Calibration of an Advanced Photon Source Linac Beam Position Monitor Used for Positron Position Measurement of a Beam Containing Both Positrons and Electrons*

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Abstract. The Advanced Photon Source (APS) linac beam position monitors can be used to monitor the position of a beam containing both positrons and electrons. To accomplish this task, both the signal at the bunching frequency of 2856 MHz and the signal at 2×2856 MHz are acquired and processed for each stripline. The positron beam position is obtained by forming a linear combination of both 2856 and 5712 MHz signals for each stripline and then performing the standard difference over sum computation. The required linear combination of the 2856 and 5712 MHz signals depends on the electrical calibration of each stripline/cable combination. In this paper, the calibration constants for both 2856 MHz and 5712 MHz signals for each stripline are determined using a pure beam of electrons. The calibration constants are obtained by measuring the 2856 and 5712 MHz stripline signals at various electron beam currents and positions. Finally, the calibration constants measured using electrons are used to determine positron beam position for the mixed beam case.

INTRODUCTION

The APS linear accelerator is used to accelerate a positron beam to 450 MeV and deliver it to a positron accumulator ring (PAR). The positron beam is produced by irradiating a tungsten target with a 1.7A, 200 MeV electron beam (1). Low-energy positrons and electrons generated in the pair-production process are captured by the S-band (2856 MHz) linac rf wave and accelerated together to the end of the linac. Positron

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position measurement using traditional log-ratio or difference-over-sum techniques breaks down for the mixed species beam because the S-band signal of each BPM pickup contains information about the electron beam current and position. As previously described (2) the first harmonic signal (2×S-Band or 5712 MHz) of each BPM pickup can be used along with the S-Band signal to determine the position of both the electrons and positrons in the mixed species beam. This paper describes a calibration procedure developed for an APS linac BPM using a pure beam of electrons. The calibration constants so determined for each BPM stripline are then used to determine electron and positron position for the mixed species beam used for injection into the PAR during normal operations.

BPM STRIPLINE SIGNALS FOR A MIXED SPECIES BEAM

The output of a pair of APS linac BPM striplines at an integer multiple *n* of the bunching frequency can be written as (2)

$$V^S(\omega_n) = \xi^S(\omega_n)\{I_p(1 \pm \eta^S(\omega_n)y_p) - (-1)^n I_e(1 \pm \eta^S(\omega_n)y_e)\}, \tag{1}$$

where I_p, y_p, I_e, and y_e, denote the positron and electron beam current and position, respectively, and $\omega_n = n\omega_o$, where ω_o is the (S-Band) bunching frequency 2856 MHz. In Equation (1), the + sign is used for the top $(S = T)$ stripline and the – sign is used for the bottom $(S = B)$ stripline (3). $\xi^S(\omega_n)$ is a parameter that depends on the bunch length, BPM stripline length, detection electronics bandwidth, cable attenuation, and number of positron or electron bunches in a linac pulse. $\eta^S(\omega_n)$ is the BPM sensitivity that depends on the azimuthal angle subtended by the stripline and the stripline distance from the center of the beam pipe. Ideally, $\eta^S(\omega_n)$ is a constant independent of frequency but in practice can depend on frequency due to the fact that at high frequencies one cannot neglect the effect of the stripline connection to the output transmission line.

Using Equation (1), the BPM stripline signals can be written as

$$W_n^{\ S} = (I_p - (-1)^n I_e) \pm \eta_n^{\ S}(I_p y_p - (-1)^n I_e y_e), \tag{2}$$

where the sign convention is the same as in Equation (1) and the shorthand notation

$$W_n^{\ S} \equiv \frac{V^S(\omega_n)}{\xi^S(\omega_n)} \tag{3}$$

$$\eta_n^S \equiv \eta^S(\omega_n) \tag{4}$$

$$\xi_n^S \equiv \xi^S(\omega_n) \tag{5}$$

is used. For n=1,2 Equation (2) represents four equations that can be solved for the electron and positron positions as functions of the measured signals and calibration parameters. The algebra is tedious but straightforward, and the result is given here in the following list of equations and definitions:

$$U_n^{\pm} \equiv \eta_n^B W_n^T \pm \eta_n^T W_n^B \qquad (6)$$

$$\chi_n^- \equiv \frac{U_n^-}{2\eta_n^T \eta_n^B} \qquad (7)$$

$$\theta_n^- \equiv \chi_n^- - \frac{\eta_n^\Delta U_n^+}{2\eta_n^\Sigma \eta_n^T \eta_n^B} \qquad (8)$$

$$\eta_n^\Delta \equiv \eta_n^B - \eta_n^T \qquad (9)$$

$$\eta_n^\Sigma \equiv \eta_n^B + \eta_n^T \qquad (10)$$

$$y_{p,e} = \eta_1^\Sigma \eta_2^\Sigma \left(\frac{\theta_1^- \pm \theta_2^-}{\eta_2^\Sigma U_1^+ \pm \eta_1^\Sigma U_2^+} \right) \qquad (11)$$

$$I_{p,e} = \frac{1}{2} \left(\frac{U_1^+}{\eta_1^\Sigma} \pm \frac{U_2^+}{\eta_2^\Sigma} \right) \qquad (12)$$

