# Beam Parameter Measurements for the APS Linac System *

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*Abstract*

The linac system is the first part of the injector for the Advanced Photon Source (APS) 7-GeV storage ring. The determination of beam emittance, optimization of beam energy and energy spread, focusing condition, and other parameters is important for positron production and for injection of positrons from the linac into the positron accumulator ring (PAR). Diagnostic lines have been incorporated into the linac design to allow measurement of critical beam parameters. Commissioning of the linac system began in October 1993. Beam parameter measurements have been made, and the results are discussed in this paper.

## Introduction

The linac system[1] of the Advanced Photon Source (APS) consists of an electron linac and a positron linac. The positrons are produced by a 200-MeV electron beam impinging on a 7-mm-thick tungsten conversion target. The design goal for the electron beam spot on the target is $\phi \leq 3$-mm in diameter. The positrons emitted from the target are captured by a pulsed solenoid coil which produces a 1.5-T axial magnetic field. The accepted positron emittance from the target is $\varepsilon$ = 1.5 mm * 220 mrad. The positron linac accepts positrons with energy of 8±1.5 MeV and accelerates the beam to 450 MeV; the beam is then injected into the positron accumulator ring (PAR). The positron beam is required to have an emittance of $\varepsilon = 6.6\ \pi\cdot$ mm-mrad in both planes and an energy spread of $\Delta E/E \leq \pm 1\%$ at the end of the positron linac. The injection efficiency will be affected if the beam emittance and energy spread at the output of the positron linac are larger than the design goals. Reliable and simple methods are needed to determine the beam emittance, beam energy, energy spread, and beam intensity for both accelerated electrons and positrons.

## Diagnostic Lines

There are two diagnostic lines in the APS linac system as shown in Figure 1. The diagnostic lines consist of quadrupole and dipole magnets, fluorescent screens, slits, and Faraday cups. The effective length of a dipole magnet is 40 cm, and its bending angle is 13.7°. The collimators and Faraday cups are outside of the vacuum. The positron diagnostic line differs somewhat from the electron diagnostic line in that it uses a single quadrupole magnet instead of a triplet in front of the dipole magnet. There are two Faraday cups in the positron line for measuring positron and electron beam intensity simultaneously. Thirty-five $\mu$m titanium foils are used to terminate the vacuum. The slit widths are adjustable, and the collimators are isolated from ground, enabling currents on the two parts of the collimator to be measured separately. The distances between the dipole magnets and the fluorescent screens were made as large as possible without exceeding the fidicial area of the screens. The fluorescent screen material is a chromium-doped alumina ceramic commonly known as CHROMOX. The beam profiles on the screen (as shown in Figure 2) are captured and analyzed by the video system[2] and their widths are then used to calculate the beam emittance and energy spread.

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## Emittance Measurement

A method for measuring beam emittance has been developed based on beam matrix calculations using TRANSPORT[3]. The beam matrix $\sigma(2)$ at any designated point (2) of a beam transfer system can be calculated from a beam matrix $\sigma(1)$ at a point of origin (1) by the formula:

$$\sigma(2) = R\ \sigma(1)\ R^T \qquad (1)$$

where R is the transfer matrix from point 1 to point 2 and $R^T$ is its transpose. The simplest transfer system for beam emittance measurement includes a quadrupole magnet at point 1, a drift space, and a beam profile measurement device at point 2. In this case, the beam profile measurement device is a fluorescent screen. From Eq. (1) we have

$$\sigma_{11}(2) = R_{11}^2\sigma_{11}(1) + 2R_{11}R_{12}\sigma_{12}(1) + R_{12}^2\sigma_{22}(1) \qquad (2)$$

where $\sigma_{11}(2)$ is the square of the horizontal or vertical half beam profile width measured on the screen. Measurements of the beam profile as a function of quadrupole magnet strength were repeated several (at least three) times, resulting in the following equations:

$$\begin{pmatrix} \sigma_{11_1} \\ \sigma_{11_2} \\ \sigma_{11_3} \end{pmatrix}_2 = \begin{pmatrix} R_{11_1}^2 & 2R_{11_1}R_{12_1} & R_{12_1}^2 \\ R_{11_2}^2 & 2R_{11_2}R_{12_2} & R_{12_2}^2 \\ R_{11_3}^2 & 2R_{11_3}R_{12_3} & R_{12_3}^2 \end{pmatrix} \begin{pmatrix} \sigma_{11} \\ \sigma_{12} \\ \sigma_{22} \end{pmatrix}_1 \quad (3)$$

