# ANALYSIS OF THE CALIBRATION REQUIREMENTS FOR THE BOOSTER BEAM POSITION MONITORING SYSTEM 

D. J. Ciardullo

June 1989

# Collider Accelerator Department <br> Brookhaven National Laboratory 

## U.S. Department of Energy <br> USDOE Office of Science (SC)

[^0]
## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

## ANALYSIS OF THE CALIBRATION REQUIREMENTS

FOR THE
BOOSTER BEAM POSITION MONITORING SYSTEM

## AD <br> BOOSTER TECHNICAL NOTE <br> NO. 143

## DOMINIC J. CIARDULLO

JUNE 5, 1989

## ACCELERATOR DEVELOPMENT DEPARTMENT BROOKHAVEN NATIONAL LABORATORY UPTON, NEW YORK 11973

# ANALYSIS OF THE CALIBRATION REQUIREMENT'S <br> FOR THE BOOSI'ER <br> BEAM POSI'TION MONITORING SYSTEM 

## Introduction:

The purpose of the calibration mode for the Booster Beam Poeition Monitoring (BFM) system is to:

1. provide a method for correctine any position measurement errors due to

- mechanicsl asymmetries in the detector and
- gain andror offeete in the processing electronios

2. provide a meanc wherety the operator can from the control room) estialish confidence as to the current operating condjtion ot each PUE station.

Measurements made on each detector prior to its installation in the Booster will provide the basic equation relating the front end electronics output to the actual bean position at a perticular PUE station:

$$
\begin{equation*}
\text { Position }=M \frac{\left(V_{A}-V_{B}\right)}{\left(V_{A}+V_{B}\right)}+P \tag{1}
\end{equation*}
$$

where:
"M" has been measured to be on the order of 100 mm and is particular to a given detector actual prototype value is approximately 93 mm )
" $V_{A}$ " and " $V_{R}$ " are the voltages on the pickup eleotrodes.

In the above equation, " $P$ " is the apparent position offset (in mm) which results from the PUE having different electrical and mechanical centers (i.e., mechanical asymmetries within the detector).

The value for $F$ does nct ascount for any offsets or unequal gains in the BPM front end electronios: thus the voltages $V_{A}$ and $V_{B}$ must be corrected for this previous to its insertion into equation [1]. This paper will primarily tocus on how the apparent heam position offset due to the BPM electronics cen be minimized by correcting $V_{A}$ and $V_{E}$ with constants ootained during a calibration routine.

Gince we wish to rbtain a position precision of 0.1 mm , we need approximately $0.1 \%$ reaolution, or 60 dB of isolation between the two input chanels at the "front end" of the processing electronics (ie, ur until both the sum and difference of the two input sienals is acguired and digjtized. This calculation is hased upon meacurements made on the prototvpe electrostatio FuEs for the Booster. Using eguation [1], and aseuming a perfect detector (i.e., $\mathrm{P}=0$ ), then f , C .1 m position resolution, we require:

$$
\begin{aligned}
& 0.1 \mathrm{~mm}=100 \mathrm{~mm} \times \frac{\left(V_{A}-V^{\prime} \mathrm{V}\right)}{\left(V_{A}+V_{B}\right)} \\
& \frac{\left(V_{A}-V_{B}\right)}{\left.-V_{A}+V_{B}\right)}=0.001-0-60 \mathrm{dH} \\
& \left(\mathrm{~V}_{\mathrm{A}}+\mathrm{V}_{\mathrm{B}}{ }^{\prime}\right.
\end{aligned}
$$

Although the processing electronios is aligned to achieve 60 dB isolation (between outputs) previous to ite installation in the Booster, a method is needed to account for any gain changes which might occur over time.

## Assumptions:

The following assumptions and approximations are made to simplify this evaluation:

1. The system ADGs have sufficient resolution for their errors not to enter into the analysis.
2. The calibration ring maintains its original coupling profile to each pickup electrode for the duration of its lifetime.
3. Since the coupling from the calibration ring to each Fickup electrode is identical to within better than -60 dB , we can assume it to act as an ideal voltage divider (i.e., equal voltages appear on each plate).

Calibration results will depend upon both the gain setting of the electronics, as well as the number of turns which are integrated over during a particular machine cycle.

