High Current Precision Long Pulse Electron Beam Position Monitor

Scott D. Nelson[1], Yu Ju (Judy) Chen, Thomas Fessenden, Clifford Holmes,
Lawrence Livermore National Laboratory. Livermore, California, USA

Abstract

Precision high current long pulse electron beam position monitoring has typically experienced problems with high Q sensors, sensors damped to the point of lack of precision, or sensors that interact substantially with any beam halo thus obscuring the desired signal. As part of the effort to develop a multi-axis electron beam transport system using transverse electromagnetic stripline kicker technology [1,2], it is necessary to precisely determine the position and extent of long high energy beams for accurate beam position control (6 - 40 MeV, 1 - 4 kA, 2 microsecond beam pulse, sub millimeter beam position accuracy.) The kicker positioning system utilizes shot-to-shot adjustments for reduction of relatively slow (< 20 MHz) motion of the beam centroid. The electron beams passing through the diagnostic systems have the potential for large halo effects that tend to corrupt position measurements.

1 INTRODUCTION

The constraints dictated by these beam diagnostic requirements indicate a system that has the advantage of only measuring high energy beams (such that sensitivity to intensity can be small). On the other hand, positional accuracy needs to be sub millimeter in order to define the outer bounds of the beam for determination of the correct transport parameters. As a result, a low *Q* structure allows for a faster response time and different parts of the beam will not effect the measurement of the beam position during later times. The completed diagnostic system involves a high accuracy beam position detection system, a data acquisition system, a computer controlled feedback system (to control the stripline kicker pulser waveforms) and the kicker pulsers themselves.

The precision beam position monitors are utilized as part of the kicker beam deflection system [3] which requires precise beam control to successfully position the beam through the subsequent output divergent septum beampipe. Accuracies of 0.5 mm are desirable for use with the kicker system and accuracies of 0.1 mm are needed for the proposed target system [3].

2 BASELINE BUG TESTING

As part of the development effort, the existing beam position monitors (a.k.a. BPM's or beam bugs) were tested to evaluate their long pulse performance. Since evolution

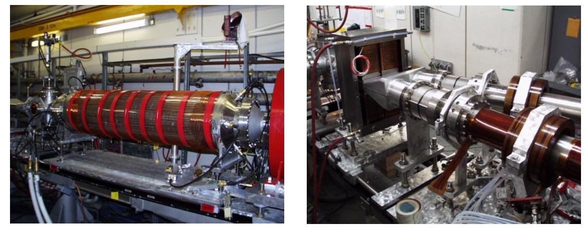

Figure 1. The quad stripline kicker (left) in the Experimental Test Accelerator (ETA-II) beamline as part of the verification experiments [3]. Downstream of the kicker, the deflected beam passes through the septum magnet (right) and into the divergent beam lines.

of the existing BPM's has been an on-going process for many years, they were used as part of the baseline experiments to determine the feasibility of using this type of design for long pulse efforts. Other designs used in beam position measurements were examined but these designs have compatibility problems with long pulse beams, with beams with high degrees of halo, or suffer from charge build up problems over the course of the beam pulse.

To simulate the long pulse beam, a pulser capable of several microseconds and kilovolts was used to drive the test stand. The stand consists of a tapered coaxial section

Figure 2. The beam position monitor test stand (left) used for measuring the accuracy and response of the various BPM's. The stand was driven by a variety of pulsers including a fast rise time pulser and a long pulse Velonex^{TM} pulser with capabilities above one kilovolt and beyond six microseconds (left).

on each end of the test stand. This provides an impedance match to 50Ω and exhibited excellent spectral uniformity agreeing to within 0.15 dB. These sections drive the straight section of beampipe which is offset to allow for displacing the current conductor with respect to the BPM. Displacements of up to one centimeter were examined. Displacements significantly beyond one centimeter cause

[1]Email: nelson18@llnl.gov

higher order modes to be established due to the beam pipe discontinuity at the displacement points. Note that the center conductor is fixed with respect to the tapered coaxial sections and so displacement of the BPM causes the center conductor to get closer to one side of the BPM thus simulating the displaced beam. One drawback of the Velonex™ pulser is its characteristic requiring a total output waveform integrating to zero. Thus, for the unipolar pulse there is a long baseline tail on the data. In this case, the decay rate for this tail has a time constant of 94 µs (its peak voltage is only 3% of the main pulse) but data beyond the main pulse should be ignored.

