

# Hiresmon: A fast High Resolution Beam position Monitor for medium and hard x-rays

Ralf Hendrik Menk<sup>a</sup>, Dario Giuressi<sup>a</sup>, Fulvia Arfelli<sup>b</sup>, Luigi Rigon<sup>c</sup>

<sup>a</sup>*Sincrotrone Trieste S.c.p.A, S.S. 14 km 163.5, 34012 Basovizza (TS), Italy*

<sup>b</sup>*Dept. of Physics - University of Trieste and INFN Via Valerio, 2  
34127 Trieste, Italy*

<sup>c</sup>*The Abdus Salam International Centre for Theoretical Physics  
Strada Costiera 11 34014 Trieste, Italy*

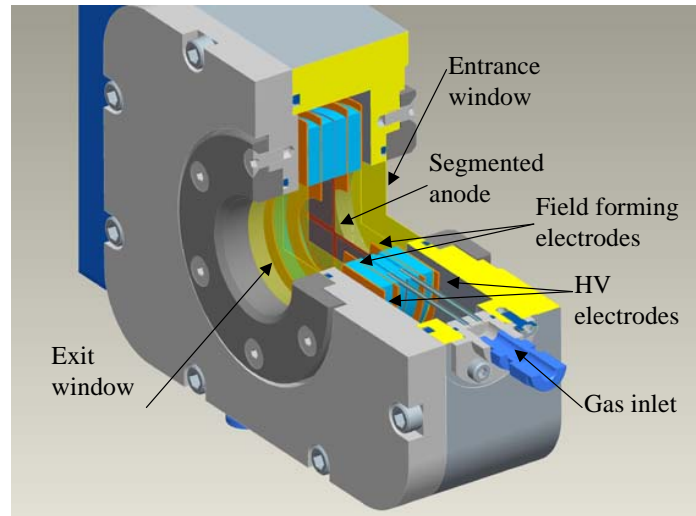
**Abstract.** The high-resolution x-ray beam position monitor (XBPM) is based on the principle of a segmented longitudinal ionization chamber with integrated readout and USB2 link. In contrast to traditional transversal ionization chambers here the incident x-rays are parallel to the collecting field which allows absolute intensity measurements with a precision better than 0.3 %. Simultaneously the beam position in vertical and horizontal direction can be measured with a frame rate of one kHz. The precision of position encoding depends only on the SNR of the synchrotron radiation and is in the order of micro meters at one kHz frame rate and  $10^8$  photon /sec at 9 KeV.

## 1. INTRODUCTION

The high resolution beam position monitor (XBPM) described in the following is specifically designed for high flux synchrotron radiation experiments such as x-ray diffraction (protein, SAXS, powder etc), EXAFS, fluorescence and x-ray imaging experiments, etc using low or medium high x-ray energies [from 5keV – 40 KeV]. Those classes of experiments require precise and simultaneous  $I_0$  calibrations in the order of some percent down to some ppm for quantitative measurements. The availability of high intensity micro beams enables time resolved experiments on samples with spatial extensions of some tenth of microns, however results may alter tremendously when fast intensity variation of the beam intensity and / or beam vibration in vertical and horizontal direction occurs. Thus a high-resolution beam position monitor is essential for these classes of experiments.

## 2. DETECTOR SETUP

The (XBPM) is based on the principle of a segmented longitudinal ionization chamber (fig. 1)[1]. In contrast to traditional transversal ionization chambers here incident x-rays are parallel to the collecting field and thus have to cross all 3 electrodes (two high voltage cathodes and the segmented read out anode) and the two windows. The advantage of this configuration is three fold. Firstly in contrast to the conventional setup here the readout current is independent from the beam position, secondly the active conversion volume is well known and thus absolute numbers of absorbed photons can be quoted and thirdly the volume can be kept small which reduces recombination tremendously. As a side effect of the latter the XBPM can be operated with low drift fields and subsequently with low voltage. As mentioned above the x-rays have to cross 3 electrodes and two windows. In order to keep absorption and scatter effects small all high voltage electrodes as well as the windows are made of metallized (two layers of 400 Å Al) Kapton foils (25µm). In case of low energy x-rays thinner foils can be used. As depicted in figure 1 the segmented read out anode, which is arranged in 4-quarter segments, is placed in the middle of the XBPM and hold on virtual ground through the attached amplifiers (DDC112). At a distance of 1 cm the anode is bracketed by two high voltage cathodes. In order to keep the collecting field



**FIGURE 1.** Sketch of the XBPM.

homogenous half the way between the anode and cathode field forming electrodes are placed that are hold on half potential through a voltage divider.