## The Calibration Signal:

The calibration signal originates from a dedicated square wave oscillator within the RPM eleotronjes. Jt is applied to the detector s oflibration ring and split into two egual voltages, esch of magnitude $V_{G} G_{c}$. where $\because$ is the calibration voltage at each pickup electrode (not necesserily $\Rightarrow$ known value) and Go is the ooupling comstant of the calibration ring. Obtaining the calibration signal through the detector provides oonfidence that all of the coarial signal cables hetween it and the eleatronics are connected. The oslibretion rine also eliminates the need for a precision splitter and matched oskles: withjn the calibration section of the BFM electrenice.

## Basic Strategy:

The anslyeis of the BPM surtem oalibretion will be developer Es followe:

- Firet, it is shown thet the pains and offsets of components located in each of the two lege which immedjatelv follow the hybrid i.e.. the sum leg and the difference leg, can be combined.
- Then. while manipulating a calibration signal at the input to the EPM electronice the sum and difference voltages measured by the eystem atoe can be used to obtain expreesione fro intermediate gein oonstante.
- These constante Gan then be used to realize expreseions for the voltages which appear at the pickup plates iwith reference to the calibration voltaee).
- The equatione developed up to thjs point take voltages which can be readily measured by the system and relate them to the voltages at each plate, normalised to the calibration signal. Once the flate voltages are known, it is a simple matter to compute the differencersum retio. Upon caloulation of this ratio. all reference to the calibration signal vanishes.
- We now have a diff/sum ratic which is corrected for the electronics associated with a particular PUE station. We need only to insert this value into equation [1] to obtain the fully corrected beam poeition i i.e. . corrected for both the electronice and the detector).


## Evaluation of Calibration Requirements:

Figure 1 A is a block diagram of the analog portion of the Booster BPM electronice, from the detector to the input of the ADCs. There are two items of interest in this diagram which serve to simplify the analysis. First, it should be noted that any losses in the cables which connect the PUEs with the electronics have been absorbed into the front and gains, GA and GR- Second, there are no DC offsets to the left of the sum and difference
block, as a result of the front erd amplifiers beine aapacitively Gourled to the hybrid.

Combine gains and offaets past hubrid:
We wish to show that the gains and offsets associated with both the Ease Line Festorer (BLR) and the Integrator oan be lumped together into one pain and one offset (refer to fipure $1 A$ ). TGfine:


The following equation relates the gum port of the hubrid to the input of ita A. T converter [ ADC'sum]:

$$
V_{B U M}=\left[V_{2}+O_{b} G_{b}+O_{i}\right]_{j}=V_{s} G_{b} G_{i}+G_{b} G_{i}+G_{i} G_{i}
$$

It should be noted that for a given eain settine and number of bunches, all of the offsete and gains associated with both the BLF and the integrator are constant. Therefore,

$$
\begin{equation*}
G_{\text {sum }}=G_{b} G_{i} \text { and } O_{\text {sum }}=G_{b} G_{i} T_{i}+O_{i} G_{i} \tag{E}
\end{equation*}
$$

are constants, and $V G U M$, the input voltage to (AIC) sum can be represented by:

$$
\begin{equation*}
V_{S U M}=V_{S} G_{S u m}+O_{\text {sum }} \tag{6}
\end{equation*}
$$

Gimilarly, the equation which relates the DIFF port of the hybrid to the input of (ADC)diff is:

$$
\begin{align*}
V_{I I F F}= & {\left[\left(V_{d}+O_{b}-\right) G_{b}+O_{i} \cdot 7 G_{i}\right.} \\
& =V_{d} G_{b} \cdot G_{i}+O_{b} \cdot G_{b} \cdot G_{i}+O_{i} \cdot G_{i} \tag{7}
\end{align*}
$$

where the primed $i^{\prime}$ ) subscripts are used to indicate the BLR-integrator Fajr in front of (ADC)diff.

As before. for a given gain setting and number of bunches,

$$
\begin{equation*}
G_{d i f f}=G_{b} \cdot G_{i}, \quad \text { and } \quad O_{d i f f}=O_{b} \cdot G_{b} \cdot G_{i},+O_{i} \cdot G_{i} \tag{8}
\end{equation*}
$$

are constants, and the input voltage to (ADC) diff can be represented by:

$$
\begin{equation*}
V_{D I F F}=V_{d} G_{d i f f}+O_{d i f f} \tag{9}
\end{equation*}
$$

