PRELIMINARY RESULTS OF RMS EMITTANCE MEASUREMENTS PERFORMED ON THE SUB-PICOSECOND ACCELERATOR USING BEAM POSITION MONITORS

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Abstract

The Sub-picosecond Accelerator at Los Alamos National Laboratory is a 1300 MHz, 8 MeV photoinjector. Concerned mainly with the exploration of bunched electron beams, the Sub-picosecond Accelerator facility is also used for a variety of other research. One ongoing task is the exploitation of the second moment properties of beam position monitor signals to measure the rms emittance. The unique properties of photoinjector beams make Gaussian assumptions about their distribution inaccurate and traditional methods of measuring the rms emittance fail. Using beam position monitors to measure the emittance, however, requires no beam distribution assumptions. Presented here are our first emittance measurements with this method on the Sub-picosecond Accelerator.

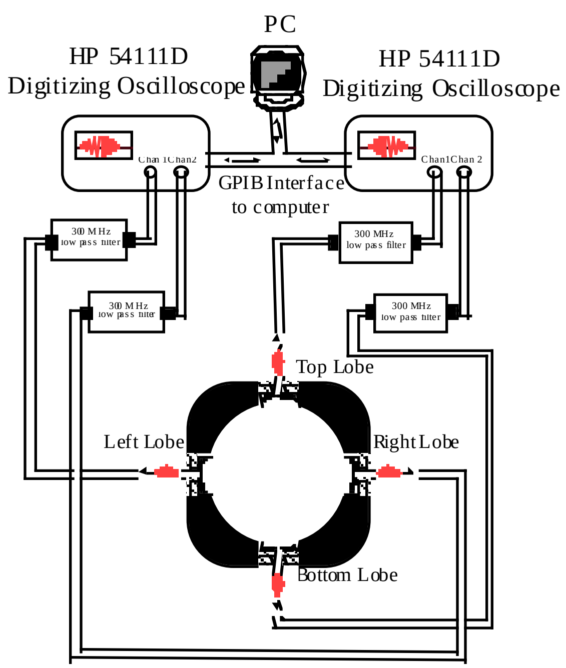

Figure 1: Schematic of data acquisition system.

1 INTRODUCTION

The primary mission of the Sub-Picosecond Accelerator facility (SPA)[1] is to explore the uses and dynamics of bunched electron beams. State of the art in its field, SPA has compressed electron pulses containing 1 nC of charge to sub-picosecond lengths[4].

Using a photoinjector as the source for the electron beam gives us the ability to dictate the shape of the initial electron pulse. In turn, this enables efficient bunching of the beam[4]. However, the attributes that make the photoinjector ideal for compression experiments also create problems for the electron beam diagnostics. A photoinjector accelerates the electrons to relativistic velocities very quickly. As a result, the beam does not have time to come to equilibrium. Its spatial distribution will be unknown and cannot be well approximated by a Gaussian[3], [5]. Therefore, when measuring the rms emittance of the beam, the diagnostic technique can make no assumptions about its spatial distribution.

Roger Miller et. al. first proposed using beam position monitors (BPMs) in a non-intercepting emittance probe[2]. Later, it was demonstrated that this technique measures the rms emittance without reference to the spatial distribution of the beam [6], making it ideal for SPA. What is presented here are the preliminary results of rms emittance measurements of the SPA beam using Miller's technique.

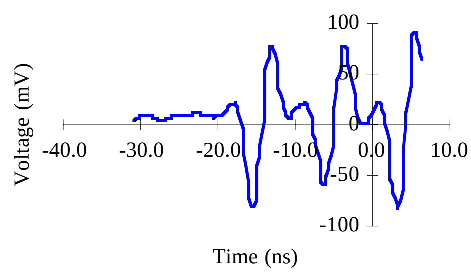

Figure 2: Typical voltage signal from a BPM electrode for two beam bunches.

2 DATA ACQUISITION

The BPMs used in this experiment are dual-axis, capacitive probes[7]. The signals generated in the four electrodes of the BPM are transported down a transmission line where they are filtered by 300 MHz, low-pass filters, digitized by two, dual channel 54111D Hp™ Oscilloscopes and captured by a PC running LabView®. (Figure 1) The oscilloscopes operate at 1 giga-sample per second. The digitized signals are filtered again by a one half Nyquist digital filter and then interpolated utilizing the well known sampling theorem. A typical result is shown in Figure 2.

After the four signals are interpolated, the peak-to-peak voltages of each micropulse is determined. Then, using the BPM calibration that has previously been determined[8], [9], the beam center, $(\bar{x},\bar{y})$, and second moment, $\langle x^2\rangle-\langle y^2\rangle+\bar{x}^2-\bar{y}^2$, are calculated. $\langle x^2\rangle-\langle y^2\rangle$ is the difference in the rms widths of the beam.

