

OPTIMIZATIONS OF NONLINEAR BEAM DYNAMICS PERFORMANCE ON APS-U LATTICE*

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Abstract

For next-generation storage ring light sources, such as the Advanced Photon Source (APS) Multi-Bend Achromat (MBA) upgrade, the strong nonlinearities introduced by the strong chromaticity sextupoles plus the small physical apertures make it challenging to achieve large dynamic acceptance (DA) and long Touschek lifetime, even when using the on-axis swap-out injection scheme. Several different methods have been explored for nonlinear dynamics optimization. The optimization objectives variously include the chromaticities up to third order, resonance driving and detuning terms, on- and off-momentum dynamic acceptance, chromatic and geometric tune footprint, local momentum acceptance (LMA), variation of betatron oscillation invariant, Touschek lifetime, etc. In addition, optimization can be performed without errors, with selected random errors, and with sets of errors that reflect post-commissioning conditions. In this paper, these different optimization methods are compared for the nonlinear beam dynamics performance of the Advanced Photon Source upgrade (APS-U) lattice, in terms of the dynamic acceptance, local momentum acceptance, and other performance measures. The impact from different error sources is also studied.

INTRODUCTION

For next generation storage rings, the combination of small physical apertures (both ID and arc) and strong chromaticity sextupoles results in small DA and short lifetime. To optimize the nonlinear beam dynamics performance, in a previous publication the effectiveness of several different optimization methods and objectives were preliminarily compared for the nonlinear beam dynamics optimization of the Advanced Photon Source upgrade (APS-U) lattice [1]. More detailed comparisons are presented in this paper.

OPTIMIZATION METHODS

Five optimization methods were employed, each designated by an acronym for convenience. LMA [2]: objective of dynamic acceptance, chromatic detuning and Touschek lifetime; ANA [3]: objective of analytically calculated nonlinear chromaticity and driving/detuning terms; CSI [4–6]: objective of the Courant-Snyder invariant and chromatic detuning; DA [7, 8]: objective of on- and off-momentum dynamic acceptance, and chromatic detuning; DET: objective of tune spread on x-y grids (with or without energy spread), and chromatic detuning. Table 1 compares the computing

time per evaluation for the APS-U lattice. From previous experience, LMA and DET always generate good solutions; other methods are less reliable.

Table 1: Computing Time (APS Weed Cluster)

Method	Computing time [core*hours]
ANA	0.04
CSI	0.23
DET	0.71
DA	6
LMA	46

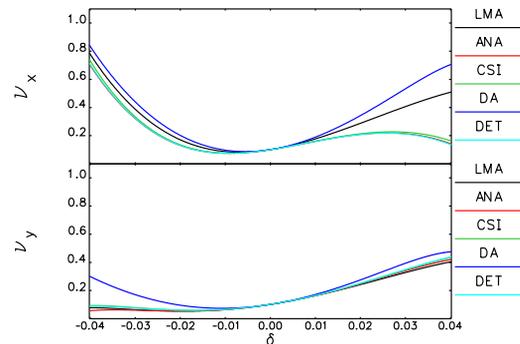


Figure 1: Comparison of chromatic tune shift in horizontal (top) and vertical (bottom) plane.

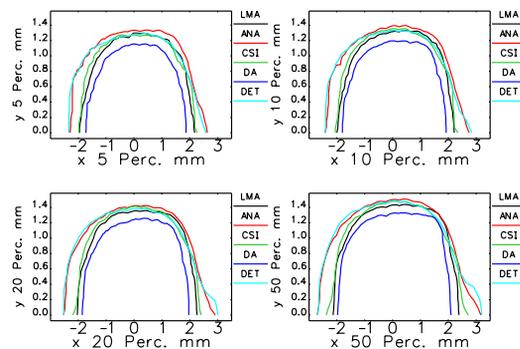


Figure 2: Comparison of dynamic acceptance of different percentiles (all observed at ID center). Real physical apertures with narrow IDs are included.

After nonlinear optics optimization, commissioning simulations [9] were performed with magnet strength, alignment, and tilt errors; BPM alignment and calibration errors; corrector strength errors; and corrections with dipole correctors,

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quad trims, and skew quads [9]. This step results in certain level of residual closed orbits and beta (dispersion) beatings.

Ensemble evaluation was performed using 100 commissioning lattices, with additional errors, namely, random and systematic multipoles errors in all magnets; steering multipoles; and ID kick maps. Some of the ensemble evaluation results (for one specific APS-U lattice) are shown in Figs. 1 through 4. The comparisons of the overall performance (with several different APS-U lattices) of these optimization methods show that DET and LMA are the most reliable.

