DESIGN AND COMMISSIONING OF A QUADRANT BPM FOR THE LNLS BEAMLINES

S. R. Marques#, F. H. Cardoso, W. C. Grizolli, L. Sanfelici, M. M. Xavier, LNLS, Campinas, Brazil

Abstract

We have recently designed and installed the first quadrant beam position monitor in the W01B-MX2 beamline. The whole monitor, including its electronics, was installed in-vacuum to reduce errors from current leakage and noise coupling from the outside of the vacuum chamber. Aspects of the mechanical and electronic design of this fluorescence-based beam position monitor, as well as the commissioning results are presented.

INTRODUCTION

The Brazilian Synchrotron Light Laboratory (LNLS) has thirteen beamlines currently in operation; nine of them are used in "hard" X-Ray experiments. The latest beamline to enter in operation, the W01B-MX2, uses the light produced by a multipolar 2 T hybrid wiggler. All other beamlines use the radiation of bending magnets. MX2 is used for protein crystallography experiments and produces photons from 5 to 15 keV. In recently designed/constructed beamlines at LNLS, an increasing number of photon beam diagnostics equipment are planned or installed. The last monitor along the MX2 beamline, installed just before the CCD detector, is a quadrant beam position monitor (QBPM) based on fluorescence detection. Design aspects, construction details and the first results will be discussed hereafter.

PRINCIPLE OF OPERATION

The LNLS QBPM is based on the model developed in the Argonne National Laboratory [1] that also originated some commercial products. The monochromatic X-ray beam crosses a thin metal foil and the back fluorescence is detected by photodiodes positioned in quadrant geometry. Hamamatsu S1227-1010BR photodiodes, with an active area of 100 mm^2 are used. As the solid angle of the fluorescence detected by every photodiode is dependent on the beam position, the well known difference over sum method is used to provide a continuous beam position measurement.

Figure 1 exemplifies the principle of operation of the monitor. The optimal distances "D" and "Z" were obtained using numerical simulations, but the implemented geometry is limited by the physical size of the photodiodes and by the available space in this design. A shorter distance "Z" would provide more sensitivity. The two kinds of foils that can be used in the monitor are made by 25 µm capton foils with 0.4 µm germanium or chromo deposition.

In order to estimate the current generated by the photodiodes, the thickness, X-ray absorption and fluorescence of the foils, as well as the geometry and sensitivity of the silicon photodiodes were considered. Currents in the range of hundreds of pA to few nA were estimated depending on the beam energy and intensity.

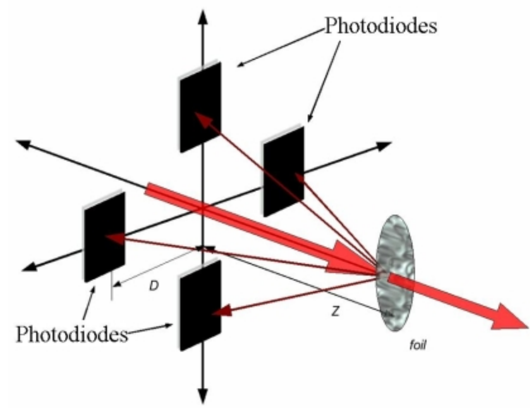

Figure 1: schematic drawing of the QBPM. The distances "D" and "Z" are 16 and 30 mm, respectively.

ELECTRONIC CIRCUITS

As the position information is encoded in the difference of the signals, the in-vacuum electronics avoid leakage problems, which are much worse than electrical random noise problems, since the latter can be minimized by proper filtering. Leakage effects can have time constants of several minutes, even hours. As matter of fact, while in the monitor designed for the APS beamlines [1], sub µA currents are available, preliminary tests showed that the available photon flux density of the MX2 beamline, about 10^{11} photons sec^{-1} mm^{-2} / 100 mA, generated sub nA currents in the photodiodes.