The beam emittance at point 1 is determined by:

$$\varepsilon = \sqrt{\sigma_{11}(1)\sigma_{22}(1) - \sigma_{12}(1)^2} \quad (4)$$

Figure 3 shows the measured emittance for a 230-MeV electron beam at the entrance to the third triplet in the electron linac. The accuracy of the measured emittance is mainly dependent on the beam profile measurement accuracy. Previous experience and simulation[4] indicate that it is possible to keep the emittance measurement error below 5%. Care must be taken during the measurements to reduce the saturation and noise background on the screen. The analysis and understanding of camera saturation effects is still ongoing.

## Energy Spread

When a dipole magnet is included in the transfer line, the square of the half-horizontal beam profile width is:

$$\begin{aligned} \sigma_{11}(2) &= R_{11}^2\sigma_{11}(1) + 2R_{11}R_{12}\sigma_{12}(1) + \\ & \quad R_{12}^2\sigma_{22}(1) + R_{16}^2\sigma_{66}(1). \end{aligned} \quad (5)$$

The dispersion at the screen position is:

$$R_{16} = \rho(1 - cos\theta) + L_3 sin\theta \quad (6)$$

where $\theta$ is the bending angle of the dipole magnet. $L_3$ is the distance from the point where the beam exits the dipole magnet to the fluorescent screen. $\rho$, the bending radius, equals $L_3/\theta$. All these values are known, and the values of $\sigma_{11}(1)$, $\sigma_{12}(1)$, and $\sigma_{22}(1)$ have already been determined in the emittance measurement. The energy spread of the electron beam can be determined as

$$\frac{\Delta E}{E} = \pm\sqrt{\sigma_{66}}. \quad (7)$$

The minimum energy spread measured for an electron beam at 200 MeV is ± 1.0%. During commissioning and operation it is very convenient to have a fluorescent screen after the dipole magnet. The electron beam energy and energy spread are easily observed on the screen and controlled by adjusting the phase of the rf power. The positron beam emittance has not yet been measured, as the mixture of electrons and positrons after the target makes that measurement somewhat difficult before the bend in the transfer line.

## Beam Energy and Intensity

The dipole magnets allow us to determine the beam energy and intensity. The fluorescent screen in the linac beamline in Figure 1 is used to monitor the position and direction of the beam before it enters the dipole magnet for energy measurement. The beam exits from the dipole magnet, passes through adjustable slits, and then the charge is collected in a Faraday cup. The bending radius and angle can be ascertained from the measurement of beam energy.

The beam intensity in the electron linac is monitored by wall current monitors. However, it is more difficult to monitor beam intensity using these monitors in the positron linac, since the electron-gamma shower produces electron-positron pairs. Electrons are also captured by the pulsed solenoid coil and are accelerated. The only way one can distinguish the $e^+/e^-$ ratio in the mixed beam is by using the dipole magnet. We monitored the $e^+/e^-$ ratio during commissioning and are still improving this ratio by tuning the positron linac. Figure 4 is the measured beam intensity of electrons and positrons at the Faraday cups after the dipole magnet in the positron linac.

## Focusing on the Target

The positron yield from the conversion target is inversely proportional to the beam spot size on the target[5]; however, we currently have no direct way to measure the beam spot on the target. We use three fluorescent screens, one upstream and two downstream of the target, to determine the best focusing conditions for positron production. Since the target is 1 meter downstream from screen $FS_2$, the required focusing current on the target is about 5 A less than the current for focusing the beam on $FS_2$. Measured focusing conditions have been compared with the calculated results based on the measured beam emittance. Both results agree quite well. The final focus is ultimately optimized by maximizing positron yield into a Faraday cup.