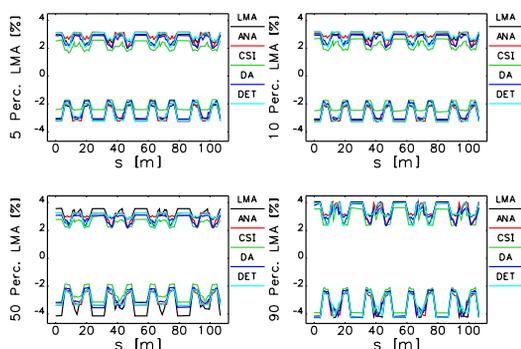


Figure 3: Comparison of LMA in two sectors with errors. Real physical apertures with narrow IDs are included.

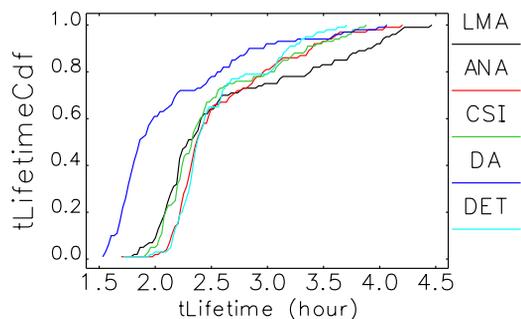


Figure 4: Comparison of Touschek lifetime, 200 mA in 48 bunches with ideal 4th harmonic cavity.

IMPACTS FROM DIFFERENT ERROR SOURCES

APS-U performance is significantly impacted by errors. To further understand this, four cases were compared in the ensemble evaluations:

- Ideal: ideal lattice, without errors
- Mul: only magnets multipole errors
- Com: only commissioning errors and the correction
- Mul+Com: commissioning errors and the correction, plus magnets multipole errors

As shown in Figs. 5 and 6, the impact on APS-U performance is mainly from residual errors following commissioning simulations [9]. These errors generate closed orbit and

optics beatings. The impact from magnet multipole errors is relatively small at the designed multipole error levels.

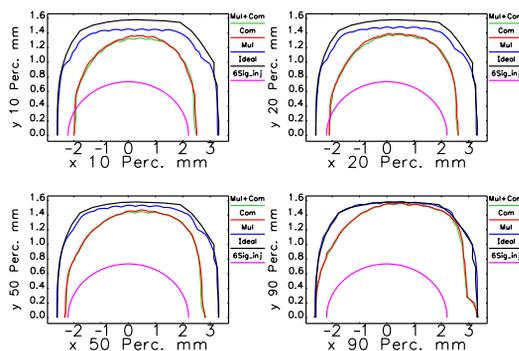


Figure 5: Comparisons of dynamic acceptance with different error sources. Ellipses denote the 6σ (full width) injected beam with 100nm by 20nm booster beam.

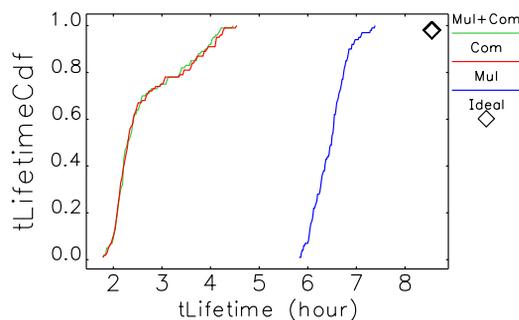


Figure 6: Comparisons of Touschek lifetime with different error sources. 200 mA in 48 bunches with round beams.

OPTIMIZATION WITH 100 COMMISSIONING LATTICES

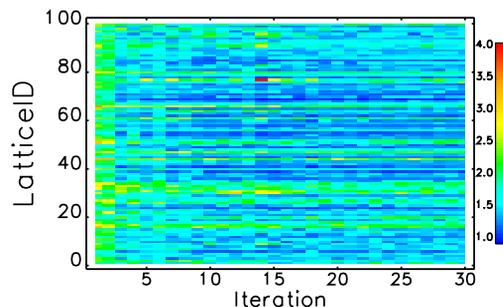


Figure 7: Local optimum penalty of 100 lattice configurations at each iteration (color code is penalty).

