BEAM ANALYSIS USING THE IPNS LINAC ESEM*

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Abstract

The Energy Spread and Energy Monitor (ESEM) is an on-line, non-intrusive diagnostic used to characterize the output beam from the 200-MHz, 50-MeV linac. The energy spread is determined from a 3-size, longitudinal emittance measurement and energy is derived from TOF analysis. Presently, a single particle distribution is used to yield energy and energy-spread results. Effort is on-going to allow for more realistic distributions to be included. Signals are detected on terminated 50-ohm, stripline BPMs. Each BPM is constructed with four striplines: top, bottom, left and right. Until recently, the ESEM signals were taken solely from bottom striplines in four separate BPM locations in the transport line between the linac and synchrotron. We have begun to use the top stripline data to examine, in more detail, beam position and attempt to measure beam size.

INTRODUCTION

Stripline beam position monitors (BPMs) are an important on-line diagnostic tool[1]. The IPNS BPMs are constructed with four 50-Ω striplines aligned with the horizontal and vertical axes of the accelerator. Each stripline is terminated on the downstream end in its characteristic impedance (50-Ω). A BPM module is shown in Figure 1. There are seven BPM modules in the 50 MeV transport line between the linac and synchrotron; the first four are also used for ESEM measurements.

Figure 1: IPNS 50 MeV line stripline BPMs.

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The ESEM diagnostic makes use of a three-size technique to determine the beam's longitudinal momentum and energy spread[2]. A drift-length parameter is used to adjust the four three-size permutations until satisfactory agreement is achieved between them. The four BPM permutations are 123, 124, 134, and 234. Figure 2 shows the section of beamline relevant to the ESEM diagnostic.

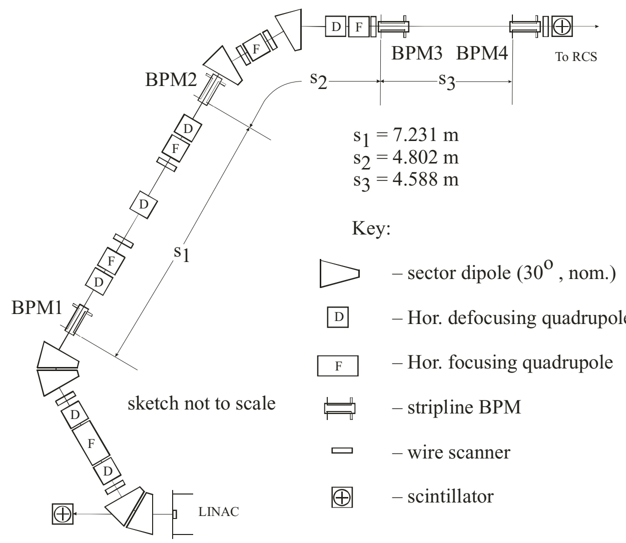

Figure 2: 50-MeV transport line with location of the ESEM stripline BPMs.

BEAM SIZE ANALYSIS

A heuristic approach is used to determine the transverse beam size using stripline BPMs. Two-point models have been used elsewhere[3] to describe beam motion and stability; here, a rigid, two-point model is used to study the beam size.

Two Beamlet Approach

The measurement assumes the beam bunch of charge Q can be represented by two equal point charges of Q/2 separated in one transverse plane by 2a. The center of the two point charges is offset from the axis of the BPM by x_0. The two-beamlet approach is shown schematically in Figure 3. A fraction of the total charge from each beamlet appears on the stripline within a polar angle of $\pi/2\gamma$, centered about $\theta=\pi/2$, where γ is the relativistic ratio of total to rest-mass energy. The charge density on each strip can be expressed as,

$$q_j = \sum_i (Q/2)\cdot(2\pi r_{ij} s_{ij})^{-1}\phi_{ij} \qquad (1)$$

where s_{ij} represents the image length on stripline j from charge i; also, ϕ_{ij} is the azimuthal angle defined as $2\tan^{-1}(w/2r_{ij})$ where w is the width of the stripline. For stripline 1, the charge density can be written as,

$$q_1 = \frac{Q}{4\pi}\left(\frac{\phi_{11}}{r_{11}s_{11}} + \frac{\phi_{21}}{r_{21}s_{21}}\right) \quad (2)$$

