STUDIES OF POSITIONAL STABILITY OF THE ELECTRON BEAM IN THE NSLS STORAGE RING*

L. H. Yu, R. J. Nawrocky, and J. Galayda
National Synchrotron Light Source
Brookhaven National Laboratory, Upton, N.Y. 11973

BNL--36561

DE86 002505

Introduction

Positional stability of the electron beam is critically important to experimental beam line users. The beam position vibration increases the effective beam size and thus reduces the brightness. So the positional stability measurement provides important information for beam lines.

Data about amplitude and frequency of beam vibration and long term beam movement at different beam ports can be useful in locating the noise source for accelerator physicists.

For the noise which can not be eliminated, a beam position monitor can provide the signal for the feedback system to stabilize the beam position. These consideration become more evident as higher brightness and better energy resolution are sought. In this paper we report a preliminary result of the beam position stability measurement at the NSLS.

Beam Position Monitor

Beam position is monitored by using the synchrotron radiation emitted in the bending magnet as shown in fig.1. The synchrotron light is reflected to a side window of beam line U15. After a reflection from a second mirror and passage through a 69 cm focusing lens, the image of the e-beam cross section is formed on a position sensing detector. The position sensing detector we used is United Detector Technology Model PIN-SC/10D planar diffused construction PIN Diode. The output of the SC/10D is fed to a sum and difference amplifier model B301-AC. The difference signal of amplitude around a range of 40 mV is fed to an amplifier of gain 10 and sent to a divider as the numerator. The sum signal of order of 1-7 volt in our case is fed to the divider as the denominator. The output of the divider ($10 \times \text{numerator} / \text{denominator}$) is the analog signal of the beam position.

The first mirror was installed into the vacuum chamber during the early stage of the storage ring construction. It was not designed for beam position or beam profile measurements. It is a 45 degree horizontally tilted stainless steel mirror and the two horizontal reflection cuts off the horizontally polarized component of the radiation. The polarization of the light from the second mirror is found to depend on the angle with the median plane, and there is a dark band in the median plane.

This loss of the the main part of the radiation would degrade the resolution of a beam profile measurement. However, fortunately, it does not influence the beam position measurement as much. We tested the optics by bumping the beam with the trim coil U2VS7. The output signal vs. trim setpoint is quite linear. The output vs. image position is calibrated by moving the SC/10D detector with a micrometer, as shown in Fig. 2. The range is limited to 1.5 mm by divider saturation. This calibration gives 63 $\mu\text{m}/\text{v}$, together with the magnification 1.72 of the optics, give sensitivity of beam position measurement: 37 $\mu\text{m}/\text{v}$.

Fig. 1. Schematic diagram of U15 Beam Position Monitor. The Magnification is 1.72.

Fig. 2. Divider output vs. image position is calibrated by moving SC/10D with a micrometer. This calibration gives 63 $\mu\text{m}/\text{v}$. The system range is limited by divider saturation (12 v).

To improve the signal/noise ratio and thus improve the resolution of the system, we replaced the power supply of B301-AC by an external power supply with less ripple. This reduces the output ripple to about 10mV, corresponding to 0.4 μm beam movement.

*Research supported by the U.S. Department of Energy.

MASTER

REPRODUCED FROM
BEST AVAILABLE COPY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Fig. 3. 40 hours record of positional signal and beam current signal. During injection the signal is out of range. The zero point was checked. Because of the difference of pen position, there is a time shift between the positional signal trace and current signal trace.

For long term beam position measurement, we need a careful test of zero point drift of the whole system. At first we used a He-Ne laser beam radiated on SC/10D to measure the drift, but we found a 0.3V output drift within 4 hours, corresponding to 20 μm laser beam movement, to our disappointment. Later we began to doubt the possibility of such a large zero point drift due to electronics, so we replaced the laser beam by a slit irradiated by an incandescent light, and formed an image of the slit on the SC/10D by a lens, and found a large reduction of noise and zero point drift. The output noise and zero point drift is reduced to 0.02V, corresponding to 1 μm image movement. This indicates the possibility that equivalent laser beam movement due to laser noise as large as 20 μm , although the laser itself is rigidly fixed, an unexpected result.