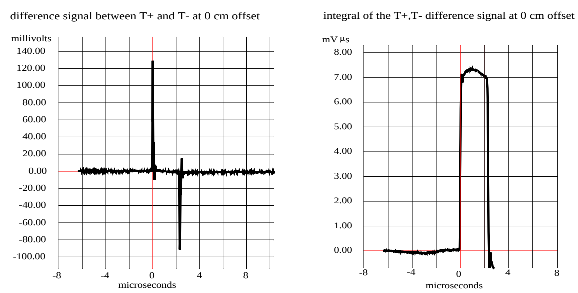

Figure 3. The waveform on the ***left*** *shows the difference signal between two opposite output ports on the BPM when the current carrying conductor is on-axis. This allows the performance of each channel to be calibrated before displacing the current carrying conductor; thus allowing for greater precision. The waveform on the* ***right*** *shows the integral. In this case, it corresponds to the positional error of this BPM and can be unfolded from the final data. [The hash in the waveforms on the left in figures 3 and 4 is a graphing artifact and is not representative of the noise in the signal. The noise is 2 mV. ed.]*

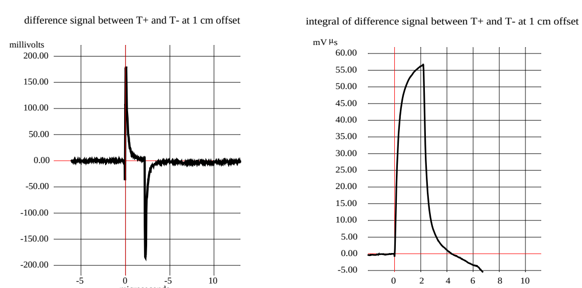

*Figure 4. Two channels on opposite sides of the BPM are acquired with a displacement of one centimeter . The difference is then computed (**left**) and the position is found by integrating (**right**). Notice that the vertical scale in Figure 4 is significantly different than that of Figure 3.*

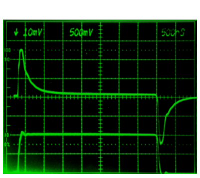

Figure 5. The region between the leading and trailing edge is magnified here exposing the baseline offset between the leading and trailing edges of the pulse.

Figure 5 shows a close up view of the differential signal with a one centimeter offset of the current conductor. Observe the baseline shift in the waveform which is caused by preferential coupling to the port closer to the current conductor. Acquiring each channel from the beam position monitor separately allows for greater control of the unfolding of the data. In the cases shown in Figures 3 and 4, the total waveforms are represented by 15,000 points with 30 points defining the rise time of the pulse.

3 BPM DESIGN AND TEST

3.1 Drawbacks of Existing BPM's

The existing test stand generates a maximum of twenty amps and so the saturation of the ferrite material is not an issue. But at an operating point of 1 - 4 kiloamps for 2 µs, a beam pulse would saturate the existing ferrite material simply due to the limited number of volt-seconds in the existing material. Likewise, the existing mechanical fabrication process for the BPM's involves several hand assembly steps as evident in the difference between on-axis signals shown in Figure 3. Although precise for a hand assembled component (appx. 1% position error due to assembly), greater precision between ports is desired in order to achieve the necessary beam position precision and to avoid extensive calibration unfolding after every data set.

As part of the effort, several other BPM concepts [4,5,6,7,8] were also considered. Although the test results for the existing beam position monitors in ETA-II looked encouraging, performance parameters for the long pulse beam test would saturate the ferrite material in the existing BPM's. Likewise, initial experimental evidence [9] indicates that thin films can survive direct exposure to 2 µs beams for profile measurements.

