OPERATIONAL EXPERIENCE INTEGRATING SLOW AND FAST ORBIT FEEDBACKS AT THE ALS*

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Abstract

A fast global orbit feedback system has been implemented at the ALS and is being used during user operation since this year. The system has two main purposes. The first is to meet the demands of some users for even improved (submicron) short term orbit stability. The second is to enable the use of more sophisticated insertion device compensation schemes (e.g. tune, beta-beating, coupling) for fast moving insertion devices like elliptically polarizing undulators, without deteriorating the orbit stability. The experience of routine user operation with the fast orbit feedback will be presented, as well as the overall feedback performance and how the integration issues with the already existing slow orbit feedback were solved.

INTRODUCTION

Using a combination of many passive measures and careful engineering as well as feedforward schemes and a slow orbit feedback system, the orbit stability at the ALS has always been very good. Since upgrade plans of the ALS include decreasing the beamsizes, experiments become more and more sensitive and other optics compensation loops create additional noise sources, a fast orbit feedback system was planned and implemented over the last years. It is a fast, distributed, global orbit feedback system similar to the approach at several other light sources [1, 2, 3]. One of the differences is the use of standard hardware and networking infrastructure, which made the implementation easier and more cost effective. The system with an update rate of 1.11 kHz was completed, commissioned, optimized and finally integrated with the slow orbit feedback system. It is in routine use during user operation since this spring and with it, the ALS now achieves submicron stability for frequencies larger than 0.01 Hz in the vertical plane.

The following sections will revisit some of the design choices, performance data for routine operation as well as details of the integration with the slow orbit feedback.

FEEDBACK SYSTEM LAYOUT

With currently available standard networking it was practical to use it directly for medium performance distributed control systems. This system consists of 12 Compact PCI chassis - the same type used elsewhere in the ALS control system - distributed around the ring on a private, switched 100 Mbit/s full duplex network. Each chassis handles 4-8 BPM inputs and 2-4 corrector magnet outputs. Each crate has a timing board to provide the interrupt synchronizing the control algorithm. Currently network packets are used to synchronize these timers which proved to be an adequate solution. More details can be found in [4]. A dual system of Digital to Analog Converters (DACs) is used with effectively about 20 Bit of resolution. The BPM system consists of Bergoz type multiplexed BPMs. Their multiplexing rate is set by external clocks, currently at 24 kHz (compared to the standard 8 kHz rate) improving the time response and lowering the BPM noise. There are also analog anti-aliasing filters between the BPM electronics and the A/D converters. Fig. 1 shows a flow diagram of the feedback algorithm.

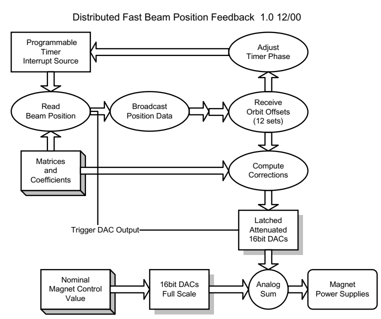

Figure 1: Flow diagram of the ALS fast feedback system. Timing of the system is completely network based, using a standard 100 MBit/s full duplex Ethernet which is also used for the data exchange between the 12 stations.

IMPLEMENTATION DETAILS

The orbit feedback systems at the ALS are implemented as global feedback systems using the SVD algorithm. A combination of fast and slow global orbit feedbacks is used in both planes with no frequency deadband to separate them. Instead, both systems have full gain all the way down to DC. The fast feedback currently uses 24 BPMs in each plane and 22 correctors in each plane with 1.11 kHz update rate. It is implemented such, that it does not cause a beam energy change, but it does not correct the RF frequency. In the SVD inversions, 12 singular values out of the 22 ones possible are used. The closed loop bandwidth of the system currently is about DC–40 Hz.

The slow orbit feedback uses 52 BPMs in each plane (at least 4 in each sector of the ALS), 26 horizontal corrector magnets, 50 vertical corrector magnets, and also provides for the RF frequency correction. It operates at 1 Hz update rate. In the SVD inversion, typically all singular values are used. The system operates with about 60% single step gain, and the bandwidth is about DC–0.1 Hz.

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To avoid interference in their frequency overlap range, the slow orbit feedback communicates with the fast orbit feedback. The method is similar to the one employed at APS, however in contrast to the APS case, there is no intentional frequency deadband. We found that the performance is actually much better without any separation between the frequency responses of the slow and fast feedback systems. To coordinate the feedback responses, the orbit setpoints used by the fast feedback are updated at the rate of the slow feedback. More details will be given in a later section.

