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# FIRST RESULTS OF AUTOMATED STARTUP AND COMMISSIONING PROCEDURES AT THE ADVANCED LIGHT SOURCE*

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*Abstract*

Rapid commissioning and automated start up procedures are crucial for many upcoming 4th generation storage ring light sources as their downtime demands are very challenging given their increased operational complexity. Detailed commissioning simulations as a tool of error analysis are not only used to guide the design process of new machines but also a prerequisite to implement an automated commissioning and start up procedure for the final machine. The current ALS can be used effectively to test the developed automated commissioning procedures for the ALS Upgrade because the lattice is very similar to the ALS-U Accumulator Ring, of which detailed commission simulations have been carried out. In this study we present first results including first turn beam threading and turn by turn beam based alignment procedures.

## INTRODUCTION

The Advanced Light Source (ALS) is a synchrotron radiation facility located at the Lawrence Berkeley National Laboratory with an upgrade into a diffraction limited light source (ALS-U) [1] in the production phase.

Detailed commissioning simulations have been carried out on both the accumulator [2] and the storage ring [3] of ALS-U that served not only as a tool for error analysis guiding the lattice design process but also to lay the groundwork of developing automated commissioning and startup procedures which will become increasingly important not only for ALS-U but for future light sources in general [4–8].

The injection system of the ALS including the linac and the booster ring will be used to inject beam into the ALS-U accumulator ring (AR) which has a very similar lattice as the current ALS and will be operated using the same Matlab Middle Layer (MML) [9] based control system. This makes the ALS a perfect test ground for ALS-U code development and commissioning procedures.

In this paper we show first results of integrating the Toolkit for Simulated Commissioning [2] into a MML based control system. First turn threading, trajectory- and pseudo orbit correction have been implemented and we demonstrate single turn trajectory beam based alignment, a procedure which is required by ALS-U [3] and other 4th generation light sources such as PETRA-IV [8].

## MEASUREMENT RESULTS

Regular beam injection into the ALS storage ring is done utilizing a four dipole kicker bump and horizontal off axis injection at about 8 mm. The measurements of this study were done using the regular injection pattern with about 1 nC nominal total charge injected into the storage ring. This corresponds to a 30 µm single shot BPM resolution. The injected beam trajectory jitter is up to an order of magnitude larger than that, and therefor the BPM signals in this study are averaged over 5 consecutive injections. For operational simplicity the RF was kept switched on and the bunch cleaner was used to dump the beam after about 100 turns.

Before the turn-by-turn data from BPMs can be used in automated correction algorithms, the data as recorded from the control system must be post-processed to account for timing- and intensity variations.

While the BPMs all trigger to the same event and therefor should start their buffer readout at the same turn, it is a common issue that for some BPMs sometimes the buffer readout begins a turn too early or too late. To align the BPMs turn-wise with respect to each other, for each BPM the turn with the maximum sum signal variation is identified, assuming that this corresponds to the injection turn. We found that this procedure is very robust under injected charge variations and reliable.

In order to identify a beam loss with the BPM sum signal, a normalization is needed to compensate variations of both the injected bunch charge and BPM sensitivities of different BPM types, as described in Fig. 1. The BPM sum signals are normalized to the sum signal of the first BPM to account for injected charge variations and with the BPM sensitivity as obtained by evaluating 1 turn data of 50 consecutive injections during regular operation conditions. A beam loss is defined when the normalized sum signal of a given BPM drops below 60 % of its nominal value.

For trajectory and pseudo-orbit correction we use a response matrix based approach with an SVD algorithm with small regularization, using 107 BPMs and 24 CMs.

### *First Turn Threading and Pseudo Orbit Correction*

The first step towards an automated startup procedure is a reliable first turn threading. This can be done by utilizing 1 turn trajectory feedback while zeroing the trajectory error after the beam loss location as described in [2]. In case of off axis injection as for ALS we take the trajectory as obtained during regular operation condition as a reference.

In the example shown in Fig. 2 the beam is lost after 1/4 of the first turn and it takes 8 correction steps to restore the reference injection trajectory.

