FIRST MOGA OPTIMIZATION OF THE SOLEIL LATTICE

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Abstract

The first optimization of the nonlinear beam dynamics of the SOLEIL synchrotron radiation light sources using Multi-Objective Genetic Algorithm is reported. After benchmarking ELEGANT against TRACY3, beam lifetime studies with the operation lattice and fine-tuning of the storage ring model, MOGA-ELEGANT was used to find the best settings of quadrupole and sextupole magnets in order to maximize the dynamic and momentum apertures used as proxies for the injection efficiency and the Touschek lifetime respectively. The solutions obtained after one month of computation in the high level computational cluster of SOLEIL using 200 CPUs are detailed. The improvement of the Touschek lifetime obtained with MOGA is confirmed by the beam-based experiments. The beam lifetime of the SOLEIL storage ring was increased experimentally by 40 % as predicted by the simulations.

INTRODUCTION

The present 3.9 nm.rad lattice of the SOLEIL storage ring (SR) has been successfully optimized over the years in order to reach high performance in terms of injection efficiency and beam lifetime. Third and fourth generation SR (DLSR: Diffraction Limited Storage Ring) are becoming more complex with many degrees of freedom to optimize. If powerful numerical analytical tools exist, the full exploration of the parameter space is extremely time consuming and out of reach of today's computer if many parameters need to be explored together.

Multi-Objective Genetic Algorithms (MOGA) have been introduced during the last decade for optimizing SR lattices thanks to the development of affordable high performance computers.

Application of Genetic Algorithms (GA) in particle accelerators started in the early 2000 (for a review, see Ref. [1] for instance). First application to synchrotron light sources dates back to the pioneering work of M. Borland and his team at the APS [2]. Beam performance improvement using MOGA has been reported since the 2000s: 25 % lifetime improvement at APS [3] and DIAMOND light source [4] for example. GAs is now part of the toolbox of most accelerators and is used to different extent as a complementary tool to existing analytical or semi-empirical methods during lattice design (especially for DLSRs) and optimization (resonant driving term minimization [5], tune shift with amplitudes control [6], frequency map analysis [7-10]).

Before using GA tools for the upgrade of SOLEIL, we wanted to assess their benefit using the present lattice of SOLEIL in order to compare simulation and experimental results. SOLEIL was commissioned in 2006 and is located south of Paris in France [11]. The main parameters of the storage ring are given in Table 1.

Table 1: SOLEIL SR Main Parameters.

Parameters	Values
Energy [GeV]	2.75
Circumference [m]	354.097
Natural Emittance [nm.rad]	3.9
Symmetry	1
Tunes (H/V)	18.155/10.229
Natural chromaticities (H/V)	-53/-19
Quadrupole Number/Families	163/12
Sextupole Number/Families	123/11

SIMULATION

The SR optic was modeled using the codes ELEGANT [12] and TRACY3 [13]. The first code is interfaced directly with MOGA; the latter has been beam-based validated for more than ten years at SOLEIL. The ELEGANT tracking method was firstly modified to agree with TRACY3 one and a series of experiments were carried out to benchmark the numerical tools before using the Touschek lifetime and injection efficiency as figures of merit of the MOGA optimization [14-17].

To save computation time a simplified model of SOLEIL without insertion devices, but including a realistic aperture limitation. Two families of quadrupole were utilized to scan the fractional part of the tunes between 0.1 and 0.4. Eleven families of sextupole were varied by MOGA keeping a chromaticity constraint of 1.2 and 2.0 respectively in the horizontal and vertical planes.

All Touschek lifetimes were computed by ELEGANT with a 6 mm bunch length, 1 mA of bunch current and 2.665 MV of RF voltage for a 1% coupling value.

After one month of computation using 200 CPUs of the SOLEIL cluster, 240 generations, 46,000 lattices have been sorted in terms of performance. The solutions with both the best lifetime and the best injection efficiency constitute the so-called Pareto-optimal front.

Since computing dynamic aperture and momentum aperture can be very long for the full 1-fold symmetric lattice, only best lattice candidates were evaluated with a more realistic error set using frequency map analysis and the latest beam-validated model of magnetic errors.

Figure 1 shows the distribution of the solutions highlighting a 70 % increase in the Touschek lifetime (51 hours versus 29 hours for the starting lattice) strongly related to the improvement of the energy acceptance negative part (Figure 2). It has been checked that this increase is directly correlated to the minimization of the tune shift with energy and more specifically of the nonlinear terms of the horizontal chromaticity which are not easy to control with usual tools (Figure 3).

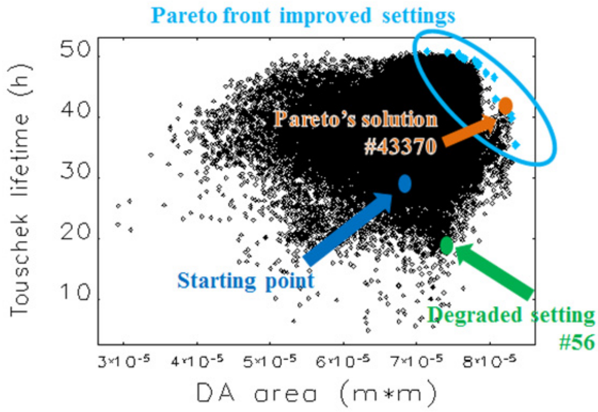

Figure 1: Dynamic aperture area and Touschek lifetime for the MOGA optimized solutions. Present (starting point), improved and degraded lattices are blue, red, and green marks respectively.