We also tested the influence of the light intensity on the beam position output signal. Although the sum signal due to an incandescent light has a 10% ripple (much larger than the synchrotron radiation intensity fluctuation due to angular vibration and window aperture), the difference signal divided by the sum has a negligible ripple.

The mirror vertical vibration is measured to be smaller than 0.2 μm by an accelerometer fixed on the vacuum chamber near the side window of U15. The mirror vertical angular vibration is measured. The second mirror in Fig. 1 is rotated to almost face the detector. A He-Ne laser is used to irradiate a 50 μm slit, the light from the slit, after being reflected from the mirror, formed an image on the detector SC/10D. The vertical angular vibration is calculated from the image vibration detected by SC/10D. The angular vibration is found to be 5×10^{-6} radian in this way. Related to the beam position measurement, this should correspond to a beam movement of about 11 μm . Hence the resolution of our system is limited by mirror vibration to 11 μm at present. There is some uncertainty about this point. Because the possible equivalent laser beam movement, as we mentioned before, is about 20 μm , less than 50 μm (the slit width), it is still possible that the measured angular vibration of 5×10^{-6} radian is not real. When we replace the 50 μm slit by a 25 μm slit, or replace He-Ne laser by an incandescent light, the image intensity becomes so low that electronics noise begins to dominate. So this measurement only provides an upper limit to the error of our beam position measurement system. Further work is still to be done to determine the mirror angular vibration, using an improved optics system.

Beam Stability Measurement

With the system described above, we monitored the beam position. Fig. 3 gives the result of 40 hours recorded on a chart recorder. This result is rich in structure. The sum signal is proportional to the ring current so we can observe sudden life time changes in Fig. 3. They are accompanied by beam position changes. This may provide some hints to the origin of the life time changes. From 12pm 4/20 to 9am 4/21 there is beam motion of period about 25 min. There were also beam position jumps up and back by about 150 μm almost every 7 to 8 hours. Since the jump range is larger than beam size ($\sim 100 \mu\text{m}$), it reduces the equivalent brightness. It would be quite an improvement if the source of this motion can be removed.

Beam displacement due to a noise source at one location of the ring is given by

$$Y_{sn} = \frac{\delta_n \sqrt{\beta_n \beta_s}}{2 \sin \pi \nu} \cos(\pi \nu - |\phi_s - \phi_n|)$$

Here β_n , β_s are the betafunction at the noise and observation position respectively. ϕ_n , ϕ_s are the corresponding phases. δ_n is the angular kick strength of the noise source. ν is the betatron tune. From this formula we can see that the ratio:

$$\frac{Y_{s1}}{Y_{s2}} = \sqrt{\frac{\beta_{s1}}{\beta_{s2}}} \frac{\cos(\pi \nu - |\phi_{s1} - \phi_n|)}{\cos(\pi \nu - |\phi_{s2} - \phi_n|)}$$

provides some information about ϕ_n (given β_{s1} , β_{s2} , ϕ_{s1} , ϕ_{s2}). This gives the source location. If the noise source is not localized, this method can still provide useful information of the source distribution.

Similar beam position monitors will be installed for more systematic long term observation on several beam ports and correlation of their output will be used to locate the noise sources.

To study the noise source of vibration, we should study the correlation between beam vibration and other possible noise sources. One possible source may be the quadrupole mechanical vibration. Quadrupole vertical vibration generates fluctuating magnetic field which in turn gives an vertical angular kick to closed orbit. To find correlation between two vibrations, we measured the coherence function. If the Fourier transform of two

vibrations are respectively given by $X(f)$ and $Y(f)$, then the auto power spectrum is defined as $G_{xx}(f) = X(f)X^*(f)$, $G_{yy}(f) = Y(f)Y^*(f)$, the cross power spectrum is defined as $G_{xy}(f) = Y(f)X^*(f)$, and coherence function is defined as

$$\gamma^2 = \frac{|G_{xy}(f)|^2}{G_{xx}(f)G_{yy}(f)}$$

If two vibrations are uncorrelated, the average of $G_{xy}(f)$ is 0, and hence $\gamma^2 = 0$. If they are perfectly correlated, $\gamma^2 = 1$. So γ^2 represents correlation.

