AN ULTRA-LOW EMITTANCE MODEL FOR THE ANKA SYNCHRTRON RADIATION SOURCE INCLUDING NON-LINEAR EFFECTS

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Abstract

An ultra-low emittance lattice based on the ANKA ring geometry is under investigation in framework of the feasibility studies for a compact low emittance synchrotron light source at the Karlsruhe Institute of Technology (Germany). An attempt to apply the concept of split bending magnets cells and to reduce the natural emittance of the bare ANKA DBA lattice from 90 nm·rad down to 2.5 nm·rad with not-vanishing dynamic aperture is described in this paper. The TME cell with split bends and a quadrupole lens in-between as well as a pair of non-interleaved sextupole lenses separated by "–I " unit transfer matrix of betatron oscillations allows to decrease the theoretical minimum emittance of ANKA ring down to approximately 6 nm·rad. Further reduction of the phase space volume requires to brake "–I " symmetry and add extra families of sextupoles, locate an additional high order field elements inside the quadrupoles, optimize the phase advance between sextupole families, shift the betatron tune point, enlarge the sextupole strength and other measures. Results of simulations are reported.

INTRODUCTION

Light source facility based on the 2.5 GeV ANKA storage ring successfully operates at the Karlsruhe Institute of Technology since 2000 [1]. At present acceleration of particles is accomplished in three steps. Electrons are accelerated up to 50 MeV in the racetrack microtron and gain the energy up to 500 MeV in the 1 Hz cycling booster synchrotron. Then particles are accumulated and ramp energy up to 2.5 GeV in the main ANKA ring. Major upgrade of existing accelerators aims either for a full energy booster synchrotron or an injector LINAC similar to one designed for MAX-IV [2] and for a low emittance storage ring inscribed into the present ANKA synchrotron geometry to preserve existing beam lines and engineering infrastructure. The main objective of the ring upgrade is to reduce the emittance of the beam by 10 times to less than 9 nm while ensure acceptable DA and large MA.

TME CELL WITH SPLIT BEND

SM-TME cell was studied comprehensively in [3]. This flexible cell originated from TME cell with a bend split and a quadrupole inserted in between. New cell provides both low emittance and large DA due to the chromatic sextupoles arranged in pairs and separated by –I transformers. Such arrangement effectively cancels all sextupole aberration terms, so the DA is defined by the next, octupole-like less severe aberrations.

Figure 1 shows the basic cell of the Low Emittance ANKA upgrade (LE ANKA). We have tuned the –I conditions in the horizontal plane over the cell, so identical horizontal sextupoles installed at the cell ends cancel the relevant nonlinear aberrations.

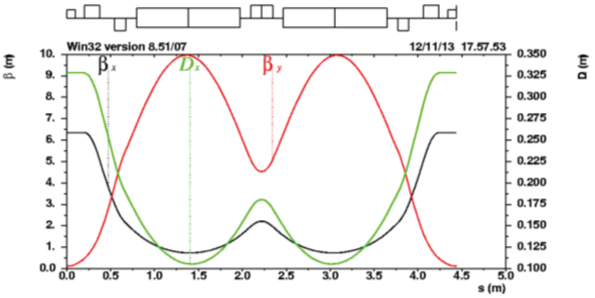

Figure 1: LE ANKA cell based on the modified TME cell. Quadrupole between the split bend allows adjusting phase advance between chromatic sextupoles.

The horizontal beta and dispersion were adjusted in the bends to achieve low emittance according the approach described in [3,4].

To correlate the emittance with the DA size, we have mistuned the –I condition by introducing stronger focusing. Figure 2 shows the DA shrink with the emittance decrease. Finally we adopted relaxed but robust version with 8.6 nm emittance and $\pm^{20}_{15}$ mm DA.

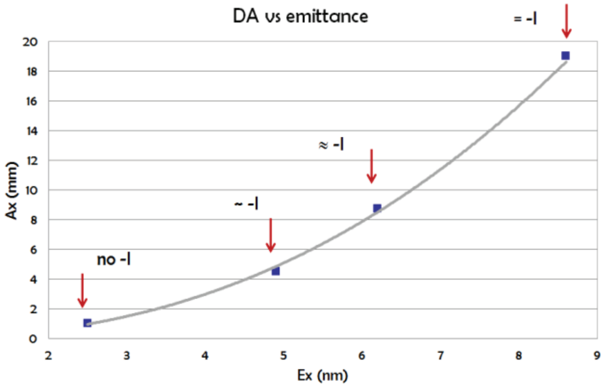

Figure 2: Horizontal DA vs. emittance for the –I detuned.

LATTICE

LE ANKA has the same circumference as ANKA, occupy the same tunnel, has the same length and structure of straight sections (4 long plus 4 short) and keep unchanged

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straights source points to use the existing beam lines and experimental hutches.

Figure 3 compares the magnet sequence of the old and new lattices while Fig. 4 shows two structures superimposed in the tunnel. The lattice functions of the LE ANKA are depicted in Fig. 5. Main parameters of two lattices are given in Table 1.