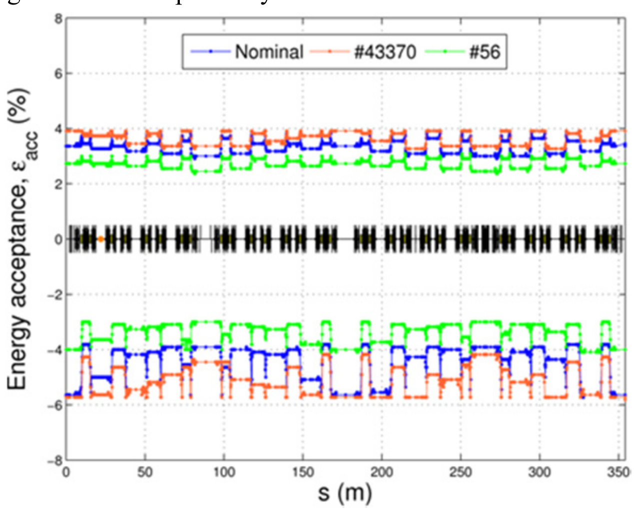

Figure 2: Positive and negative energy acceptances along the SOLEIL SR for the so-called present lattice (blue), improved lattice (red) and degraded lattice (green).

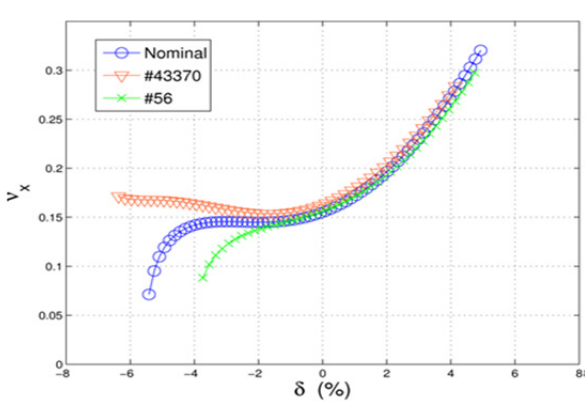

Figure 3: Variation of the horizontal tune versus energy for the present lattice (blue), an improved lattice (red) and a degraded lattice (green).

The increase of the dynamic aperture area of 24 % is not so much relevant since the present injection efficiency is already close to 100 %.

BEAM-BASED EXPERIMENT

Among all the solutions, one group is of particular interest because it is close to the existing working point of the SR. After a thorough analysis using the accurate lattice model in TRACY3, two solutions were selected to be experimentally tested in the real machine: a higher (#43370) and a lower (#56) lifetime solutions. During the experiment Touschek lifetime was maximized whereas gas contribution was minimized: a total beam current of 150 mA was stored in 104 bunches with a transverse coupling of 1 % and a RF-voltage of 2.7 MV. The calculated gas lifetime was 102.4 hours for a pressure of 3 10^{-10} millibars. Table 2 and Table 3 show that measured lifetimes agree with the MOGA prediction within the error bars of the measurement for both improved and degraded lattices. The injection efficiency is not impacted by the new setting. It is worth noting that the online optimization of the lattice was not able to foresee such an improvement because the relative change of the sextupole strengths (up to 10–15 %) proposed by MOGA is significantly larger than the allowed online variations.

Table 2: Comparison of simulated (TRACY3) and measured Touschek lifetimes for the lattices tested experimentally.

Lattice	Simulated Lifetime (h)	Measured Lifetime (h)
Nominal	23.8	20.1 ± 0.7
#433370 (improved)	29.9	30.5 ± 0.8
#56 (degraded)	12.2	10.7 ± 0.6

Table 3: Comparison of simulated (TRACY3) and measured total lifetimes for the lattices tested experimentally.

Lattice	Simulated Lifetime (h)	Measured Lifetime (h)
Nominal	19.8	16.8 ± 0.5
#433370 (improved)	24.8	23.5 ± 0.5
#56 (degraded)	11.1	9.7 ± 0.5

CONCLUSION AND OUTLOOK

This is the first time that MOGA or any GA has been applied to the SOLEIL SR optimization. MOGA reveals itself as a powerful means to optimize the beam dynamics and is complementary to other tools. The convergence of the algorithm is slow and needs a stable lattice as a starting seed to save the computation time. MOGA was able to find improved lattices and predict their performance in terms of Touschek lifetime and injection efficiency. The quality of these results relies heavily on

ISBN 978-3-95450-182-3

the accurate modeling of the lattice including all the magnetic measurements and on the online benchmarking of our simulation codes since 10 years. As advantages, MOGA enables the exploration of areas of the parameter space which were never explored before. It is flexible and can be used to optimize other figures of merit for forthcoming studies such as the horizontal emittance for the SOLEIL upgrade lattice to a level of hundred picometers.

ACKNOWLEDGMENT

The authors are thankful to the members of the accelerator physics group for many discussions and suggestions during this study.

We are also grateful to M. Borland for his guidance using ELEGANT. The second author expresses his gratitude to N. Carmignani for fruitful exchanges during his learning stage of MOGA and ELEGANT codes.

Configuration and installation of MOGA-ELEGANT on the SOLEIL cluster and parallel programming was only possible with the help of both Ph. Martinez and A. Diaz Ortiz.

This study is part of the PhD work [18] of Xavier Nuel Gavaldà within the oPAC European Project [19] funded from the European Union's Seventh Framework Program for research; technological development and demonstration under grant agreement no 289485.

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