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ONLINE OPTIMIZATIONS OF SEVERAL OBSERVABLE PARAMETERS AT THE ADVANCED PHOTON SOURCE*

Yipeng Sun†, ANL, Argonne, IL 60439, USA

Abstract

Online optimizations are known to be powerful tools which may quickly and efficiently improve the particle accelerator key performance parameters in a model-independent way. In this paper, it is presented on the online optimizations of several observable parameters at the Advanced Photon Source storage ring. These observable parameters include the beam lifetime, injection efficiency and topup efficiency, transverse beam sizes, and turn by turn beam position monitors. It is demonstrated that the particle accelerator performance may be greatly enhanced in a relatively short time frame, by optimizing these observable parameters.

INTRODUCTION

For storage rings performance improvement, the dynamic acceptance, local momentum acceptance, tune shift with amplitudes, resonance driving terms, nonlinear chromaticity and other nonlinear terms may be optimized in numerical tracking simulations with a lattice model [1–3]. Some of these physics quantities may take a considerably long time to compute in simulations, such as local momentum acceptance. Recently it is observed that online optimizations [3, 4] also become popular as these methods are model independent and are also quite efficient in finding an optimized solution. Another advantage of online optimization is its capability to observe some specific physics quantities instantly [4] on an operating particle accelerator, i.e. beam lifetime. In two previous publications [5, 6], it is presented on some online optimizations of beam lifetime and vertical beam size.

For the latest work presented in this paper, Python framework is employed as it provides many powerful libraries and the open source nature. Online optimizations tools are scripted in Python framework. The scripts are expected to be compact and the optimization process is designed to be highly automated. The development of these online optimizations tools, as discussed in the following sections, may be potentially useful for APS (Advanced Photon Source) operation optimizations, and for future APS-U (Advanced Photon Source Upgrade [7]) commissioning.

ONLINE MINIMIZATIONS OF TRANSVERSE BEAM SIZES

In this section, online minimization of vertical beam sizes along the APS storage ring is presented. A total of 59 families of skew quadrupole magnets were employed as tuning knobs to adjust the transverse coupling and the vertical dispersion in the APS storage ring. Starting from initially zero current skew quadrupoles, small vertical beam sizes along the APS storage ring may be achieved in a relatively short optimization time.

Previously online minimization of vertical beam sizes in the APS storage ring has been performed [5], which showed very promising results. The potential issue with the previous optimization setup is that it is running in serial mode. This tends to be slow when many PVs need to be read and written simultaneously. A parallelized optimization script has been developed, taking advantage of the Python multiprocessing module. By cocurrently launching multiple threads with Python multiprocessing module, it is possible to greatly reduce the running time in reading and writing PVs. The reduction of running time is proportional to the number of processors. After this optimization, the typical running time is reduced to 5 to 10 minutes, a factor of more than 6 in improvement.

The new parallelized optimization script has been tested in machine studies, which works as expected. The online minimizations of vertical beam size is shown in Fig. 1. It is observed that, the latest optimization manages to reduce emittance ratio to roughly 1% in a short time of 5 minutes, starting from initial conditions of zero strength skew quadrupole magnets. There is negative correlation between the vertical beam size and summed beam loss monitor readings, as shown in Fig. 2. This means that it may also be possible to employ the summed beam loss as optimization objective [4].

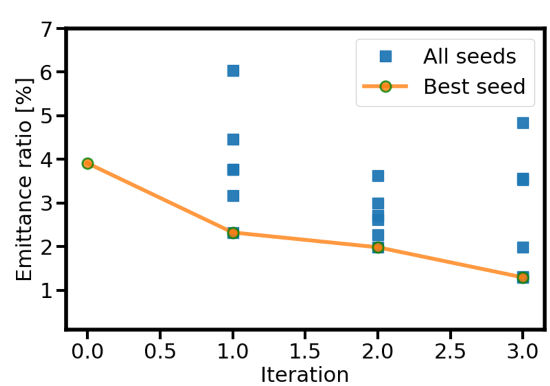

Figure 1: Online optimization of transverse emittance ratio by tuning skew quadrupole magnets current. There are 3 iterations with 6 seeds per iteration, showing best seed and all seeds.

