A TURN-BY-TURN VERTICAL PROFILE MONITOR

R. Scott Smith, Stuart Henderson, D. Hartill, Laboratory of
Nuclear Studies, Cornell University and Tong Chen, R.H.Siemann, Stanford
Linear Accelerator Center, Stanford University

Abstract

A turn-by-turn vertical beam profile monitor has been developed at the Cornell Electron Storage Ring (CESR). The instrument optically images the vertical beam distribution with an array of optical fibers that transport visible synchrotron radiation to an array of photo-multiplier tubes. Each PMT signal is recorded by a turn-by-turn data acquisition system. With this instrument, we compare profiles of colliding and non-colliding electron bunches, from which we calculate an upper limit on the coherent beam-beam effect.

1 INTRODUCTION

The beam-beam interaction is thought to significantly limit luminosity in lepton (e+e-) storage rings; yet, experimental data is lacking. We know that the beam-beam force focuses in both transverse planes and that it may lead to a multi-turn oscillation in transverse beam size [1]. At the Cornell Electron Storage ring (CESR), we have developed a turn-by-turn vertical profile monitor suitable for observing synchrotron radiation at optical wavelengths. The monitor is compact, unimodular, and portable. We can distinguish bunches spaced at least fourteen nanoseconds apart and observe, in principle, beam density out to 5σ. Our real limitation in the out lying region is noise from photon-statistics.

2 DEVICE CHARACTERISTICS

The vertical profile monitor is basically a 10x2 array of optical fibers where each row transports visible light to a photo-multiplier tube. The optical fiber has a core diameter of 100 microns, sub-sampling the optical resolution of the beam telescope (174 microns). The total array size is approximately 1750x250 square microns, compared to the vertical Gaussian beam width of 200 microns. The ratio of the horizontal to vertical beam size is 10 at the point of observation. We may rotate the array about the image centroid and vertically translate it.

The Hamamatsu TO-8 PMT, used in our instrument, is small and compact – having a total volume of 1760 mm^3. The small size has allowed us to install the set of PMTs atop the fiber array assembly and, thereby, make a compact portable instrument. The TO-8 PMT is most sensitive to the shorter wavelengths of the visible spectrum, peaking at ≈450 nm. We digitize signals with a fast ADC system, recording the size of one bunch of one train with each run. The ADC full range input is ±1 V, corresponding to ±2000 ADC counts [2]. We sample at the rotation frequency of CESR (390.6 kHz).

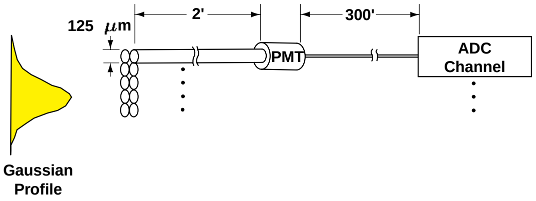

Figure 1: An image of the beam magnified by approximately unity is focussed onto a 10x2 array of fiber optics, where each row supplies a single PMT with light. The PMT signals are amplified and recorded on individual ADC channels.

3 CALIBRATION

We are interested in observing variations in the beam intensity distribution. Our linear CCD provides a time average picture for comparison, which is reliably Gaussian. A little reflection reveals that the area under the Gaussian curve should be constant for short time scales– typically a few thousand revolutions. Accordingly, we describe the intensity distribution by

$$\varrho(y,\sigma,\mu) = \frac{A}{\sqrt{\pi}\sigma}\exp\left(\frac{-(y-\mu)^2}{2\sigma^2}\right) \tag{1}$$

The Gaussian width displayed by the CCD is in principle, if not measurably, larger than the Gaussian width in Eq(1). On a turn-by-turn basis, variations in the intensity distribution may be attributed to changes in σ and Schottky noise within the beam. The dipole contribution from Schottky noise is 10^{-3} smaller than the betatron amplitude of a few to several microns. Photon-statistics will prevent us from observing Schottky noise. In fact, photon-statistics will place a limit on all of our observations.

