# Investigating the sensitivities of the photon beam line flux with a deforming electron beam orbit

Ian C. Hsu
*Department of Nuclear Science, National Tsing Hua University and Synchrotron Radiation Research Center, Hsinchu, Taiwan 30043*
(Received 17 October 1996; revised manuscript received 31 December 1996)

Beam experimental and numerical studies are performed to examine the effects of an electron beam position and orbit slope at the source point on the photon beam lines' flux. Results obtained from the beam line studied herein indicate that 10 $\mu$m vertical beam position displacement causes a relative photon flux change of $0.9\% \pm 0.3\%$, as measured at the entrance slit downstream. This observation corresponds to the numerical results. On the other hand, a vertical beam angular change of 10 $\mu$rad causes a relative photon flux change of $1.2\% \pm 0.4\%$. The different mechanisms causing the beam line flux to fluctuate by the beam position change and by the beam angular change are discussed as well. [S1063-651X(97)11005-4]

PACS number(s): 07.85.Qe, 29.20.Dh, 52.65.Cc

## I. INTRODUCTION

A photon beam line having an extremely high resolution is one of the primary characteristics of a third generation synchrotron radiation light source. Such a characteristic has caused the beam lines' optical systems to become quite sensitive to their photon sources' position and angle, i.e., the electron beam orbit. A fundamental issue in all of these light sources, the beam line flux fluctuates due to instabilities of the electron beam position and angle. This study examines the beam line flux sensitivity due to an electron beam's positional and angular changes at the source point of the beam line. The fact that synchrotron radiation sweeps in the horizontal plane accounts for why the sensitivity of the vertical beam displacement is significantly higher than that of the horizontal beam displacement. Therefore, the former is addressed herein. Beam experimental and numerical studies are undertaken. The former are performed by varying the size of either the electron beam's orbit local position bump or that of the local angular bump. Changes in the beam line flux are measured at the entrance slit downstream. Those two types of local bumps are created by four correction magnets. The strength of four correction magnets must adhere to a certain ratio to control the amplitude and slope of the electron beam's orbit at a given position in a ring [1]. The general method proposed herein can be applied in any synchrotron radiation light source. The Taiwan light source (TLS) of the Synchrotron Radiation Research Center (SRRC), is one of several third generation synchrotron radiation light sources currently operating. The experiments in this study are conducted on the 6-m-HSGM (six-meter high-energy spherical grating monochromator) [2] beam line at the TLS. In addition, the optical parameters of the beam line of the 6-m-HSGM are used in the numerical studies as well.

This study experimentally provides a conversion factor of the electron beam's orbit instabilities to the beam line flux fluctuations. This study also provides further insight into the decoupling of the instability sources which may originate from either the accelerators or the beam line systems, e.g., vibration of mirrors. Also, with a knowledge of this conversion factor, accelerator physicists can use their own diagnostic devices to investigate the orbit instabilities, and subsequently to convert their results into the effects on beam lines. Comparing the beam experimental and numerical results allows us to check the front part of the beam line's optics system. Results obtained from the beam line studied herein indicate that 10 $\mu$m vertical beam position displacement causes a relative photon flux change of $0.9\% \pm 0.3\%$, as measured at the entrance slit downstream. This observation corresponds to the numerical results. In addition, a vertical beam angular change of 10 $\mu$rad causes a relative photon flux change of $1.2\% \pm 0.4\%$. The above two values depend on the electron beam size and the slit size, as well as the beam line's optics. The general requirement of the beam line's relative photon flux fluctuation is around 0.1% to 0.5% [3] for a typical high resolution beam line of a third generation synchrotron radiation light source. Herein, the beam experimental studies provide a more thorough understanding of the different mechanisms causing the beam line flux to fluctuate by the beam position change and by the beam angular change.