3.2 Unfolding BPM Position Data

To determine the position of the beam from the waveforms generated by the BPM's, it is necessary to take into account the calibration of each port of the BPM (both time and amplitude correction) and to remove differences between the port responses. The early time coupling effect comes from [9] with voltage V produced at a port

$$V(\theta, \rho, t = 0) = I_b K \frac{1 - \rho^2}{1 - 2\rho\cos\theta + \rho^2}$$

with the beam at relative displacement $\rho = r/r_a$ from the centerline (r_a = beampipe radius) and at an angle θ with respect to the port in question (0^o is directed toward the port). K is a calibration constant related to the resistance of the foil and may be determined using the on axis case, $\rho = 0$. The curves in figure 6 illustrate the variations for t=0; but expressions are available for general expressions in t.

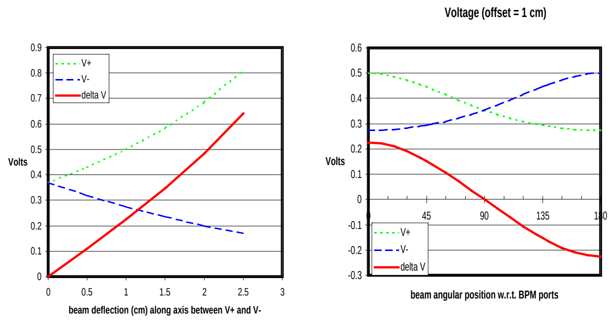

Figure 6. The various parameters of the received voltage are related to the position of the beam centroid in the beampipe. Note that the underlying equation assumes that the beam radius is small with respect to its displacement.

3.3 Design Parameters for Long Pulse BPM's

As a consequence, the design parameters for the long pulse high precision beam position monitors were determined to allow for a 2 µs beam pulse [10] at 2 kA. Since the skin depth for materials such as nichrome and stainless steel is 6 µm at 70 MHz, the thickness of the existing material can be expanded. 1 mil stainless steel foil, having a surface resistivity of 0.036Ω/square, yields a bulk resistance, R, of 3.4 mΩ across the portion of the foil exposed to the flux in the BPM

$$R = \frac{1}{\sigma_s \delta_s}\left(\frac{V_m \sigma_n \delta_n}{V_p / Z_0}\right)$$

where σ_s, σ_n are the conductivities for stainless and nichrome respectively, δ_s, δ_n are the skin depths (in this case the material thicknesses dominate so $\delta_s=\tau_s$, $\delta_n=\tau_n$), V_m, V_p were the voltages during the coefficient determination (0.37V and 1 kV respectively). V_p was fed into the Z_0 = 50Ω transmission line that drives the test stand.

4 CONCLUSIONS

The precision required as part of the operation of the kicker and target systems dictates a high precision beam position monitor with an accuracy between 0.5 and 0.1 mm. In the case of the kicker system, these BPMs must also be able to withstand a 2 µs long 2kA beam pulse. Initial results with the existing BPMs indicate that operation with a two microsecond beam at two kiloamps will be possible provided that:

1. Data is acquired from each BPM port separately. This allows the calibrations for each port to be unfolded from the data.

2. Measurements of the radiation effects on cables [11] indicate that several volts can be induced onto typical RF cables at high X-ray levels. However, for most applications there should be sufficient shielding around the various incidental X-ray sources.

3. Partition the vertical scale of the signal using multiple data acquisition systems. This may be necessary until reater dynamic range (more than 8 bits) is available from ommonly available high speed acquisition systems. The ade-off is signal-to-noise errors caused by the partitiong.

4. Time resolution from commonly available high speed cquisition systems is more than adequate for these applitions. It is important to get sufficient resolution on the ading edge of the pulse such that the rise time of the inteal is preserved. Self triggering on the received waverm reduces jitter in the measurement.

5. Signal cables should be of sufficient quality to preserve the leading edge of the pulse. More importantly, they should be matched and low in dispersion in order to avoid problems during the difference calculations.

6. Although the range of currents over which the BPM must operate is large, the necessary precision at each current level can be different. Thus the low current levels used in the calibration process do not have to be single-shot acquisitions. The benefits of laser welded foils, made possible by the move to 1 mil stainless, are expected to alleviate some of the existing error in the BPMs caused by hand welding the 0.2 mil nichrome foils

5 ACKNOWLEDGMENTS

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