3 MEASUREMENTS

I have performed two types of measurements. The first is a check of the BPM calibration. The second is the emittance measurement itself.

3.1 Calibration check

To check the calibration, I first transport the beam to the BPM location. Then, without changing the upstream focusing, I move the beam center to several positions in the BPM aperture with a simple steering coil. Since the beam focusing is constant, $\langle x^2\rangle-\langle y^2\rangle$ is constant. Therefore, if the calibration is correct, a plot of the second moment versus $\bar{x}^2-\bar{y}^2$ should be a straight line with slope equal to one. Figure 3 is a typical result. Each point represents averages of approximately 99 beam shots. I do this because the SPA electron beam is unstable shot-to-shot but reasonably stable when averaged.

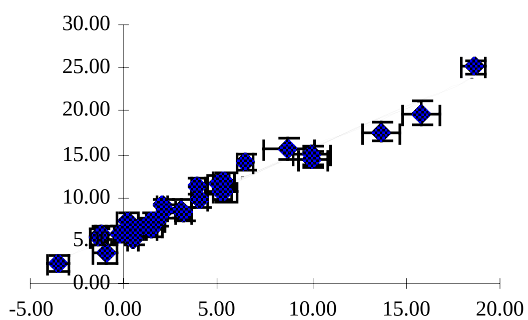

Figure 3: Second moment (mm^2) versus $\bar{x}^2-\bar{y}^2$ (mm^2). The slope is equal to 095± 0036.

Since the values of $\bar{x}^2-\bar{y}^2$ and the second moment are both determined by the BPM signals, this is not an absolute check on the accuracy of the BPM calibration. However, it does provide a check on its consistency.

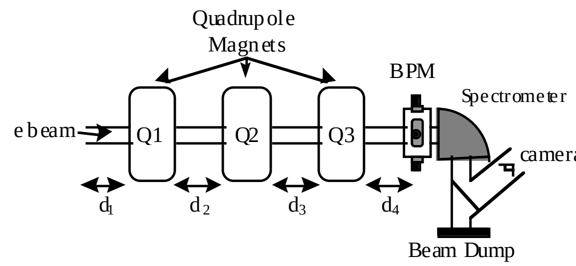

Figure 4: Schematic of beam line section used for emittance measurements.

3.2 Emittance measurement

To measure the emittance, we use a section of beam line like that shown in Figure 4. The quadrupole magnets are set to a number focusing strengths, each one carefully chosen to avoid numerical instabilities in the final result[10]. At each setting, 99 beam shots are grabbed and the average value of $\langle x^2\rangle-\langle y^2\rangle$ is determined.

Since the section of beam line in Figure 4 is linear, it is represented by a linear transfer matrix for each setting of the quadrupoles. Then, it can be shown that the value of $\langle x^2\rangle-\langle y^2\rangle$ at the BPM position is linearly related to the rms beam parameters, $\langle x^2\rangle$, $\langle xx'\rangle$, $\langle x'^2\rangle$, $\langle y^2\rangle$, $\langle yy'\rangle$ and $\langle y'^2\rangle$, at the entrance to the first quadrupole[2]. Changing the focusing of the quadrupoles at least six times results in a set of linear equations that can be solved to obtain the rms beam parameters at the entrance to the first quadrupole. Then, the rms emittances are given by

$$\varepsilon_x = \sqrt{\langle x^2\rangle\langle x'^2\rangle-\langle xx'\rangle^2}\,,$$

and

$$\varepsilon_y = \sqrt{\langle y^2\rangle\langle y'^2\rangle-\langle yy'\rangle^2}\,.$$

I have performed several emittance measurements on the SPA beam using this technique. For a 1 nC per bunch beam, a typical result is

$$\varepsilon_x = 5.3\ \pi\ \text{mm mrad} \pm 0.27\ \pi\ \text{mm mrad}$$

and

$$\varepsilon_y = 4.3\ \pi\ \text{mm mrad} \pm 0.34\ \pi\ \text{mm mrad}.$$

Expressing these as normalized emittances gives

$$\varepsilon_{xn} = \beta\gamma\varepsilon_x = 94\ \pi\ \text{mm mrad} \pm 4.8\ \pi\ \text{mm mrad}$$

and

$$\varepsilon_{yn} = \beta\gamma\varepsilon_y = 76\ \pi\ \text{mm mrad} \pm 6.0\ \pi\ \text{mm mrad}.$$

The errors are estimated according to [2].

4 CONCLUSIONS

Overall, our progress to this point is promising. We are getting reasonable results using Miller's technique.

