

# SLOW ORBIT FEEDBACK AT THE ALS USING MATLAB \*

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## Abstract

The third generation Advanced Light Source (ALS) produces extremely bright and finely focused photon beams using undulators, wigglers, and bend magnets. In order to position the photon beams accurately, a slow global orbit feedback system has been developed. The dominant causes of orbit motion at the ALS are temperature variation and insertion device motion. This type of motion can be removed using slow global orbit feedback with a data rate of a few Hertz. The remaining orbit motion in the ALS is only 1-3 micron rms. Slow orbit feedback does not require high computational throughput. At the ALS, the global orbit feedback algorithm, based on the singular valued decomposition method, is coded in MATLAB<sup>®</sup> and runs on a control room workstation. Using the MATLAB<sup>®</sup> environment to develop, test, and run the storage ring control algorithms has proven to be a fast and efficient way to operate the ALS.

## 1 INTRODUCTION

Maintaining the proper electron beam orbit is an important operational issue for all light sources. The most commonly used figure-of-merit for orbit stability is that the beam should be stable to one-tenth of the beam size. That is, the optics for most light source experiments can tolerate a ten percent fluctuation in the beam before it adversely affects the experiment. Shown in Table 1, this implies a very tight tolerance for orbit motion at the ALS (table calculated assuming 1.8% coupling), [1].

Table 1: Beam stability requirements

| Beam Location    | Horizontal         | Vertical          |
|------------------|--------------------|-------------------|
| Straight Section | 24.6 $\mu\text{m}$ | 2.0 $\mu\text{m}$ |
| Bend Magnet #1   | 5.3 $\mu\text{m}$  | 4.4 $\mu\text{m}$ |
| Bend Magnet #2   | 10.3 $\mu\text{m}$ | 1.2 $\mu\text{m}$ |

In reality, obtaining this tight a control over the orbit over all frequency ranges is extremely difficult. Local and global orbit feedback algorithms can potentially regulate the beam position to accuracy of the position monitor (BPM) system, however, building a BPM system which is accurate to the micron level is quite difficult. Many third generation light sources have BPM

systems capable of sub-micron level accuracy over relatively short time intervals. At the ALS, the electron beam can be accurately measured to .6  $\mu\text{m}$  horizontally and .8  $\mu\text{m}$  vertically over a .1-300 Hertz frequency range. The problem for measuring beam motion at the ALS is over longer time intervals. The two major sources of error are current dependence of the BPM electronics and physical motion of the vacuum chamber. Harmonic correction algorithms can mitigate these problems, but it is very difficult to maintain micron level orbit stability over long time periods. Due to these problems, we have taken a very conservative approach to adding orbit feedback to the ALS storage ring.

In addition to the original 96 BPMs in the ALS storage ring, a pair of very accurate BPMs have been installed in each insertion device straight section (20 BPMs in total), [2]. By rigidly mounting these BPMs to each insertion device structure that is installed in a temperature controlled housing, the positional stable of the BPM is very good. The relative motion between the BPM and storage ring floor is a few microns per week, [3]. With the addition of these new monitors, global orbit feedback in the horizontal plane has been added to the standard operation of the ALS.

High-level magnet control and conditioning of the ALS storage ring is done using a commercial software package from the Mathworks Inc. call MATLAB<sup>®</sup>, [4]. MATLAB<sup>®</sup> is an excellent language for algorithmic prototyping. The global orbit feedback algorithm was designed and implemented in MATLAB<sup>®</sup>. Although MATLAB<sup>®</sup> is far from a real-time programming language it has proven to be an efficient and stable software product for running global orbit feedback.

## 2 ORBIT MOTION AT THE ALS

For a light source, electron beam stability is important over a huge frequency range—days to hundreds of megahertz. This paper focuses on slow orbit motion. Slow orbit motion will be subdivided into really slow motion, less than .1 Hertz (drift), and faster motion, .1-300 Hertz. Table 2 is a relatively conservative listing of the observed orbit stability at the ALS without feedback. (0-300 Hertz is the bandwidth of the BPM system.)

### 2.1 Slow Orbit Drift

The dominant source of orbit motion in the ALS is slow drift due to temperature variations. There are three basic causes of thermal variations: 1) change in ambient air temperature of the storage ring tunnel, 2) change in the low conducting water (LCW) temperature, and 3)

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change in the photon beam power as the electron beam decays. The regulation specification is  $\pm 2$  and  $\pm 1$  degrees Celsius for the air and LCW temperature, respectively. However, temperature regulation to this level is difficult to achieve day-to-day.

Insertion device motion is the next largest source of slow orbit distortion. The ALS experimenters can freely adjust the insertion device gap at any time. Feed forward tables are empirically generated to compensated for this motion. The accuracy of a given table is 5-10  $\mu\text{m}$  rms.

