GLOBAL SCAN OF ALL STABLE SETTINGS (GLASS) FOR THE ANKA STORAGE RING*

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Abstract

The design of an optimal magnetic optics for a storage ring is not a simple optimization problem, since numerous objectives have to be considered. For instance, figures of merit could be tune values, optical functions, momentum compaction factor, emittance, etc. There is a technique called “GLobal scan of All Stable Settings” (GLASS)[1], which provides a systematic analysis of the magnetic optics and gives a global overview of the capabilities of the storage ring. We developed a parallel version of GLASS, which can run on multi-core processors, decreasing significantly the computational time. In this paper we present our GLASS implementation and show results for the ANKA lattice.

INTRODUCTION

ANKA is the synchrotron light source of the Karlsruhe Institute of Technology (KIT)[2]. It consists of 4 super periods with two double bend achromats each. Each DBA structure contains 2 bending magnets, 5 quadrupole families and two chromatic sextupole families to control the vertical and horizontal chromaticity. We want to study all linear stable settings of ANKA at 2.5 GeV by scanning all possible quadrupole settings. At the moment, ANKA is operated in three different modes, in low-emittance with the natural emittance of 50 nm rad[3], low-β_y mode with vertical beta value of 1.9 m in the straight sections[4] and low-α_c-mode with reduced momentum compaction factor.[5].

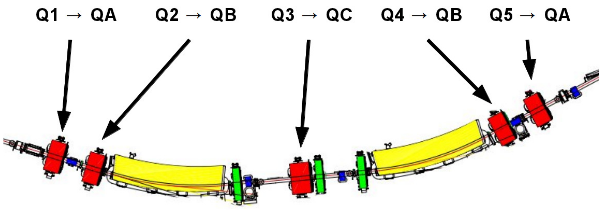

Figure 1: One half of the super period showing the reduced number of quadrupole families.

For our studies, we considered a symmetric super period by reducing the number of quadrupole families from 5 down to 3 (see Fig. 1), which allowed us to decrease the computation time. Since the ANKA storage ring consists of 4 identical super periods, we need to consider only one super period to check for linear stability of each set of quadrupole settings. The linear stability criterion is given by

$$|\mathrm{tr}(M_{\mathrm{x,y}})| < 2, \tag{1}$$

where $M_{\mathrm{x,y}}$ is the transversal transfer matrix of one super period.

We also considered fringe field integrals and quadrupole components in bending magnets to get a realistic model at 2.5 GeV[6]. To decrease the computation time, we implemented a parallel C++ code using OpenMP.

GLASS SCAN

The quadrupole strength scan was performed in the range of -2.4 to 2.4 m^{-2} with a resolution of 0.02 m^{-2} for the ANKA magnets corresponding to the maximum possible current. The compiled C++ code checked the linear stability criterion of 240^3 quadrupole settings in only 11 seconds on 12 cores and filtered out all unstable settings. Only 3% of all possible quadrupole settings are stable for the ANKA lattice at 2.5 GeV, but not all of them are feasible for the real machine. Therefore, we considered only the settings that satisfy the following constraints:

- $\beta_{x,y} < 40\,\mathrm{m}, \quad |\eta_x| < 2\,\mathrm{m}, \quad J_x, J_s > 0,$
- no tune resonance up to the 2$^{\mathrm{nd}}$ order,

where $\beta_{x,y}$ is the transversal beta function, $|\eta_x|$ the horizontal dispersion function and J_x, J_s are the damping partition numbers. The constraints were checked with the Accelerator Toolbox (AT)[7] for MATLAB, which took 28 hours on a single core. Then, we queried the resulting database with stable solutions and computed the corresponding emittance for each of them. In Figure 2 all stable settings are shown in the quadrupole-strength-space, classified by different colors into three emittance ranges. As shown in Figure 2, we found two islands of stable settings but only the one with the positive quadrupole strengths for QA family and negative for QB family contains emittance values lower than 100 nm rad. The other island has emittance values that are greater than 770 nm rad. Hence this region is not interesting for further studies on low-emittance optics.

We were also interested in low beta values in the straight sections. Since there are three insertion devices installed in

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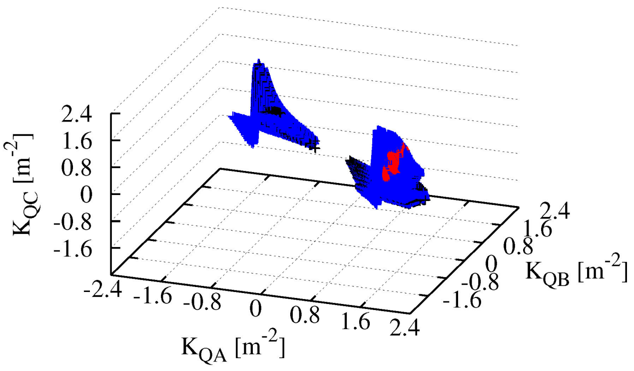

Figure 2: Natural emittance of all linear stable settings in quadrupole strengths space. Red: $10 < \epsilon < 100$, blue: $100 < \epsilon < 1000$, black: $\epsilon > 1000$ [nm rad].

the straight sections of ANKA at the moment. All of them require a low beta value. Figure 3 shows the beta function diagram and corresponding emittances in the straight section.