From simulation, we anticipated that the rms normalized emittances should be a factor of 10 lower than what we measure. However, we have inadvertently been operating with a sizable magnetic field in the region of the photo-cathode, increasing the emittance.

A second issue is the accuracy of the measurement, which is not as good as we hoped. This can be attributed to two factors: the limited accuracy of the digitizing oscilloscopes and the shot-to-shot instability of the electron beam.

At a 1 giga-sample per second digitizing rate, the Hp™ 54111D oscilloscopes are effectively limited to six bit accuracy. Experimenting with an oscilloscope that has 8 bit accuracy and a 500 mega-sample per second digitizing rate has shown marked improvement.

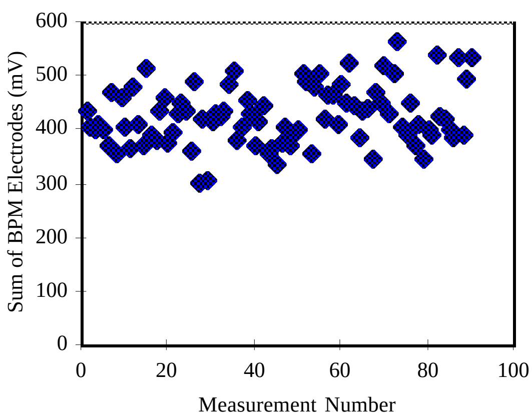

Figure 5: Sum of BPM Electrodes (beam intensity) versus measurement number for 90 beam shots.

As mentioned, SPA's shot-to-shot stability is poor. Figures 5 and 6 demonstrate this. Figure 5 shows a plot if beam intensity (sum of the BPM's four electrodes) versus measurement number for 90 beam shots. Figure 6 shows a plot of $\langle x^2\rangle - \langle y^2\rangle$ versus measurement number for the same 90 beam shots. We hope to improve the stability in the next few months.

5 ACKNOWLEDGEMENTS

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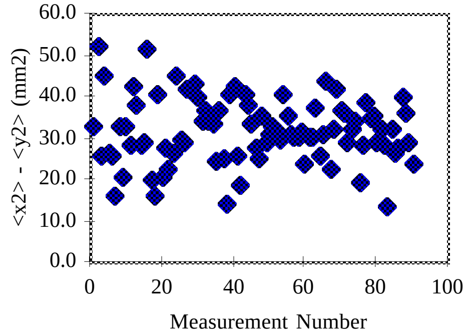

Figure 6: $\langle x^2\rangle - \langle y^2\rangle$ (mm^2) versus measurement number for 90 beam shots.

REFERENCES

[1] B. E. Carlsten et. al., "Subpicosecond Compression Experiments at Los Alamos National Laboratory," Micro Bunches Workshop, Upton, NY, September 1995.

[2] R. H. Miller et al., "Non-intercepting Emittance Monitor," Proc. 12th Int. Conf. On High Energy Accelerators, (Fermilab, 1983), p. 602 (1983).

[3] B. E. Carlsten, et. al., "Measuring Emittance of Non-thermalized Electron Beams From Photoinjectors," 14th International Free Electron Laser Conference, Kobe, Japan, August 23-28, 1992, Los Alamos National Laboratory document LA-UR 92 2561.

[4] B. E. Carlsten and S. J. Russell, "Subpicosecond Compression of 0.1-1 nC Electron Bunches with a Magnetic Chicane at 8 MeV," Physical Review E, Volume 53, Number 3, p. 2072-2075.

[5] K. Kim, "RF and Space Charge Effects in Laser-driven RF Electron Guns, " Nucl. Instrum Methods Phys. Res., vol. A275, p. 201, 1989.

[6] S. J. Russell and B. E. Carlsten, "Measuring Emittance Using Beam Position Monitors," Proc. of the 1993 Part. Accel. Conf., p. 2537, IEEE 93CH3279-7.

[7] J. D. Gilpatrick, et. al., "Design and Operation of Button-Probe, Beam-Position Monitors," Proc. of the 1993 Part. Accel. Conf., p. 2334, IEEE 93CH3279-7

[8] J. F. Power, et. al., "Characterization of Beam Position Monitors in Two-Dimensions," 16th International LINAC Conf., Ottawa Ontario, CANADA, 1992.

[9] S. J. Russell, et. al., "Characterization of Beam Position Monitors for Measurement of the Second Moment," Proc. of the 1995 Part. Accel. Conf., p. 2580, IEEE 95CH35843

[10] S. J. Russell, "Unstable Matrix Equations and Their Relationship to Measuring the Emittance of an Electron Beam Using Beam Position Monitors," (private communication).