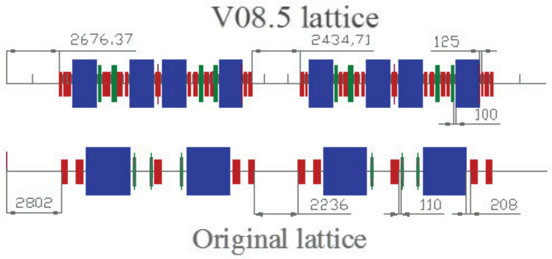

Figure 3: Location of main elements in the original (lower plot) and split magnet LE ANKA super-period.

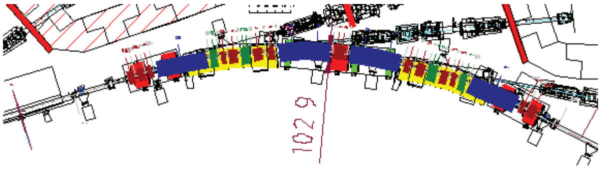

Figure 4. LE lattice superimposed over the old one: split 11.25° gradient bends – in blue, quads - in red, sextupoles in green. present 22.5° bending magnets - in yellow.

Table 1: Original ANKA and Split LE ANKA Lattices

Lattice	original	split
Qx/Qy	6.8/2.6	10.83/10.34
Cx/Cy	-12.3/-14.7	-21.5/-40.4
ε_x (nm·rad)	83	5÷8.6
Energy spread	9.02E-04	1.31E-03
Compaction α	9.15E-03	4.69E-03
Energy loss, MeV	6.22E-01	5.75E-01
Partition Jx/Jy/Je	0.97/1/2.03	2.11/1/0.89
magnet parameters		
B(T) / G_b (T/m)	1.5/-	1.39/-9.4
Gm× L (T/m*m)	20×0.32	70×0.24
Sm× L (T/m^2*m)	700×0.1	1500×0.15

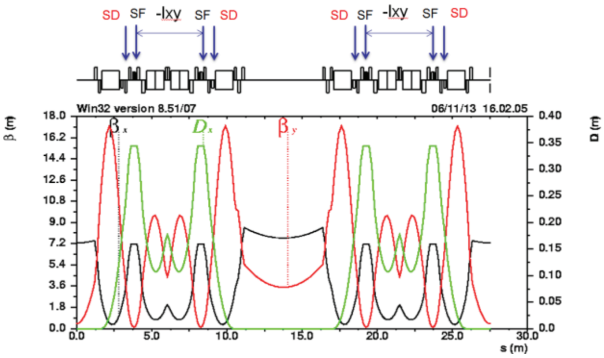

Figure 5: A quarter of the LE ANKA ring. The horizontal sextupoles location satisfies to –I condition.

The negative gradient G_b =-9.5 T/m was introduced in the dipole magnets to further reduce the natural emittance due to increasing of horizontal partition number as well as to find suitable behavior of beta functions. Due to the strong focusing in an ultra-compact lattice composed of split bends, the maximum quadrupole gradient reach 70–90 T/m and the maximum sextupole gradient grows to ~1500 T/m^2. Nevertheless, the required field in quads and sextupoles is reasonable because the aperture of focusing elements will be reduced from present 70 mm down to 25 mm.

To provide achromat conditions in straight sections, two dispersion suppressors are placed at both sides of LE cell. Two anti-symmetric LE cells with dispersion suppressors create one super-period (a quarter of the LE ANKA ring).

The distance between magnetic elements in a split lattice is more than 100 mm which is attainable for modern small gaps magnet technology. The length of long straight section in the LE lattice is slightly reduced to 5.4 m (5.6 m in old one) while the length of short straight section is increased to 2.43 m (now it is 2.24 m). The source points and radiation directions from straight sections are the same as in present ANKA ring.

Additional decrease of the horizontal emittance (to ≈5 nm) can be reached by insertion of damping wigglers.

NONLINEAR DYNAMICS

Horizontal sextupole pairs separated by the –I transformers provide large DA and dynamical MA (±6%). Figure 6 shows on- and off-energy DA at the injection azimuth with betas (h/v) 7.7/0.4 m. Figure7 demonstrates the tune bandwidth which exceeds $\Delta E/E = \pm 6\%$.

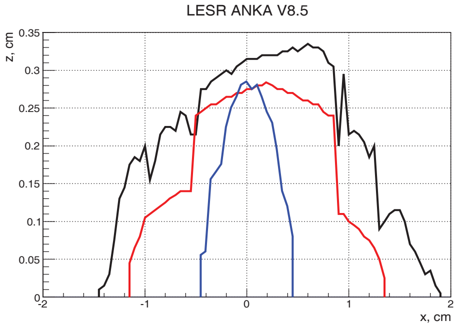

Figure 6: DA plot: $\Delta E/E$ = 0 is in black, $\Delta E/E$ = +6% is in red, $\Delta E/E$ = –6% is in blue.

