EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/81-106
2 September 1981

A MULTISTEP PARALLAX-FREE X-RAY IMAGING COUNTER

A. Breskin, G. Charpak and J.C. Santiard

CERN, Geneva, Switzerland

ABSTRACT

With a large preamplifying gap of 2 cm, combined with a localization multi-wire chamber, it is shown that measurement of the pulse height provides the depth of the atom which absorbs a monoenergetic low-energy X quantum to a great accuracy. The preliminary results show that for 8 keV X-rays, accuracies of a fraction of a millimetre are achieved. No error is introduced by the limited efficiency of the absorbing gap, thus permitting the use of low-cost argon mixture fillings. Large-surface parallax-free gaseous detectors of planar structure can be built for monoenergetic diverging sources.

(Submitted to Nuclear Instruments and Methods)

1. INTRODUCTION

The localization of X-ray quanta by gaseous detectors faces a basic difficulty. The thickness of the detectors required for reaching a large efficiency introduces localization errors for photons impinging on the entrance window at angles very inclined to the normal and being absorbed at various depths across the gap.

One way to overcome the difficulty is to have the photons absorbed in a wide-gap drift volume with a radial electric field centred at the source¹⁾. This field is normally provided by spherical electrodes, and several recent experimental results have confirmed the validity of this method²⁻⁵⁾. However, it applies only to situations where the photon source is at a fixed position, namely at the centre of the entrance window. The construction problems connected with spherical structures make it difficult to store imaging detectors with a great variety of entrance window radii.

The analysis of the properties of multistep avalanche chambers, where amplification occurs in successive amplifying structures⁶⁾, has shown that it is possible to build parallel-gap structures that are free of parallax errors⁷⁾. The principle is simple (fig. 1). If monoenergetic photons are absorbed, by photoelectric effect, in the gas of a parallel-plate amplifying structure, the pulse height is proportional to $e^{\alpha(L-z)}$, where L is the gap width, z is the distance between the entrance window and the photoelectron which is supposed to produce a punctual swarm of ionization electrons, and α is the Townsend coefficient. If this pulse height can be measured, the depth z is obtained with an accuracy that is a function of the pulse-height resolution, the gain, and the gap width. The parallax error due to ignorance of the depth at which an X-ray photon is absorbed in a large gap can then be corrected.

An easy way of measuring this pulse height and localizing the position of the avalanche is to transfer the electrons of the avalanche from the first stage to a second amplifying gap that consists of a multiwire chamber or another

parallel-plate structure. The recent work of our group at CERN⁶⁻⁸⁾ has shown that this can be done either way, with a rigorous proportionality between the transferred electrons and the initial avalanche size in the first amplifying gap. In this article we report some measurements demonstrating the validity of this concept. The amplifying gap was combined with a multiwire proportional chamber (MWPC). Accuracies as good as 0.5 mm FWHM have been obtained over absorption depths of 2 cm.

2. ACCURACY OF ABSORPTION DEPTH MEASUREMENT

If a photon of definite energy liberates N_0 ion pairs at a depth z in the gas of a parallel-plate amplifying structure, the total number of electrons collected by the anode is

$$N = N_0 e^{\alpha(L-z)} .$$

In most cases it is rather difficult, without amplification, to detect directly the pulse produced by the initial charge N_0 liberated by the photoelectrons. If one wishes to detect the photons absorbed near the anode, where the gain is close to unity, then a further amplification step is necessary.

It has been shown that a constant fraction of the total number of the electrons produced in the avalanche can be transferred to a following element, for example a drift space followed by a MWPC. This fraction f is very close to the ratio of the electric fields in the drift space and the amplifying gap. It can be conveniently set at values close to 20% or 30%. The electrons transferred to the second amplifying element give rise to a pulse whose resolution is a function of many parameters: initial amplification factor, transfer efficiency, final amplification, electronics noise, and linearity. It has been observed however, that the energy resolution (FWHM) for 6 keV photons can always be kept at values close to $\Delta E/E = 25\%$, which we will take as an average value for our discussion. The final pulse height is proportional to

$$E = N \cdot f \cdot m ,$$

where m is the gain in the end-step localizing MWPC. Since we may consider that f and m are constant and do not depend on the conversion depth z in the first element, then the resolution on z will be

$$\Delta z = \frac{\Delta E}{E} \frac{L}{\ln G_{\max}} = \frac{\Delta E}{E} \frac{1}{\alpha} ;$$

