GLOBAL OPTIMIZATION OF THE ANKA LATTICE USING MULTIOBJECTIVE GENETIC ALGORITHMS (MOGA)*

M. Streichert†, N. Hiller, E. Huttel, V. Judin, B. Kehrer, M. Klein‡,
S. Marsching, C. Meuter, M.J. Nasse, A.-S. Müller, M. Schuh, N.J. Smale
Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Abstract

The optimization of a storage ring lattice is a multiobjective problem, since the parameter space of possible solutions can be very large and a high number of constraints have to be taken into account during the optimization process. In this paper we used Genetic Algorithms (GA) and MultiObjective Genetic Algorithms (MOGA), which can solve such problems very efficiently and rapidly, to find the optimized settings for the ANKA storage ring lattice.

INTRODUCTION

ANKA is the synchrotron light source of the Karlsruhe Institute of Technology (KIT)[1]. It consists of 4 super periods with two double bend achromats (DBA) structures each. Each DBA structure contains 2 bending magnets, 5 quadrupole families and two chromatic sextupole families to control the vertical and horizontal chromaticity. We implemented a Global Scan of All Stable Settings (GLASS)[2], based on linear optics to find all possible quadrupole settings of the ANKA lattice. However, the GLASS technique requires a lot of computational power. To decrease the computation time, we considered a symmetric super period by reducing the number of quadrupole families from 5 to 3. Furthermore, we implemented a parallel code to make use of multicore computers. However, the whole scan took up to 28 hours. For optimizations with all five quadrupole families, the GLASS technique is no longer an effective approach. Hence we employed much faster genetic algorithms to find optimal quadrupole settings. We used the GLASS scan to benchmark GA and MOGA for the three quadrupole families and performed global optimizations with GA for all five quadrupole families.

GENETIC ALGORITHMS

GA optimization is a promising technique to find the optimal solution in a multi-dimensional, non-continuous parameter space. This technique can easily be implemented with the existing simulation models for ANKA and does not require knowledge or gradient information of the response function. We compared the GA results with the GLASS results to benchmark and to explore the optimum settings for the GA, for instance the population size, the maximum number of generations etc. We performed GA optimization to find the optimal low-emittance optics. Since not all settings of quadrupole strengths lead to stable or feasible solutions, we implemented the following constraints in GA:

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

where $M_{\mathrm{x,y}}$ is the transversal one turn transfer matrix, $\beta_{x,y}$ transversal beta function, $|\eta_x|$ the horizontal dispersion function and J_x, J_s are the damping partition numbers. Beam energy dependent fringe field integrals and quadrupole components in the ANKA bending magnets[3] were taken into account in our optimizations to get a realistic model for the ANKA lattice at the beam energy of 2.5 GeV. The optimization was performed in the range of -2.4 to 2.4 m^{-2}, corresponding to the maximum possible current for the ANKA quadrupole magnets. For a fair comparison of both techniques, we discretized the parameter space for the GA optimization with the same grid spacing (0.02 m^{-2}) as for the GLASS scan, reduced the number of quadrupole families from 5 down to 3, and turned off the sextupole magnets.

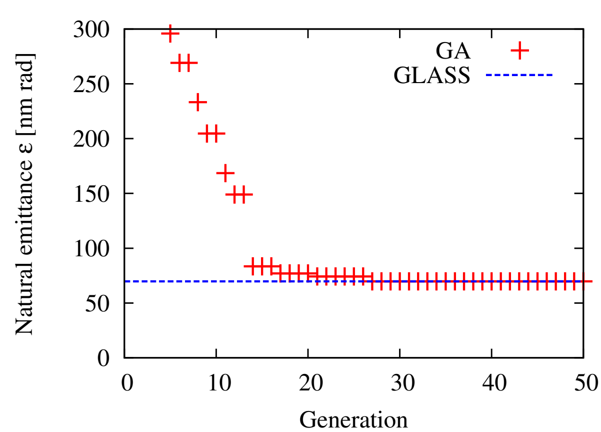

Figure 1: Comparison of the GA with the GLASS results. Minimization of the emittance at 2.5 GeV with minimal chromaticity values of -10 as additional constraint.

After 50 generations the GA converged to the same value of 69.8 nm rad, which we found by using the GLASS (see Fig. 1). However, for the whole GLASS scan, 28 hours

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† max.streichert@student.kit.edu
‡ now at SOLEIL, Gif-sur-Yvette, France

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of computation were needed, whereas the GA optimization took only 36 minutes. The difference between both techniques is that the GLASS scan provided all stable settings with their properties, while GA only found the setting with the lowest possible emittance satisfying all above mentioned constraints.

Low-emittance Optics

Since the result of the GA optimization with 3 quadrupole families showed a good agreement with the GLASS result, we increased the number of quadrupole families to 5 and relaxed the constraint for the natural chromaticity to -16, which is the lowest possible value that can be compensated by ANKA's sextupole magnets.
The GA found the optimal stable setting with an emittance of 38.3 nm rad within 200 minutes on a single core. The corresponding optical functions are shown in Figure 2. The emittance of the low-emittance optics currently used at ANKA is 50 nm rad[4], which is 23% higher than the value found by the GA.

