MASTER

SINGLE PASS COLLIDER MEMO CN-341

AUTHOR: D. Pappas, S. Tentindo

DATE: August 25, 1986

TITLE: Measured Resolutions of the Arc and Linac
BPM Systems

A. Introduction

The 6" long final focus beam position monitors (short FF BPM's) are longer, thus deliver more signal after a 15 nanosecond filter, than either the Linac or Arc monitors.

The purpose of this note is to compare the resolution of the Arc vs. Linac electronics when applied to a short FF 2" diameter BPM.

A method of calibrating the Arc modules is also tested and briefly discussed. The range of each DAC setting to minimize digitization error is also calculated.

B. Conclusion

As can be seen in figure 1, the Linac module has better resolution than the Arc module up to 6×10^9 particles. The Arc resolution keeps improving, while the Linac resolution appears to level out to ≈ 20 microns.

The Arc system appears to saturate at 2.4×10^{10} particles, when the RF Head output is at 2 volts. The Linac system saturates at $\sim 4.8 \times 10^{10}$ particles. This result was expected, because the Linac module is designed for a longer monitor than the Arc.

To increase the maximum range for either module, an attenuator could be inserted at the input of the module for the Linac system, and at the input of the RF Head for the Arc system. This would, however, hurt the resolution on both systems. Decreasing the gain (in the RF Head for the Arc or the analog board in the Linac) would also increase the range, and would probably improve the resolution at all intensities as well. The Arc system may be more versatile, since the RF Head is a separate component.

Calibration of the systems is also a vital concern. The Linac calibration system is not discussed, but the large change in offset as a function of beam

* Work supported by the Department of Energy, contract DE - AC03 - 76SF00515.

intensity (figure 4) is one difficulty. The small magnitude of the offset vs. beam intensity slope in the Arc modules (figure 5) shows that one calibration is good over a large spread in beam currents.

C. Apparatus

The pulse generator consists of 4 differentiated avalanche transistors in parallel, timed to within ± 50 ps. The pulses are combined with a 4 : 1 power combiner (figure 2a). The signal is injected down 300' RG223, passes through an external attenuator, and is then routed either into the Linac test system or Arc test system.

The Linac test system consists of a 1 : 4 splitter, which injects equally sized pulses into each of the Linac module inputs (figure 2b).

The Arc test system consists of a 1 : 2 splitter, a 2 - nanosecond filter, an RF Head, and a TNH module (figure 2c).

D. Pulse Intensity calculations

For the FF BPM, the expected pulse area for the first half of the bipolar pulse is (for 5×10^{10} particles);

$$\begin{aligned} \text{Area} &= Q \left(\frac{\text{electrode angle subtended}}{2\pi} \right) (\text{cable} + \text{monitor impedance}) \\ &= \left[(5 \times 10^{10} e^-) (1.6 \times 10^{-19} \text{ coul}/e^-) \left(\frac{1}{8} \right) (25\Omega) \right] \\ &= 25 \text{ V} \cdot \text{ns} \end{aligned} \tag{1}$$

The area of the pulse generator can be calculated by multiplying the full width at half maximum of the first half of the bipolar pulse by the amplitude (figure 3);

$$\text{Generated pulse area} = (77 \text{ volts})(.55 \text{ ns}) = 42.3 \text{ V} \cdot \text{ns}.$$

This pulse must be split into 4 for the Linac test system, and into 2 for the Arc test system. Since the splitters are power splitters, the signal is reduced by a factor of 2 for the Linac module and only $\sqrt{2}$ for the Arc's. Therefore, the maximum intensities simulated in the respective systems are;

$$\begin{aligned} I_{\text{max}}(\text{Arc}) &= (37.4 \text{ V} \cdot \text{ns})(1/\sqrt{2})(5 \times 10^{10} e^- / 25 \text{ V} \cdot \text{ns}) \\ &= 6 \times 10^{10} \text{ particles} \end{aligned}$$

$$I_{max}(Linac) = 4.2 \times 10^{10} \text{ particles}$$

The signal amplitude is then adjusted with a 1 dB step attenuator and equivalent intensities can be calculated.

The 300 foot length of RG223 is not included in this calculation because all of the short FF monitors will be equipped in the same manner. Also, the two-nanosecond filter used before the Arc RF Head is implemented only to insure proper wave shaping of the incoming pulse to the RF Head. The effect of this filter on the output of the RF Head is negligible (< -0.3 dB).

E. Resolution

(i.)

Table #1 shows a sample output of Arc module #11 for 20 readings at DAC setting 1023 (maximum internal attenuation) and manual attenuation 8 dB (equivalent beam intensity = $2.4 \times 10^{10} e^-$).