Correcting the closed orbit is important to achieve stored beam when large machine errors occur during a shut down. For off-axis injection in particular this can be done by averaging the BPM readings over several turns. Using the toolkit

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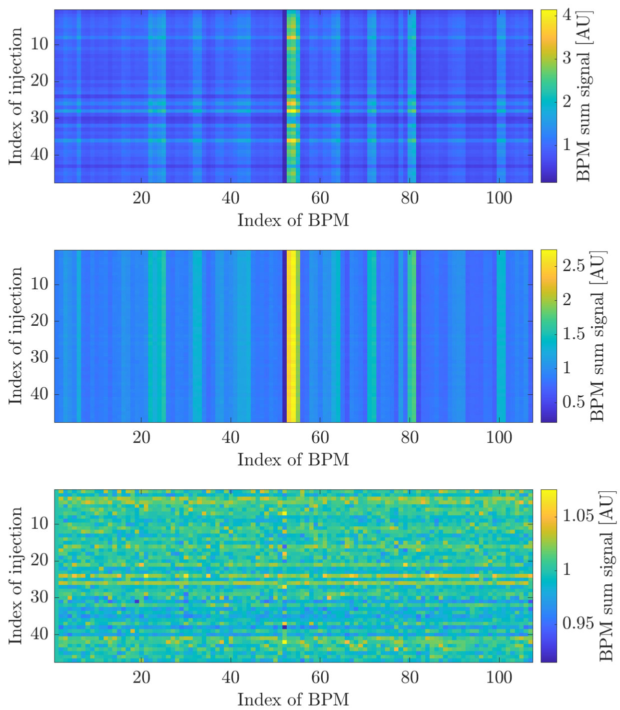


Figure 1: Relative BPM sum signal variation for the first turn over 50 consecutive injections during nominal operation. The top plot shows the sum signal for each BPM and each injection as recorded from the control system. The center plot shows the sum signal variation after normalization with the injected bunch charge as measured by the first storage ring BPM sum. The bottom plot shows the final sum signal after subsequent normalization with the BPM sensitivity. The overall peak to peak variation is thereby decreased from about 400 % to 5 %, suitable for beam loss detection.

framework this can conveniently done by changing the number of requested turns and the readout mode to pseudo-orbit.

In the example shown in Fig. 3 the pseudo-orbit correction decreases the orbit error from 2.1 mm to 0.5 mm rms in the horizontal plane and from 610 µm to 57 µm in the vertical plane, respectively.

### *Single Turn Beam Based Alignment*

As described in detail in [3], stored beam can not be achieved in the ALS-U storage ring without reducing the BPM offsets significantly to about 100 µm, which is much smaller then what can be realistically achieved on the measurement bench before commissioning. Thus, a beam based alignment procedure must be carried out using only a few turns of beam transmission. In this section we demonstrate the successful implementation of the algorithm which was used in the commissioning simulations in [3].

The BBA layout is exemplified in Fig. 4. A vertical CM at the beginning of the ring was chosen to excite the beam trajectory vertically at the QD quadrupole in sector 6 at a 107° phase advance downstream in order to perform beam based alignment of the adjacent BPM which is located 20 cm upstream. Each trajectory is measured by calculating the average BPM readings over 5 consecutive injections. The CM is exercised in 4 steps between ±1 mrad and the quadrupole strength is varied by ±5 %.

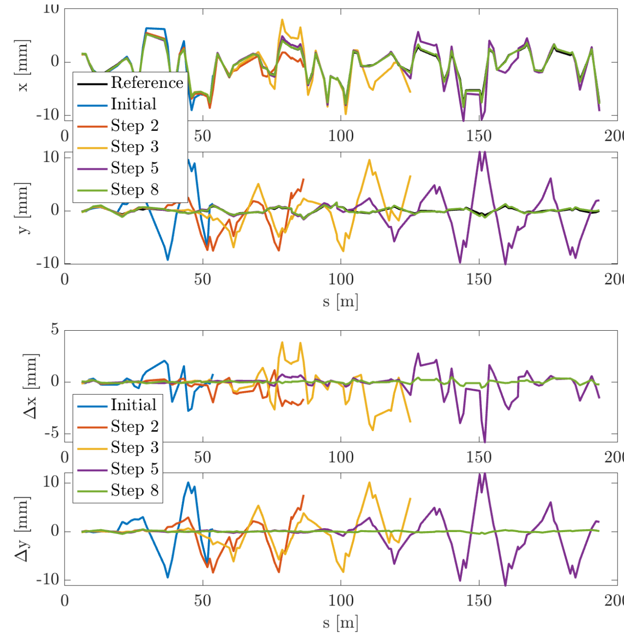


Figure 2: Example of first turn threading at ALS. The two plots at the top show the horizontal and vertical trajectory as during user operation (black), after introducing random dipole errors with corrector magnets (blue) and at 4 correction steps (red to green). The bottom two plots show the trajectories with respect to the reference injection trajectory during user ops. The machine was perturbed by randomly exciting all corrector magnets with an rms value of 3 mrad.

