Turn by Turn Beam Profile Monitor by Utilizing the Non-linearity of the Photo-Detector

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ABSTRACT

In the electron storage ring, due to the high revolution frequency, the beam profile information that was detected by using the synchrotron radiation is always an average of many turns of the electron beam. In many cases of experimental accelerator physics studies, a turn by turn monitoring of the beam profile is necessary. In this paper, we proposed a method which may perform a turn by turn beam profile monitor if the SR intensity is large enough. The idea and the theory will be discussed in this paper. The computer simulation results and a preliminary test experimental results will also be presented.

1. INTRODUCTION

In many accelerator physics experiments, e.g., the coherent damping time measurement and the dynamic aperture study experiments, we like to know to the turn by turn variations of the beam positions. Usually, it is accomplished by the button type or the strip line type electrode beam position monitors(BPM). However, the measurements done by these types of BPM only gave us the information of the position of the beam centroid. If the beam centroid motion combined with the decoherence mechanism, the BPM would not be able to distinguish them. That means that by using the BPM, we can not distinguish the coherence damping or the decoherence. In order to distinguish them, we need to monitor the beam profile, simultaneously. For lepton machines, the synchrotron radiation provides a very useful beam profile information. However, to perform a turn by turn beam profile monitor, we need a very fast detecting system. For the speed requirement we need, the commercial photo diode array and the following up electronic system is not available neither a cost reasonable approach. In this paper, we proposed a method to monitor the beam profile by using a fast single photo diode.

2. THEORY

Most P-N silicon photo-diodes are linear (better than *1%*) over a wide range of magnitude of the incident power. In linear region, the total photocurrent is independent of the incident photon beam size as long as the total power is the same. At high photon intensity, however, non-linearity is introduced due to the device saturation. Total photocurrent in non-linear region now is not only dependent on the incident total photon power but also dependent upon the photon beam size. This means that in the non-linear region, we can get the photon beam profile information by means of measuring the total photocurrent.

In figure **1**, we used three different photon beam intensity to demonstrates the above idea. In the figure the total power for the three cases is *1mW*. If all the three cases are operated at linear region, then each photon in each cases will induce the same photocurrent. Thus the total current I_p is the sum of all individual photons. Since the photon numbers are the same in these three cases, the total currents are also the same for them. However, if the three cases are operated at non-linear region, a photon in the different cases will induce different amount of photocurrent. In the less saturated case, a photon will induce more photocurrent. Thus in non-linear region, the photocurrent increases as the incident photon beam size increases (with its total power unchanged).

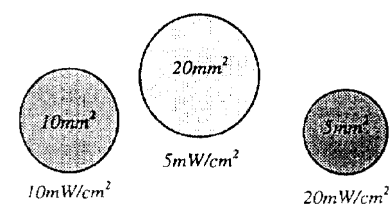

Fig. 1 Demonstration of the relations between the incident photon beam size and its power intensity for the same total power (*1mW*)

Figure 2 shows the photocurrent density $J(p)$ (A/mm^2) as a function of the incident power density p (mW/mm^2), where we have supposed that in the non-linear region $J(p)$ is proportional to $p^{0.5}$. The total photocurrent I_p, i.e., the signal current of the photo-diode is then the integration of the photocurrent density over the whole photon spot size:

$$I_p = 2\pi \int J(p)\, r dr$$

where r is the distance from the center of the incident photon beam profile. In our computer simulation, we suppose that the power distribution of the light is gaussian, i.e.,

$$p(r) = \frac{1}{2\pi\sigma^2} exp^{\frac{-r^2}{2\sigma^2}}$$

The result is shown in figure 3 for total current I_p vs. various power density distribution of total power *1mW*.

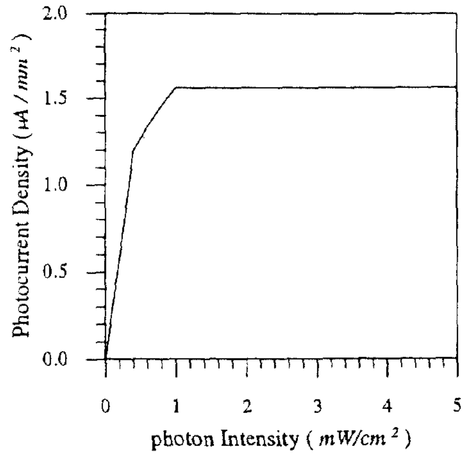

Fig. 2 Response function of the photo-diode

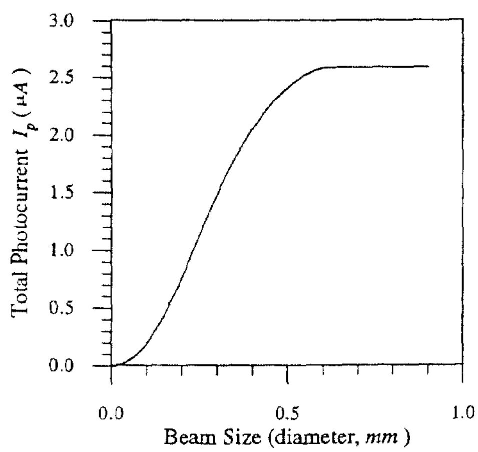

Fig. 3 Total photocurrent for various power density distribution of total power 1mW