FAST FEEBACK PERFORMANCE

The commissioning of the fast orbit feedback started about a year and a half ago. Initially the system was configured as a single channel local feedback to simplify the optimization. Later it was optimized in its full configuration. Since the spring of this year, the fast orbit feedback is used routinely during user operation at the ALS. The results so far have been very good. There were no significant problems with the system, it is very easy for the operators to use, the overall reliability was very good and the user response to the improved stability was positive.

Currently the fast orbit feedback is set up to provide a closed loop bandwidth of about 30 to 40 Hz. This is not the limit of what is achievable with the system, but rather a compromise to allow for an initial, smooth transition to the fast feedback. At higher gain, work remains to be done on how to better deal with intermittent noise on some of the ALS BPMs. With the current parameters, submicron, fast orbit stability is achieved in the vertical plane. The integrated vertical rms orbit motion between 0.01 and 500 Hz is significantly below 1 μm at a beta function of 3.65 m and a vertical beamsize of 23 μm. Horizontally the integrated rms orbit motion was reduced from 4-5 down to 2 μm at a beta function of 13.5 m and a beamsize of 300 μm. The fast feedback corrects orbit noise below 15 Hz down to the BPM noise floor (compare Fig 2), without exciting higher frequencies in a significant way.

INTEGRATION OF FAST AND SLOW ORBIT FEEDBACKS

The main reason, why it was necessary to keep two somewhat independent orbit feedback systems, is that there are not enough corrector magnets with high bandwidth available. Only 22 high bandwidth corrector magnets exist in each plane. To achieve a sufficient long term orbit stability, significantly more corrector magnets are used in the slow feedback. Since there are no demonstrated solutions, how to incorporate corrector magnets with very different bandwidth (2 versus 80 Hz) into the same feedback systems, a layout with two separate feedback systems was chosen.

This layout has the potential to cause unintended interference effects between the two systems, leading to oscillations or periodic steps/spikes in the orbit. In the past, the

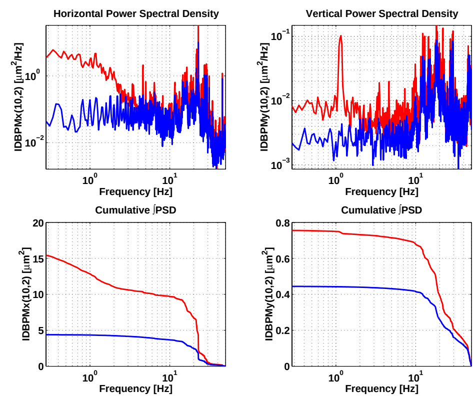

Figure 2: Power spectral density of the closed orbit motion between 0.1 and 50 Hz with the fast orbit feedback in open and closed loop. The measurements were taken with an independent acquisition system at a BPM not included in the feedback system. The noise floor is not subtracted in these plots.

use of frequency deadbands has been implemented, so that the frequency response of the two systems does not contain significant overlap, with some success in reducing the interference effects. However, the deadband approach has one main disadvantage: in order for it to work, the deadband has to be fairly wide, leaving a reasonably large range of frequencies, where neither of the feedbacks is effective. Often this deadband happens to be exactly in the range, where transient orbit distortions due to insertion device motion occurr. An improvement over the pure deadband approach was implemented earlier at the APS [5]. In that approach, the fast and slow orbit feedbacks communicate. The slow orbit feedback updates the setpoints of the fast feedback by adding the orbit steps it intends to do in its next feedback step. In the APS system, the fast feedback is DC blocked, so there is no need to have absolute golden orbit values in the setpoints for the fast feedback.

The implementation at the ALS is somewhat different. In our case, both feedback systems have full gain at DC, so there is no frequency deadband. Therefore the setpoints of the fast feedback system act as absolute, golden orbit values. At the ALS the slow orbit feedback updates the setpoint values of the fast orbit system with its update rate (i.e. 1 Hz). The new setpoints are based on the current orbit, plus the action the slow feedback anticipates to do in its current step.

The results of this approach to avoid interference between the fast and slow orbit feedbacks are very good (see Fig. 3). No interference has been observed at all. The combination of the two systems behaves exactly like the sum of the positive effects of each of the systems.