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† yisun@anl.gov

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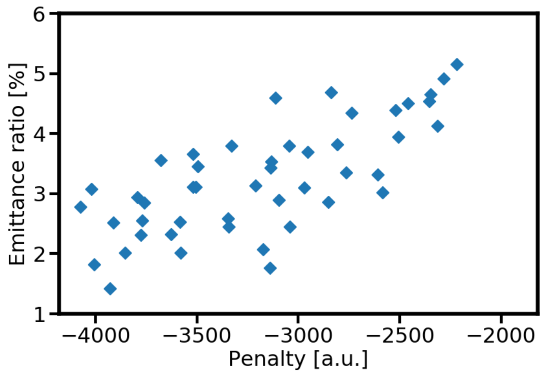

Figure 2: Transverse emittance ratio of all the seeds, versus sum of beam loss, with optimization objective of sum of beam loss.

ONLINE OPTIMIZATIONS OF APS TOPUP EFFICIENCY AND INJECTION EFFICIENCY

Achieving higher injection efficiency is critical for quickly starting of the storage ring operation for photon users. On the other hand, topup efficiency also needs to be high for maintaining the required beam current in topup operation mode. For APS-U which employs swap out mode [7], injection efficiency determines the upper limit of single bunch current, by assuming that the charge of incoming bunch is fixed. Injection efficiency is dependent on many parameters of upstream and downstream systems, as listed below.

- initial beam conditions from upstream accelerator system, such as the transport line from booster synchrotron
- voltage and timing of septum magnets and injection kickers
- sextupole magnets and skew quadrupole magnets, in special sectors hosting injection kickers or small physical apertures
- dynamic aperture of the storage ring
- physical aperture distributions around the storage ring.

Optimizations of topup injection efficiency are performed on the APS storage ring, by tuning the voltage of two septum magnets and four injection kickers, plus timing settings of four injection kickers. As shown in Fig. 3, the optimization effectively improved topup injection efficiency from 56% to 78% in just three iterations.

For optimizations on injection efficiency of a single bunch, a total of 28 families of sextupole magnets are tuned in APS sectors hosting the minimum physical aperture and the four injection kickers. The kicker voltage setting is employed to form a closed bump. As shown in Fig. 4, the optimization effectively improved injection efficiency from 16% to 60% in a short time of 10 minutes. The measured kick aperture in Fig. 5 confirms the validity of the optimized solutions.

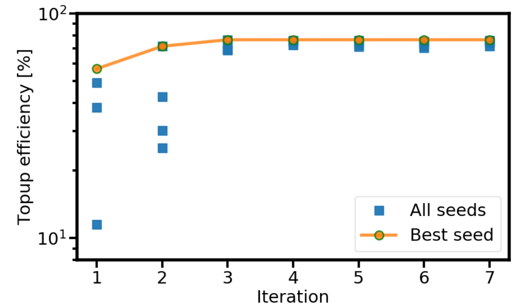

Figure 3: Optimizations of topup injection efficiency, by tuning septum and kickers voltage, plus kickers timing.

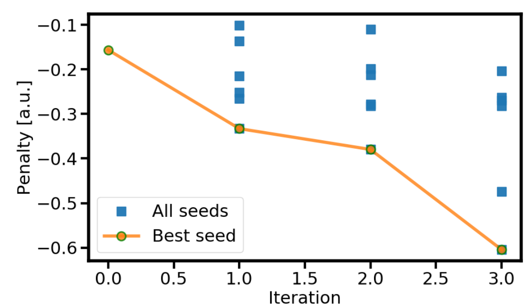

Figure 4: Optimizations on injection efficiency of a single bunch, by tuning 28 families of sextupole magnets in sectors hosting the minimum physical aperture and the four injection kickers.