The electronic circuit was made as simple as possible using low power components whenever available, since efficient extraction of heat from the vacuum vessel is difficult. Figure 2 shows a simplified block diagram of the QBPM circuit; only one channel is shown.

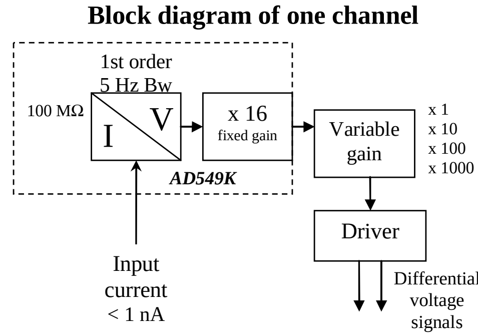

Figure 2: Block diagram of one QBPM channel.

#sergio@lnls.br

Electronic Design Considerations

The current to voltage conversion stage, also called transimpedance stage, uses an ultra low input bias current operational amplifier, and very good quality passive components to provide both low thermal drift and leakage. A “T network” circuit amplifies the transimpedance gain by 16. This approach increases the overall noise by a factor 4, but we chose this topology in order to avoid the potential problems caused by GΩ resistors in this design.

A programmable gain instrumentation amplifier in the signal chain, usually adjusted with gain 1, can be used if the photon flux is much smaller than usual. An audio differential voltage amplifier generates the signals that are transmitted to the 16-bit AD card through shielded twisted pair (STP) cables. In fact, the differential signals are converted back to single-ended very near the AD card, by a low-cost homemade electronics.

Several cautions should be taken for measuring small currents; even in the range of few nA, the theoretically simple current to voltage circuit based on just one operational amplifier and one resistor cannot work properly if low-quality cables, improper connectors or poor shielding is used [2]. The printed circuit board was developed with gaps and no solder masks are used in order to avoid leakage currents. Figures 3 and 4 show the printed circuit board (PCB) ready to be installed in vacuum.

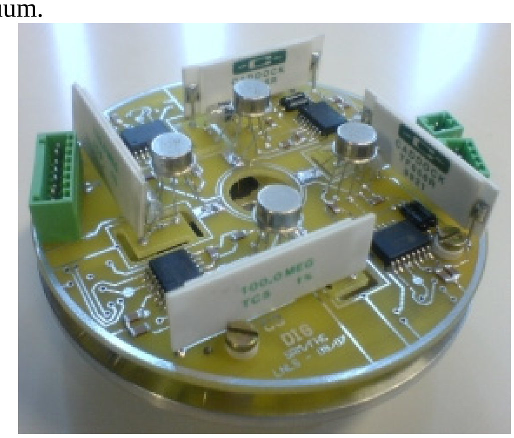

Figure 3: Top view of the LNLS QBPM PCB with all electronic components.

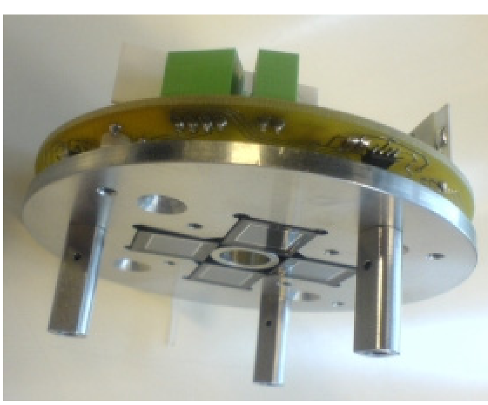

Figure 4: Bottom view of the LNLS QBPM in-vacuum electronics. The photodiodes and the circular aperture for the X-Ray beam are shown.

The four output drivers located on the bottom side of the board are not visible on the Figure 3 and are connected to the metal stand through small copper blocks, also not visible on Figure 4. This is necessary to lower the temperature of the drivers, which was near the maximum value recommended in the datasheets. In the Figure 4 one of the drivers is visible in the bottom side of the PCB, but in this picture the heat sink was not installed yet.