In Equations (11) and (12) the + sign is used for the positron position and the – sign is used for the electron position. Equation (11) reduces to the familiar difference over sum result for the case where η_n^S is constant.

CALIBRATION OF APS LINAC BPM STRIPLINES USING AN ELECTRON BEAM

The calibration procedure for a pair of BPM striplines consists of using an electron beam to measure the calibration constants ξ_n^S and η_n^S by changing the electron beam position using a corrector for various beam currents. For each position and beam current the n=1 signal at 2856 MHz and the n=2 BPM stripline signal at 5712 MHz are detected using an HP8562A spectrum analyzer connected to the striplines by approximately 30 m of quarter-inch heliax. The spectrum analyzer was set up to detect pulsed rf with rf bandwidth (RBW) = 1 MHz, video bandwidth (VBW) = 3 MHz, and a span of 16 MHz. The linac was set to produce 30 ns beam pulses at a 30 Hz rate. Each beam pulse consisted of 86 electron and positron bunches separated by half an rf wavelength at 2856 MHz (2). A side benefit of using a high-energy electron beam to calibrate the striplines is that scraping is minimized because of the low beam emittance.

From Equation (1), the power output in dBm of the striplines as a function of electron beam position and current can be written as

$$P_n^S = 20\log\left(\frac{\xi_n^S I_e}{\sqrt{50\Omega \bullet 10^{-3}}}\right) \pm \left(\frac{20}{\ln 10}\right)\eta_n^S y_e, \tag{13}$$

$$P_n^S = P^S(\omega_n), \tag{14}$$

where the + sign refers to the top stripline (S=T) and the – sign refers to the bottom stripline (S=B). Equation (13) shows that the slope of a linear fit to the power output for a given frequency labelled by n is proportional to η_n^S. In addition, by measuring the power as a function of position for various beam currents, the gain parameter ξ_n^S is determined by a linear fit to the position intercept of Equation (13) as a function of beam current.

The position of a 580 MeV electron beam was changed over a range of 5 mm in the vertical plane for various beam currents using a corrector upstream of the test BPM striplines. The corrector excitation current was calibrated for the beam position by recording the electron beam position using the BPM striplines connected to standard processing electronics. Each stripline was bench calibrated to determine its sensitivity in dB/mm using a wire strung down the center of the BPM excited at the bunching frequency 2856 MHz and moved to various transverse positions (4). This means that the calibration constants determined in this procedure ultimately derive from the original BPM bench calibration measurements. Each position scan was repeated for various electron beam currents from 5 to 31 mA. The beam current was measured using a wall current monitor adjacent to the BPM striplines under calibration.

TABLE 1. Calibration Parameters Determined Using a Pure Electron Beam

Stripline (S)	**Frequency Index *n***	$\frac{\xi_n^S}{\sqrt{50\Omega \bullet 10^{-3}}}$ **mA^{-1}**	$\left(\frac{20}{\ln 10}\right)\eta_n^S$ **dB/mm**
Top - (T)	1	2.63×10^{-3}	0.84
Top - (T)	2	0.12×10^{-3}	1.11
Bottom - (B)	1	2.78×10^{-3}	0.88
Bottom - (B)	2	0.40×10^{-3}	0.40

Table 1 summarizes the calibration results. The stripline sensitivity parameter η_n^S is given in terms of the average slope from Equation (13) found for all beam currents. The gain parameter ξ_n^S is determined from the best fit line to the position intercept from Equation (13) vs. the beam current. One can see by comparing the parameters in the table that this pair of striplines is quite well matched at 2856 MHz compared to 5712 MHz. When designing a pair of striplines specifically for the purpose of detecting the beam positions of particles in a mixed species beam, some care should be taken to try to match the striplines at both frequencies of interest.

POSITRON AND ELECTRON POSITION MEASUREMENT FOR A MIXED SPECIES BEAM

The calibration constants determined in the previous section are now used to measure the position of electrons and positrons in the mixed species beam used to inject into the PAR. The HP8562A spectrum analyzer was set up as in the calibration procedure except for the span. At each frequency, the spectrum analyzer was set to zero span so that fluctuations in each stripline signal could be observed over time and averaged. Zero span proved helpful when measuring the 5712 MHz signal, which was nearly at the noise floor of –60 dBm. Nominal beam energy was measured to be 395 MeV for the positrons and 380 MeV for the electrons by using a spectrometer located at the position of the BPM striplines under test.