In order to avoid deformation of the high voltage electrodes due to Coulomb forces (and subsequently deformation of the collecting volume) also the windows are metallized and hold on ground potential. Both windows feature the same distance to the HV cathodes as the cathodes to the anode. The XBPM is accommodated in a sealed aluminum vessel and flushed with the conversion gas (preferably  $N_2$ ). In order to minimize external pick-up the analog part of the readout electronics is placed in the sealed housing as well. The analog readout is connected to the digital part through a sealed feed through. The entire electronics is build around the Burr Brown DDC 112, which is basically an analog integrator, combined with a 20-bit delta sigma converter. Each DDC 112 featured 2 channels and a single serial digital output. Two or more DDC 112 can be daisy chained keeping a single serial digital output. Utilizing thin coax cables the four quarter segments of the readout anode are connected to the four channels of two DDC112 and integrate for a predefined integration time the positive charges released by photo electrical absorption or a Compton Effect in the conversion gas. An on-board micro controller is used as a state machine generating all necessary initialization signals for the DDC 112 and the integration timing (from 0.5 ms to some s). Seven different gains can be set (ranging from 50 pC – 350 pC full scale range) in order to adjust the optimum working conditions to different experiments. Moreover the micro controller handles the communication to the outer world via RS 232 or USB 2. The input noise of the DDC 112 can be quoted with 10 ppm  $\sigma_{rms}$  at the highest gain for the typical input capacity of 200 pF of a quarter segments.

### 3. MODE OF OPERATION

As mentioned above the XBPM is an ionization chamber in the classical sense that measures ionization released in the conversion gas after a photoelectrical absorption or by a Compton Effect. As explained later, position encoding here is based on the localization of the barycenter of this ionization and is not based on the centroid of scattered radiation as used in other systems.

Since the XBPM is supposed to remain in the beam path it should be operated with light gases such as  $N_2$  in order to keep absorption for low energy x-rays low. The choice of  $N_2$  features another advantage since it is in ballistic equilibrium with knock-on electrons from the electrodes, which are subsequently released in the active volume and vice versa. Moreover it is a molecule, which can quench avalanche processes due to the emission of UV photons. In principle other gases and air can be used as well. The to a certain extent distributed incident X-rays release after a photoelectrical absorption and thermalization of the photoelectrons typically  $n_e = E_\gamma / W_{ion}$  electrons, where  $E_\gamma$  is the x-ray energy and  $W_{ion}$  is the mean energy to create a free electron / ion pair in the gas ( $\sim 30$  eV for  $N_2$ ). Position encoding in the XBPM is based on the determination of the center of gravity of this extended charge distribution. If  $I_1$  are the currents measured on the four quadrant segments then

$$\sum I_i = \sum \varepsilon \cdot \frac{E_\gamma}{W_{ion}} \cdot \phi_i \cdot c = \varepsilon \cdot \frac{E_\gamma}{W_{ion}} \cdot c \sum N_i \quad (1)$$

is the integrated intensity, where  $\varepsilon$  is the quantum efficiency ( $\sim$  absorption),  $c$  the conversion factor between charge an ADC bins,  $\phi=N/\tau$  the photon flux per integration time  $\tau$ . The beam position in x and y can be found by building the center of gravity:

$$x = \frac{(N_1 + N_4) - (N_2 + N_3)}{\sum N_i} \Delta x \quad \text{and} \quad y = \frac{(N_1 + N_2) - (N_4 + N_3)}{\sum N_i} \Delta y \quad (2)$$

where  $\Delta x$  and  $\Delta y$  are spatial extensions of the charge cloud in horizontal and vertical direction, respectively, which is a convolution of the beam size with the range of the photoelectrons and the transversal diffusion. It is obvious that (2) can only be applied if (1) is greater than zero. Under the assumption that the beam is in the middle and all segments are calibrated such that they measure the same photon numbers  $N$  the error in the position encoding can be calculated taking into consideration Poisson statistics and error propagation as [2]:

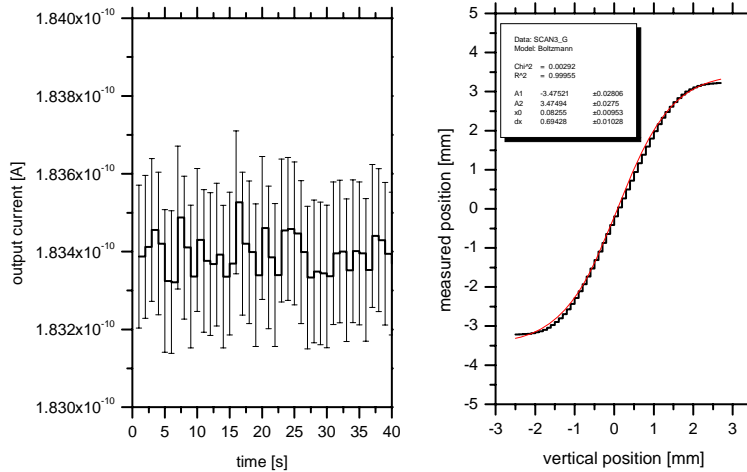
$$\sigma_x = \frac{\Delta x}{2} \cdot \sqrt{\frac{\varepsilon \cdot N + \sigma^2}{\varepsilon^2 \cdot N^2}} \quad \text{and} \quad \sigma_y = \frac{\Delta y}{2} \cdot \sqrt{\frac{\varepsilon \cdot N + \sigma^2}{\varepsilon^2 \cdot N^2}} \quad (3)$$

