# First Experiments of the Digital Global Feedback in SRRC

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## ABSTRACT

The digital global feedback system (DGFB) was implemented to suppress orbit drift, low frequency beam motion, and orbit perturbed by insertion devices. Measured response matrix and singular value decomposition (SVD) [1, 2, 3] techniques were applied in this experiment. The feedback controller is based on PID algorithm [5]. Digital filtering techniques were used to removed noise of electron beam position reading, to compensate eddy current effect of vacuum chamber, and to increase bandwidth of orbit feedback loop. The infrastructure of digital feedback system is composed of orbit acquisition system, gigabit fiber links, digital signal processing hardware and software, high precision digital-to-analog converters. The experimental results is presented in this report.

## 1 INTRODUCTION

The Synchrotron Radiation Research Center is one of the third generation synchrotron light sources which are characterized by low emittance of the charged particle beams and high brightness of photon beams radiated from insertion devices. Any vibrations and orbit drift that lead to distortions in the closed orbit will result in a larger effective emittance. Together with the brightness reduction, beam motion induced incident light position and angle varying can degrade the advantages of using synchrotron light. Insertion devices are essential to produce high brilliance synchrotron radiation, however it influences the electron orbit and the lattice of storage ring. Global feedback system is used to eliminate these undesirable effects. From control points of view, global feedback is an typical multiple input multiple output (MIMO) problems. Technicalwise, it is difficult to implement an analog matrix operation consisting of large amount of BPMs and correctors. Consequently, digital processing was used here to implement global feedback system.

In dealing with a low emittance synchrotron light source, implementing a global feedback system becomes more difficult than before based on the following technical considerations. BPM resolution has to be better than 10 mm, decoupling the interference between global and local feedback loops, integrating these two feedback loops for better tunability, bandwidth of 10 - 100 Hz is necessary to suppress vibration and power supply ripple related beam motion, etc. The global feedback system is integrated with the existed control system. BPMs data and correctors readback are updated into control system dynamic database in the period of 100 msec. Digital global feedback system is bounded on I/O as well as computation. It is important to arrange the real time task and to arbitrate computer bus properly in order to optimize system performance.

## 2 EXPERIMENTAL SETUP

The global orbit feedback system includes 26 BPMs and 18 correctors in the vertical plane for this study. The response matrix of the system was measured by vertical beam displacement while sequentially varying the corrector strengths, and then is inversed by SVD skill. This method is part of the extension of local feedback technique. The advantage of the method used in this system is that it is not sensitive to the beam instability while measuring the response matrix.

Intrinsically, the performance of feedback system is limited by BPM resolution. The BPM processing electronics are based switched electrodes design, which is widely used around synchrotron radiation facilities. Presently, the BPM resolution is about several micron, one micron resolution will be achieved after upgrade. The BPM data is acquired by 16 bit A/D cards which are installed at one VME crate. The crate is used as orbit server. The orbit server provides fast beam position information to be used for feedback loop. It also provides slow orbit information for centralized database. The fast orbit information is sent via gigabit fiber linked reflective memory to corrector and computation needs in the VME crates.

Present system consists of two VME crates, i.e. orbit server VME crate, and corrector and computation VME crate. Within corrector and computation server, a VME bus to ISA bus adapter is used to provide PC and VME crate communication. The bus adapter is fit onto slot 1 of VME crate as system controller. All programs were developed and debugged on PC and downloaded to DSP board. The DSP board carrying TMS320C40 module handles all signal processing, including a digital low pass filter (LPF) and PID controller [4, 5]. It takes 1 ms to complete feedback processes including operation of PID, digital low pass filtering, matrix operation, BPMs data reading from reflective memory, and corrector settings. All parameters can be remotely adjusted from graphical users interface of control system. The sampling rate of feedback system is 600 Hz currently. It will be upgraded to about 2 kHz and the correctors setting will be sent out via 16 bits DAC channels so that sub-μrad steering resolution can be achieved.