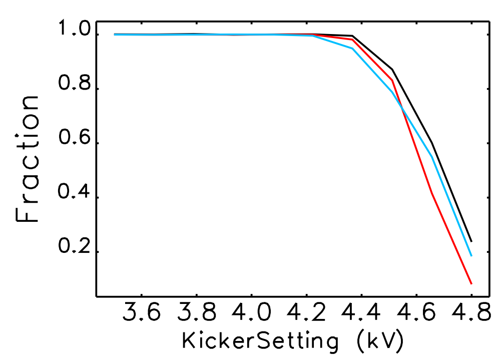

Figure 5: Measured kick apertures of nominal operation lattice (red curve), and the optimized solutions (black and blue curves) with improved injection efficiency.

ONLINE OPTIMIZATIONS ON NONLINEAR BEAM DYNAMICS WITH TURN BY TURN BPM DATA

In this section, a new optimization objective is proposed for online optimizations of single particle nonlinear beam dynamics in storage rings. The measured turn by turn BPM orbit data is employed to calculate the proposed optimization objective. As the decoherence effect is due to tune shift with

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transverse amplitude, it may be possible to reduce the tune shift with transverse amplitude, by optimizing the turn by turn BPM orbit data.

Shown in Fig. 6 is horizontal phase space of a bunch, where 6D tracking is performed for different number of turns. There are 100 macro particles in the bunch. Initial horizontal amplitude is 8 mm for the bunch centroid. As shown in Fig. 7, bunched beam simulation illustrates different decoherence effect due to tune shift with transverse amplitude. When the sextupole magnets strength is reduced to 90%, the beam motion is more "coherent", which results in larger overall horizontal amplitude in turn by turn BPM reading.

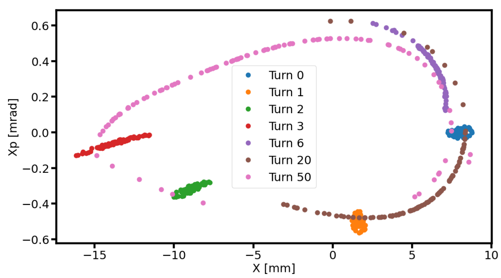

Figure 6: Horizontal phase space from 6D tracking, bunch shown for different number of turns.

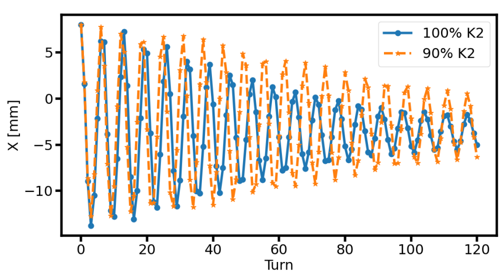

Figure 7: Bunched beam (100 macro particles) simulation illustrates decoherence effect due to tune shift with transverse amplitude.

For machine studies, all sextupoles magnets in 40 sectors (a total of 280 sextupoles magnets) are employed as tuning variables. The online optimization objective is the average amplitude of the turn by turn BPM orbit data. As shown in Figs. 8 and 9, the optimizations manages to work as designed. More machine studies are needed.

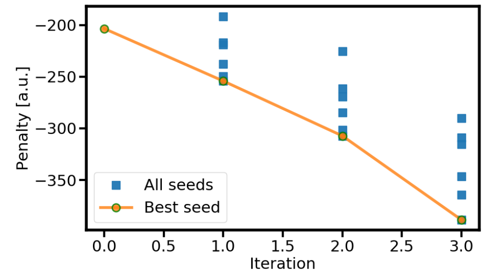

Figure 8: Online optimization of horizontal oscillation amplitudes from turn-by-turn BPMs by tuning sextupole magnets current.

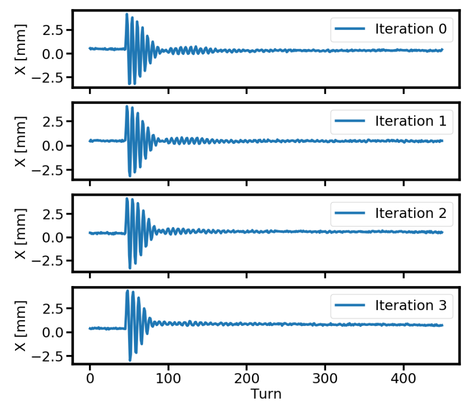

Figure 9: Turn-by-turn BPM at each iteration, showing the "best" with minimum penalty.

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