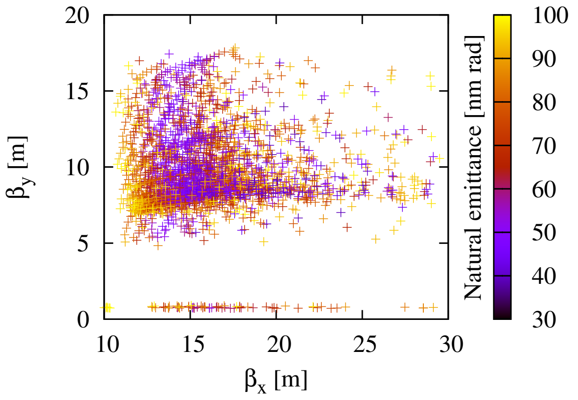

Figure 3: Beta functions in the straight sections of the ANKA for the stable optics with corresponding emittance values lower than 100 nm rad.

A low momentum compaction factor is also an interesting parameter, since the bunch length depends directly on it. At ANKA we use low-α_c optics at 1.3 GeV to decrease the bunch length and produce coherent synchrotron radiation (CSR). As Figure 4 shows, there are stable optics configurations with bunch lengths shorter than 5 mm, which can be considered for production of CSR at a beam energy of 2.5 GeV.

The GLASS scan found relatively low emittance values of 18 nm rad, but the corresponding horizontal natural chromaticity has a high negative values of -34, hence this optics is not possible for the ANKA machine with the current sextupole magnets. To decrease the emittance and compensate the natural chromaticity, the ANKA ring would need to be upgraded. Figure 5 shows the relationship between natural chromaticity and emittance.

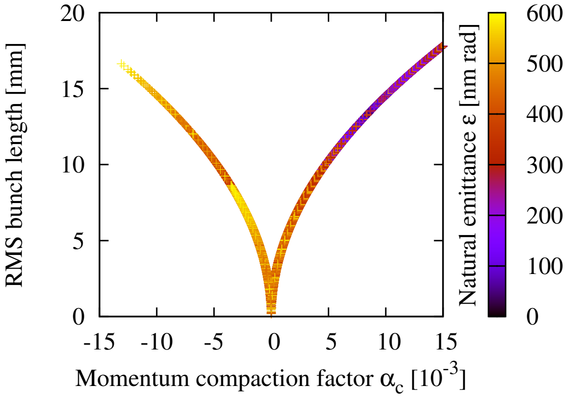

Figure 4: Relationship between momentum compaction factor α_c, natural emittance and natural bunch length RMS at infinitesimal current for 2.5 GeV optics.

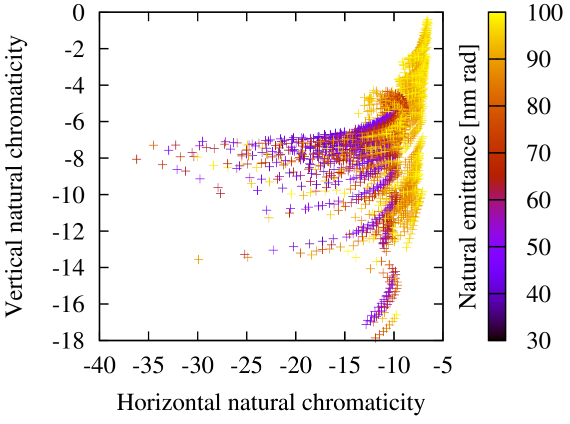

Figure 5: Horizontal and vertical chromaticity values for the stable optics with emittance values lower than 100 nm rad and beam energy of 2.5 GeV.

Furthermore, we found a stable setting with a low possible emittance of 38.6 nm rad with chromaticity values of $\nu'_{x,y} = (-15.90, -7.16)$ that can be compensated by the sextupole magnets. The corresponding optical functions are presented in Figure 6. The emittance of the existing low-emittance optics is 50 nm rad, which is 23% higher than the value found by the GLASS analysis.