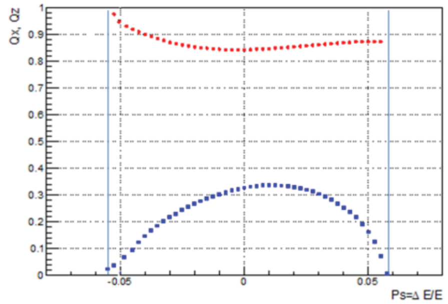

Figure 7: Tunes as a function of energy deviation.

In real life the momentum acceptance is limited by the RF system at the level of ±2%. The horizontal DA with the RF cavities on is more than ±12 mm in the worst (-2% of energy deviation) case.

For these parameters the Touschek lifetime in a multi-bunch mode (200 mA current, 500 MHz RF frequency and 2.2 MV RF voltage) is > 20 h. For a single-bunch mode the Touschek lifetime degrades as it is shown in Fig. 8, but even at 100 mA it is still 1000 s.

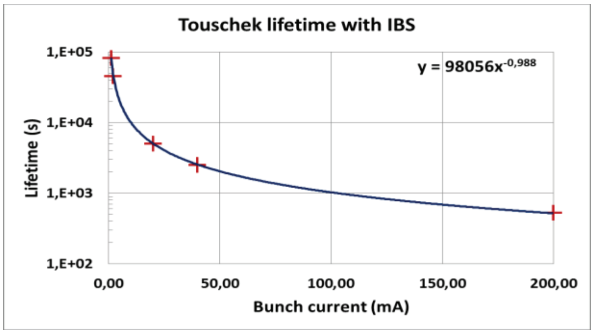

Figure 8: Single-bunch Touschek lifetime vs. current.

MAIN MAGNETIC ELEMENTS

There are 32 defocusing dipole magnets with parameters given in Table 3. The magnet field maps are shown in Fig. 9 and Fig. 10.

Table 3: Parameters of the LE ANKA Gradient Dipoles

Type	C-shape defocusing
Number	32
Effective magnetic length	1.18 m
Curvature radius	6.0097 m
Bending angle	11.25°
Vertical gap	±13 mm
Field at the reference orbit	1.38761 T
Quadrupole strength K_1	-1.15139 m^{-2}
Good field region (h×v)	(±20) × (±12.5) mm^2
Good field quality, $\Delta B/B_0$	$\pm1\times10^{-4}$

Main characteristics of the quadrupole and sextupole magnets are given in Table 4 and Table 5 respectively.

Table 4: Main Specs of Quadrupoles

Total number	112
Working gradient	50 – 70 T/m
Inner pole diameter	∅26 mm
Effective magnetic length	100 – 250 mm
Good field region	∅24 mm
Gradient quality	≤ 0.1 %

Saturation field map for the quadrupole and the sextupole is shown in Fig. 9. At the sextupole yoke the coils for the steering magnets and the skew-quadrupole corrector will be wound.

Table 5: LE ANKA Sextupoles Specs

Type of sextupole	SF	SD
Number	16	16
Maximum gradient, T/m^{-2}	716	-1580
Inner diameter, mm	∅30	∅30
Effective length, m	0.15	0.15
Good field region, mm	∅24	∅24
Gradient quality	≤ 1%	≤ 1%

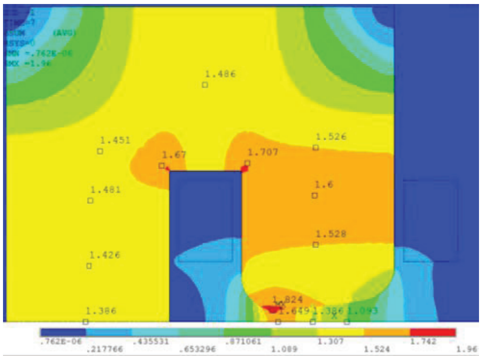

Figure 9: Field map of gradient bending magnet.

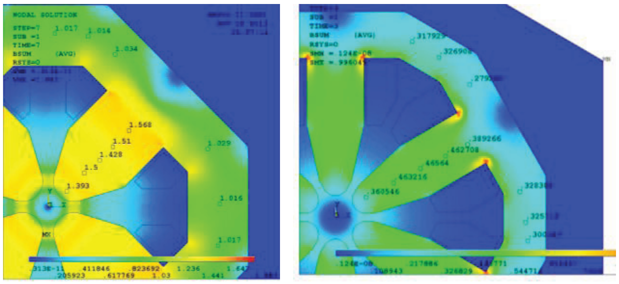

Figure 10: Saturation field map for quadrupole and sextupole.

CONCLUSION

Feasibility study of the LE ANKA lattice is performed. A novel concept of the low emittance cell with –I optical transformation between the horizontal chromatic sextupoles is applied and provided the DA comparable with the physical one and the MA as large as ±6%. The natural emittance of LE ANKA is 10 times less than ever before for the same general boundary conditions – energy and circumference and straight sections location. In this sense the new LE ANKA lattice corresponds well to new technology trend.

REFERENCES

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