where r_{11}=b–a–x_0, r_{21}=b+a–x_0, $s_{11}=2r_{11}\tan(\pi/4\gamma)$, $s_{21}=2r_{21}\tan(\pi/4\gamma)$, b is the stripline radius (3.85 cm), x_0 is the beam offset, and a is the beam half-width. The sign of x_0 can be either positive or negative. Likewise on stripline 2, the charge density is given as,

$$q_2 = \frac{Q}{4\pi}\left(\frac{\phi_{12}}{r_{12}s_{12}} + \frac{\phi_{22}}{r_{22}s_{22}}\right) \quad (3)$$

where the other length parameters may be inferred from Fig. 3. The stripline current can be obtained by integrating the product of charge density and bunch velocity over the azimuthal widths. It is important to note that the axial charge distribution on the stripline is not uniform but will vary with the distance from the beamlet within each polar angle. Averaging the density over the longitudinal extent of the image charge, the average current within the polar angles of both beamlets for stripline 1 is approximately,

$$I_1 = \frac{Q}{4\pi}\left(\frac{1}{r_{11}s_{11}} + \frac{1}{r_{21}s_{21}}\right)w\beta c \quad (4).$$

where βc is the average bunch velocity.

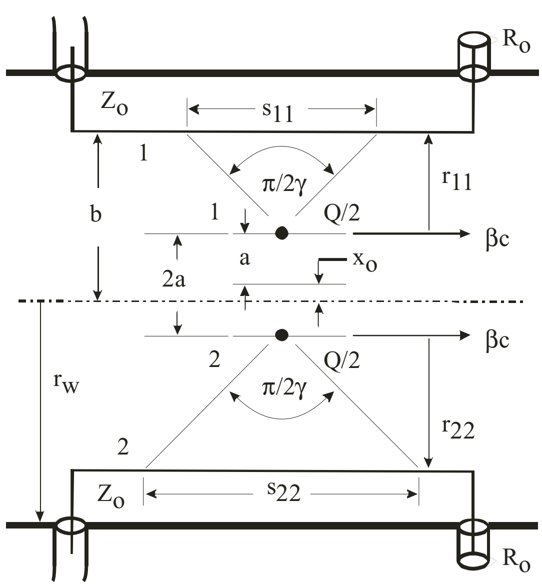

Figure 3: Cross-section of a BPM module showing the parameters used in the two-beamlet approach for measuring beam size.

Outside of the inner polar angle, the current drops to,

$$I_1 = \frac{Q}{4\pi}\frac{w\beta c}{r_{21}s_{21}} \quad (5)$$

From this simple model, it can be seen that the temporal shape of the image current will depend on the separation between the beamlets; therefore the shape of the image current provides information on the size of the beam.

Beam Size Calculation

BPM 4 is located near a waist in the horizontal and vertical dimensions of the 50 MeV beam. This location has periodically been used as a target site for nuclear physics experiments and several beam size diagnostics have been placed here, including wire scanner (WS), scintillator, and segmented Faraday cup (SFC). The BPM beam size measurement begins with the collection of H- macropulse data from both horizontal striplines using a fast, deep memory oscilloscope (Tektronix TDS7254-3M). All BPM signals are recorded as 8-bit data at a rate of 5 samples per ns. Data acquisition continues for 100 µs to completely encompass the length of the <80 µs macropulse. A 500 kilosample (kS) data set is generated for each sampled stripline. Deterministic noise is removed from the data sets, where feasible, up through the fifth harmonic of the linac[4]. An FFT of a 400-ns window of data (2 kS) is used to examine the average microbunch structure. Working in the frequency domain, the spectra are corrected for cable attenuation. The time-domain signal is reconstructed using the amplitudes of the principal harmonics and rectangular pulse-train phasing to provide the minimum pulsewidth. The time-domain signal is then modelled with a double Gaussian function as shown in Figure 4. The two functions represent the profiles from the left and right beamlets. From Fig. 3, the axial length of the charge distribution may be written as,

$$\tan\left(\frac{\pi}{4\gamma}\right) = \frac{s_{22}}{2r_{22}} = \frac{s_{12}}{2r_{12}} \quad (6)$$