Figures 1-2 show the electron beam orbit in the insertion device straight sections for a typical day before the orbit feedback system was operational. The horizontal orbit is more sensitive to temperature variation.

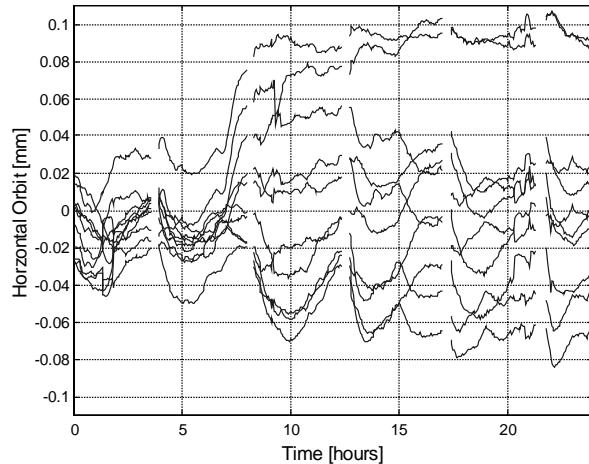


Figure 1: Horizontal orbit stability without feedback, August 15, 1998.

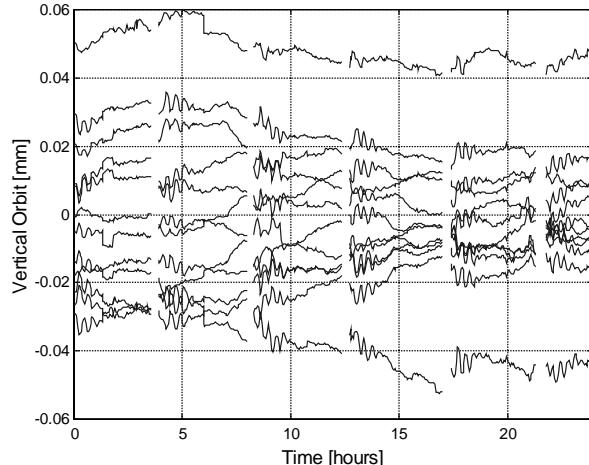


Figure 2: Vertical orbit stability without feedback, August 15, 1998.

## 2.2 "Fast" Orbit Motion

The dominant cause of "fast" orbit motion, .1-300 Hertz, at the ALS is vibrations. Power supply regulation is a common cause of orbit stability problems in this

frequency range, however, it thankfully has not been an issue at the ALS. Figure 3 shows the power spectrum for of the orbit motion in the horizontal plane from .1-300 Hertz. The rms motion from .1-300 Hertz is typically 3.0  $\mu\text{m}$  horizontally and 1.2  $\mu\text{m}$  vertically. These numbers have not changed very much over the last five years which implies that the ALS can inherently meet its stable goal, Table 1, in this frequency range without orbit feedback.

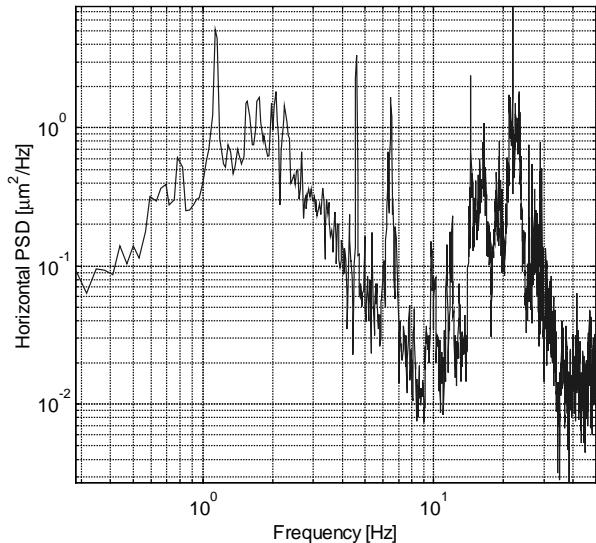


Figure 3: Power spectral density of the horizontal orbit.

