# A DIGITAL FEEDBACK SYSTEM FOR TRANSVERSE ORBIT STABILIZATION*

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## Abstract

We report on the design of a prototype digital feedback system for the storage rings at the NSLS. The system will use a nonlinear eigenvector decomposition algorithm. It will have a wide dynamic range and will be able to correct noise in the orbit over a bandwidth in excess of 100 Hz. A Motorola-162 CPU board will be used to sample the PUE's at a minimum rate of 1 KHz, an HP-742rt board will be used to read the sampled signals and to generate a correction signal for the orbit correctors and another Motorola-162 will implement that signal.

## 1 INTRODUCTION

In synchrotron radiation facilities the stability of the orbit (*i.e.* the time dependent changes in the orbit) is extremely important. An unstable orbit reduces the effective brightness of the photon source and increases the dynamic aperture of the beam thus reducing lifetime. Usually, the orbit can be stabilized with a feedback system. At present there are two feedback systems operating at the National Synchrotron Light Source (NSLS). A global feedback [1], using an harmonic correction algorithm, and a local feedback [2] that achieves higher beam stability at the insertion devices. The feedback systems are very successful at reducing beam noise at frequencies of up to 50 Hz. However, above 30 Hz there is a significant reduction of gain in the system.

After the present feedback systems were implemented, significant noise was observed at frequencies above 50 Hz. In particular there is a strong noise at 60 Hz. Thus, there is a need for a higher bandwidth of the feedback system. In addition, the present systems are based on analog hardware. Hence, they are not flexible to changes in the algorithm. It is therefore beneficial to develop a digital feedback system that will satisfy the present needs and will be flexible enough for future improvements.

## 2 LOGICAL DESIGN

In implementing the digital feedback system, we are using the eigenvector decomposition based orbit correction method described in Refs. [3, 4]. This method will yield the 'minimum' kick vector required for a desired accuracy of orbit correction. The orbit correction algorithm is depicted in great details in Ref. [4] and will not be explained

here. In this paper we will only describe the filtering techniques used to implement the feedback.

**System Overview**
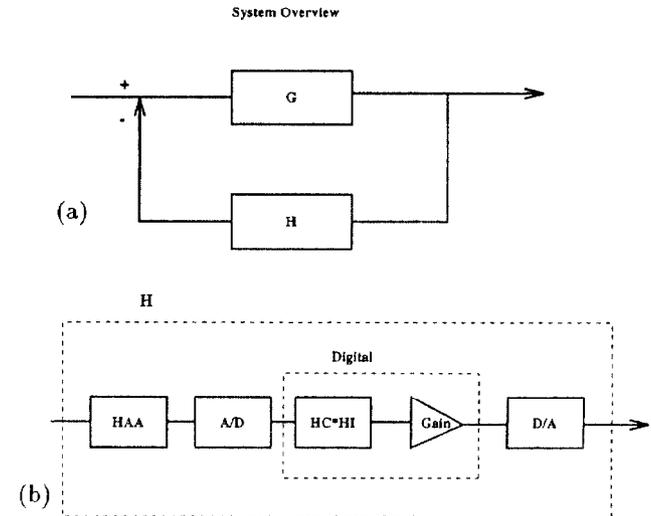


Figure 1: (a)Block diagram of the ring and feedback loop. (b) block diagram of the feedback system.

Two of the most important tools used in feedback systems are the Laplace transform and the Z transform. Both techniques are used to help in the design of systems in frequency domain. Their main advantage is that they allow the user to use simple multiplication to find the response of two consecutive systems, instead of convolution. The Laplace transform is used for continuous signals and is defined by

$$F(s) = \int_0^\infty f(t)e^{-st}dt \qquad (1)$$

where $f(t)$ is the time signal. The Z transform is used for discrete signals and is defined by

$$F(z) = \sum_{n=0}^{n=\infty} f(n)z^{-n} \qquad (2)$$

where $f(n)$ is the time signal. For frequency response use $s = j2\pi f$ in the Laplace transform or $z = \exp(j2\pi fT)$ in the Z transform. Where $T_{samp}$ is the sampling time.