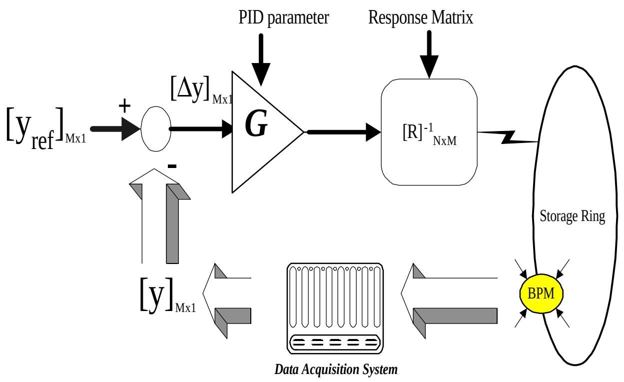


Figure 1: Block diagram of digital global feedback.

## 3 DIGITAL SIGNAL PROCESSING

A schematic diagram of the feedback system is shown in Figure 1. The position error vector [Δy] in the figure 1 is filtered by a LPF in order to compensate the system response dominated by eddy current effect of vacuum chamber. Filters are also used to extend close loop bandwidth and to eliminate processing noise.

Then control algorithm is applied to position error vector. Control algorithm of the digital global feedback is executed in corrector and computation VME crate. The conventional PID controller function G(z) is given by

$$G(z) = K_p + \frac{K_i}{1-Z^{-1}} + K_d(1-Z^{-1})$$

where $K_p$, $K_i$, $K_d$ are the proportional, integral, and derivative controller gains, respectively. The gain coefficients should be positive value for negative feedback. The desired response of feedback system can be adjusted by PID parameters to achieve control goals. Steady state error of global feedback system is close to zero when the open loop DC gain is large enough. Therefore long-term drift can be completely corrected. Output vector from PID controller is multiplied with the inverse-model matrix ($R^{-1}$) and is sent to correctors for updating settings.

## 4 PERFORMANCE OF DIGITAL GLOBAL FEEDBACK LOOP

Test results of the global feedback system has been done with changing the gap of insertion devices and externally applied perturbation. The results are shown in Figure 2, 3 and 4. The cutoff frequency of LPF is 60 Hz, and the combination of PID parameters are chosen to fulfill control goals - to minimize orbit change due to any type of perturbation. The PID parameters was not optimized yet. It will be modified together with promoting the bandwidth of feedback. Following description was based on the parameters $K_p$ = 0.8, $K_i$ = 0.03 and $K_d$ = 0.

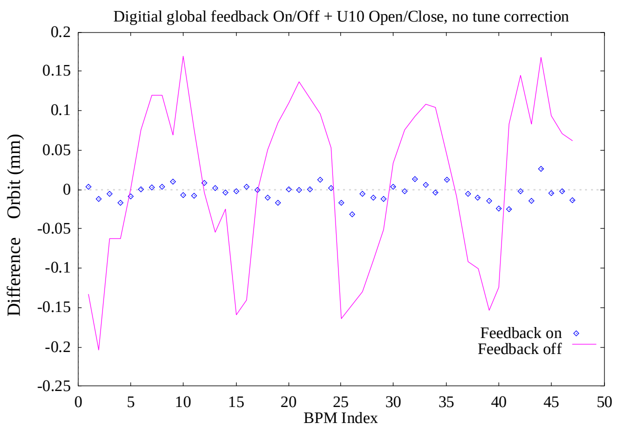


Figure 2: Difference orbit between undulator open and close with feedback on/off.

There are two installed insertion devices at the storage ring. One is a 2-meters long prototype undulator with 10 cm period (U10), the other is 4-meters long wiggler with 20 cm period (W20). Orbit will be changed due to field errors of the insertion devices. The orbit changed without and with DGFB while adjusting the U10 gap as indicated in figure 2. The difference orbit is defined to be the orbit changed of U10 gap at 220 mm and at 24.5mm. The displacement of orbit was much smaller when the digital global feedback was turned on in comparison with the case when it was off. Similar experiment has been done for W20. The result is shown in figure 3. The gap motion of W20 is from 230 mm to 22.5 mm.

