

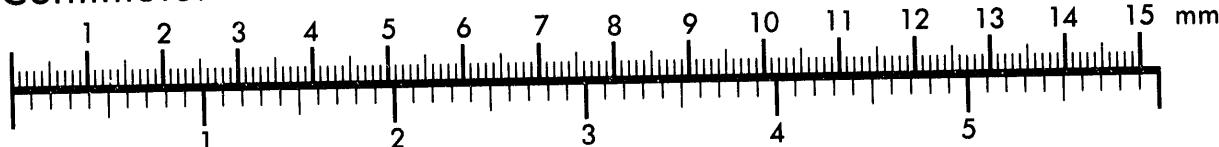


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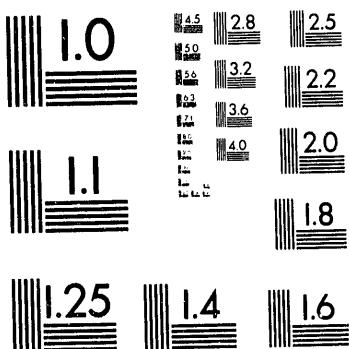
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## Results From the AGS Booster Transverse Damper<sup>1</sup>

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### Abstract

To reach the design intensity of  $1.5 \times 10^{13}$  protons per pulse in the AGS Booster, transverse coupled bunch instabilities with an estimated growth rate of  $1500\text{s}^{-1}$  have to be damped. A prototype transverse damper has been tested successfully using a one turn digital delay and closed orbit suppression implemented in a programmable gate array. An updated damper, which includes an algorithm to optimize damping for a changing betatron tune, will also be presented.

### I. INTRODUCTION

As the intensity of protons per pulse in the AGS Booster increases, the resistive loss in the vacuum pipe will induce a force on the beam which causes the beam's transverse oscillations to increase with time and ultimately results in beam loss. [1] Figure 1A illustrates the damping method used to prevent beam loss from such coupled bunch transverse instabilities. On every turn of a particular bunch, its position at a PUE sensor is measured and processed. The kick needed to dampen transverse oscillations, once calculated, is placed on a queue and is clocked out as the beam arrives at the kicker on the next turn.

The processing unit consists of several sub-blocks which are illustrated in figure 1.B. The sum and difference signals are normalized using an analog normalizer. The normalized voltage signal is then integrated, which results in a voltage level proportional to the transverse position of the beam with respect to pipe center. The horizontal and vertical beam position values are then digitized to an eight bit resolution. These two eight bit values are fed into a digital block which generates the proper kick to apply to the bunch as it passes through the kicker plates on the next turn.

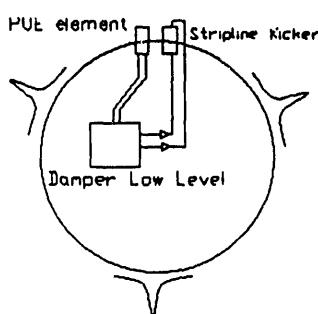


Figure 1A. Damper system in the AGS Booster

<sup>1</sup>This project was made possible through funding from the U.S. DOE.



Figure 1B. Sub-blocks in the Damper low level system

### II. DESIGN OF DAMPER SYSTEM

#### A. Damping Algorithm

The goal of the Damper is to reduce the coherent dipole motion of the beam. The coherent motion of the PUE can be expressed in terms of the Courant-Snyder invariant  $\epsilon$ :

$$\epsilon = \pi(\gamma X^2 + 2\alpha XX' + \beta X'^2)$$

where  $\alpha$ ,  $\beta$ ,  $\gamma$  are the Twiss parameters and  $X$ ,  $X'$  are the position and angle of the beam at the PUE. A kick  $\theta$  at the kicker location will change  $\epsilon$  by:

$$\begin{aligned}\Delta\epsilon &= 2\pi(\alpha X + \beta X')\theta \\ &= 2\pi[(\alpha \cos(2\pi Q) - \sin(2\pi Q))X_1 + \beta \cos(2\pi Q)X'_1]\theta\end{aligned}$$

where the second line shows  $\Delta\epsilon$  as a function of the position and angle of the previous turn;  $Q$  is the betatron tune. The expression for  $\Delta\epsilon$  becomes particularly simple for  $Q=4.75$ :

$$\Delta\epsilon = 2\pi X_1 \theta$$

Therefore, by making the kick proportional and opposite in sign to the previous turn,  $\epsilon$  will be reduced monotonically. This mode of operation was used in the prototype system.