Figure 1 shows the derived position of the electrons and positrons as a function of corrector current. The corrector was the same one used in the calibration procedure described in the previous section. The figure clearly shows the electrons and positrons moving in opposite directions under the influence of the corrector field. The ratio of the absolute value of the electron-to-positron slopes from the best fit line in the figure is 0.98±0.13, which agrees with the energy ratio 0.96 to within measurement error.

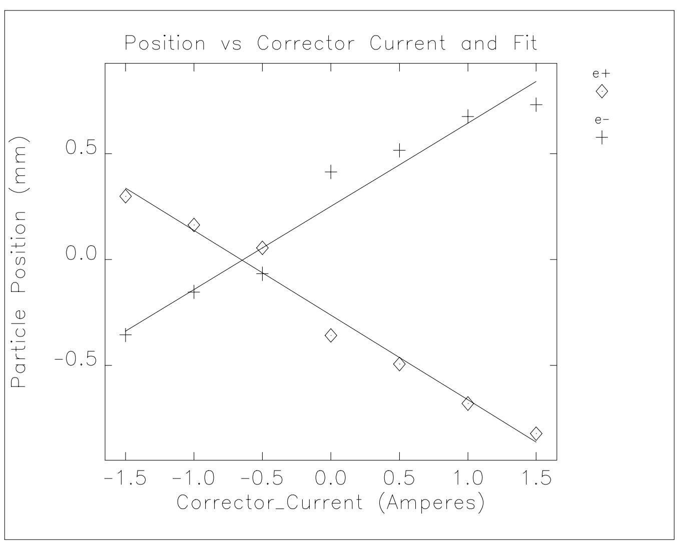

FIGURE 1. Positron and electron position vs. corrector current.

Figure 2 shows the electron and positron beam current for each corrector current. The figure indicates there is probably some amount of scraping occurring at the extreme values of corrector current, and hence, the beam position. The average positron and electron currents from the figure are seen to be about 15 and 11 mA, respectively. This is about a factor of two higher than the values recorded at the Faraday cup current monitors located downstream of the spectrometer. The difference is most likely due to the relative calibration between the Faraday cup and the wall current monitor used in the electron beam calibration procedure.

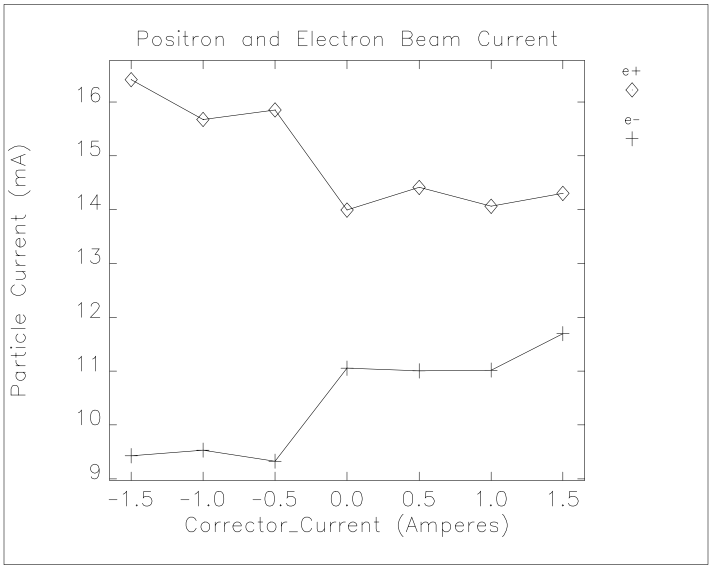

FIGURE 2. Positron and electron beam current vs corrector position.

CONCLUSION

This paper has described a calibration procedure used to calibrate a pair of APS linac striplines to measure the particle position of a mixed species beam consisting of electrons and positrons. The calibration procedure consisted of measuring the stripline signals at 2856 and 5712 MHz for various positions and beam currents for a pure electron beam. The calibration constants determined were then used to derive the electron and positron beam positions for the mixed species case. The final calibration of the stripline ultimately derives from the bench calibration used for the single particle beam case (an electron beam for the APS linac). The noise apparent in Figure 1 is mostly due to the fact that the 5712 MHz signal for both striplines was near the noise floor at –60 dBm. A practical design of a BPM system used to detect the position of a mixed species beam should include optimized striplines at 5712 MHz rather than the bunching frequency (2856 MHz). This should not be a problem since the fundamental beam signal is naturally large in any case.

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