The following technique was proposed to find APS-U lattice solutions with better performance: Include all 100

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commissioning/ensemble configurations in the lattice non-linear optics optimization process (possible for the faster methods, which take much less computing time), and try to find APS-U lattice solutions which are robust against all 100 commissioning/ensemble configurations.

This may not be possible for method LMA because of the required computing time. Faster methods (such as DET) were employed instead. Figure 7 shows the local optimum penalty of 100 lattice configurations at each iteration, where 10-20 sextupole seeds are used for each iteration. It is observed that some configurations have larger penalty functions, and that the average performance can be improved.

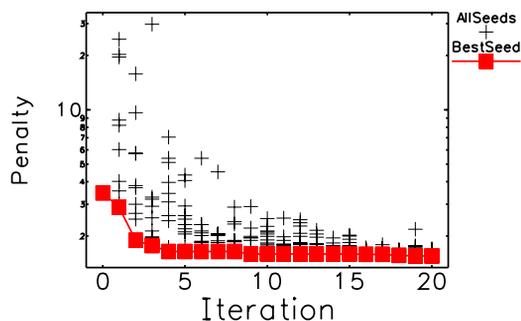


Figure 8: Penalty of all sextupole seeds and best seed (averaged over 100 lattices).

This approach seems promising for finding APS-U lattice solutions with better performance. Using DET method, plus all 100 commissioning configurations, the average penalty function (over 100 lattices) was reduced, as shown in Figs. 8 and 9. The optimization converges in about 5-10 iterations.

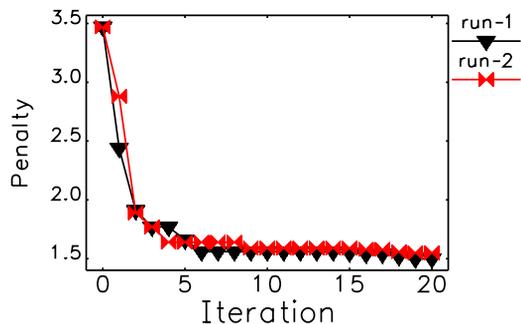


Figure 9: Global optimum penalty at each iteration of two independent runs.

After this optimization, two cases were compared with the same ensemble evaluation procedures as employed above, for 100 commissioning configurations: DET with lattice solution found by DET method; OptAll with lattice solution found by DET optimization for 100 commissioning lattices. The dynamic acceptance of these two cases are compared in Fig. 10, while the Touschek lifetime distributions are compared in Fig. 11. The performance improvement is

smaller than what was expected from penalty reduction, which seems originate from differences between the optimization objectives (DET) and evaluation criterion (DA and Touschek lifetime).

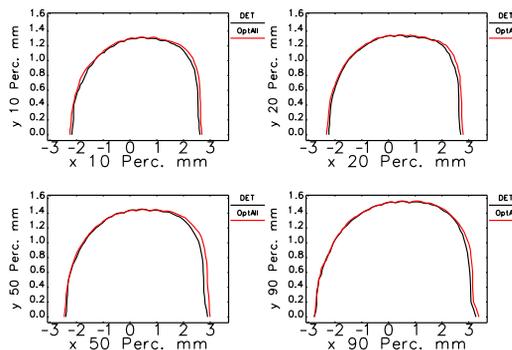


Figure 10: Comparisons of DA.

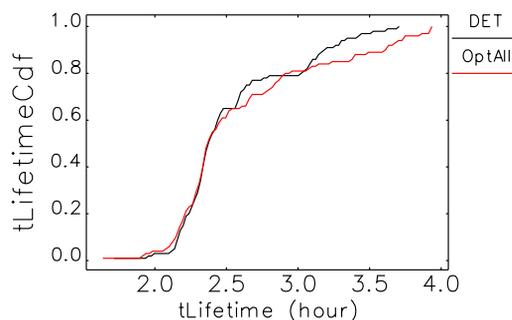


Figure 11: Comparisons of Touschek lifetime.

CONCLUSIONS

Comparisons of performance with several different APS-U lattices of five different optimization methods show that DET (tune spread on grids) and LMA (tracking for DA and Touschek lifetime) are the most reliable. It was shown that APS-U performance reduction is mainly from residual errors from commissioning simulations, which originate in magnet strength/tilt, BPM/corrector and alignment errors. The approach of APS-U lattice optimization with 100 commissioning configurations using the DET method for fast evaluation seems promising in finding APS-U lattice solutions with better performance, but so far yielded only modest improvements.

ACKNOWLEDGMENT

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