SINGLE PASS COLLIDER MEMO

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Introduction

Early experience (1981-1982) with jittery position measurements in the C10 (Collider Injector Development) and Sector 1 BPM (beam position monitor) system led us to ask whether the source of the observed noise was in the beam or in the BPM electronics. Prior to July, 1983, the signal from each BPM strip was individually processed. It occurred to us that the signal from each strip, when normalized by the sum of the signals from the two adjacent strips, made possible two independent measurements of the beam position in the plane containing the strip. When a single parameter is measured twice, one can look at the correlation of the measurements over a statistical sample of events. This will allow one to distinguish real parameter variations from measurement errors. In this case, a strong correlation in the two measurements from a given strip indicates beam jitter, whereas a lack of correlation indicates either that there is beam jitter in the normalizing plane or that the processing electronics is noisy in at least one channel. The five possible cases are illustrated in Figure 1, wherein x_N is the x-position as derived from the north strip and x_S is the x-position as derived from the south strip. These plots are interpreted as follows:

Correlated Noise (beam jitter).

The expressions for x_N and x_S are derived in enclosure (1). If one compares equations 2 and 4 therein, it is clear that real beam motion should appear along a straight line at $45^\circ/225^\circ$ to the horizontal axis. This data is said to be "correlated."

Figure 2 shows the experimental demonstration of correlated noise. During the recording of the HISTOS for a fairly stable beam, the beam was moved twice by known amounts in the y-plane, starting with the position $y = 0$. The data on the two plots are for identical beam pulses. Note that the horizontal axis is expanded about 50% with respect to the vertical axis so that correlated noise in Figure 2 should appear at $36^\circ/216^\circ$ with respect to the horizontal axis. The tick marks for both axes are 0.1 mm each.

Anti-correlated Noise (normalization noise).

The beam position in a given plane for HISTOS uses the sum of the strip signals in the complimentary plane for normalizing to the beam intensity. Equations 6 and 7 of enclosure (1) show that any noise in the normalizing signal, whether systematic (due to beam jitter) or statistical would appear in the HISTOS plot "anti-correlated", that is, the data should appear along a straight line at $135^\circ/315^\circ$ ($144^\circ/324^\circ$) to the horizontal axis.

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Single Strip Noise.

By contrast, noise on one of the strips in the plane of the HISTOS plot will appear as a horizontal line for S or B, and as a vertical line for H or T.

Multiple Sources of Noise.

Each of the types of noise described above can be combined. For instance, equal amounts of single strip noise on each strip will appear within a circle on the HISTOS plots in both planes.

Helmut Wiedemann suggested the experiment the results of which are contained in Figure 2.

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Figure 1. Predicted HISTOS Plots: (a) correlated noise (beam jitter); (b) anti-correlated noise (normalization noise); (c) north channel of processing electronics noisy; (d) south channel of processing electronics noisy; and (e) no beam jitter or noise.

(a) L100 53 - XNORTH VS XSOUTH

14-JUN-1993 16 16 07 18

(b) L100 53 - YTOP VS YBOTTOM

14-JUN-1993 16 14 51 04

Figure 2. Experimental HISTOS Plots. (a) and (b) represent simultaneous data. GPMO L10053 is located at the beginning of girder 1-1A. The y-position was varied by changing YCOR L10051 located about 9-m upstream.

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Enclosure (1)

1. Calculation of position of a single-bunch beam from the signal on a single strip.

The signal on a single strip in the horizontal plane is a function of the position of the beam in the monitor. Let us choose the signal on the north strip, N , and let $x = 0$ be the center of the monitor. Expand $N(x)$ in a Taylor's Series about $x = 0$:

$$N(x) = N(0) + dN(0)/dx \cdot x + \frac{1}{2} d^2N(0)/dx^2 \cdot x^2 + \dots$$

In the linear approximation we drop all but the first two terms. We also now normalize N to the beam intensity which is proportional to $T + B$, the sum of the signals on the top and bottom strips:

$$N/(T + B) = a_0 + a_1 \cdot x$$

At some value of $x = -c$ the signal N in the linear approximation drops to 0:

$$0 = a_0 - a_1 \cdot c$$

or

$$a_1 = a_0/c$$

From symmetry, one can also say that at $x = c$, $N = T + B$ thus

$$1 = a_0 + a_1 \cdot c$$

or

$$a_1 = (1 - a_0)/c$$

Therefore $a_0 = \frac{1}{2}$, $a_1 = 1/(2 \cdot c)$, and

$$N/(T + B) = (x/(2 \cdot c) + 0.5) \quad (1)$$

or

$$x_N = 2 \cdot c \cdot (N/(T + B) - 0.5) \quad (2)$$

where the subscript for x indicates the value of x is calculated from the signal on the north strip.

Likewise

$$S/(T + B) = (0.5 - x/(2 \cdot c)) \quad (3)$$

and

$$x_S = 2c(0.5 - S/(T+B)) \quad (4)$$

2. Calculation of position from the difference signal.

Combining equations 1 and 3, one has:

$$(N - S)/SUM = (x/(2c) + 0.5) - (0.5 - x/(2c)) = x/c$$

or

$$x = c(N - S)/SUM \quad (5)$$

where $SUM = T + B = N + S$.

3. Calculation of noise signals.

To find the effect of random noise from either (or both) T and B on x_N , we substitute

$$T + B \rightarrow T + B + \delta(T + B)$$

into equation 2. Then

$$\begin{aligned} x_N &= 2c(N/(T+B+\delta(T+B)) - 0.5) \\ &= x_N - 2cN\delta(T+B)/(T+B)^2 \end{aligned} \quad (6)$$

Likewise

$$x_S = x_S + 2cS\delta(T+B)/(T+B)^2 \quad (7)$$

By comparison, the random noise on N is independent of S. Let $N \rightarrow N + \delta N$. Then

$$x_N = x_N + 2cN\delta N/(N(T+B))$$

If the beam is near $x = 0$, then $N \approx (T+B)/2$ and

$$x_N = x_N + cN\delta N/(T+B)^2 \quad (8)$$