ORBIT FEEDBACK DEVELOPMENT AT THE ALS*

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Abstract

The slow orbit feedback system at the ALS has been continually improved over the years. The most recent upgrades were the incorporation of an RF-frequency feedback and the switch to higher resolution digital to analog converters (DACs). In addition all readouts of beam position monitors (BPMs) and most of the controls for corrector magnet power supplies were ported to a new control system based on compact PCI (cPCI) intelligent output controllers (IOCs). These upgrades were part of the implementation of a new fast global orbit feedback system which has been designed over the last year and a half and is entering its commissioning stage. One feature of the fast orbit feedback (with 1 kHz update rate) is the use of standard computer and networking equipment.

1 INTRODUCTION

The ALS is a third generation synchrotron light source and has been in operation since 1993. Many of the experiments carried out nowadays require very high resolution or measure very small asymmetries and therefore require extremely high orbit stability. On the other hand there are new sources of orbit distortions created with the installation of additional (fast moving) insertion devices and the implementation of more and more feedback or feed-forward loops (e.g. optics compensation).

To reduce the impact of long term orbit drifts due to thermal effects and of motion on intermediate time scales due to insertion device scans, a combination of a slow, global orbit feedback system (1 Hz update rate) and feed forward systems for each insertion device (10 – 200 Hz update rate) are used [1]. This yields a long term orbit stability (over time spans of a week) of about 10–20 μm, dominated by thermally induced drifts in the physical position of the beam position monitors.

Since recently, there is user demand to improve especially the short term orbit stability further. This demand is for example driven by the progress in dichroism experiments, which are capable of detecting smaller and smaller asymmetries. Vertical orbit stability (and therefore photon energy stability) is especially crucial for microscopy experiments trying to measure small dichroisms.

2 RF-FREQUENCY FEEDBACK

One recent addition to the slow orbit feedback was the inclusion of an RF-frequency feedback leading to a large improvement of the horizontal orbit stability in the twelve arcs of the ALS. The feedback uses newly installed, very stable beam position monitors in four arcs. It compensates for changes of the ring circumference caused by changes in insertion device gaps (on the timescale of several seconds), by changes in air or magnet support temperatures (on the timescale of an 8 hour user fill) or by seasonal changes of the accelerator ground plate (especially at the beginning and end of the rain season). In contrast to all corrector magnet channels of the slow orbit feedback, which operate with unity gain, the frequency feedback is set to a gain of about 1/50. The resolution of the DAC used to control the frequency modulation input of the master oscillator defines a smallest frequency increment of about 0.3 Hz.

Besides correcting the beam orbit in the arcs, the frequency feedback also improves the long term stability of the beam energy. Without the feedback, the electron beam energy could drift by up to 0.1% over the course of a week. Now the energy stability is much better than 0.01% which has been verified with resonant depolarization measurements. No long-term drifts of the (dispersion weighted) average corrector magnet strength have been observed.

Fig. 1 shows an example of the improved stability in the horizontal plane. Without RF-frequency feedback, the orbit in one arc drifted by as much as 80 μm over the four days after startup in January 2001. With feedback over the same period in 2002, the drift was reduced close to the magnitude of the fast orbit jitter. With this new addition to the orbit feedback system, the orbit stability in the arcs of the ALS is now about as good as in the straight sections.

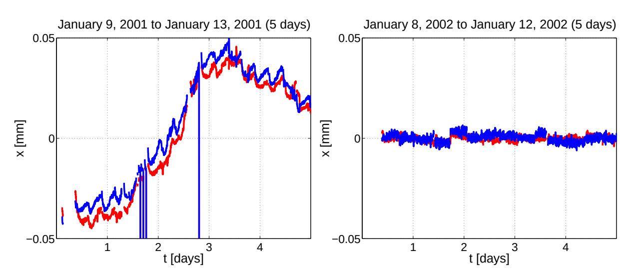

Figure 1: Orbit drift over 5 days in one arc of the ALS with or without rf-frequency feedback.

3 HIGH RESOLUTION DACS

All corrector magnets at the ALS are fairly strong (2-3 mrad) magnets, providing a much larger dynamic range than normally necessary for orbit feedback. 1 bit of the original 16 bit DACs used to control the corrector power supplies was equivalent to an orbit change of 0.3-0.6 μm. Using an SVD algorithm for the orbit correction potentially

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multiplies this discretization effect, leading to the potential of oscillations of the feedback system with its update rate (compare [2]). There are three possible ways around this effect:

1. Decrease the dynamic range of the corrector magnets.
2. Simulate and correct for the discretization errors in the correction algorithm.
3. Increase the resolution of the DACs.