$$\Rightarrow \sigma \approx \frac{1}{SNR}$$

where  $\sigma$  is the electronics noise in terms of photons per integration time of the readout electronics attached to a single channel. From (3) it is obvious that the XBPM is working the better, the higher the signal-to-noise ratio SNR.

## 4 MEASUREMENTS OF SPATIAL RESOLUTION

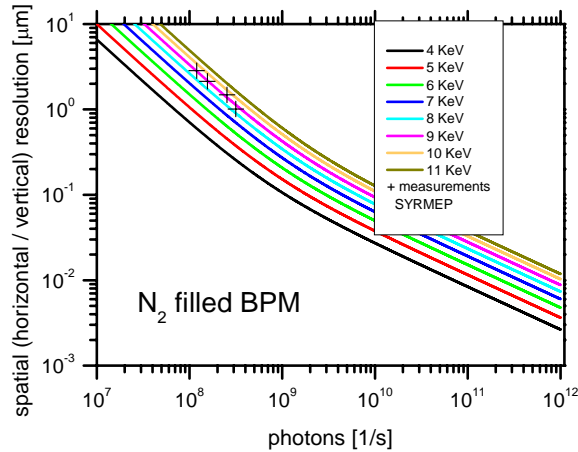
Measurements to determine the intensity precision and the inherent spatial resolution of the XBPM were carried out at the SYRMEP bending magnet beamline during a 2.4 GeV operation of Elettra.



**FIGURE 2.** Left: Intensity measurement versus time for 500 samples per point and right: 4mm scan around the center of the XBPM.

The XBPM was mounted on a NEWPORT x-y stage with a nominal resolution of 100 nm two meters downstream a tantalum slit system, defining an aperture of 0.5 mm \* 0.5 mm. The x-ray energy ranged from 9 to 35 KeV. The average flux density at 9 KeV can be quoted with  $1.4 \cdot 10^8$  photons /s for the aforementioned machine parameters. The integrated current on four sectors is depicted in figure 2 versus time at a constant horizontal position of the beam. Each point is the average of 500 sampling points. The error bar indicated is 0.1% which means a single sampling point precision of 2%. For the resolution measurement the XBPM was scanned in steps of 100  $\mu$ m downstream the fixed aperture. Zero indicates the middle of the sensitive volume of the XBPM. 500 samples (which

corresponds to 1 sec integration time) were taken at each position. The measured sigma in position resolution over 500 samples at that intensity was about 1  $\mu\text{m}$  for the single shot measurement. Since the sigma of the spatial extension of the charge cloud is in the order of 1 mm one would expect a linear position encoding of roughly 4 mm. This is confirmed by the measured position response versus the real position. As expected the curve has sigmoidal shape with a linear response of approximately from  $-2$  mm to 2 mm (figure 2). The theoretical resolution as function of the photon flux is shown in figure 3 with the energy as a free parameter.



**FIGURE 3.** Inherent resolution limit of the XBPM for 1 kHz sampling rate

The curves represent the inherent limits for single shot experiments with a repetition rate of 1 kHz. Results of measurements at the bending magnet beamline at 9 KeV are shown as well for photon fluxes between  $10^7$  and  $10^8$  photons / s. According to these curves the inherent limit at the saturation level of the electronics for 1 kHz sampling time should be in the order of some tenth to some hundreds of nano meter.

## CONCLUSION

It could be shown that a XBPM on the basis of a segmented longitudinal ionization chamber can provide simultaneous information of the beam intensity with a precision better than 0.3 % and encode the beam position in the sub micron range with 1 KHz sampling rate. The inherent spatial resolution is limited by the SNR of Poisson statistics in case of photon fluxes  $> 10^8$  photons / sec.

## ACKNOWLEDGMENTS

The authors are indebted to Claudio Fava for the mechanical design of the XBPM and are grateful to Giuseppe Cautero for fruitful discussions.

## REFERENCES

1. Myalitsin, V.K., Besch, H.-J., Schenk, H.W., Walenta, A.H. Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Volume A323, Issue 1-2, 1 December 1992, pp 97-103
2. Wagner, H., Orthen, A., Besch, H.J., Martoiu, S., Menk, R.H., Walenta, A.H., Werthenbach, U, Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment Volume 523, Issue 3, 11 May 2004, Pages 287-301