## II. EXPERIMENT

The experiments are performed by varying the size of either the electron beam's orbit local position bump or that of the local angular bump. Changes in the beam line flux are measured at the entrance slit downstream. The photon flux was measured by a photon electric detector located next to the entrance slit. The sensitivity certainly depends on the size of the entrance slit. The slit size was set at 50 $\mu$m in all of the experimental and numerical studies presented herein. The electron beam orbit position bump and angular bump were created by using four vertical orbit correction magnets. Therefore, the electron beam position and angle could be independently controlled at the beam line's source point. Figure 1 depicts a typical orbit position bump (upper) and a typical orbit angular bump (lower) used in the experiments. The beam line's source point is located at the angular bump's zero-cross point.

The electron beam position and angle at the beam line's source point were calculated by reading two beam position monitor (BPM) values: one upstream and one downstream of the source point. Herein, we demonstrate how they were calculated. The orbit between the two BPM's can be assumed to have been deformed by two dipole errors, which are separated by 90° in the betatron phase [4]. By using the two BPM

 

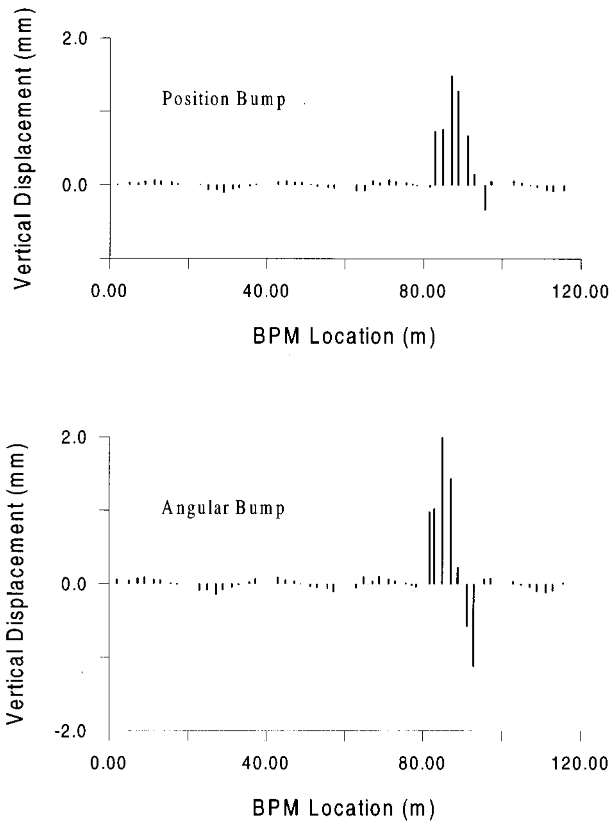


FIG. 1. The position bump and the angular bump.

readings and their betatron phases and Twiss parameters [4], as well as the closed-orbit distortion equation [5], the strength of the assumed dipole errors can be obtained. The orbit position at the beam line's source point can be identified by again applying the above results to the closed-orbit distortion equation by knowing the betatron phase and Twiss parameters of the source point. The orbit slope at the source point can be derived by the same method.

As Fig. 2 indicates, the BPM's resolution at experimental

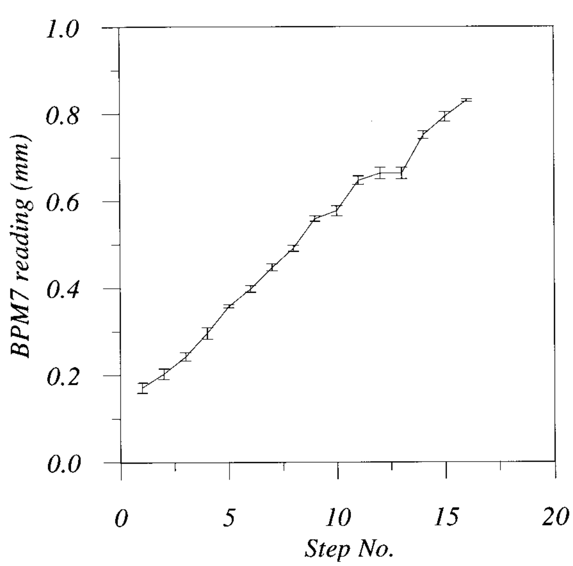


FIG. 2. The raw data of one of the BPM readings. The error bar is the standard deviation of ten measurements.