DYNAMIC APERTURE

Not all linear stable settings with low emittance are feasible for the real machine, since non-linear effects lead to small dynamic aperture and the beam becomes unstable. To determine the quality of a given optics, tracking simulations need to be performed. For the GLASS scan we turned off the sextupole magnets and considered only the natural chromaticity. Then, we turned on the sextupole magnets

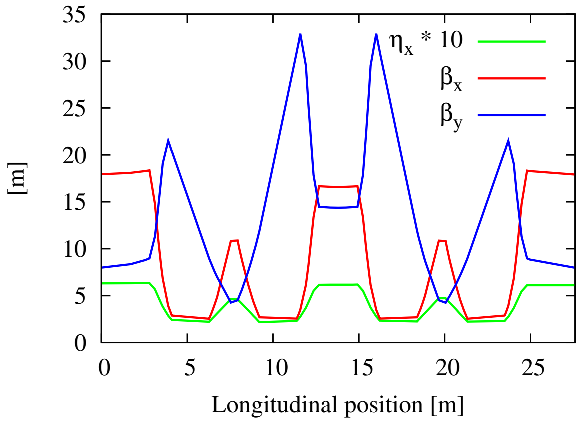

Figure 6: Low-emittance optics with a natural emittance of 38.6 nm rad and tunes h/v = (7.13/1.67). The figure shows one super period of the ANKA lattice.

and set the chromaticity to $\nu'_x = 2, \nu'_y = 6$. These values were determined by measurements to be optimal for damping of beam instabilities at ANKA. Figure 7 shows the geometric dynamic aperture for the described low-emittance optics with different momentum deviations dp with in units of the natural energy spreads σ_e. Figure 8 shows that there are lots of stable optics with emittance values lower than 90 nm rad and the squared dynamic aperture greater than the physical aperture, which can be considered as possible operating points. For the dynamic aperture simulations we considered only half of the electron beam pipe with the physical aperture of 10.4 cm^2, since the beam is symmetric to the horizontal plane.

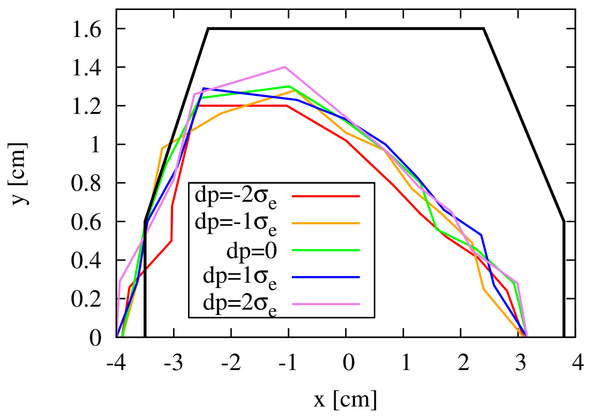

Figure 7: Dynamic apertures of the low-emittance-optics shown in Fig. 6 with chromaticity values $\nu'_x = 2, \nu'_y = 6$, for different momentum deviations dp, where $\sigma_e = 9.13463 \cdot 10^{-4}$ is the natural energy spread at the beam energy of 2.5 GeV. The black line marks the physical aperture at ANKA.

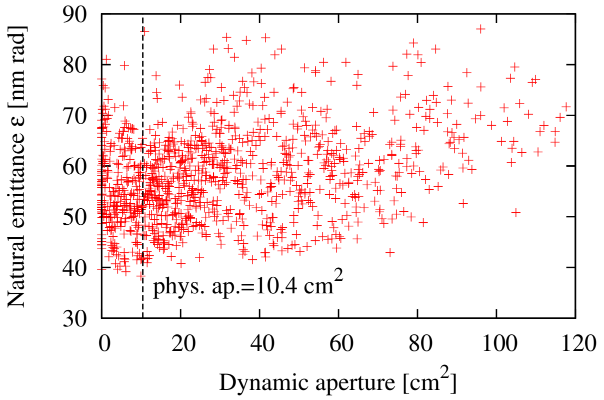

Figure 8: Dynamic apertures with corresponding natural emittance values and chromaticity values set to $\nu'_x = 2, \nu'_y = 6$ at 2.5 GeV.

SUMMARY AND OUTLOOK

The GLASS technique allows us to explore the global linear properties of the machine and provides us with a systematic method to find stable optics. We performed GLASS at ANKA successfully and we could find a realizable optics with lower emittance than the currently used optics. However, the GLASS technique requires a lot of computational power. To decrease the computational time, we implemented a parallel code to make use of multicore computers. If we want to optimize more parameters than three, the GLASS technique is no longer an effective approach. Hence we are exploring genetic algorithms to find optimal settings in much shorter time. First studies show a good agreement with the optimum settings found with GLASS, while reducing the computational time to only several minutes[8].

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