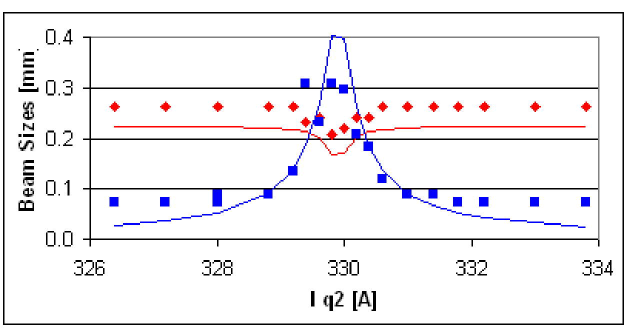

Figure 8: Measured (dots) and calculated (lines) horizontal (red) und vertical (blue) beam sizes.

BUNCH LENGTHENING BY RF PHASE MODULATION

In April 2005 the bunch lengthening by RF phase modulation was successfully tested. Similarly to what was observed in an experiment performed at KEK [4], an RF phase modulation at twice the synchrotron frequency with ± 5° showed the best results. An increase of the lifetime of 5 hours could be achieved. The bunch length is about 50% longer (1.5 cm) estimated from the beam frequency spectrum [5]. Evolution of current and lifetime are shown in Figure 9.

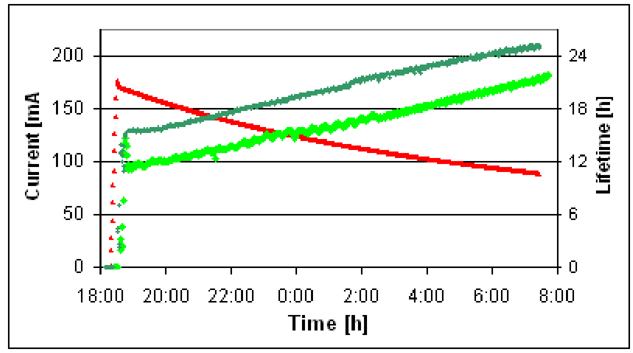

Figure 9: Current and lifetime with phase modulation on (upper dark green and red curve) and lifetime with phase modulation off (soft green).

FURTHER PLANS: LOW BETA SECTIONS

The future operation of insertion devices with gaps down to 5 mm is only feasible with a low vertical beta. Furthermore some beam lines prefer a small horizontal source size, too. Thus the installation of a low beta section (in both planes) is foreseen for two sections. This will need the replacement of the quadrupole doublets by triplets. The optics is shown in Fig.10. The tune is changed to qx / qy = 7.3, 3.2, the natural chromaticity is -13.7 / -8.5 and the emittance 60 nmrad.

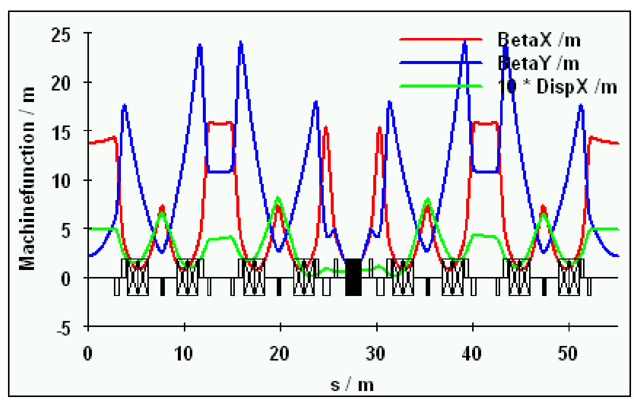

Figure 10: Beta Function for the planned low beta optics.

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