To accommodate a betatron tune other than 4.75, data for  $X'_1$  must also be taken. In a future Damper implementation, the PUE position information from two turns previous to the kick,  $X_{-2}$ , is used as well as  $X_1$ .  $\Delta\epsilon$  is then:

$$\begin{aligned}\Delta\epsilon &= -G[(\cos(4\pi Q) / \sin(2\pi Q))X_1 + (\cos(2\pi Q) / \sin(2\pi Q))X_{-2}] \\ &= -G[C_1 X_1 + C_{-2} X_{-2}]\end{aligned}$$

where  $G$  is the loop gain and the coefficients  $C_1$  and  $C_{-2}$  are tune dependent. They are shown in Figure 2. With these coefficients, the damping rate is independent of the betatron tune. Such a scheme will be implemented with a non-recursive digital filter.

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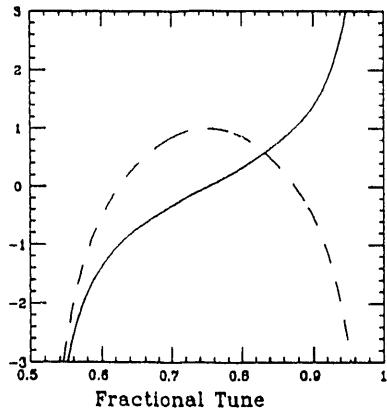


Figure 2. Coefficients for 2-turn damping algorithm. The solid line is  $C_2$  and the dashed line is  $C_1$ .

#### B. Analog normalizer

As was explained in the introduction, the PUE difference signal is normalized with the sum signal in order to obtain an intensity independent value for position. The schematic illustrated in figure 3 shows the analog normalizing circuitry used in the system. Essentially, the sum signal is the input to an auto-gain control circuit which keeps the output level of a voltage controlled amplifier constant for a changing sum intensity.

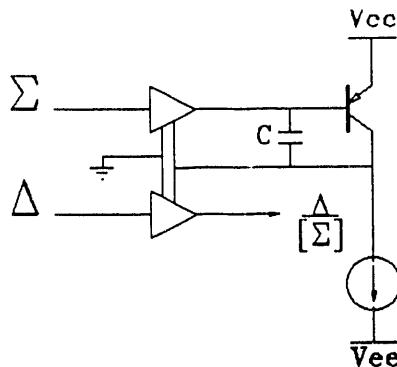


Figure 3. Schematic for Analog Normalizer

This is achieved by using the output from the amplifier to limit the charging of a capacitor. The voltage on the capacitor, in turn, feeds back to the gain control of the amplifier. Thus a feedback is established in which the charge on the capacitor, which is directly related to the time integral of the sum signal, controls the level of the output. As the intensity of the sum signal increases, less current is available to charge the capacitor, which results in less gain on the amplifier. Consequently, the output level is always held at a set level determined by the amount of dc current set to charge the capacitor. The result of this auto-gain control is that the voltage controlling the gain is related to the inverse of the time integral of the sum signal. By using this same

voltage to set the gain of a matched amplifier whose input is the difference signal, the desired normalization takes place. The advantage of this particular scheme is that a dual voltage controlled amplifier with a 40dB dynamic range could be utilized, resulting in a high level of sensitivity.

#### C. Fast Integrator

The output from the normalizing circuitry, must be integrated every rf period of the accelerator. In the case of the AGS Damper, the bunches have a maximum duty factor of .75 and a maximum frequency of 4.5 MHz. Also, it is true that the signals from the PUE are AC coupled, which means that no set zero baseline is available for integration. The schematic shown in figure 4. represents the scheme which is utilized in the damper system. The normalizer signal is split into two integrating channels, which effectively halves the bandwidth through either channel. This is achieved with the use of fast track and hold amplifiers. As a result of this scheme, one amplifier tracks the current bunch while the other holds the baseline level. Consequently, a zero baseline level is established by subtracting the held level from the channel signal. Once the integration is finished, the two channels are analog multiplexed to form a single channel which outputs an integral value for every beam bunch