The orbit displacement of W20 is more than the case of U10 since the field of wiggler is stronger than that of the undulator. At present, only 26 out of 49 BPMs and 18 correctors were used in the vertical feedback system. It was noticed that at some of the BPM locations, as indicated in figure 2 and 3, the beam orbit difference were relatively larger than others. These BPMs were found to be those which were not included in the feedback loop. Further study is needed in order to improve the performance of the feedback system.

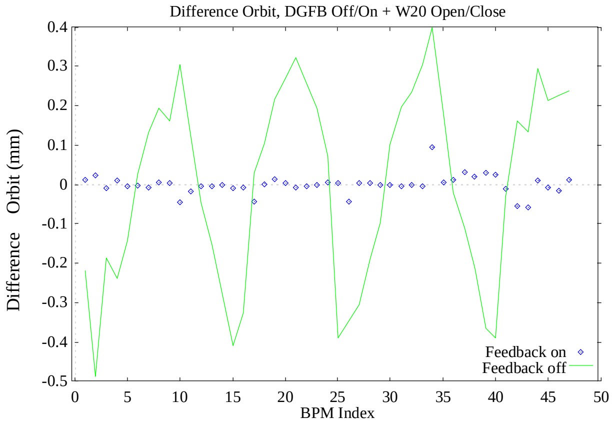


Figure 3: Difference orbit between wiggler open and close with feedback on/off.

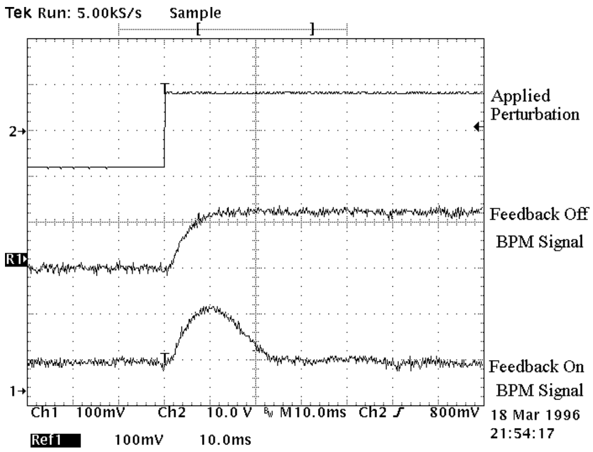


Figure 4: Time response of the feedback system.

Step response of the beam at selected BPM with and without feedback is shown in figure 4. Perturbation was applied to one of the correctors with 0.4 A step change (upper trace). A step change beam position shown 10 msec transient (middle trace) caused by eddy current effect of vacuum chamber. Vacuum chamber of SRRC at corrector site is an elliptical shape with dimension (40 mm, 19 mm) in major and minor axis respectively. Thickness of the vacuum chamber is 4 mm. Effective thickness in horizontal is about two fold larger than in vertical due to cooling channel and sheath of heater integrated with vacuum chamber. Cutoff frequency of horizontal correctors is 20 Hz at -3 dB field penetration. Cutoff frequency is increased to about 80 Hz of vertical corrector is due to two fold larger in aspect ratio and effective thickness. This feature was confirmed by bench measurement with Hall sensor and dynamic signal analyzer.

Step perturbation can be suppressed within 20 msec when feedback loop is close, this number can be optimized by adjusting control parameters. Reducing the response time is limited by current sampling rate.

## 5 CONCLUSION

Performance of the DGFB system will be improved as we gain operation experience and hardware upgraded. Furthermore, horizontal DGFB will be implemented in analog with the vertical DGFB. The configuration of feedback system will be distributed in three VME crates for operational version. Every crate will play its own role as beam position server, corrector server, and computation server. This arrangement is convenient for routine machine operation and DGFB system development. The sampling rate of system will be improved when data acquisition system is modified.

## 6 ACKNOWLEDGEMENTS

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