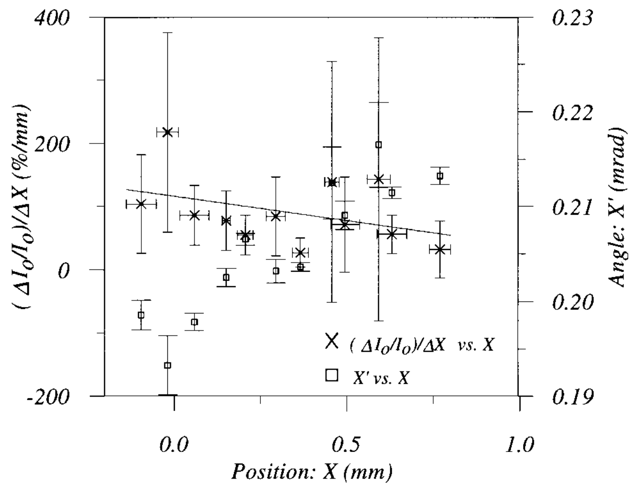


FIG. 3. Results of the position bump variation. The horizontal axis denotes the beam position at the source point at each step. The left vertical axis represents the relative photon flux fluctuation ($\Delta I_0/I_0$) per unit beam position displacement at the source point. The beam angle's value at each step was plotted on the right vertical axis, showing the $X$-$X'$ correlation.

time was about 10 $\mu$m. For the case involving the position bump in each step, about 20–40 $\mu$m of the beam position at the source point were varied. For the case involving the angular bump in each step, about 20–40 $\mu$rad of the beam angle at the source point were varied. We began with a reasonably good orbit, i.e., the rms of the vertical displacements less than 200 $\mu$m. The angle of the vertical focusing mirror (VFM) was then adjusted until a maximum photon flux was obtained [6]. This adjustment ensured that the focused photon beam's center passed through the center of the entrance slit. After each step of either the position bump or angular bump variations, the change in photon flux was recorded; the VFM was then readjusted until obtaining the maximum photon flux again. Then the next step of the variation was proceeded with. This procedure would ensure that the results obtained herein would not depend on special initial conditions (i.e., the initial beam orbit). Gaining the maximum photon flux by adjusting the VFM's angle is a routine fine tuning done by the beam line user after every injection.

Figure 3 presents the measurement results for which only the position bump was varied. The horizontal axis denotes the beam position at the source point. The left vertical axis represents the relative photon flux fluctuation ($\Delta I_0/I_0$) per unit beam position displacement at the source point. While varying the beam positions, the beam angle should remain unchanged. Due to the position bump's imperfection, the beam angle at the source point slightly changes. This figure also plots the beam angle's value at each step on the right vertical axis, i.e., the $X$-$X'$ correlation. The angular bump study results presented below clearly imply that the effects due to the beam angle changes in those sizes (with most of them less than 5 $\mu$rad between each step) can be neglected as compared to the effect caused by a 20–40 $\mu$m change per step. Therefore, from this figure, we can infer that 10 $\mu$m vertical beam position displacement causes a relative photon flux change of $0.9\% \pm 0.3\%$.