The first method is not very practical since some applications (like local orbit bumps) still require a fairly large local corrector strength. One specific implementation of the second method was originally used at the ALS for the vertical slow orbit feedback. Unfortunately it requires a large number of computations and is therefore not suited for a fast orbit feedback and in addition it does not fully overcome the resolution limitation: it only avoids oscillations of the feedback.

Therefore the third method was finally implemented at the ALS as part of the upgrade for a fast orbit feedback: high resolution DACs were installed to control all correctors. A staged approach was chosen with two 16 bit DACs, with the fine DAC currently reduced by a factor of 10, yielding an overall resolution of about 19.5 bit. The board layout is flexible and allows for a later modification of the factor between the fine and coarse DACs. The output of the coarse DAC is low pass filtered, to reduce the overall output noise of the system.

The high resolution DACs work extremely well and as expected they helped to improve the slow/intermediate orbit stability (on the timescale of several update cycles of the system, i.e. several seconds) significantly from about 1 μm to about 0.1 μm.

4 FAST GLOBAL ORBIT FEEDBACK

Employing a combination of good passive measures and careful engineering of noise sources like power supplies and the cooling system, the short term closed orbit stability in the ALS fulfills the user requirements up to now. In the range between 0.1 and 500 Hz the integrated closed orbit motion in the insertion device straights is below 2 μm in the vertical plane and about 3 μm in the horizontal plane (one sigma beam sizes at 1.9 GeV at that position are about 23 μm vertical and 300 μm horizontal).

The constant expansion of the ALS creates new sources of closed orbit noise. Elliptically Polarizing Undulators [3] for example require fast focusing and coupling compensation, to minimize their influence on the beamsize, which in turn creates fast distortions of the orbit. Other noise sources are active tune/chromaticity compensation schemes, the cryogenics of superconducting magnets or beamlines, etc. To prevent a deterioration of the current orbit stability due to those upgrade projects and ultimately provide a short term submicron orbit stability a fast, global orbit feedback system was designed. The initial goal is to operate at an update rate of up to 1 kHz.

4.1 Feedback System Layout

With the advent of higher performance networking it is practical to use it directly for medium performance distributed control systems. In the past higher-cost specialized solutions were often required such as reflective memory. The requirements for this feedback system appear to be compatible with 100 Mbit/s networking and standard processors.

The system consists of 12 Compact PCI chassis distributed around the ring on a private, switched 100 Mbit/s network. Each chassis handles four BPM inputs and four corrector magnet outputs. There are additional channels available in the crate that are used for the (slow) control system interfacing of other powersupplies of the ALS. The subsystems were designed for compatibility with existing ALS controls hardware (e.g. cabling) and are also used for other upgrades and expansion. Each crate has a timing board to provide the interrupt synchronizing the inputs and outputs of the control algorithm. The initial plan is to use network packets to synchronize these timers. If necessary, there is a backup plan to distribute a precision timing signal to the cards via hardware.

The program flow is interrupt driven. After the interrupt the magnet currents calculated in the last cycle are set, the BPMs are read, the readings are shared via network packets, and the array computations to determine the next outputs are performed. All 12 processors are running in parallel. The most time consuming operation is the sharing of the data via the network. In addition there is a slow loop running, which synchronizes the timer boards. The optimization of the parameters of the controller which computes the new setpoints is described in section 4.2.

The 12 systems share the BPM values via UDP broadcasts. These broadcasts are sent at about the same time by all systems but they do not collide on the network since a full duplex switch is employed. All systems can in fact transmit simultaneously. The first packet coming into the switch is transmitted by the switch to all outputs at once, and the other 11 packets are queued and re-sent sequentially. This process requires about one third of the total time budget for an update cycle. The feedback software checks to see if all BPM values are available for the current cycle. The network is separate from other controls to reduce the potential for delays.

Several timing tests were run to determine whether the chosen CPU and network configuration could accommodate the timing requirements. So far all tests were positive, demonstrating the feasability of a 1 kHz system with standard computer and networking hardware. The ultimate tests of the full system with beam will begin later this summer.

