

AN APPARATUS FOR MEASURING TURN-BY-TURN TRANSVERSE BEAM PROFILE IN ELECTRON STORAGE RINGS[†]

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Abstract

A new apparatus is designed to measure the beam profile turn-by-turn using synchrotron light. The apparatus consists of optical fibers, photo multiplier tubes and digitizers. It is cost efficient and easy to operate. Monte Carlo simulations have shown that the apparatus has an acceptable resolution. The concept has been tested preliminarily at the SLC damping ring, and a full equipment is being set up at CESR to observe coherent beam-beam phenomenon.

1 INTRODUCTION

The beam-beam interaction has been one of the most important physical effects that limit circular collider performance, and this issue has not been well understood. One reason is the lack of experimental data on the detailed characteristics of the beams. For example, turn-by-turn beam profile information is needed to study the coherent beam-beam effect. This effect is expected to be unimportant[1] but has never been looked for at the beam-beam limit. An equipment that could be used for this measurement is the BEXE detector at LEP[2,3]. This is an X-ray detector with radiation-damaged semiconductor material. It has shown the coherent motion of beam under collision[4]. However, these observations have not been accompanied by a set of parameters at the time of observation, and systematic studies have not been reported. In addition, it apparently is difficult to operate and extremely costly.

In virtually every e^+e^- storage ring, the beam profiles are measured by TV cameras or photo diode arrays. They are too slow to obtain turn-by-turn information. A sweep camera with a synchronous sweep could be used, but these are expensive and not generally available at colliders. No beam-beam data from one has ever been reported.

The apparatus described in this note is less expensive and should be simple to operate. The limitation is the resolution of the optical system of the synchrotron light monitor, including diffraction and depth of field.

2 THE APPARATUS

The basic idea is to combine optical fibers and photo multiplier tubes (PMT). The flexibility of optical fibers allows close spacing in the image plane, while the PMTs provide the speed and the sensitivity.

The diagram of the system is shown in Figure 1. At the image plane of the synchrotron light monitor, the optical fibers form an array that split the image. Then, each fiber is fed into a photo multiplier tube that converts

the light signal into an electric signal. In order to obtain the one-dimensional distribution, the image can be integrated across the other direction. The simplest way to do this is to make a matrix of fibers at the image plane. Suppose the vertical profile is to be monitored, all the fibers in each horizontal row are fed into the same PMT. The length of the fibers should be short, in the order of a meter, as long as they can reach the PMTs. Therefore, the quality of the fiber is not crucial. If the optical system is out of the radiation area, normal plastic fiber will do the job. Otherwise, one needs to find "radiation hard" optical fibers. The diameter of the fiber should be chosen to match the beam image size, as well as the number of channels. The optical fibers used at CESR are made by Fiberguide Industries. The fibers saturate at 50,000 rad at a loss of 11.5 dB/km. The irradiation process was steady. The fiber core has a diameter of 100 microns, as the beam image size is 250 microns.

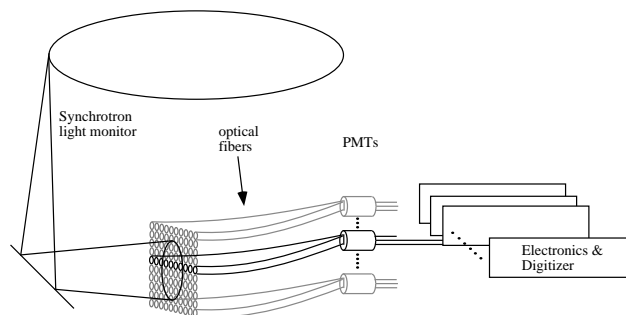


Figure 1. The diagram of the turn-by-turn profile monitor.

The photo multiplier tubes should have fast response. Especially in case of multibunch operation, the rise and fall times should be shorter than the bunch space. PMTs with typical gain are enough to provide the signal. One choice of the PMT is Hamamatsu R5600. This ultra compact PMT sealed in a TO-8 metal can has a rise time of 0.65 ns and gain of 3×10^5 .

After the PMTs, the signals need to be stretched or sampled by fast track/hold circuits. Then, the signals are digitized in parallel by multichannel digitizers. The ADC has to be fast enough to catch the data turn-by-turn. For instance, the digitizing period has to be shorter than 7 μ s for PEP-II and 2.5 μ s for CESR. Normal control computers cannot read data at this fast rate, and the digitizer needs to have its own buffer to store the profile temporarily. The data acquisition system should be designed according to the operation mode and observation purposes.

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The cost of the whole system is estimated to be about \$20,000. The most expensive part of the system is the digitizers, which depends on the number of channels.

An alternative of the parallel data acquisition system is to do it in serial. One can make the length of the fibers of each channel different. At the other end, all fibers are fed into the same PMT. The output will be a series of pulses space by 10 ns that give the profile. This scheme needs only one channel of electronics, but the digitizer has to be much faster.

A test to prove the principle of this apparatus was performed at the SLC south damping ring. Both parallel and serial schemes are tested. Signals observed by oscilloscope are suitable for digitizing.

