The Diamond Beam Position Monitor and Test at TSLF

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1. Introduction

With the advance of the user experiments using synchrotron light source, the accurate control and the stable supply of photon beam have become indispensable. Therefore, the photon beam position monitor with high position sensitivity less than a few microns and stability under high heat load is required. The maximum total power and density of undulator radiation of the SPring-8 will reach about 11 kW and 470 kW/mrad^2, respectively. As a candidate to satisfy these requirements, we have been developing the beam position monitor using a diamond foil as a position sensitive device that operates in a photoconductive mode. The prototype monitor was tested on the TSLF (Tristan Super Light Facility) beamline at KEK. The design of the monitor and results from the beam tests are presented.

2. Diamond Monitor

A schematic view of the diamond monitor is shown in Fig.1. A synthetic polycrystalline diamond film is made through the chemical vapor deposition process (CVD) and is used as an active element [1]. There are electrodes on both sides of the diamond and external voltage is applied between these electrodes to produce an electric field in the diamond. When photon beam irradiates the diamond, free carriers (electrons and holes) are created by the interaction of photons with the diamonds. These carriers drift along the electric field and generate a current in the external circuit [2]. The electrodes of the monitor are segmented into four parts to obtain the information of the two-dimensional beam position. With the currents from each electrode, the beam centroid can be found in the following formulae :

$$X = A_X \times \frac{(I_{U\text{-}R} + I_{D\text{-}R}) - (I_{U\text{-}L} + I_{D\text{-}L})}{I_{U\text{-}R} + I_{D\text{-}R} + I_{U\text{-}L} + I_{D\text{-}L}} \tag{1}$$

$$Y = A_y \times \frac{(I_{U\text{-}R} + I_{U\text{-}L}) - (I_{D\text{-}R} + I_{D\text{-}L})}{I_{U\text{-}R} + I_{U\text{-}L} + I_{D\text{-}R} + I_{D\text{-}L}} \tag{2}$$

, where $I_{U\text{-}R}$, $I_{U\text{-}L}$, $I_{D\text{-}R}$, $I_{D\text{-}L}$ (U : upper, D : down, R : right, L : Left) are currents from each electrode and Ax, Ay are coefficients to be calibrated.

The superior thermophysical properties of diamond, such as high thermal conductivity, low thermal expansion, large mechanical stiffness and radiation hardness, make it possible to be used in a harsh environment on the front ends of beamlines, where other semiconductor detectors can not be used.

A photoconductive current of the monitor is proportional to radiation power absorbed in the diamond monitor. Therefore, the sensitivity to hard x rays radiated near the axis is emphasized in comparison with a photoelectron-emission type monitor that has the high sensitivity to UV and soft x rays. It can reduce background radiation of soft x rays from bending magnets.

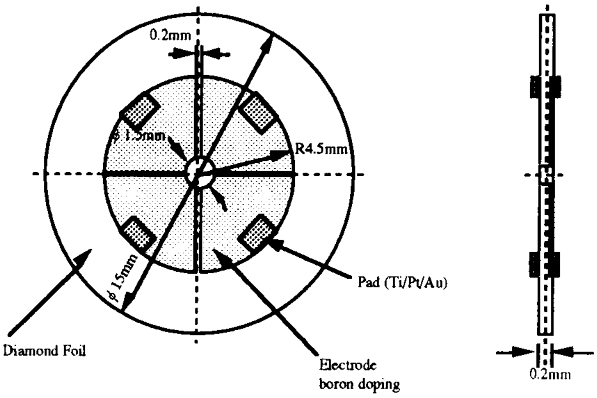

Fig.1 A schematic view of the diamond monitor

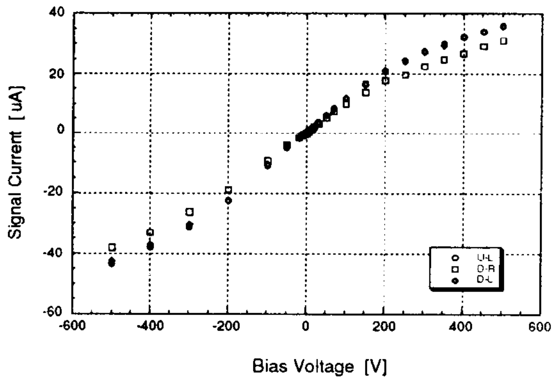

Fig.2 The signal currents from each electrode as a function of bias voltage (E_b : 8 GeV, I_b : 30 μA, K : 1.05)

3. Experimental Result

3-1 Experimental condition

The diamond monitor was tested at the TSLF beamline. TSLF is a high brilliant beamline constructed in the TRISTAN main ring remodeled in order to attain the very low emittance of a few nm rad [3]. The undulator is a planar type (λ_u:4.5cm, N_λ:120) [4]. The monitor was installed in the beamline at 20m distance from the undulator. The data was taken under the operation at beam energy of 8 GeV, beam current of 30 μA ~ 5mA and K value of ~ 1.1, which gave the fundamental photon energy of 8.4 keV.