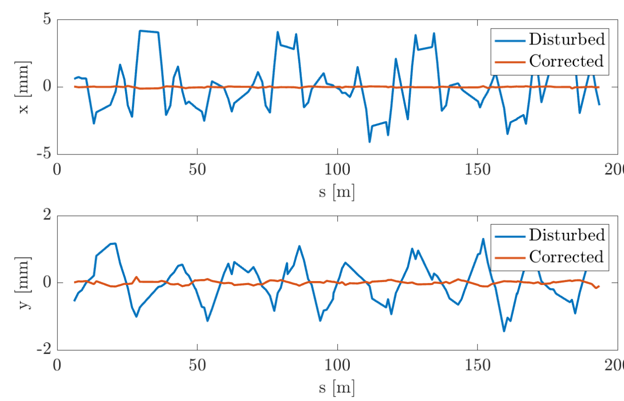


Figure 3: Horizontal (top) and vertical (bottom) orbit as measured by averaging turn-by-turn BPM readings over the first 50 turns after injection before (blue) and after (red) correction. The machine was perturbed by randomly exciting all corrector magnets with an rms value of 1 mrad.

Data evaluation is visualized in Fig. 5. For each CM excitation we record the vertical offset variation at all BPMs downstream of the BBA-BPM as a result of the quadrupole excitation variation as a function of the beam offset at the BBA-BPM. A line fit reveals the zero crossing and the average of all individual zero crossings determines the fitted

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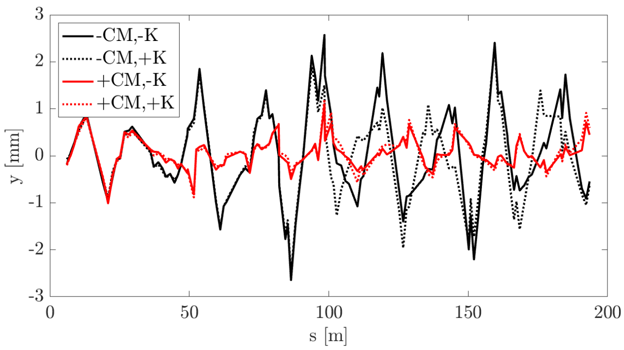


Figure 4: Exemplary vertical trajectories as recorded during the 1 turn BBA procedure. Shown are the trajectories for two different CM excitations in black and red and for two different quadrupole excitations in solid and dashed, respectively. The CM is located $s = 30$ m and the quadrupole at $s = 94$ m.

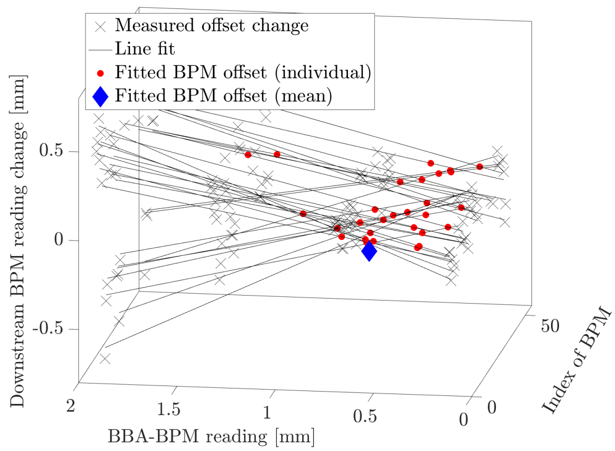


Figure 5: Illustration of trajectory-BBA results for one BPM using 1turn trajectories. The $x$-axis shows the reading of the BPM targeted for BBA; the $y$-axis the index of the downstream BPMs; and the $z$-axis the difference in the trajectories as recorded at the downstream BPMs when changing the quadrupole strength from 95% to 105% of the nominal. A black dot represents the measurement for one of the 3 upstream CM excitations; the black lines are linear fits. The red dots mark the zero crossing of these lines and the blue diamond shows the averaged BPM offset. In this example the offset derived with trajectory BBA is 472 µm, which is close to the 512 µm as calculated with stored beam BBA.

BBA-BPM offset. It is worth noting that we excluded 1/3 of the downstream BPMs that had the smallest response to the quadrupole change which in this case leaves 37 BPMs for the measurement.

In this example the fitted vertical BPM offset is 472 µm, which is 39 µm off from the nominal 512 µm offset that was derived from stored beam BBA. This is a promising result given the relative robustness and simplicity of the routine. In future dedicated beam times we will evaluate its performance on a larger ensemble of BPMs and analyze the reproducibility.

## CONCLUSION

We present first results of automated startup procedures using turn-by-turn BPM readings at the ALS storage ring. Both first turn threading and pseudo orbit correction were successfully implemented and a beam based alignment procedure using single turn transmission was shown.

While still in an early prototype stage, the tools have been successfully used during machine startup in cases when the regular procedures did not provide stored beam.

The integration of the Toolkit for Simulated Commissioning into the Matlab Middle Layer ALS control system was demonstrated successfully. However, because of the fundamental design differences between a simulation focused and a machine control system focused code infrastructure, the authors tend towards using a purely MML based approach for future code developments in order to fully integrate the automated startup procedures into the ALS control system.

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