Since the validity of rombining the gains and offsets of both the BLF and the integrator has been established. the expressions relating the signals at the input of the BPM electronics to those at (ADC) eum and (ADC)diff are as followe (refer to Figure 1B):

$$
\begin{align*}
& V_{\text {grj }}=V_{s} G_{s u m}+O_{\text {sum }}=\left(V_{A} G_{A}+V_{B} \mathcal{B}_{B} G_{\text {sum }}+O_{\text {sum }}\right.  \tag{10}\\
& \left.V_{D I F F}=V_{d} G_{d i f f}+O_{d i f f}=U_{A} G_{A}-V_{P} G_{B}\right) G_{d i f f}+O_{\text {diff }}  \tag{11}\\
& \text { where: va and vie the two PUE plate voltages } \\
& V_{s} \text { and } V_{d} \text { are the output voltages from the sum } \\
& \text { and difference ports of the hybrid. } \\
& \text { respertively, and } \\
& \text { Gsum. Gditf are the values defined in [5] and [8] } \\
& \sigma_{\text {sum }} \text {, Odiff }
\end{align*}
$$

Obtain intexmeliate gein constants:
It is desired to te able to determine the differm ratio of the plate voltages. corrected far any gains or offsets due to the electronics. Eince it is not possible to explicitly acquire all of the gains needed to calculate the voltages at each pickup, it is necessary to work with intermediate constants which can be readily measured by the svistem. These constants are obtained while manipulatine a calibration signal at the input to the BPM electronice.

Equations [10] and [11] are the general expressions relating the gains and offsets within the BPM electronics to the voltages actually appearing at the sum and difference ADCs, respectively (refer also to Figure 1B). Since these are the only voltages which are accessible to the BPM controller (via the system ADCs), several readings must be taken during a cal sequence in order to obtain sufficient information to calibrate the electronics. The required readings will be divided into three separate cases:

$$
\begin{aligned}
& \text { 1. } V_{A}=V_{B}=0 \\
& \text { 2. } V_{A}=V_{C} G_{C} \text { and } V_{B}=0 \\
& \text { 3. } V_{A}=0 \text { and } V_{B}=V_{C} G_{C}
\end{aligned}
$$

where $V_{C} G_{C}$ is the calibration signal appearing at each pickup electrode.

Case 1. $V_{A}=V_{B}=0:$

During this portion of the calibrstion seguence, the gain of each chamel of the BPM electronics is set to zero. Settine $V_{A}$ and $V_{P}$ to zero in [10] and [11] gives:

$$
\begin{align*}
& V_{\text {SUM }}=\sigma_{\text {sum }}  \tag{12}\\
& V_{\text {DIFE }}=\sigma_{\text {diff }} \tag{13}
\end{align*}
$$

and the offeets ficr both the sum and diff leps in Fifure 1 P are the veltaees measured by each respective Abc.

Case 2. $V_{A}=V_{C} G_{C}$ and $V_{B}=0:$
With the caljbation signal at input $A$ and no sifnal at input, $B$, equations " 101 End $[117$ herome:

$$
\begin{align*}
& \left.V_{C} G_{C} G_{A} G_{\text {eum }}=V_{\text {Orm }} A-\sigma_{\text {erm }}\right) \tag{14}
\end{align*}
$$

where Vorm $A$ and VDIFF $A$ are the voltages at the ADCs when $V_{A}=V_{6} G_{C}$ and $V_{B}=0$.

Note that each term on the right side of equations [14] and [15] is known. We now define a new pair of variables, each of which represents the result of the subtraction of two measured values:

$$
\begin{align*}
& V_{\text {scA }}=V_{\text {DUM A }}-O_{\text {sum }}  \tag{16}\\
& V_{\text {dcA }}=V_{\text {DIFF_A }}-O_{\text {diff }} \tag{17}
\end{align*}
$$

Case 3. $V_{A}=0$ and $V_{B}=V_{C} G_{C}$ :
With the calibration signal at input $P$ and no eignal at input $A$, equations [10] and [11] become:

$$
\begin{align*}
& V_{C} G_{C} G_{B} G_{\text {sum }}=\left(V_{\text {SUM }} B-O_{\text {sum }}\right)  \tag{18}\\
& V_{C} G_{C} G_{B} G_{d i f f}=\left(V_{\text {DIFF_B }}-O_{\text {diff }}\right)  \tag{19}\\
& \text { where } V_{\text {SUM }} B \text { and } V_{D I F F} B \text { are the voltages at } \\
& \text { the } A D C \text { when } V_{A}=0 \text { and } V_{B}=V_{C} G_{C} .
\end{align*}
$$