The offset is calculated from the formula;

$$offset = \frac{(Channel\ 1 - Pedestal\ 1) - (Channel\ 2 - Pedestal\ 2)}{(Channel\ 1 - Pedestal\ 1) + (Channel\ 2 - Pedestal\ 2)} K \quad (2)$$

The K-factor is 12,500, for the 2" FF BPM which is not rotated. The resolutions obtained are equivalent to the rotated case, since a rotation adjusts the K factor (PCMM) to account for the change in measured differences. The resolution is calculated from;

$$\sigma_{offset} = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2} \quad (3)$$

where $n = 20$, $x_i = i^{th}$ offset measurement.

The resolution could also have been calculated from the r.m.s. of the noise in the signal and pedestal measurements (using abbreviations C = Channel, P = Pedestals throughout the rest of paper);

$$\sigma_{offset} = K \left[\left(\frac{\partial(offset)}{\partial C1} \delta_{C1} \right)^2 + \left(\frac{\partial(offset)}{\partial C2} \delta_{C2} \right)^2 + \left(\frac{\partial(offset)}{\partial P1} \delta_{P1} \right)^2 + \left(\frac{\partial(offset)}{\partial P2} \delta_{P2} \right)^2 \right]^{1/2} \quad (4)$$

where the r.m.s. noise in the pedestals is equal to the r.m.s. in the channel readings. When this is calculated using the averaged pedestal and channel readings

from table #1;

$$\begin{aligned}
 \sigma_{offset} = & K \left[\left(\frac{1}{(C1 - P1) + (C2 - P2)} + \frac{C1}{(C1 - P1) + C2 - P2} \right)^2 (\sigma_{C1})^2 \right. \\
 & + \left(\frac{1}{(C1 - P1) + (C2 - P2)} + \frac{P1}{(C1 - P1) + C2 - P2} \right)^2 (\sigma_{P1})^2 \\
 & + \left(\frac{1}{(C1 - P1) + (C2 - P2)} + \frac{C2}{(C1 - P1) + C2 - P2} \right)^2 (\sigma_{C2})^2 \\
 & \left. + \left(\frac{1}{(C1 - P1) + (C2 - P2)} + \frac{P2}{(C1 - P1) + C2 - P2} \right)^2 (\sigma_{P2})^2 \right]^{1/2} \\
 = & 9.7 \text{ microns}
 \end{aligned} \tag{5}$$

This corresponds closely with the deviation in table #1, which was calculated from equation (3).

(ii.)

The twenty readings in table #2 are from the reference Linac module #0. The offsets are calculated similarly as for the Arc module. The resolution of this module is comparable to that of the Arc module at high intensities, but at lower intensities the resolution of Linac module #0 is much worse than either the Arc #11 module or the production line Linac module. Therefore, the resolution graphed in figure #1 are taken from the data obtained with the production line module, which had passed all of the inspection procedures required.

The offsets for the Linac module were calculated from the formula

$$offset = K \left(\frac{C(difference) - P(difference)}{C(sum) - P(sum)} \right) \tag{6}$$

where K = 12,500 for a monitor which is not rotated.

Again, the deviation for the module can be calculated from eq. (4), where

C1 = difference channel, C2 = sum channel. However, eq. (5) now becomes;

$$\begin{aligned}
 \sigma_{offset} &= K \left[\left(\frac{1}{(C2 - P2)} \right)^2 (\sigma_{C1})^2 + \left(\frac{-1}{(C2 - P2)} \right)^2 (\sigma_{P1})^2 \right. \\
 &\quad + \left(\frac{1}{(C2 - P2)^2} \right)^2 (\sigma_{C2})^2 \\
 &\quad \left. + \left(\frac{-1}{(C2 - P2)^2} \right)^2 (\sigma_{P2})^2 \right]^{1/2} \\
 &= 11 \text{ microns}
 \end{aligned} \tag{7}$$

This formula shows that the deviation of the sum channel is negligible with respect to the difference channel if it is large; *i.e.*

$$\left(\frac{1}{sum} \right)^4 \ll \left(\frac{1}{sum} \right)^2 \quad \text{for } sum \gg 1 \tag{8}$$

The result obtained from (7) is a little larger than the result in table 2, which was obtained from eq. (3). This may be due to the digitization error, because the deviation on the difference channels is less than 1 count.

F. Calibration

The calibration of the Linac module has been standardized and is beyond the scope of this paper. Uncalibrated offsets for a Linac module are shown in figure 4. The problems in calibration can be seen, one of which is the large slope of the offset vs. beam intensity.

The Arc calibration scheme is still under discussion. An uncalibrated offset is shown in Figure 5a. The small slope of this offset is typical of all modules tested.