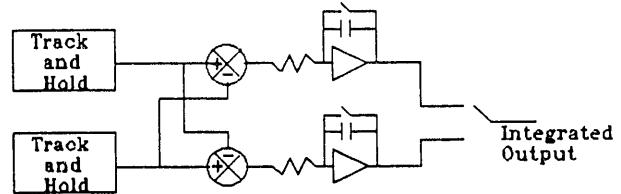


Figure 4. Fast Integrator Circuitry

#### D. Digital Kick Calculator

In section A. it was explained that, in the case of a fractional betatron tune of .75, the damping kick is directly related to the current position value. However, the closed orbit component of the position value was neglected. It is necessary, to subtract the portion of the position information which is due to the closed orbit. The block diagram illustrated in figure 5 demonstrates a way to digitally implement closed orbit suppression. Initially, all registers and memory is cleared. As position information is fed into the algorithm, a running average is taken. Also the values are stored on a circular buffer. In this implementation, an average of 32 bunches is taken. Once 32 values are stored in the buffer, the next bunch position information overwrites the earliest value in the buffer and an average of these 32 values is taken. Since 32 is a power of 2, averaging is done simply by using an accumulator whose output is shifted 5 bits, ie. divided by the number 32. Once this value is obtained, it is subtracted from the current position information. The value is then placed into

a register and is latched to the output at the appropriate time. The digital system is implemented using a programmable logic array, which integrates all the logical blocks illustrated in figure 5, except the 32x8 bit buffer. A fast static ram memory device was used to implement the buffer.

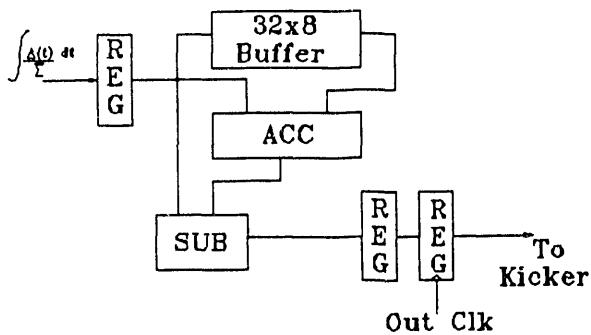


Figure 5 Digital Closed Orbit Suppression Logic

#### E. Timing Considerations

It is crucial for the proper operation of the AGS Booster damper system that retrieval of position information be synchronized with the beam and the damping kick be administered at the correct time with respect to the beam. Consequently, timing signals to the system must be synchronized with the Booster rf frequency. The rf low level system produces an rf signal which is phase locked to the accelerating bunches at the location on the ring where the damping system resides. This signal is used to control and synchronize all signals necessary for damper operation. One problem which arises is that there is a fixed output delay time from the moment of latching the output data to the time when voltage is developed on the kicker plates. This time delay corresponds to a phase shift which changes with rf frequency. In order to compensate for this delay, a second rf signal was sent to the damper system which is time advanced by the exact amount of output delay existing in the system. In this way, the voltage on the kicker plates is phase locked to the beam at all frequencies.

### III. RESULTS OF PROTOTYPE SYSTEM

In order to simplify construction and experimentation, the first prototype system was constructed for damping in one transverse direction; the vertical plane was chosen due to the higher likelihood of instability in this dimension. Also, as was explained in section A, the prototype system was designed to operate with a betatron tune of 4.75. Making this tune assumption enables the simplification of the digital kick calculation, since at this tune the kick is proportional to the position value of the bunch on the previous turn. The prototype system allowed for switching the polarity of the

kicker voltage, which enabled both damping or antidamping. This was useful, since successful antidamping causes beam loss which can be seen on a current monitor. In order to show damping, a small kick was applied to produce transverse oscillations that slowly decayed with time when the damper system was off. With the damper system activated, the coherent oscillations could be damped within about 1.5 ms. With anti-damping on, a persistent oscillation could be observed and, with increased loop gain, beam was lost.

### IV. REFERENCES

[1] E. Raka, "Damping the transverse resistive wall instability in the AGS Booster," AD Booster technical note No. 137, Brookhaven National Labs, New York, 1989.

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