3-2 Signal properties

The signal currents from each electrode of the monitor as a function of bias voltage applied to the diamond are shown in Fig.2, when photon beam passed through the center of the monitor. The signal current increased as bias voltage increased and an inverse current flowed when an applied voltage was inverted. Because the current direction can not change in case of a photoelectron emission, the monitor operated in a photoconductive mode. The signal current became saturated with the increase of bias voltage. It can be explained by the effect of the drift velocity saturation of free carriers in the diamond. Even in the case where no bias was applied to the monitor, some current was observed and it was 2~3 order smaller than that in the bias applied case. It shows the operation in a photoelectron mode.

3-3 Sensitivity to the beam motion

For a calibration of the monitor, the current signal was measured by moving the monitor across the beam in horizontal and vertical direction. The calibration curve for a vertical scan is shown in Fig.3. The ratio of normalized current difference shown in eq.(2) is proportional to the beam position near the axis. The linear working ranges, where the linearity error is within 10%, are ±1mm for both direction. The calibration coefficients(Ax, Ay) for horizontal and vertical direction are 1.37 and 1.26, respectively.

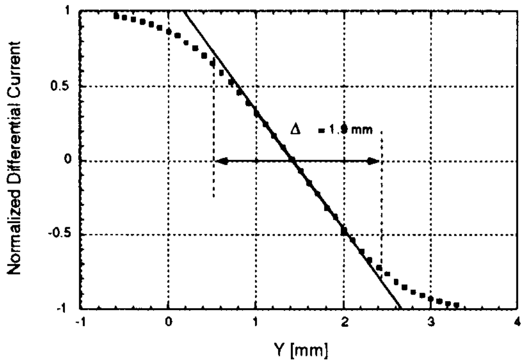

Fig.3 Calibration curve of the monitor with bias voltage of -25V (E_b : 8 GeV, I_b : 0.15mA, K : 1.07)

Figure 4 shows the results of the scan measurements performed with 10 μm step for vertical scan, when the monitor operated in a photoconductive mode with bias voltage of 10 V. The clear jumps of the position signal ensure that it has a position sensitivity of less than 3 μm.

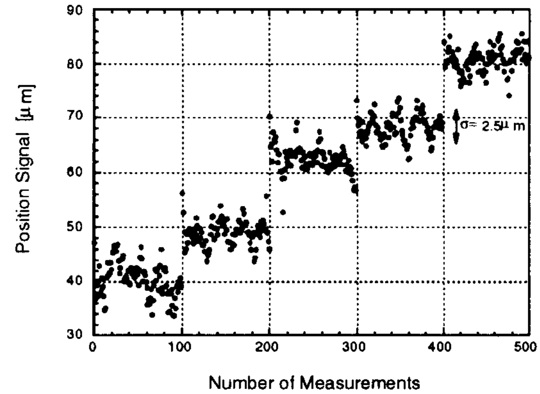

Fig.4 Scan measurement performed with 10 μm step (E_b : 8 GeV, I_b : 1.15mA, K : 1.1)

3-4 Stability test

Figure 5 shows the horizontal beam positions measured by the diamond monitor and the normalized signal currents of the wire monitor during a single stored beam period of 6 hours. The wire monitor located downstream of the diamond monitor had operated simultaneously as a reference [5]. The signal currents of both monitors decreased in proportion with the beam current that varied from 130 μA to 50 μA. Because the wire monitor was set at the position of half maximum of the signal currents and its signal current was normalized by the beam current, it corresponds to the beam position. Though the normalized signal current includes large error due to small beam current, the same tendencies of beam movements can be seen.

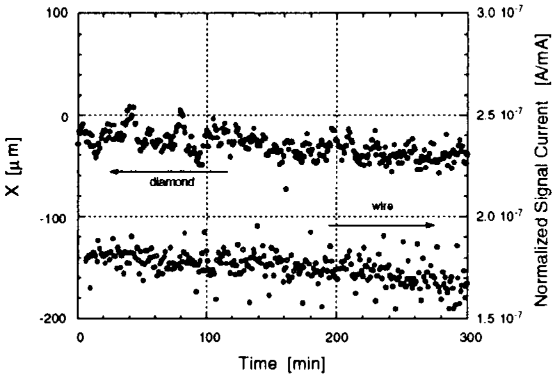

Fig.5 The horizontal beam position measured by the diamond monitor and normalized signal current of the wire monitor (E_b : 8 GeV, I_b : 130 ~ 50 μA, K : 1.1)

4. Conclusion

The beam test results shows that the diamond monitor can be operated in a photoconductive mode. It has a linear working range of ±1 mm and the position sensitivity of less than 3 μm. Though the beam was assumed to be stable in the position sensitivity test, the fluctuation of the beam during the measurement and time difference between each sequential reading of signals gave additional error. Therefore, the better position sensitivity is expected in practice. Still in the low beam current condition, the stability of the monitor was also confirmed by the continuous operation. The monitor can also operated in a photoelectron emission mode with no bias voltage, therefore, these operation modes can be switched by the on-off control of the bias voltage. The studies on the subject of the effect of background radiation, transmission of photon beam and radiation damage on the monitor are under way.

References

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