During the bench tests, vacuum levels bellow 10^{-4} mbar were reached without problems with the electronics powered on. This is enough for the final section of the MX2 beamline.

Shielding and Thermal Considerations

Besides the low-leakage layout, this design provides inherent electrical shielding, as the grounded vacuum chamber acts like the external braid of a triaxial cable. In the vessel, the electronics circuit is confined inside another metal enclosure connected to the zero volts potential. If necessary, the ground and zero volts potential can be connected together in one of the both ends of the STP cables, but bench tests indicated that using the monitor electronics isolated inside the vessel improves the mains noise rejection. We believe this improvement is due to a better isolation from ground noise generated by spurious currents commonly present in the ground line. The floating circuit works well in this case, mainly due to the outside shielding and to the differential output signals.

Besides good shielding, the design provides good thermal stability, since the experimental hall temperature cycles are not seen by the in-vacuum electronics. The power dissipated for the electronics is practically independent of the presence of beam. The measured warm-up time is about 30 minutes. As the electronics is not usually turned-off, this is not a problem.

Figure 5 shows the mechanical design of the monitor. The inner shielded compartment is supported in such a way that it can be precisely positioned relative to the beam.

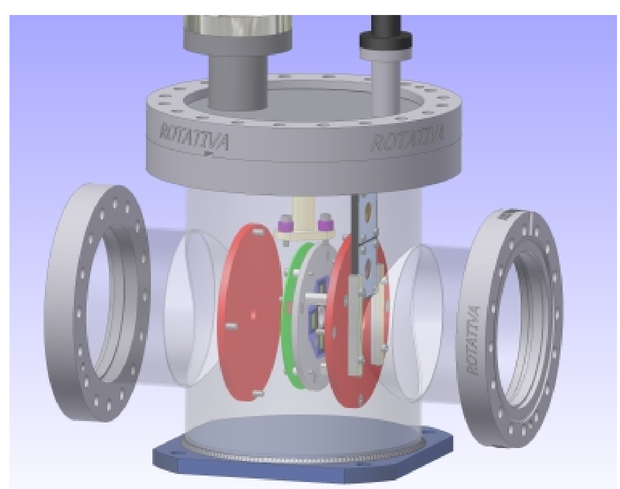

Figure 5: Mechanical design of the QBPM monitor. The reading electronics, including the photodiodes, is located in an aluminum enclosure electrically isolated from the steel vessel.

FIRST RESULTS

Figure 6 shows the sensitivity of the difference over sum signals of the monitor to horizontal movements. The vertical response is identical. In the calibration procedure shown in this figure, the inner enclosure was moved against the beam. Good linearity up to several millimeters was found. Part of the ripple in the calibration curve can be attributed to nonlinearities induced by the vertical positioning system.

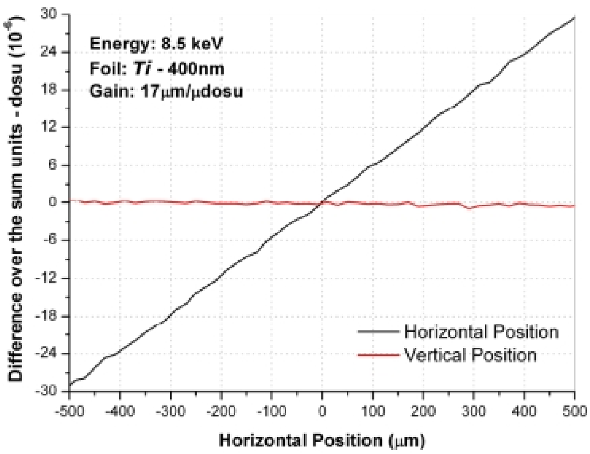

Figure 6: Calibration curve of the LNLS QBPM. The response is linear up to several millimeters.

Besides the calibration curve, during the commissioning of the QBPM, a set of tests was performed to verify the monitor performance. One of them was the use of angular movements of the second mirror (located after the monochromator) to produce vertical displacements of the X-ray beam. Figure 7 shows that the results are in perfect agreement with the expected data.