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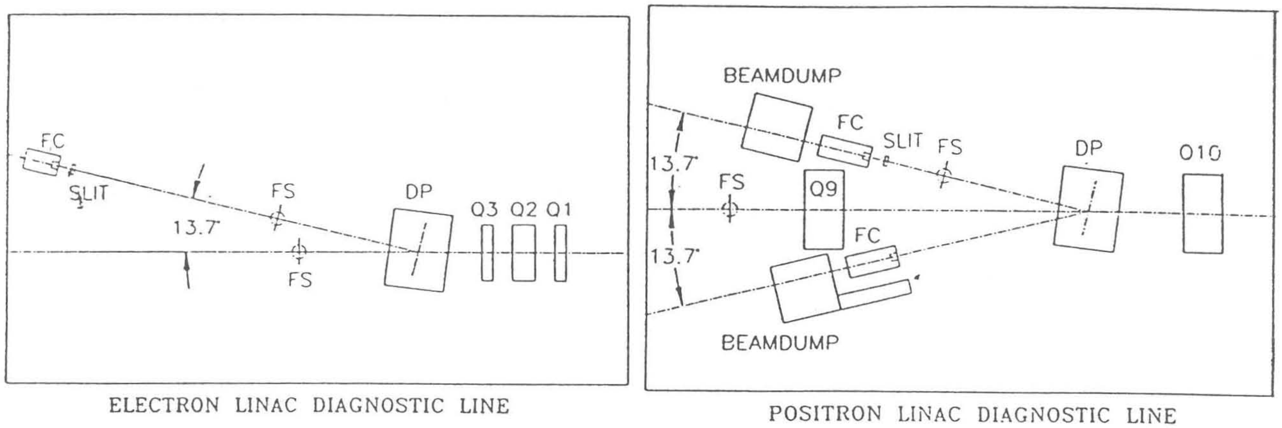


Fig. 1 The layout of the diagnostic line.

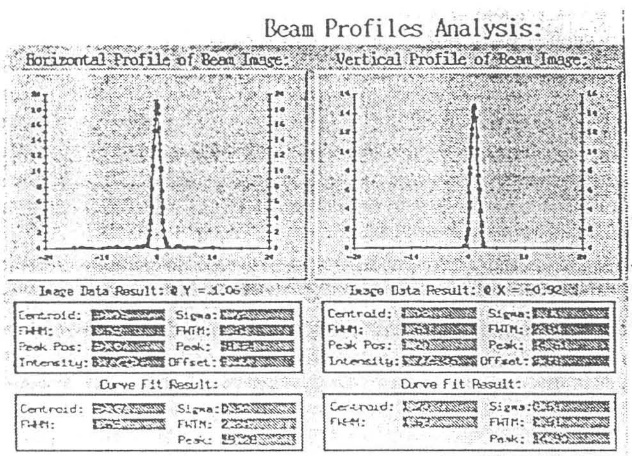


Fig. 2 The measured beam profiles.

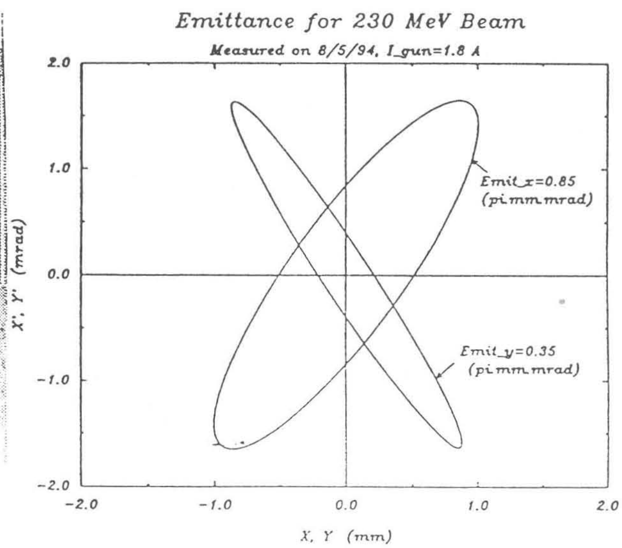


Fig. 3 The measured beam emittances.

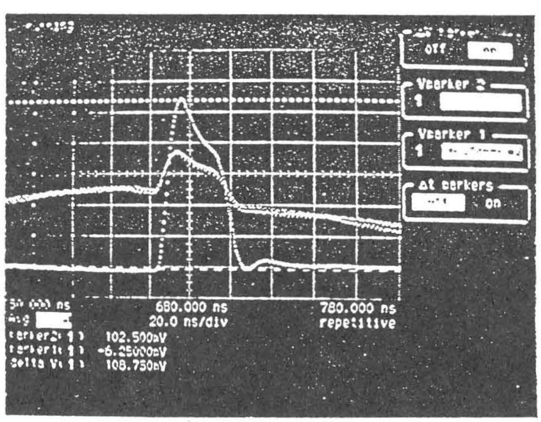


Fig. 4 The positron beam intensity