Operations with the Digital Orbit Feedback System in the NSLS X-ray Ring*

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Abstract

The digital filtering and the eigenvector decomposition-based orbit correction is performed by two dedicated HP 742/743 rt micros which communicate with Motorola CPU based orbit-measuring and orbit-correction systems. The correction algorithm in the DFbk was orthogonalized with respect of the analog global harmonic feedback. Operational results concerning improvements in the noise suppression at low frequencies and especially in the dc drift as well as in the orbit stability are shown. Efforts are underway to improve the resolution of the orbit measuring system and the sampling rate using 16 bit 400 kHz ADC's which will allow orbit sampling with high resolution at 4 kHz frequency.

1 THE FEEDBACK SYSTEM

The hardware, software and filter design have been described earlier in [1]. The principles of digital filtering and feedback control as applied to our system as well as details of the NSLS digital feedback system is discussed in [2].

Hardware. The feedback system consists of three micros; the HP-742rt CPU based feedback micro, the Motorola-167 CPU based orbit micro and the Motorola-133 CPU based trim micro. The communication between the micros is done by the Bit-3 bus adapter boards through shared memory in the trim and in the orbit micro.

The orbit micro samples the PUE data at 555 Hz rate and the data is stored in memory. This memory is mapped by the adapter board to the address space of the feedback micro which calculates the orbit correction and optimizes it. The data communication between the feedback and trim micros is again through memory mapping. The trim micro then controls the power supplies of the orbit corrector magnets. The most computational intensive task is that of the feedback micro. Hence, we chose an HP 742rt, which runs more than to run six times faster than a Motorola 167/162 for this kind of application.

Software The orbit and trim micros are using the NSLS Control Monitor [3], which have been modified to place the read and set points into shared memory, and to synchronize data collection with the feedback micro.

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The digital feedback program is an object oriented code written in C++ and running on the HP 742rt. At every cycle (555 Hz) the program "measures", "filters" and "corrects" the orbit. Thus the reading of the PUE values from the shared memory, the filter and correction calculations, the writing of the new trim values into the shared memory and the actual changing of the trim values have to be done within 1.8 msec.

For orbit correction we are using the Eigenvector Decomposition based orbit correction method described in Ref. [4]. This method will yield the 'minimum' kick vector required for a desired accuracy of orbit correction. It is also a very fast algorithm. The correction algorithm in the DFbk was orthogonalized with respect of the analog global harmonic feedback.

Elements of the feedback The feedback system and its elements are illustrated in Fig. 1.

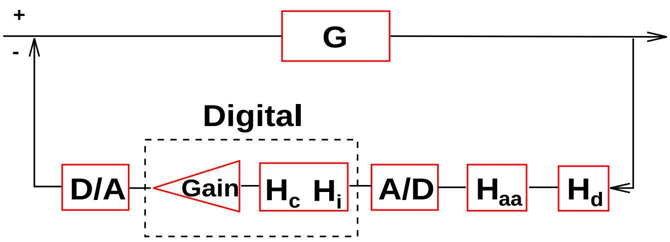

Figure 1: Block diagram of the ring and feedback loop showing the elements of the feedback system.

The G(s) Laplace transform, which represents the effect of the vacuum chamber, behaves like a single pole low pass filter, with the pole measured at ≈25 Hz. H_{AA} is an "anti aliasing" filter which limits the bandwidth of the signal in order to prevent aliasing (folding) of the signal spectrum after the D/A conversion. It is a low pass filter with a single pole at ≈80 Hz. $H_d(z) = z^{-3}$ represents the phase delay due to sampling time, computation time and conversion time. (See Fig. 5) The H_c filter is designed to compensate for elements in the system G that may be limiting the bandwidth and adding phase retardation to the system. The $H_c(z)$ z-transform behaves as a high pass filter:

$$H_c(z) = \frac{1}{G(z)} = 8.026\frac{1-0.751z^{-1}}{1+z^{-1}} \qquad (1)$$

H_I is an integrator, which together with the gain is used to limit the bandwidth of the system and to stabilize it.

$$H_i(z) = 1.69 \times 10^{-3} \frac{1 + z^{-1}}{1 - (1-\epsilon)z^{-1}} \qquad (2)$$

Note that a pure integrator (where the decay term, ϵ, is zero) generates infinite gain at DC, hence, the correction at DC is absolute. However, stability requires a decay term in the integrator. The closed loop response of this system is

$$T = \frac{G}{1 + g_o G H_{tot}}, \qquad (3)$$

where $H_{tot} = H_{aa} H_d H_c H_i$.