Figure 4 presents the measurement results for which only the angular bump was varied. Horizontal axis depicts the

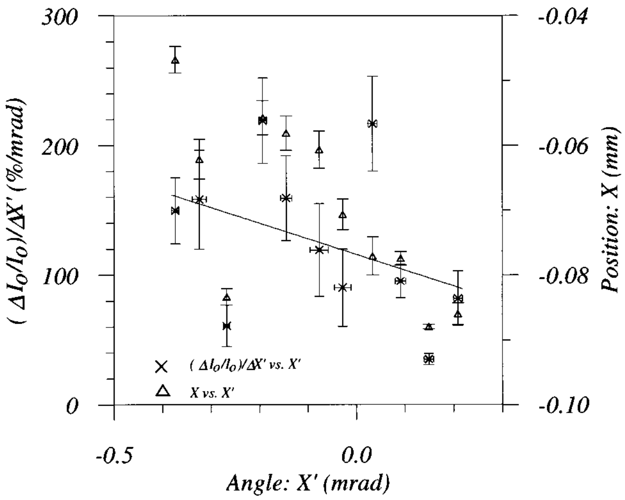


FIG. 4. Results of the angular bump variation. The horizontal axis denotes the beam angle's value at the source point at each step. The left vertical axis represents the relative photon flux fluctuation ($\Delta I_0/I_0$) per unit beam angular change at the source point. The beam position at each step was plotted on the right vertical axis, showing the $X'$-$X$ correlation.

beam angle at the source point. The left vertical axis represents the relative photon flux fluctuation ($\Delta I_0/I_0$) per unit beam angular change at the source point. While varying the beam angles, the beam position should also remain unchanged. Again, due to the angular bump's imperfection, the beam position at the source point slightly changes. This figure also plots the beam position's value at each step on the right vertical axis, i.e., the $X$-$X'$ correlation. The position bump study results also imply that the effects due to the beam position changes in those sizes (with most of them less than 10 $\mu$m between each step) is minor as compared to the effect caused by a 20–40 $\mu$rad change per step. Therefore, from this figure, we can infer that 10 $\mu$rad vertical beam angular change causes a relative photon flux change of $1.2\% \pm 0.4\%$.

During the experiments, the BPM value is the average of ten readings. We, therefore, have the error bar for each BPM value. Through the error propagation, we derive the error bars for the position and slope at the source point. They are the horizontal error bars denoted in Figs. 3 and 4. Herein, only one data set is denoted in each figure. The photon flux value is also the average of several readings, which also provide the error bar of the photon flux value. The error propagation, including the photon flux error, the position, and the slope errors, are all used herein to derive the vertical error bars in Figs. 3 and 4.

## III. NUMERICAL STUDIES

Figure 5 depicts the front part of the layout for the 6-m-HSGM beam line, i.e., the beam line object of our experiments. According to this beam line's optics system, we performed a ray tracing study for the case involving position bump change. The vertical electron beam size ($2\sigma$) at the source point of the beam line was around $75 \pm 15$ $\mu$m during the experiments mentioned in Sec. II. The reduction in photon flux can be calculated for a Gaussian photon beam passing through a slit with a 50 $\mu$m opening. The relation be-

