A Position Sensitive Detector for Monitoring Electron Beam Stability using Synchrotron Radiation

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Movements of the stored electron beam and their causes are one of the most keenly researched design and operating considerations of the latest generation of synchrotron radiation sources. The detector described is an inexpensive device using a commercially supplied semiconductor head but its resolution is superior to the photodiode arrays currently in use at Daresbury. It has good performance at low cost and is considerably less complex than a detector based on a charge coupled device. Design and development of the required signal processing is discussed together with the spatial and temporal performance. Some preliminary results from the Daresbury SRS beam are also included.

1. Introduction

It is a general requirement of all storage rings to be able to monitor and control the position of the electron beam [1]. In order to meet the monitoring requirements on the Daresbury Synchrotron Radiation Source (SRS) a number of optical diagnostics are already in use [2]. The latest addition to this optical facility is a position sensitive detector (PSD). Other laboratories are considering the use of similar devices [3,4]. This detector allows the centre of a focussed synchrotron light spot to be determined with an accuracy of the order of 10μm in the image plane. With the current optical layout this allows the electron beam tangent position to be determined with a resolution of around 20 μm, which vertically is 15% of the typical beam size (σ). The detector is based on a silicon head and printed circuit board supplied commercially by SiTek Laboratories [5]. This paper summarises the development, testing and calibration of the detector. During periods of stored beam for users of the SRS the device has been used to monitor the position of the electron beam.

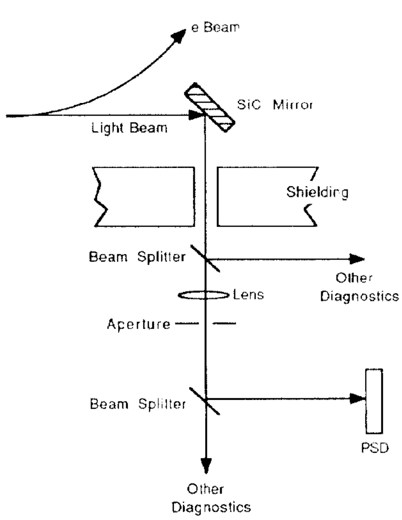

Figure 1. Schematic layout of the synchrotron light area.

2. Development

2.1 Optical Layout

Visible synchrotron radiation is reflected off a cooled silicon carbide mirror into the Synchrotron Light Area (SLA). Since the SLA is a multi-diagnostic facility only a fraction of the light is available for the PSD. A sketch of the present layout is given in figure 1. A simple lens arrangement is used to focus the light onto the detector. This gives a magnification of 0.56 which results in typical beam sizes (σ) at the PSD of 0.7mm and 70μm in the horizontal and vertical planes respectively.

2.2 Detector Design

The detector head consists of a slab of silicon (6.4 x 6.4 x 0.5 mm) mounted in a glass fronted package. The slab is doped front and back to produce a PIN junction diode. Two electrodes are mounted opposite each other on both the front and back of the head, one set for each axis (figure 2) leaving an active area of 4.0 x 4.0 mm. These electrodes apply the 15 V reverse bias and collect the generated photocurrents. The magnitude of the current collected at each electrode is linearly related to the distance from the charge carrier generation point to the electrode due to the resistive nature of the surfaces.

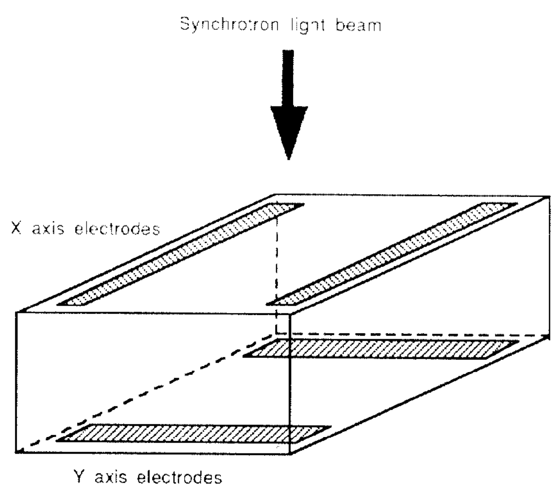

Figure 2. Sketch of the photodetector head.

2.3 Signal Processing

Figure 3 is a block diagram of the processing electronics used to convert the four photocurrents into two position dependent voltages. There are four stages involved in the signal processing. Firstly there is current to voltage conversion followed by dark current offset. Thirdly the four voltages, two for each axis, are fed into operational amplifiers which take the sum and difference of each pair. Finally a position dependent signal for each axis is obtained from the ratio of the difference and sum signals. This technique is intended to ensure that the outputs are intensity independent.