Table 2: Beam stability w/o orbit feedback

| Frequency                                 | Magnitude  | Dominant Cause  |
|---|--|---|
| Two weeks<br>(A typical experimental run) | Horizontally $\pm 200 \mu\text{m}$<br>Vertically $\pm 100 \mu\text{m}$ | 1. Magnet hysteresis<br>2. Temperature fluctuations<br>3. Component heating between 1.5 GeV and 1.9 GeV |
| 1 Day                                     | Horizontally $\pm 125 \mu\text{m}$<br>Vertically $\pm 75 \mu\text{m}$  | Temperature fluctuations  |
| 4 Hour Fill                               | Horizontally $\pm 50 \mu\text{m}$<br>Vertically $\pm 20 \mu\text{m}$   | 1. Temperature fluctuations<br>2. Feed forward errors   |
| Minutes                                   | 5 to 10 $\mu\text{m}$  | Feed forward errors   |
| .1 to 300 Hz                              | 1 to 3 $\mu\text{m}$   | Ground vibration  |

## 3 SLOW GLOBAL ORBIT FEEDBACK

A slow global orbit feedback system in the horizontal plane has been in operation at the ALS since September 1998. Before that time, orbit correction was only done at the beginning of an experiment run. Besides the feed forward correction to compensate for insertion device motion, the storage ring magnet control would be static for the length of the run—typically two weeks. As shown in Table 2, the ALS is surprisingly quite stable

without orbit correction. However, in order to meet the tolerances in Table 1 a slow global orbit feedback system needed to be developed.

### 3.1 The Global Feedback Algorithm

The following example is the entire horizontal global orbit correction routine for the ALS using a singular valued decomposition (SVD) method. The present algorithm uses 18 BPMs, 12 corrector magnets, and the first 10 singular values of the response matrix,  $Sx$ .

```
X = getx;
[U, S, V] = svd(Sx);
DeltaAmps = - X / U(:,1:10);
stepsp('HCM', DeltaAmps);
```

Once the ALS database access functions `getx` (get the horizontal orbit) and `stepsp` (step the corrector magnet setpoint) have been written, this relatively involved global orbit correction method can be accomplished in four lines: 1) get the horizontal orbit, 2) compute the SVD of the response matrix, 3) find the corrector changes via Gaussian elimination, and 4) apply the correction.

### 3.2 Results

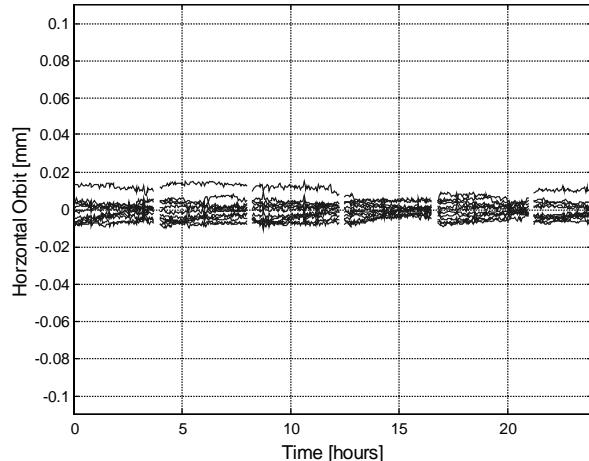


Figure 4: Horizontal orbit stability with feedback on, February 6, 1999.

One could correct the orbit in Figure 4 to the micron level, however the orbit correction algorithm is presently run over-constrained. This is a conservative measure done so that the feedback system does not track vacuum chamber motion so well. More corrector magnets will be used in the future since the measured motion of the vacuum chamber in the insertion device straight sections is small—a few microns, [3].

### 3.3 An Aside

The word "feedback" is used in a rather cavalier way in this paper. The transient response of the beam position

to a corrector magnet change is only a fraction of a second (the aluminium vacuum chamber is quite thin at the location of the straight section corrector magnets). If the data rate of the "feedback" loop is 10 seconds, then it is essentially an open loop system. In fact, only the open loop system dynamics are important. A more appropriate word for this type of orbit correction would be a retry system.

## 4 ACCELERATOR CONTROL USING MATLAB

MATLAB® is a high-level matrix manipulation language originally developed to be an efficient programming environment for using the LINPACK and EISPACK libraries in the heyday of FORTRAN. MATLAB® is convenient software package to control particle accelerators for a number of reasons.

- Matrix algebra is coded very similar to how it is written on paper.
- MATLAB® supports a huge number of subroutines.
- An active workspace eases debug and development of algorithms. This is particularly important during accelerator physics studies when machine time is very expensive.
- Excellent graphics.
- Ease of importing and exporting data.
- Basic graphical users interface capabilities.
- Interfaces to C and Fortran subroutines. Hence, connecting MATLAB® to the ALS database and EPICS was relatively easy.
- Platform independence.

MATLAB® is an interpreted language, hence the computational speed does not compare favourably to a compiled language. However, the fact that MATLAB®'s built-in functions are compiled greatly mitigates the speed disadvantage of using an interpreted language. When controlling magnet power supplies, the slow link in the system is the ramp rate of the supply, not MATLAB®.

## 5 ACKNOWLEDGMENTS

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## 6 REFERENCES

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