A version of the apparatus exists at CESR. It is a compact device that includes the fiber array and ten Hamamatsu R5600 PMT's on a single stage. We may horizontally translate the stage, vertically translate the fibers, and rotate the array about its midpoint. The array is an arrangement of 2x10 optical fibers.

The apparatus has been placed in the tunnel and has been observed a beam of electrons(not in collision) with an oscilloscope. Calibrating the gain on each channel, we observed a gaussian shaped beam. Preparations have begun to digitize the signals with an Omnibyte Multichannel Analog Digitizer, which is a 20 channel, 12 bit 12 MHz digitizer. We are encouraged by recent attempts to digitize peak signals, where the vertical tune shift was observed while shaking the beam.

3 MONTE CARLO STUDY OF THE RESOLUTION

A draw back of this apparatus is the optical system resolution due to the wavelength of the visible light. The limit comes from diffraction (especially in vertical plane) and depth of field. This will limit the beam size variation that can be observed by the apparatus. To address this issue, a Monte Carlo study was carried out.

The Monte Carlo code simulates fitting the data to a Gaussian distribution with the presence of the optical resolution and electronic noise. The signal was generated as a Gaussian distribution at the number of evenly spaced sampler locations. The width of the distribution was given by $\sigma_{tot} = \sqrt{\sigma_{beam}^2 + \sigma_{res}^2}$, where σ_{beam} is the beam size and σ_{res} is the optical system resolution, including diffraction and depth of field. The center of the distribution was randomly chosen in between the two center samplers. Then, the noise, generated by an Gaussian distributed random number with a variance taking as a percentage of the maximum of the Gaussian distribution, was added to each data point.

This data was then fit to a Gaussian. The algorithm is the following: First, cut the data points that are less than 5% of the maximum. Only the strong signal data are used. Second, the mean, or the center, is found by linearly interpolating the maximum signal bin by making the area on both sides equal. Then, the Gaussian curve fitting can

be reduced to a simple linear fit: The function

$y = Ae^{-\frac{(x-\bar{x})^2}{2\sigma^2}}$ can be rewritten as $\ln y = \ln A - \frac{1}{2\sigma^2}(x-\bar{x})^2$. Substituting $\ln y$ by Y and

$(x-\bar{x})^2$ by X, we have $Y=a+bX$. After the linear fitting, the coefficients a and b are found. Therefore, the width of the Gaussian curve is $\sigma = \sqrt{-1/2b}$, and the beam size can be calculated by $\sigma_{beam} = \sqrt{\sigma^2 - \sigma_{res}^2}$.

In this Monte Carlo study, the parameters were chosen based on CESR. The optical system had a resolution of 150 micron, including diffraction and the depth of field[5]. The data points were spaced by 100 micron, corresponding to the diameter of the optical fiber. The CESR synchrotron light monitor has an image of 250 micron vertical beam size. In the study, beam sizes of 150 to 250 micron were simulated. The noise with a deviation of 0.5% to 5 % of the peak signal were studied.

Figure 2 plots the results of the Monte Carlo simulation. For each set of parameters, the process was repeated 100 times. The uncertainty is the rms difference between the measured beam size and the given beam size. The results show that the uncertainty is proportional to the noise, as expected, and independent of beam size at the studied range. The results tell us that this apparatus can observe the beam size variation beyond 5 micron with 1% of the electronic noise. If the variation is expected at certain frequency (e.g., twice of the tune), the uncertainty may be improved by looking at frequency domain.

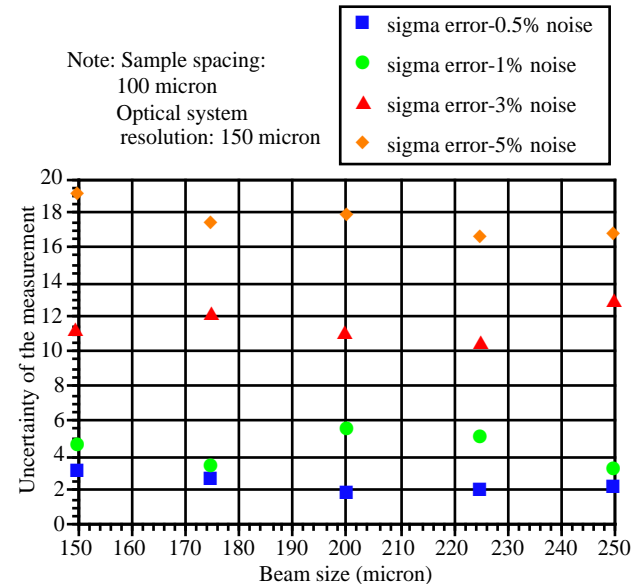


Figure 2. The uncertainty of beam size measurement with noise and optical smear.

4 CONCLUSION

The preliminary study shows that an apparatus consisting of optical fibers and PMTs can provide turn-

by-turn beam profile information at a reasonable resolution. The apparatus is simple, low cost. It should be easy to operate and, once setup, can take data during routine operation.

An apparatus has been built at CESR and observations are beginning.

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