As in case 2 above, we define:

$$
\begin{align*}
& V_{S c B}=V_{S J M} B-O_{\text {Sum }}  \tag{20}\\
& V_{d c E}=V_{I I F E_{-}}-O_{\text {diff }}
\end{align*}
$$

A set of calibration constants consistine of $V_{s e A}, V_{d c A}, V_{s c R}$ and $V_{\text {dcP }}$ is reguired for fach gain setting of the BPM electronice used during a particular machine cycle. Modifying the mumber of integrating turns ( $N$ ) will also require a new set of constants. One should note however. that sincf the integrator offset is directly froportional to the number of turns, each set of calibration constants (for different values of $N$ ) is linearly related. Therefore, for g given gain setting. two sete of calibration constants are sufficient to calculate the romection for any other number of turne.

Qbtain exprescions fer FuE voltages:
Equations [16], [17], [20] and [21] can be used to realize expressions for the voltages at each plate, normalized to the caljbretion signal. Multiplying both sides of equations [10] and [11] by $V_{C} \int_{C}$ and rearrenging terms gives the following:

$$
\begin{align*}
& V_{C} G_{C}\left(V_{S U M}-O_{\text {sum }}\right)=V_{A} V_{C} G_{C} G_{A} G_{\text {sum }}+V_{B} V_{C} G_{C} G_{B} G_{\text {Sum }} \tag{20}
\end{align*}
$$

where boldface type is used to distinguish between variables during actual operatior and the calibration "constants" (ie, with respect to a particular machine cycle). Substituting equations [16] and [20] into [20]. and equations [17] and [21] into [23]:

$$
\begin{align*}
& V_{C} G_{C}\left(V_{S U M}-G_{s u m}\right)=V_{A} V_{S C A}+V_{B} V_{S c} B \\
& V_{C} G_{C}\left(V_{D I F F}-o_{d i f f}\right)=V_{A} V_{d c A}-V_{B} V_{d c} B \tag{25}
\end{align*}
$$

Equations [24] and [25] can now be solved simultaneously for $\mathrm{V}_{\mathrm{A}}$ and $\mathbf{V}_{\mathrm{B}}$, normalized to the calibration signal:

$$
\begin{align*}
& \frac{V_{A}}{V_{C} G_{C}}=\frac{\left(V_{\text {SUM }}-O_{\text {Sum }}\right)\left(V_{d C B}\right)+\left(V_{\text {DIFF }}-O_{\text {diff }}\right)\left(V_{S C B}\right)}{\left[V_{S C A} V_{d C B}+V_{d C A} V_{S C B}\right]}  \tag{26}\\
& \frac{V_{B}}{V_{C} G_{C}}=\frac{\left(V_{\text {SUM }}-o_{\text {Sum }}\right)\left(V_{\text {dCA }}\right)-\left(V_{\text {DIFF }}-o_{\text {diff }}\right)\left(V_{\text {SCA }}\right)}{\left[V_{\text {SCA }} V_{d C B}+V_{\text {dCA }} V_{S C B}\right]} \tag{.27}
\end{align*}
$$

It is now possible to write expressions for both the corrected
difference and the corrected sum of the two flate voltages. The resulting expressions ere:

Performing the ratio of eq.[28] to eg.[59] eliminates any dependance on the calibraticn signal, and yields the following equation:


## Conclusion:

It is desired to have some method of calibrating the Booster BPM system so that a high level of confidence in its measurement accuracy can be maintained after its initial installation. Analysis indicates that a calibration routine can be performed which provides sufficient information to compensate for long term active component drift within the BPM electronics. This information, when combined with a knowledge of the detector offset, can be used to determine the absolute position of the beam.

Equation [30] provides a numerical value which can be inserted into [1] to obtain the actual position of the beam, corrected for apparent offsets due t.c both the detector and the electronics. Constants obtained through a calibration routine operate on the sUM and DIFF voltages retrieved by the BPM system during machine operation (boldface type).

## Acknowledgement:

The help of Vincent Stanziani in the development of these calibration requirements is greatly appreciated. Many of his ideas and circuit modifications were instrumental in minimizing the amount of hardware required to achieve our calibration goals.



[^0]:    Notice: This technical note has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-AC02-76CH00016 with the U.S. Department of Energy. The publisher by accepting the technical note for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this technical note, or allow others to do so, for United States Government purposes.