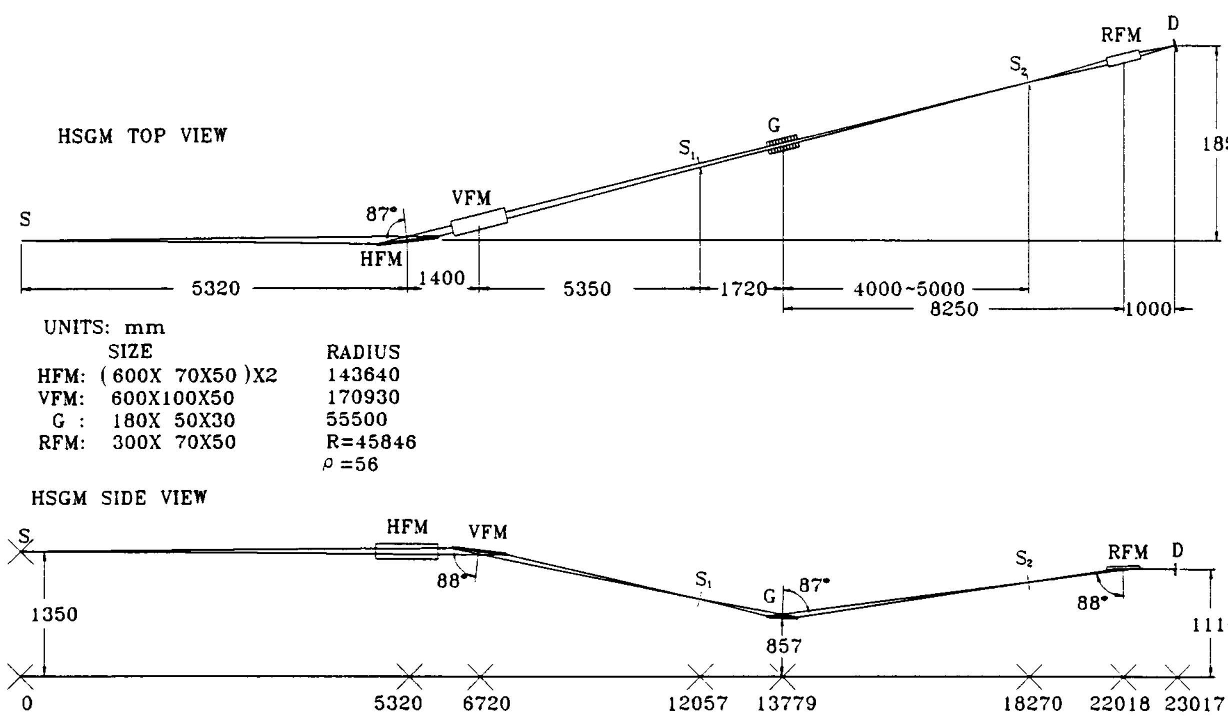


FIG. 5. The front part layout of the 6-m-HSGM beam line.

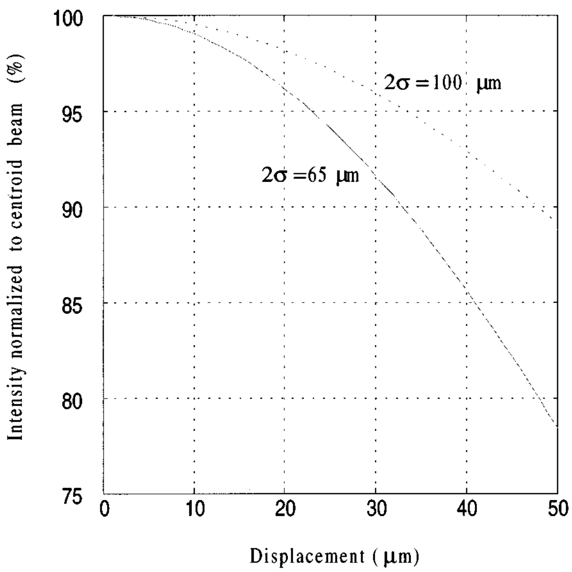


FIG. 6. The photon beam line ray-tracing results. The intensity reduces (normalized to the photon beam flux without orbit deviation) as the beam centroid deviates.

tween the electron beam size at the source point and the photon beam size at the slit is the lateral magnification of the optics system: starting from the source point through the VFM and ending at the slit. The ray-tracing results by the program SHADOW [7] show that the lateral magnification is 1.0.

Normalized to the photon beam flux without orbit deviation, Fig. 6 depicts that the intensity reduces as the beam centroid deviates. This figure presents the results for the two different vertical photon beam sizes, where $2\sigma$ equals 65 and 100 $\mu$m. For the latter case, a vertical beam position displacement of 20 $\mu$m would cause a relative photon flux loss of 2.0%. This finding corresponds to the experimental results. As discussed in Sec. II, for the left vertical axis in Fig. 3, the intensity reduction has been normalized to the displacement size for different initial conditions, which are different orbit positions representing the horizontal axis.