The fiber array performs a discrete sample of the image intensity. From this sample, we have two methods of reconstructing the profile behavior. The first method is a least squares fit. Although the best method for quantifying the density distribution, we will not be using it. We will use a simpler method. Before discussing changes in the Gaussian width, we need to know the device resolution. Stimulating vertical betatron motion is simple; and by shaking the beam at several intensities and measuring the beam position and distribution at the synch-light observation point, we directly calibrate the detector. The figure below depicts the FFT amplitude of a single channel as a measure of oscillation amplitude. The signal falls into the noise region near five microns.

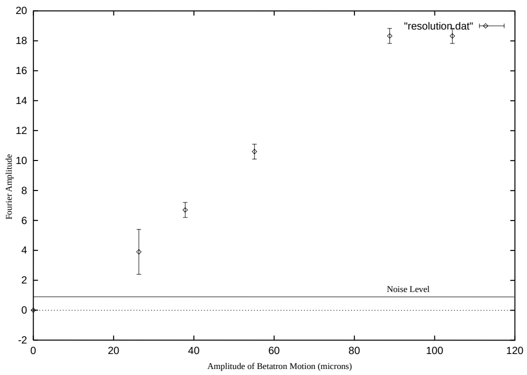

Figure 2: The response of a channel to centroid motion is measured. The channel lies one σ away from the centroid equilibrium position and has a resoluton of five microns.

4 MEASUREMENTS

We measure the device resolution by taking the difference of channel signals that flank the centroid. Below, we present the spectrum from a stimulated oscillation of 33 microns ±10 microns.

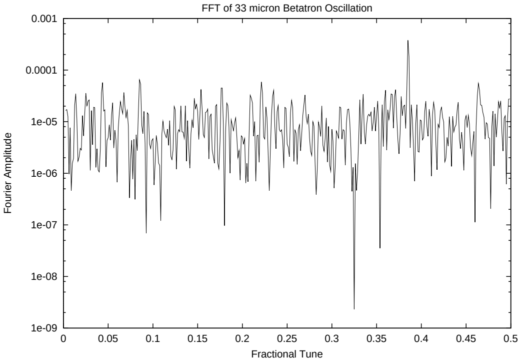

Figure 3: A FFT of a stimulated betatron oscillation of 33 μm. The signal was constructed by taking the difference of channel signals on either side of the centroid.

The signal to noise ratio is 7.91, indicating a resolution of four microns. Why did we not see a significant improvement? The derivative of Eq(1) with respect to the centroid position is

$$\frac{\partial \varrho}{\partial \mu} = \frac{(y-\mu)}{\sigma^2}\varrho \tag{2}$$

The extrema of Eq(2) lie at $\pm\sigma$ and imply that we do not gain much signal strength elsewhere.

A similar analysis is performed to investigate variation in the beam width. Strictly speaking, Eq(1) is non-analytic with respect to σ; but sufficiently far from the origin, we may make a first order expansion.

$$\frac{\partial \varrho}{\partial \sigma} = \left(\frac{(y-\mu)^2}{\sigma^3} - \frac{1}{\sigma}\right)\varrho. \tag{3}$$

The difference of channel signals lying within $\pm\sigma$ and those outside this region will increase the signal to noise ratio.

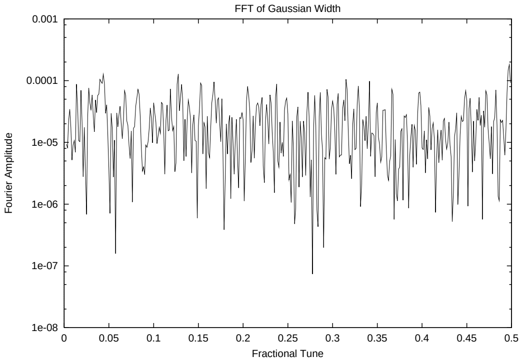

Figure 4: The difference in channel signals within $\pm\sigma$ of the centroid and those outside this range will measure the device response to oscillations in the Gaussian width of the beam. The response is flat.

We have performed this analysis on colliding beam data where the bunch currents were 7 mA and the vertical tune 9.61. The spectra is flat, implying that a more elaborate method of least squares fitting is not required. We can say that any oscillation in beam size is less than four microns. A four micron oscillation in beam size corresponds to a 4% change in emittance.

5 REFERENCES

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[2] Henderson, Stuart. 'A Beam Loss Diagnostic System for CESR.' These Proceedings.