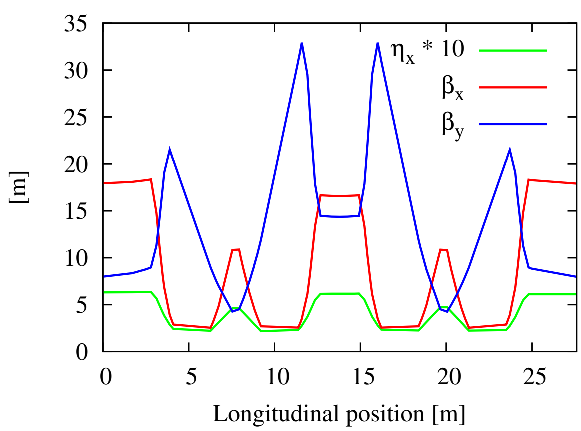

Figure 2: Low-emittance optics with a natural emittance of 38.3 nm rad, tune values of $\nu_{x,y}$ = (7.13, 1.67) and chromaticity values of $\nu'_{x,y}$ = (-15.90, -7.16). One super period of the ANKA lattice is shown.

Low-β_y Optics

We were also interested in low beta values in the straight sections of ANKA as this is required by the three insertion devices installed there. We wanted to improve the currently used low-β_y optics[5], which has a with a β_y of 1.9 m in the straight sections and an emittance value of 53 nm rad. The optimized optics (see Fig. 3) has a vertical beta of 0.7 m in the straight sections and a natural emittance of 51 nm rad, which is an improvement in both quantities.

Low-α_c Optics

A low absolute value of the momentum compaction factor is also an interesting parameter, since it directly determines the bunch length. At ANKA we use a low-α_c optics to decrease the bunch length and produce coherent synchrotron radiation (CSR)[6]. With the GLASS scan (see

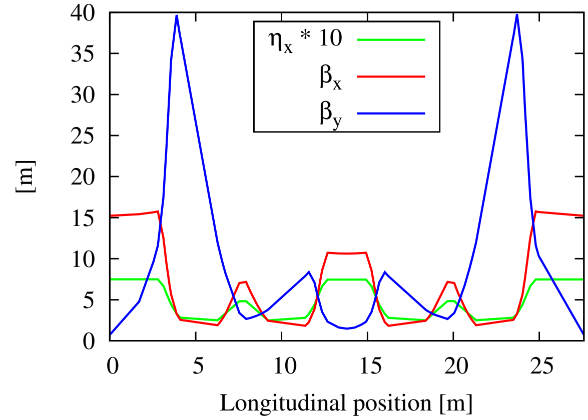

Figure 3: Low-β_y optics with a vertical beta of 0.7 m in the straight sections, an emittance of 51 nm rad, tune values of $\nu_{x,y}$ = (6.44, 4.53), and chromaticity values of $\nu'_{x,y}$ = (-11.10, -12.69).

Fig. 4) we found a stable optics with bunch lengths shorter than 5 mm, which can be considered for production of CSR at the beam energy of 2.5 GeV. For the GA optimization we added a maximum emittance value of 300 nm rad as an additional constraint. With this, we found a stable optics (see Fig. 5) with an RMS bunch length of 0.60 mm (2.0 ps).

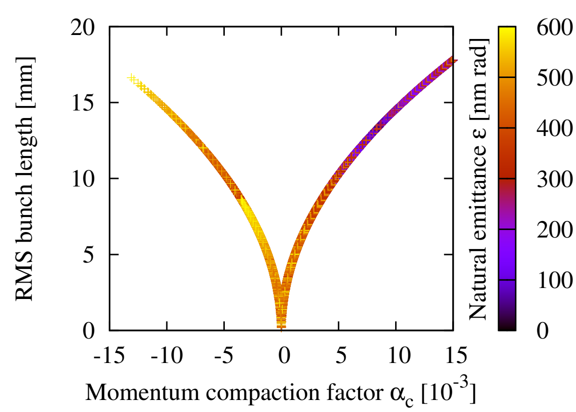

Figure 4: Relationship between momentum compaction factor α_c, natural emittance, and natural RMS bunch length for an infinitesimal current at 2.5 GeV as calculated by the GLASS method.