## IV. RESULTS AND DISCUSSION

Experimental and numerical results obtained herein indicate that a vertical beam position displacement of 10 $\mu$m could cause a relative photon flux change of $0.9\% \pm 0.3\%$, as measured at the entrance slit downstream. In addition, a vertical beam angular change of 10 $\mu$rad would cause a relative photon flux change of $1.2\% \pm 0.4\%$. The above two values depend on the electron beam size and the slit size, as well as the beam line optics.

During the experiment, the electron beam current was restricted around 20 mA. At this low current, the electron beam is more stable, and the relative photon flux fluctuation remained below 0.2%, while no orbit variation was implemented. The source point position changes made by the bump are around 20–40 $\mu$m per step; therefore, the size of the background fluctuation is always below 10% of our measurement.

During the experiments, when varying the position bump over a large range of the displacement, the photon flux $I_0$ could be brought back to the original value, e.g., the value before the orbit was changed, after readjusting the VFM's angle. However, when varying the angular bump, in most cases, the previous maximum value could not be obtained after readjusting the VFM's angle. This inability is owing to the fact that when the source angle was changed by introducing the angular bump, part of the photon beam fell outside the VFM. Therefore, the photon flux could not be brought back to the previous value by adjusting the VFM's angle. However, for the case involving a variation in source position by introducing the position bump, the photon flux was reduced, since part of the focused photon beam fell outside the entrance slit. Therefore the photon flux could be brought back to the previous value by adjusting the VFM's angle. This difference is owing to the fact that the photon beam is incident into the VFM with a very small grazing angle, and that the distance between the source point and the mirror is large. In a normal (design) situation, the incident photon beam nearly covers the entire VFM. The above discussion also explains why the data of angular variation (Fig. 4) has a greater uncertainty. From the above observation, if a decrease in photon flux occurs, the origin of beam position errors can be distinguished from the origin of beam angle errors by optimizing the VFM's angle.

As discussed above, to estimate the correlation between orbit slope and flux loss numerically, the energy dependence of the opening angle, i.e., the angular spectrum, of synchrotron radiation as well as the spectrum response function of the photon electric detector must be considered. Such a circumstances is more complicated than the case involving the orbit position's change.

## ACKNOWLEDGMENTS

I would like to thank S. J. Chen of SRRC for help in the BPM data acquisition program. Dr. G. H. Luo, Dr. K. L. Tsang, and S. C. Chung of SRRC are acknowledged for collecting the beam line data as well as providing Fig. 5. I would also like to thank P.-C. Tseng of SRRC for providing the SHADOW ray-tracing results. This study was supported by the National Science Council (Contract No. NSC85-2112-M-007-019) and SRRC of Taiwan.

[1] J.-P. Koutchouk, in *Frontiers of Particle Beams; Observation, Diagnosis and Correction*, edited by M. Month and S. Turner (Springer-Verlag, Berlin, 1989), pp. 54 and 55.
[2] S. C. Chung *et al.*, Rev. Sci. Instrum. **66**, 1655 (1995).
[3] C. T. Chen, and other beam line users in TLS (private communication); J. N. Galayd, Y. Chung, and R. O. Hettel, in *Synchrotron Radiation Source–A Primer*, edited by H. Winick (World Scientific, Singapore, 1994), pp. 344-345.

[4] E. D. Courant and H. S. Snyder, Ann. Phys. **3**, 1 (1958).
[5] M. Sands, Stanford Linear Accelerator Center Report No. 121, 1970, p. 52 (unpublished).
[6] The VFM tuning mechanism of the 6-m-HSGM beam line of the TLS, was constructed only for angular adjustment not for positional adjustment. Restated, the VFM can only be rotated, not shifted. That accounts for why, in this experiment, we only adjusted the VFM angle to obtain the maximum photon flux.
[7] B. Lai and F. Cerrina, Nucl. Instrum. Methods Phys. Res. Sect. A **246**, 337 (1986).