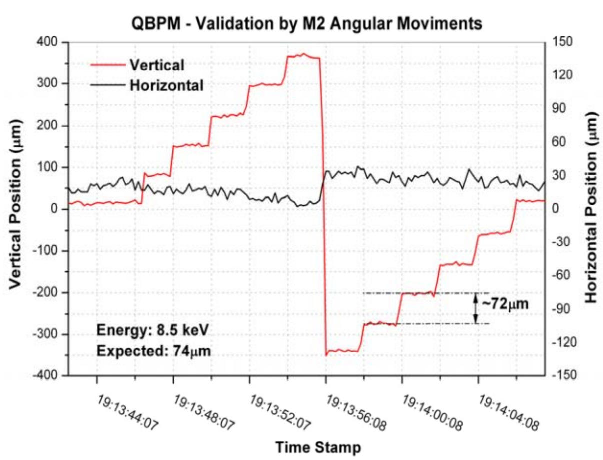

Figure 7: Vertical displacements provoked by angular movements of the second mirror located between the monochromator and the position monitor.

Another possibility of the QBPM is to extract the I_0 information from the photodiodes intensities. Currently the total error of the I_0 information obtained from the photodiodes is about 1%.

Figure 8 shows a typical 12-hour shift. A typical refill in the LNLS storage ring takes 15 to 20 minutes. Experiments during the beamline commissioning showed that the fast drifts during the first half hour of operation were mainly due to thermal stabilization of the optics. Experiments are being performed to determine the causes of the slow drift that occurs in the first 6 hours in several, but not all, shifts. In some cases, energy drifts with amplitudes from 1 eV to 3 eV are correlated with vertical beam movements observed in the QBPM readings. Currently, tests are being carried out to clarify these energy drifts.

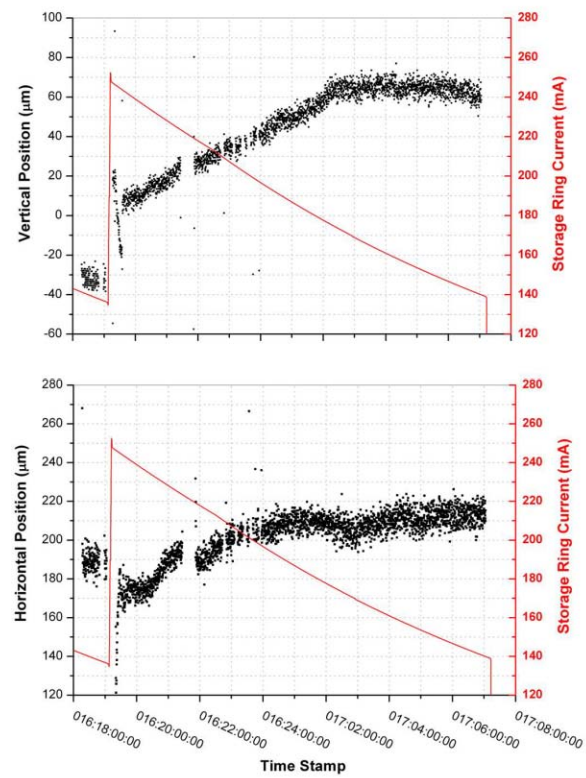

Figure 8: Vertical (upper) and horizontal (lower) positions of the X-Ray beam. The time stamp is in the "dd:hh:mm:ss" format.

CONCLUSION

The QBPM monitor has been used routinely since the end of 2007 in the MX2 beamline and it is an essential piece of diagnostic instrumentation. The in-vacuum electronics allowed the position information to be extracted from few pA current signals providing a resolution better than 5 μm.

REFERENCES

[1] R. Alkire, G. Rosenbaum, G. Evans, Design of a vacuum-compatible high precision monochromatic beam-position monitor for use with synchrotron radiation from 5 to 25 keV. J. Synchrotron Rad. 7, (2000), 61-68.