MULTIOBJECTIVE OPTIMIZATION

However, in most situations multiple parameters have to be optimized simultaneously. For instance, to optimize the brightness of an insertion device not only the local beta function has to be minimized but also the emittance. In this case, the optimum solution is no longer a single point but a front of optimum solutions, the so-called Pareto optimum (PO). For our simulations we used a controlled elitist

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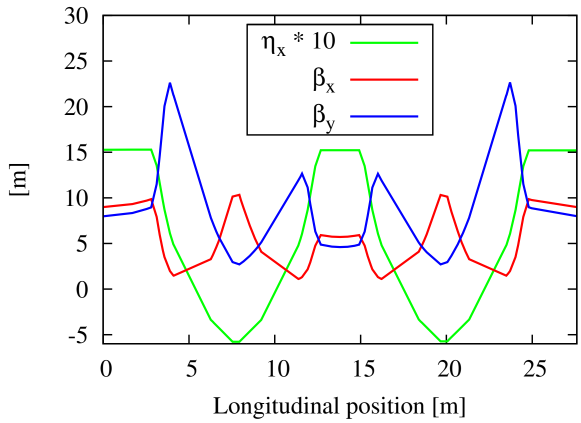

Figure 5: Low-α_c-optics with a momentum compaction factor of $2 \cdot 10^{-5}$, an RMS bunch length of 0.60 mm (2.0 ps), a natural emittance of 280 nm rad, tune values of $\nu_{x,y}$ = (6.45, 2.96) and chromaticity values of $\nu'_{x,y}$ = (-8.84, -8.31).

genetic algorithm (a variant of NSGA-II [7]), which is already implemented in MATLAB's Optimization Toolbox.

β_y – Emittance Optimization

We performed a MOGA optimization to find the PO between the vertical beta function in the straight sections and the natural emittance. Figure 6 shows that MOGA found two separated regions with optimum solutions, one with particularly low beta values (A), and the other with relatively low emittance values (B). This demonstrates clearly the advantage of MOGA, since optimum quadrupole settings were found in a non-continuous solution space, as can be seen from the two disjunct regions in Figure 6. The optimization took 220 minutes on a single core.

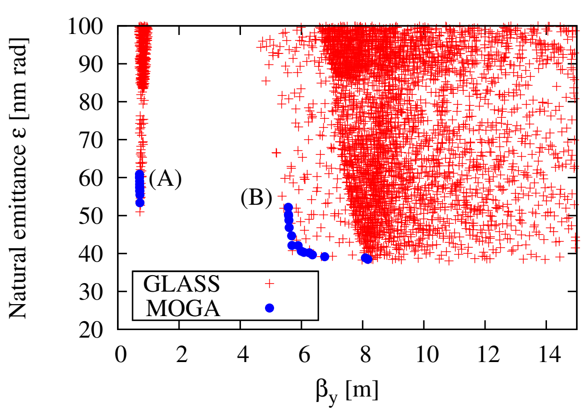

Figure 6: Vertical beta values in the straight sections and natural emittance values calculated with GLASS and MOGA for ANKA at 2.5 GeV.

Bunch Length – Emittance Optimization

As Figure 4 demonstrates a low absolute value of the momentum compaction factor leads to an increase in the natural emittance. We were interested to find the optimum between short bunch lengths and low emittances. The MOGA optimization yields a PO which, as shown in Figure 7, is in good agreement with the GLASS results.

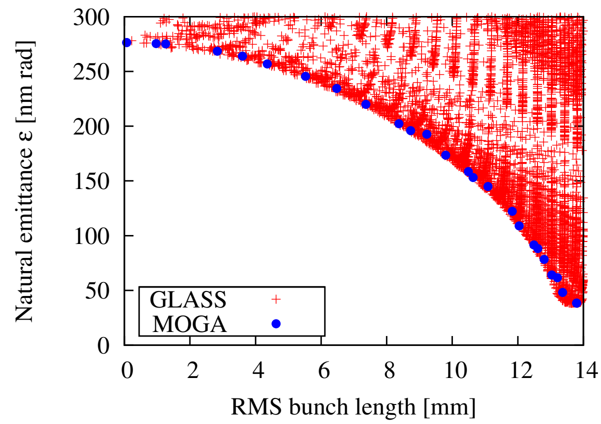

Figure 7: RMS bunch lengths and natural emittance calculated with GLASS and MOGA for the 2.5 GeV ANKA lattice.

SUMMARY AND OUTLOOK

We performed the global optimizations using genetic algorithms for the ANKA storage ring at 2.5 GeV. This technique is a valuable tool to explore the optimal linear stable optics of the ANKA ring. We plan to implement the obtained optimized optics at ANKA in an up-coming machine development shift.
Furthermore, the GA or MOGA can be also used to study non-linear effects considering sextupole, octupole magnets etc. to perform high order optimizations.

REFERENCES

[1] `http://ankaweb.fzk.de`

[2] M. Streichert et al. "Global Scan of All Stable Settings (GLASS) for the ANKA Storage Ring", ICAP 2012

[3] M. Streichert et al."Simulations of Fringe Fields and Multipoles for the ANKA Storage Ring Bending Magnets", IPAC 2012, p.1626

[4] E. Huttel et al., "Operation with a Low Emittance Optics at ANKA", PAC 2005, p.2467

[5] E. Huttel et al., "Low Beta Structure for the ANKA Storage Ring", EPAC 2008, p.2034

[6] A.-S. Müller et al., "Far Infrared Coherent Synchrotron Edge Radiation at ANKA", PAC 2005, p.2518

[7] Deb, Kalyanmoy. Multi-Objective Optimization Using Evolutionary Algorithms. John Wiley & Sons, 2001

ISBN 978-3-95450-116-8