Figure 4 is the frequency spectrum of beam vibration. Fig. 5 is the frequency spectrum of a quadrupole magnet vibration. The coherence function is shown in Fig. 6. This indicates that not only the harmonics of 60 Hz, but also 12 Hz, 24 Hz, 30 Hz and 156 Hz are coherent between beam vibration and the magnets vibration. Other frequencies are uncorrelated.

The coherence between beam position and magnet vibration does not necessarily mean the beam position vibration is caused by the magnet vibration, they may both be caused by another common source. To study this, we induced impact on a quadrupole (U2Q2) with a large solenoid contractor and measured the resulting beam position vibration. The ratio between beam movement and magnet vibration amplitude at U2Q2 is calculated to be 2.6.

Fig. 4.

Fig. 7.

Fig. 5.

Fig. 8.

Fig. 6.

Fig. 9.

The result is shown in Figs. 7, 8, 9. Fig. 9 shows a correlation between U15 beam motion and U2Q2 vibration at 42, 75, 102, 128, 158 and 232 Hz. Compare Fig. 8 with Fig. 5, we can observe the difference of beam movement with and without impact on U2Q2, although the change is much smaller than the vibration amplitude without impact.

This data can be used to estimate the ratio between beam movement and magnet vibration amplitude, and hence give some information about whether beam vibration is caused by the magnet vibration. For example, at 102 Hz, vibration measurement at U2Q2 gives 10.5 mV output (Fig. 7), according to the calibration of our accelerometer: 6.9 v/g, the acceleration is about 1.5 cm/s². Divided by $\omega^2 = (2\pi \cdot 102 \text{ Hz})^2$, this gives about 0.04 μm as vibration amplitude. Fig. 8 gives position monitor output 17 mV, by calibration 37 $\mu\text{m}/\text{v}$, this gives 0.63 μm beam movement. The ratio of these two is 0.63 $\mu\text{m}/0.04 \mu\text{m} = 16$.

The ratio at 75 Hz is measured in the same way as 7.3, different from 102 Hz, and both are different from the calculated ratio. It is unknown why it is different. One possible explanation is that different frequencies are related to different vibration mode of the magnet. Since we measured the vibration on the top of the magnet, for same amplitude at the top, the amplitude and moving direction at the magnetic poles may be different from at the top, and different for different modes, so the beam responds differently.

If we take the ratio of beam vibration amplitude and ambient (without impact) magnet vibration amplitude at 60 Hz, using Fig. 9, 10 in the same way, we find the ratio to be 390, i.e. 20 times larger than 102 Hz. So, if we want to explain the beam vibration by quadrupole vibration, we have to make either one of the following assumptions. First, we may assume 20 or so magnets with similar kick strength act together in phase to produce the observed beam vibration at U15. This seems unlikely because magnets are distributed around the storage ring with more or less randomly distributed phase, they tend to cancel each other instead of being in phase. Secondly we may assume 60 Hz vibration is particularly strong at the poles of the magnets than at the tops. This also seems unlikely, because 60 Hz is not an eigen frequency of the magnet vibration (we did not observe 60 Hz vibration enhanced by the impact). Hence our analysis indicates that the 60 Hz vibration is not generated by quadrupoles.

However, the ratio for 12 Hz is 11, same order of magnitude as 102 and 75 Hz. Hence the 12 Hz vibration, a major component of the beam vibration, can be accounted for by quadrupole vibration.

Conclusion

The beam position monitor used at NSLS is described, with a resolution of 1 μm without considering mirror vibration. An upper limit of the resolution is 11 μm , given by a preliminary measurement of mirror angular vibration. Further improvement of this measurement can lower the upper limit.

Preliminary result of long term beam movement and vibration of beam position is reported. These measurements are correlated with ambient and controlled mechanical vibration of a quadrupole. The 60 Hz vibration seems unlikely to be caused by quadrupole mechanical vibration, but 12 Hz beam vibration can be accounted for by this vibration.

In time, correlation with ambient and controlled electrical variation will be measured. These measurements and more efforts on monitors at other beam ports to locate noise source are under way.

Reference

- [1] M. Bergher, 3857, Vol. NS-26, No. 3, IEEE Trans. Nucl. Sci. (1979)