Implementation The digital feedback system with one HPrt micro can be used to control either the horizontal or the vertical plane of the X-ray ring. A second, an HP-743rt CPU-based, micro was recently added to the existing system, and thus shortly we will be able to control both planes simultaneously.

2 RESULTS

Since 1991 until recently, as Standard Operations, the X-ray ring orbit was controlled by two analog feedback systems; a global harmonic feedback [5] and a local feedback [6]. The global harmonic feedback uses 16 PUE's and 16 correctors to take out the (8-11)-th harmonics from the orbit. It can stabilize the orbit on the 'global' PUE's [1] to Δx $< 7.5\mu$ and Δy $< 5\mu$ short term oscillations. The long term dc drift, however, can be Δx $\approx 100\mu$ and Δy $\approx 20\mu$ or more. Typically, the rms orbit drifts during the first 7 hrs of the beam are $x_{rms} =\approx 50\mu$, and $y_{rms} =\approx 20\mu$. The local feedback system consists of a set of 4-corrector local bumps and keeps the orbit in the insertion devices to $< 2\mu$ stability, [2] which the harmonic feedback could not deliver.

In Figs. 2 the horizontal beam position at some PUE's in the X-ray ring is shown as a function of time during a typical 7 hrs period after injection. It is a relative beam position, relative to the starting orbit at each PUE. The notation (G), (L) and (-) refers to PUE's which are part of the global harmonic feedback (G), the local feedback loops (L) or which are not part of either feedback system, except of course the digital. Fig. (a) corresponds to operation with only the analog feedbacks (global harmonic and local), while fig. (b) was plotted with digital feedback only.

There is a marked improvement not only in the control of the 'digital only' but also in the stability and long term drift of 'global' PUE's, while the movement on the 'local' PUE's is less than the resolution (2.5μ).

Figs. 2 show the time dependence of the beam position on a few selected PUE's. To have a complete picture about the orbit on all (48) PUE's in the ring, the corresponding difference orbits (between the start and the end of the observation) is shown on Figs. 3. With Standard Ops (fig.a)

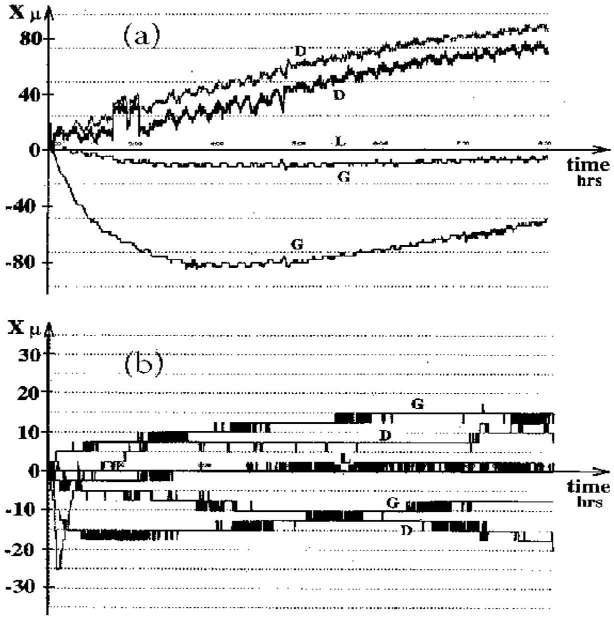

Figure 2:

Position vs time with (a) Standard Ops, (b) digital feedback.

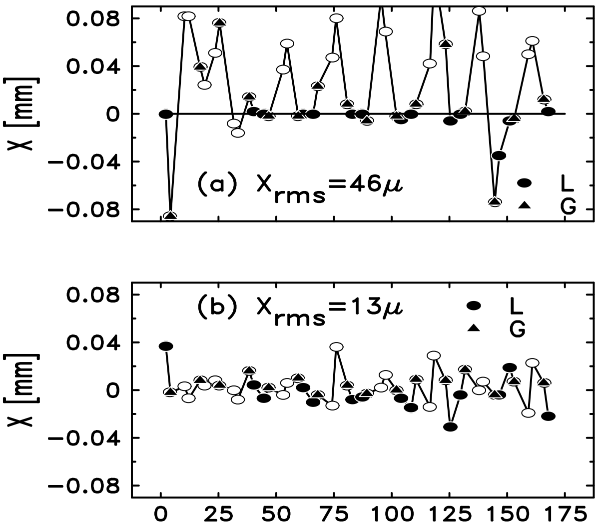

Figure 3:

Orbit change with (a) Standard Ops, (b) digital feedback.

the rms orbit change was 46 μ, while it was restricted to $x_{rms} = 13\mu$ with digital feedback (fig. b). Similar studies in the vertical plane showed a typical rms orbit change of $\approx$20 μ with Standard Ops, and $\approx$5 μ when both, digital feedback and Standard Ops have been used.

The measured horizontal and vertical frequency response of the system is shown in Fig. 4. Curves (a), (b)

[1] The 16 PUE's, which are part of the analog global harmonic feedback

[2] The resolution of the PUE system is 2.5 μ.

and (c) correspond to no feedback, digital feedback only and both, harmonic and digital feedback turned on. The digital feedback has a bandwidth of ≈15 Hz with a horizontal and vertical noise reduction of 20 - 25 db at f = 1 Hz. The dc-noise reduction, which we measured at f = 0.1 Hz, was found to be ≈40 db. The bandwidth of the system can be greatly extended and the noise further reduced in the 2 - 100 hz region, when both, the digital and the harmonic feedback (with its >100 Hz bandwidth) was used.

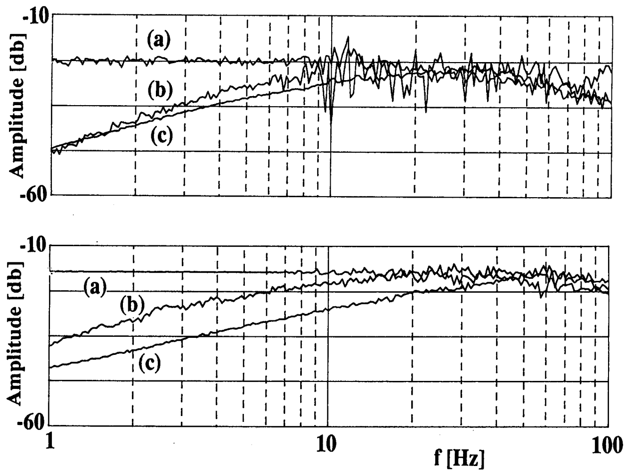

Figure 4:

Measured horizontal and vertical frequency response of the system, (a) no feedback, (b) DFbk only and (c) both, harmonic and digital feedback.

The phase delay due to sampling time, computational time and conversion time was measured by driving a trim magnet with a square-signal of a pulse generator and monitoring the correction signal coming from the digital feedback system. Fig. 5 shows that the delay is ≈2.5 cycles.

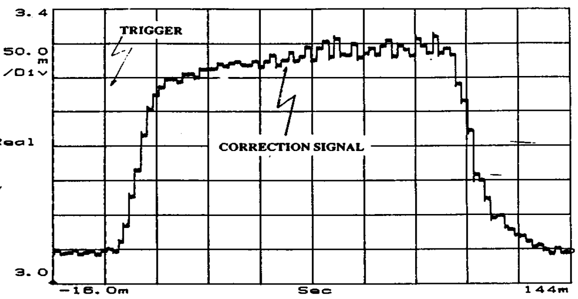

Figure 5: Measured delay in the system

3 SUMMARY

Our findings show that the digital feedback is very effective, taking out the dc-drift from the orbit and keeping it stable to $\approx 10\mu$. Presently, the digital feedback has a bandwidth of ≈15 Hz with a dc-noise reduction of ≈40db. Until the bandwidth of the digital feedback is increased using a faster sampling rate and higher resolution data, the three feedbacks are working together.

Efforts are underway to improve the resolution of the orbit measuring system and the sampling rate. We will use an Analogic DVX-2503 16-bit 400 kHz multichannel Data Acquisition System having 8 differential input ports and three Analogic DVX-2701 high-speed, high-accuracy 32 channel multiplexers. This setup will allow sampling of the 2x48 PUEs (in the horizontal and vertical plane) with high resolution at 4 kHz frequency. The upgraded feedback system will have a bandwidth of over 100 Hz and will make the use of additional analog global and local feedback unnecessary. The higher resolution also will allow us to use a notch filter.

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