In the figure, three different step responses to a corrector magnet not included in the feedback system are shown. Using only the slow feedback, the distortion initially is very large and it takes several seconds to be taken out. Using only the fast feedback, the distortion never gets as large and is mostly corrected within a small fraction of a second. However, because of the limited number of corrector

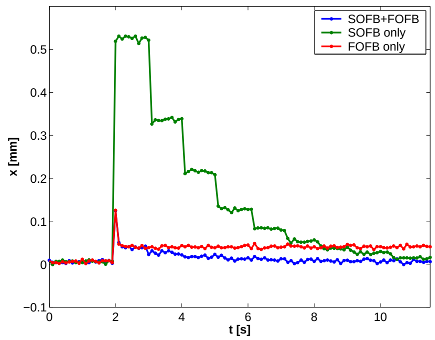

Figure 3: Response of the fast and slow orbit feedback systems to a step in a corrector magnet.

magnets and the reduced number of singular values in the SVD inversion, the correction is not perfect. The last trace shows the combined effect of both feedbacks. The initial behaviour is identical to the fast feedback case, but then the slow feedback relatively quickly takes out the remaining error.

Long Term Orbit Stability

The long term orbit stability at the ALS is very good, however, it does not reach the submicron level of the short term stability, yet. The long term drift over the course of a week is approximately 3 micron rms (both in the horizontal and the vertical plane). Fig. 4 shows the evolution of the horizontal and vertical rms orbit error over the course of 1.5 days. The reason why the rms error does not start at zero is, that only a limited number of corrector magnets (smaller than the number of BPMs) was used in the orbit feedback. However, this systematic error is very stable over time, it changes on the timescale of about a year, as the misalignment of the storage ring increases. It is not of importance, since the beamline alignment drifts on a similar timescale by larger amounts relative to the storage ring.

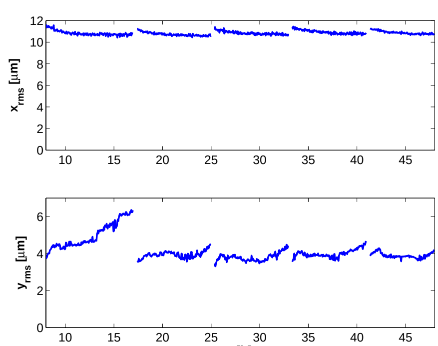

Figure 4: Rms orbit error over the course of 1.5 days. The first fill is after a beam dump, i.e. the thermal stability of the ring is not as good creating somewhat larger slow orbit drifts.

The main remaining reasons for long term orbit drift at ALS are the physical movement of BPM chambers, the current and fill pattern dependence of BPMs and the before mentioned use of less corrector magnets than BPMs (and a relatively limited number of BPMs (52) and correctors). The effects are listed here in the order of their importance at the ALS and all three effects have been measured and quantified directly or indirectly. The current and fill pattern dependence of the Bergoz BPMs is relatively small above 200 mA and will be even less relevant in top-off, so it is not a long term concern. To address the first and the third issue, plans are in place to monitor the physical motion of at least a subset of the BPMs online during user operation, as well as to convert more (76) BPM electronics and buttons to the better performing type being used for orbit feedback.

FUTURE PLANS

Planned upgrades for the next year include a notch filter to directly target steady 60 Hz noise, the switch to faster network (gigabit), use of ADCs with higher speed (which will allow digital filtering to improve the BPM resolution and noise), use of DACs with shorter access times and further improvements to the timing system. There are plans to integrate the slow and fast orbit feedback systems into one system in the long term. We also plan to evaluate newer digital BPM systems to quantify the gain in BPM performance achievable with those systems.

To improve the slow orbit stability it is planned to install monitors to measure the physical location of BPM buttons (pickups placed on invar rods) and 24 additional, stable BPM electronics and improved BPM button assemblies.

SUMMARY

With the combined use of a fast and a slow orbit feedback system the ALS now achieves submicron stability in the vertical plane for frequencies larger than 0.01 Hz. The communication of the slow and fast orbit feedback systems avoiding frequency deadbands and instead running both feedback systems with full DC gain works very well. Anticipating future user demands, we will continue to improve the orbit feedbacks in a steady, evolutionary process. There are still significant upgrades planned to the fast orbit feedback, including upgrades to the networking, and processor speed, better ADCs/DAC, and further optimized digital filters. In terms of the slow stability there are plans to incorporate additional, stable BPMs as well as to start to monitor the physical motion of BPMs online.

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