A typical feedback system is illustrated in Fig. 1a. The closed loop response of this system is

$$T = \frac{G}{1 + GH} \qquad (3)$$

When converting an analogue (continuous) signal into a digital (discrete) one, it is important to put a low pass filter before the conversion that will limit the bandwidth of the signal in order to prevent aliasing (folding) of the signal spectrum after conversion. This filter is called "anti aliasing" filter ($H_{AA}$). Fig. 1b illustrates the various elements of the feedback system. The compensation filter ($H_c$) is designed to compensate for elements in the system $G$ that may be limiting the bandwidth and adding phase retardation to the system. This filter is a high pass filter. The integrator $H_I$ together with the gain are used to limit the bandwidth of the system and to stabilize it. Note that a pure integrator generates infinite gain at DC. Hence, the correction at DC is absolute. A pure integrator has the problem that it has "infinite memory", i.e. there are no decay terms in it. Hence it will tend to grow in time. This problem is known and can be solved. However, it is beyond the scope of this paper.

## 3  TECHNICAL APPROACH

We approach the development of the feedback system in three phases; hardware implementation and test, proof of principle and final system.
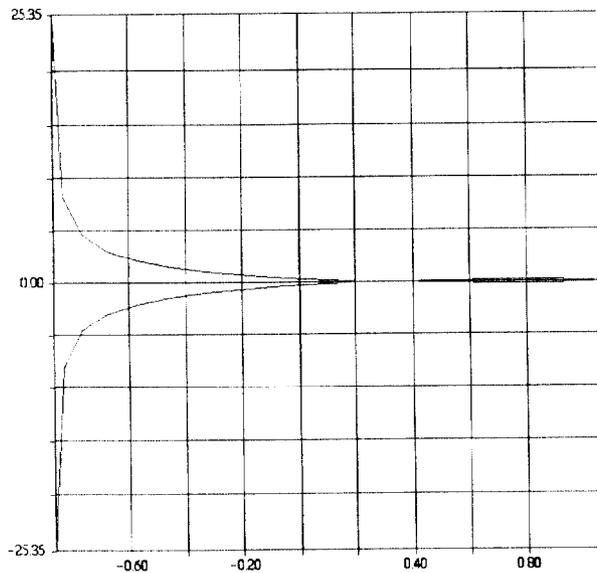
Figure 2: Plot of the open loop response $1 + G H$ in the complex plane the frequency varies from $-\infty$ to $\infty$.

### 3.1  Hardware implementation and testing

We are now in the middle of this phase. During the phase we are implementing and testing most of the hardware needed for the second phase. The hardware is being tested at data rates between 2 Hz and 125 Hz. Without much modification to the existing software the feedback loop will be closed at 60 Hz data rate and we are hoping to achieve a correction bandwidth of up to 4 Hz. The maximum noise amplification will be 13 dB (4.5) at 6 Hz.

### 3.2  Proof of principle

In this phase we will implement a useful feedback system. The system will work with a data rate slightly higher than 700 Hz and will achieve correction in a bandwidth of 55 Hz. The maximum noise amplification will be 8.25 dB (2.6) at 75 Hz. The components of the system are; The ring vacuum chamber which behaves like a single pole low pass filter at 50 Hz.

$$G(s) = \frac{2\pi 50}{s + 2\pi 50} \tag{4}$$

The anti aliasing filter will have a pole at 85 Hz.

$$H_{AA} = \frac{2\pi 85}{s + 2\pi 85} \tag{5}$$

The compensation filter is a single zero high pass filter that compensates for the vacuum chamber. Its Z domain function is:

$$H_c = 5.35 \frac{1 - 0.626 z^{-1}}{1 + z^{-1}} \tag{6}$$

The system integrator expressed in the Z domain is:

$$H_I = 7.2 \times 10^{-4} \frac{1 + z^{-1}}{1 - z^{-1}} \tag{7}$$

There is also a one cycle (1.4 msec) delay due to sampling time, computation time and conversion time. The delay is expressed in the Z domain by $z^{-1}$. At 50 Hz, this delay contributes 25° to the phase retardation.