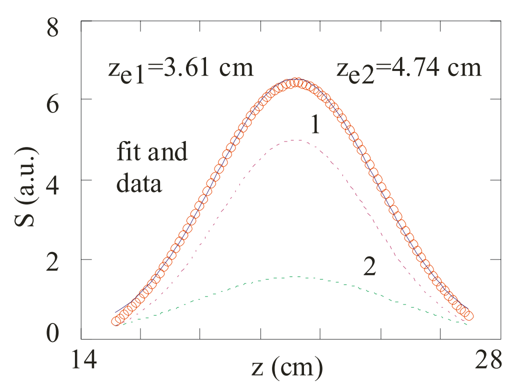

Figure 4: Reconstructed time domain signal, BPM 4R; composite 1/e-width = 3.88 cm.

representing one equation and two unknowns, a and x_0. The offset is determined by the ratio of the left and right amplitudes and is expressed approximately as,

$$x_o = \left(\frac{R-L}{R+L}\right)\frac{b}{2} \tag{7}$$

Using s_{22} and converting the e-width to FWHM values ($s_{22}=2(\ln 2)^{1/2}z_{e1}$), the beam size expression becomes,

$$a = b - x_o - \frac{s_{22}}{\tan\left(\frac{\pi}{4\gamma}\right)} \tag{8}$$

Performing the measurement on four separate linac macropulses near the midpoint (40 μs) of each pulse, the following result is obtained,

$$a = 0.61 \pm 0.09 \text{ cm},$$

for a FWHM value of 1.22 ±.17 cm. The BPM size result is compared with fits to WS, scintillator, and SFC data in Table 1.

Table 1: Horizontal beam size measurements near BPM 4

DIAGNOSTIC	FWHM (cm)
BPM	1.22
WS8	1.32
Scintillator	1.87
SFC	1.26

Measurement Challenges and Discussion

The BPM striplines are raised up above the inner radius of the BPM chamber by approximately 0.8 cm. Magnetic field generated by the beam can penetrate the loop formed by the stripline and its support structure. On the downstream end, the structure is tied immediately to a 50-ohm terminator. The voltage induced by the time-varying magnetic field can be equal to or greater than that generated by the image charge of the beam, especially at the upstream end of the 50 MeV line where the microbunch pulsewidths are shortest. We are presently considering building a new BPM where the striplines are approximately flush to the inner surface to negate the effects of the linked magnetic field.

Solutions to the double Gaussian fitting procedure are not unique. The opening angle of the charge on the stripline is only estimated here, but should be calculated more precisely. Also, the microbunch is not a point source but is extended in the direction of motion.

An advantage of this approach, is that it does not preclude the use of round beams as is the case when employing radial magnetic fields to monitor beam size[5,6]. As shown by the scintillator image in Figure 5, the beam at the BPM 4 location is roughly circular.

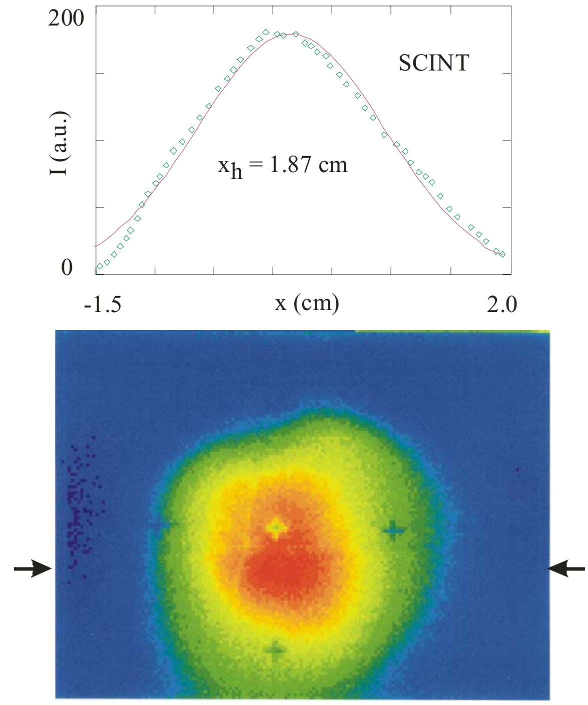

Figure 5: False-color scintillator image, digitized horizontal data (arrows), and fit.

ACKNOWLEGDEMENT

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