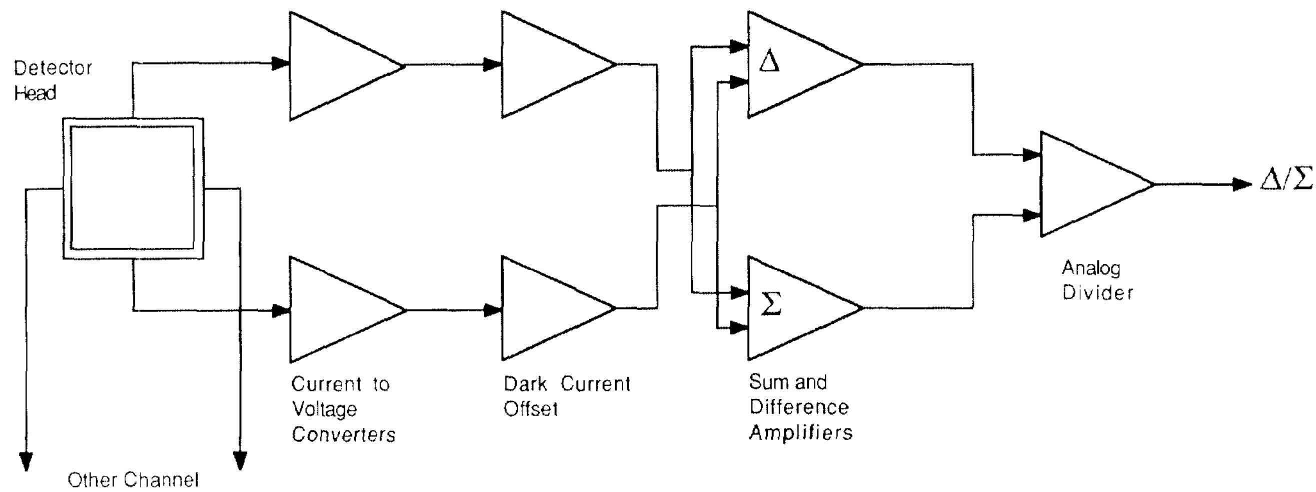

Figure 3. Schematic of the signal processing electronics.

3. Performance

3.1 Stability

By monitoring the output signals with and without the head attached it has been shown that the dominant source of electrical noise comes from the head. This noise is equivalent to ±1μm of movement at the PSD. A mercury lamp has been used to find the contribution of mechanical vibration to the overall noise of the device. This has been found to be equivalent to ±5μm of movement at the PSD. The long term drift of the device has also been monitored and found to be excellent, typically equivalent to less than 10μm over 24 hours. It is important that the dark current offset is regularly monitored as any long term changes in this setting will affect the accuracy of the PSD.

3.2 Frequency Response

The risetime of the detector head allows a maximum bandwidth in excess of 4 MHz. With the signal processing electronics this falls to a value of around 50 kHz. However, if required, the frequency response could be increased to that of the head itself by upgrading the electronics.

3.3 Calibration

The detector can only measure the position of a light spot accurately if it falls entirely on the active region. Since the synchrotron spot has a roughly Gaussian profile (i.e. long tails), as soon as the centre of the beam moves from the centre of the detector errors are incurred. The magnitude of this error increases quickly when the beam image passes a certain displacement threshold. This threshold depends heavily on the image width and hence the optical magnification of the system.

The device has been calibrated in situ by applying compensated bumps of known size to the electron beam. For the displacements applied linear plots have been obtained, suggesting that for movements of the electron beam of less than 3mm this off-centre effect is negligible.

4. Monitoring of the SRS

As an example of the capability of the PSD the vertical position of the electron beam in the SRS during a stored beam period has been measured. Figure 4 shows the drift observed over a 10 hour period. A drift of around 100μm is observed which is in good agreement with other diagnostic results [1].

Thermal stresses on the silicon carbide mirror will affect the position of the beam image. However, initial results indicate that the mirror reaches a thermal equilibrium in less than 2 hours of exposure to the beam.

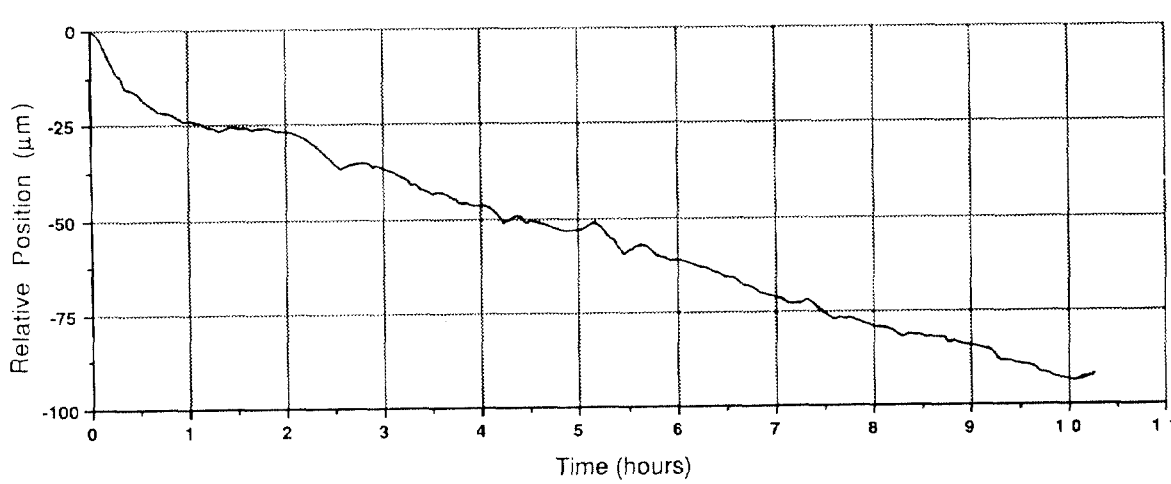

Figure 4. Example of vertical position drift of a stored 2GeV beam. The starting current is 190mA and the final current 125mA.

5. Conclusions

The PSD is an inexpensive device that has been used to measure drifts in the electron beam at the SRS. Despite the simple concept the PSD is capable of detecting changes in the position of the electron beam of less than 20μm. It is intended that the device will be used routinely to monitor the position of the stored beam at the SRS facility. As part of the ongoing position stability studies at the SRS the PSD is expected to play an important role.

Acknowledgements

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References

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