The polar plot of $1 + G H$ is depicted in Fig. 2. Since the plot does turn around the origin, it can be understood that the closed loop will be stable. The closed loop response is plotted in Fig. 3.
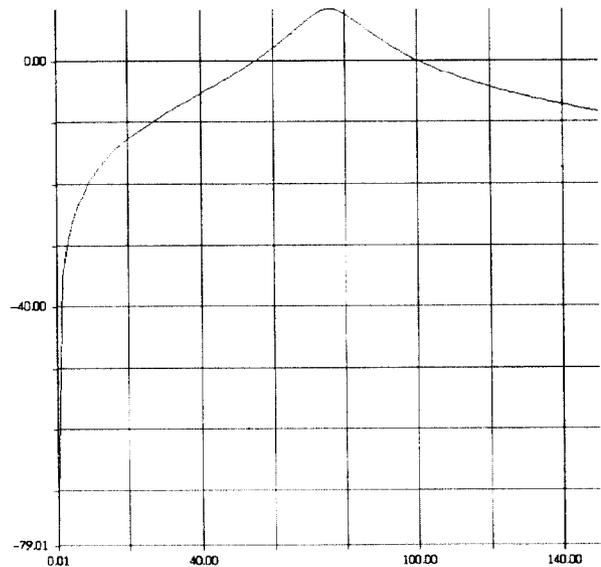
Figure 3: Close loop response $G/(1 + G H)$ amplitude in dB vs. frequency in Herz.

## 3.3 Final system

In this system we will implement data rates above 1 KHz and we will achieve correction up to 100 Hz and more. In addition we will increase the resolution of the digital signal to achieve better correction and will add narrow bandwidth correctors to correct known noise sources (60 Hz, etc).

# 4 ARCHITECTURE

## 4.1 Hardware

The system will rely, mostly, on existing hardware with several modifications. The basic layout is depicted in Fig. 4. There are four micros involved. The PUE micro will sample the PUE data at a rate of up to 1.5 KHz. The data is then transfered to the feedback micro which calculates the orbit correction and optimizes it. The kick values are then transfered into the trim micro which, in its turn, sets the new values to the trims power supplies. The communication between the micros is done directly on the VME bus through shared memory. The most computational intensive task is that of the feedback micro. Hence, we chose an HP 742rt, which we estimate to run six times faster than a Motorola 162 for that type of application. We have added a fourth micro (control micro) to the design in order to isolate the PUE and feedback micros from the general control network. These micros are expected to operated at close to full load. Thus, any requests addressed to them on the network may slow them down, reducing the feedback data rate. The control micro will sample the PUE micro at 20 Hz and will make this data available to workstations for existing control programs [5] such as Real Time Orbit, Fast Orbit History, etc. This micro will also send commands to the feedback micro and display data on its status. If the need arises, it is possible that either the PUE micro or the feedback micro will write 200 Hz or higher orbit history to a DAT tape.

## 4.2 Software

The PUE, trim and control micros use a variation of the existing NSLS real time monitor [6]. Their programming was modified to place the read points and set point into shared memory, and to synchronize data collection with the feedback micro. The device read points for the PUEs will be read through the control micro, and will be updated at a frequency of 20 Hz, which is the present PUE sampling frequency. A new monitor was written for the feedback micro, based on the HP-RT operating system. The orbit correction code is a modification of the code that was used for orbit correction in Refs. [3, 4]. This is an object oriented code written in C++.

# 5 PRELIMINARY STUDIES

## 5.1 Algorithm

A preliminary study was performed on the NSLS VUV ring, using the existing global feedback system. The eigen-

orbits and eigen-kicks [3, 4] were fed to the feedback system instead of the harmonic data. The result was a reduction of 17 db in the noise up to 20 Hz. It is expected that the future system will perform much better since it include more trims and PUEs and it optimizes the kick values.
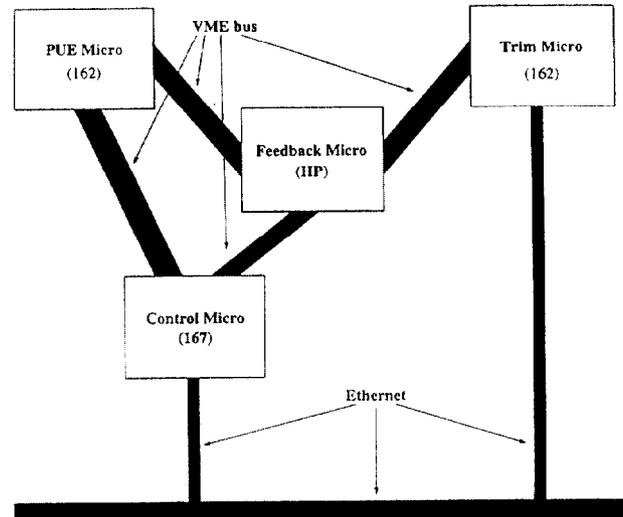


Figure 4: Layout of the feedback system.

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