3. EXPERIMENT

We had examined this idea by using a He-Ne laser to simulate the synchrotron light. The setup of the laser beam experiment is shown in figure 4. The power of the He-Ne laser is *0.8mW*, which is sufficient to saturate the photo-diode. We use a function generator to modulate the He-Ne laser intensity at frequency of *1MHz*. The movable convex lens is used to change the incident photon beam size. The photo-diode (PIN10DI manufactured by UDT) is biased at about *+0.7V*, which facilitates the saturation for the laser intensity we used. The output of the photo-diode is then magnified by an amplifier of gain *147V/V* and output resistance *50ohm*. The CCD camera is used to measure the laser beam size. The results are shown in figure 5. We can find that the minimum power intensity to saturate the photo-diode is about $0.8mW/\pi\,(1mm)^2 \cong 0.255mW/mm^2$.

The total photon power of synchrotron radiation in the storage ring of SRRC is about an order of 10^{-2} (*mW*) at single bunch mode, *1mA*. The photon beam size is approximately the same order as the He-Ne laser we used in the laser beam experiment. Thus the power intensity is not sufficient to saturate the photo-diode as what we predicted in figure 5.

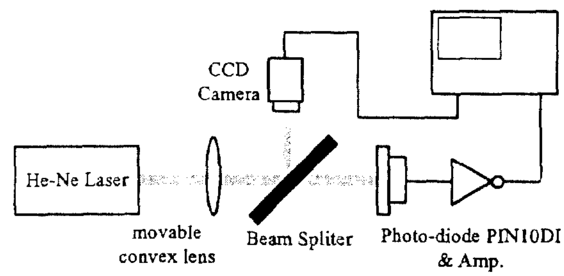

Fig. 4 Experiment Setup

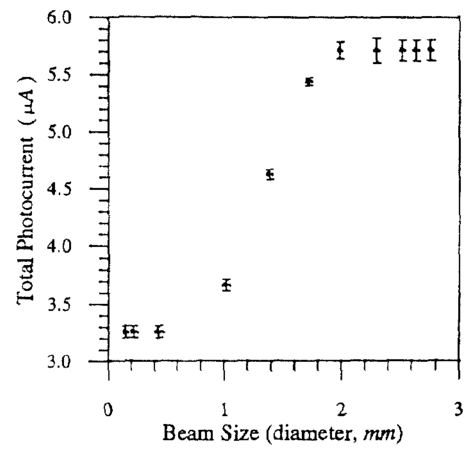

Fig. 5 Plot of the photocurret vs. incident photon beam size (He-Ne laser; total incident photon power = *0.8mW*)

Figure 6 shows the signals of the photo-diode as synchrotron radiation incident on it. From the figure we see that the photo-diode can detect the revolution frequency of the electron beam. In the experiment, however, we found it fail to sense the beam profile changes. This is due to the low power intensity of the SR as mentioned above.

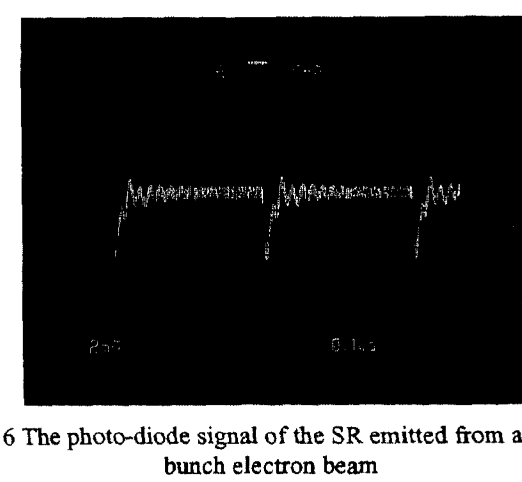

Fig. 6 The photo-diode signal of the SR emitted from a single bunch electron beam

4. Discussion

The results from the laser beam experiment proved the feasibility of the idea we first mentioned. That is, we can use the non-linearity of the photo-diode to sense the beam profile changes as long as the total power of the incident photon is the same.

As the method is applied for sensing the electron beam profile changes in the storage ring, it was found that the SR power intensity is too small to saturate the photo-diode. To solve the problem, we proposed two methods as follows:

1. Use an external light source to saturate the photo-diode first. In this case the changes of electron beam profile may be detected although the SR intensity is small.
2. Find an absorber which can be easily saturated by the SR from the electron beam. The more the absorber is saturated, the larger the transmitted SR is. The differences between the transmitted SR of different power intensity can then be measured by the photo-diode operated at the linear region.

Reference

1. Melles Griot, Optics guides 5, Ch. 22.