The calibrated offset in Figure 5c is obtained by measuring the gain ratio as in Figure 5b. The beam position formula;

$$\text{position} = \frac{(\text{Channel 1} - \text{Pedestal 1}) - (\text{Channel 2} - \text{Pedestal 2})}{(\text{Channel 1} - \text{Pedestal 1}) + (\text{Channel 2} - \text{Pedestal 2})} K \tag{9}$$

now becomes;

$$\text{position} = \frac{(\text{Channel 1} - \text{Pedestal 1}) - MUL \times (\text{Channel 2} - \text{Pedestal 2})}{(\text{Channel 1} - \text{Pedestal 1}) + MUL \times (\text{Channel 2} - \text{Pedestal 2})} K \quad (10)$$

where;

$$MUL = \text{gain ratio measured in calibration} = \frac{(\text{Channel 1} - \text{Pedestal 1})}{(\text{Channel 2} - \text{Pedestal 2})} \quad (11)$$

This procedure may be conducted for several different DAC settings, and the slopes and intercepts of the gain ratios tabulated as a function of beam intensity. Figure 5c shows that the offset is reduced to zero using this calibration scheme.

G. Digitization error for Arc

Different DAC settings in the Arc and Linac systems change the amplifier gains to reduce digitization error when the readings are close to the pedestal level.

For the Arc system, let x and y define the difference between the two channel and pedestal readings. The beam position is then calculated from;

$$\text{Beam position} = k \frac{x - y}{x + y}$$

The error in beam position can then be computed from

$$\begin{aligned} \sigma_{\text{digitization}} &= \left[\left(\frac{\partial(\text{position})}{\partial x} \delta_x \right)^2 + \left(\frac{\partial(\text{position})}{\partial y} \delta_y \right)^2 \right]^{1/2} \\ &= K \left[\left(\frac{1}{x+y} - \frac{x}{(x+y)^2} \right)^2 (\sigma_x)^2 + \left(-\frac{1}{x+y} + \frac{y}{(x+y)^2} \right)^2 (\sigma_y)^2 \right]^{1/2} \end{aligned}$$

if $\sigma_x = \sigma_y = 1$ for digitization error, and $x = y$ for a nearly centered beam;

$$\sigma_{\text{digitization}} < K\sqrt{2} \left[\frac{1}{2x} - \frac{x}{4x^2} \right]$$

In general, then the digitization threshold for a centered beam is given by;

$$x > \frac{K}{2 \sqrt{2} \sigma_{\text{digitization}}} \quad (12)$$

where;

- 1) x = digitization threshold, number of counts from pedestal level
- 2) K = PCMM
- 3) $\sigma_{\text{digitization}}$ = maximum allowable digitization error.

It is important to use the correct PCMM in this calculation, since there are no compensating factors. For the rotated 2" diameter FF BPM, PCMM = 17,700. For $\sigma_{\text{digitization}} < 15$ microns, the digitization threshold is

$$x = 420 \text{ counts}$$

The TNH module has a total of 2000 counts on either side of the pedestal level. Therefore, there is a factor of 5 in range for any one DAC setting.

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, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness 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. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

G. Acknowledgements

We appreciate the guidance of W. Kozanecki in this project, and the assistance of J.-L. Pellegrin and J.-C. Denard.

The help of M. Ross, C. Fordham, and S. Wagner has also been indispensable.

Figure #1

Figure #2

(a) PULSE GENERATOR

(b) LINAC TEST SYSTEM

(c) ARC TEST SYSTEM

9-86

5531A2

Figure #3

Generated Pulse 8/22/86
40 dB attenuation
200 mv/div
1 ns/div

Figure #4a

Figure #4b

Table #1

Channel 1	Channel 2	offset	gain factor
3772	3772	654	1.1122
3752	3754	701	1.1122
3776	3750	650	1.1122
3754	3752	673	1.1122
3776	3754	676	1.1122
3754	3752	672	1.1122
3776	3754	676	1.1122
3754	3752	681	1.1122
3776	3754	681	1.1122
3754	3752	685	1.1122
3776	3754	685	1.1122
3754	3752	689	1.1122
3776	3754	689	1.1122
3754	3752	692	1.1122
3776	3754	692	1.1122
3754	3752	695	1.1122
3776	3754	695	1.1122
3754	3752	697	1.1122
3776	3754	697	1.1122
3754	3752	701	1.1122
3776	3754	701	1.1122
3754	3752	701	1.1122
3776	3754	701	1.1122

Arc module #11
 external attenuation 8 dB
 equivalent intensity = $2.1 * 10^{**10}$

DEC 1-2014.3

DEC 1-2014.3 DEC 2-2015.4

Table #2

REGISTRATION- 514.7 25.3 510.1
 DEC settings= 00

1-3	sum	1-2	1-3 offset
422	998	546	-368.9
485	997	546	-381.3
484	996	546	-394.5
484	998	546	-393.7
484	997	547	-394.1
485	997	547	-381.3
485	998	545	-390.9
485	998	547	-380.9
485	996	547	-381.7
485	998	548	-360.9
484	999	545	-393.7
485	998	545	-380.3
485	998	547	-380.9
484	997	546	-407.0
484	999	545	-393.3
484	998	547	-393.7
484	997	547	-394.1
485	998	547	-360.9
484	999	545	-393.3
485	997	546	-381.3

Linac module #0
 external attenuation 0 dB
 equivalent intensity = $4.2 * 10^{**10}$