4.2 Controller design

The controller which is used to compute the new output setpoints in each feedback system step is crucial for the overall performance of the feedback system. In order to

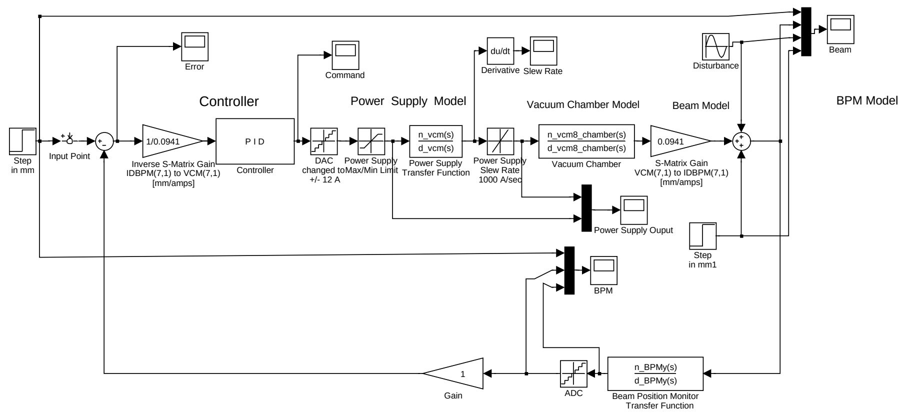

Figure 2: One of the Matlab-Simulink models used to optimize the performance of the smallest building block of the feedback system: One BPM, one ADC and DAC, the controller and one corrector magnet.

optimize it, it is essential to have a good model of the complete feedback system. Therefore, a set of transfer function measurements (measuring current, magnetic fields or beam motion both on tests stands and on the accelerator) was carried out, characterizing all important elements involved (i.e. power supplies, magnets, vacuum chambers, beam, BPMs). Examples of measured transfer functions are shown in Fig. 3. The figure shows the transfer functions of a corrector power supply and the combined transfer function of power supply, magnet, vacuum chamber, beam and BPM. It also shows the transferfunction of a corrector in an arc, which has a much lower cutoff frequency.

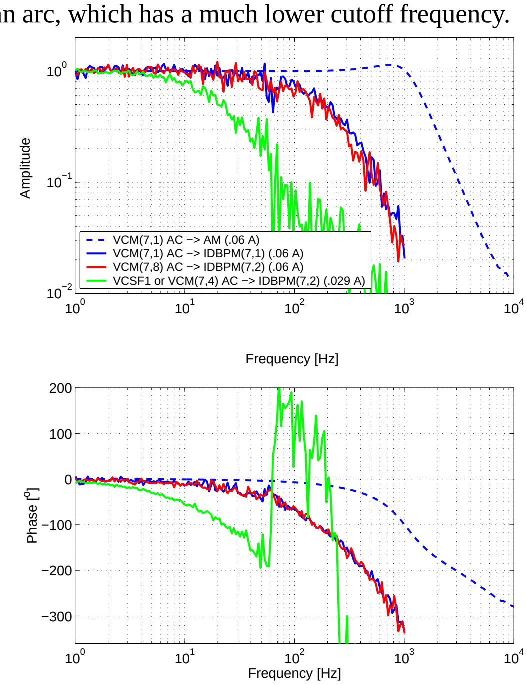

Figure 3: Transfer function of an ALS corrector magnet power supply and combined transfer function of power supply, magnet, vacuum chamber and beam.

For the simulations to optimize the controller, all transfer functions were fitted and some non-linearities (e.g. slew rate limits of power supplies and discretization effects of DACs and ADCs) were included as well.

The simulations are performed in Matlab, using the Simulink toolbox. Fig. 2 shows an example of one of the models used to optimize the system. This specific model consists of the smallest building block of the system (just one BPM and one corrector magnet). The results of the simulations indicate that the hardware limitations (bandwidth of powersupplies, magnets, vacuum chamber and BPMs) are at high enough frequencies, allowing good noise suppression in the desired frequency range (up to more than 60 Hz). Limitations due to parallelization have to be studied in more detail, and a systematic optimization of the controllers for the full parallel system has to be performed.

5 SUMMARY AND OUTLOOK

The slow orbit system of the ALS is continually improved leading to very good slow orbit stability. Future improvements will include the implementation of high precision online measurements of the physical locations of BPMs. A design for a fast orbit feedback system for the ALS was completed. Its purpose is to maintain the current, good short term stability of the closed orbit and ultimately improve it to submicron stability for future experiments. All hardware components have been designed and installed. Several performance tests have been carried out and the software development is mostly finished. To optimize the controller, transfer function measurements were performed, enabling the creation of Simulink models to study the system. The commissioning of the system will start later this summer. For the future, network upgrades are planned to increase the update rate, as well as improvements of individual components.

6 REFERENCES

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