α is dependent on the maximum gain $G_{\max}$ attained across the full first amplifying gap. If we take for $\Delta E/E$ the upper value of 25% and a gap of 2 cm, then for a gain of 10^3 , which is easy to achieve in stable conditions, the value of α is 3.5 ion pairs/cm and $|dz| = 0.8$ mm (FWHM), which is very attractive indeed. Figure 2 shows the z resolution versus $G_{\max}$ in the first element.

3. EXPERIMENTAL RESULTS

We have verified this concept, for a chamber of 100×100 mm², with the following experimental set-up (fig. 1):

- an amplifying gap (L) 20 mm deep;
- a transfer gap 10 mm deep;
- a MWPC made of 20 μ m wires, 2.54 mm apart, with a 10 mm gap.

A beam of 8 keV photons collimated to 0.2 mm was sent through a side window, at various depths of the absorption gap. The gas flowing in the counter was a mixture of 98.4% argon and 1.6% propane.

The tests were done at three different gains:

$$e^{\alpha L} = 2.5 \times 10^2, \quad 4.2 \times 10^3, \quad 10^5 .$$

The gain of the MWPC was adjusted so as to reach the same total maximum gain for the whole counter, i.e. about 5×10^5 in all three cases. The pulse height was measured from the two cathodes of the MWPC gated by the signals of six anode wires. A charge-sensitive preamplifier, ORTEC 142, was used, followed by a linear amplifier. We were limited by the dynamic range of the preamplifier, so we could not cover the full gap of the first amplifying element. Figure 3 shows the variations of pulse height with absorption depth and the experimental energy resolution (FWHM)

observed at each measuring point. The energy resolutions for the corresponding gains of 2.5×10^2 , 4.2×10^3 , and 10^5 were 16%-40%, 16.5%-30%, and 17%-50%. In all three cases the mean value over most of the measured range was about 22%, and the large numbers at the end of each range were due to electronics noise.

Figure 4 shows a 2 mm separation between two collimated beams for the different gains, at different depths across the amplifying gap. The escape peak is visible, and its harmful effect will be discussed later. The position resolution Δz has been calculated from the measured $\Delta E/E$ data values and is plotted in Fig. 5.

For a gain of 4.2×10^3 , which is quite convenient, we see that we have a FWHM of 0.4 mm for most of the chamber depth, as expected.

It is clear that the limit in depth accuracy is such that it can match the lateral accuracy reached by the best read-out methods. We are considering the use of logarithmic amplifiers in order to solve the dynamic range problem.

4. SOME ADVANTAGES AND LIMITATIONS OF THE METHOD

The big advantage of the method is that flat structures can fully replace spherical structures, without the limitations attached to a fixed radius. The disadvantage is that it applies only to monochromatic radiations. Another advantage is that there is no need for a 100% absorption in the conversion gap. Those photons which are absorbed after the conversion gap give rise to smaller pulses and are easily eliminated by the electronics. In contrast, in a spherical drift chamber it is essential to have full absorption since the traversing photons are detected with full efficiency in the localization chamber.

This leads to the necessity of having xenon as a conversion gas in spherical drift chambers, whilst a cheap gas such as argon is convenient for the multistep chambers.

However, it should be emphasized that the escape peaks, which are frequently observed satellites of the main photoelectric peaks, may introduce a serious source of background since they make it impossible to correlate, in a non-equivocal way,

the pulse height and the depth. This may also lead to the adoption of xenon in some cases, but without the necessity of reaching full efficiency, thus permitting the use of thin gaps.

Figure 6 shows an energy spectrum of 5.9 keV photons in the argon-propane mixture and in 90.5% Ar + 8% Xe + 1.5% triethylamine (TEA). It can be seen that the escape peak has almost disappeared; the tails on both sides of the distribution are due to imperfect collimation.

We have tested the rate capability of such a structure, and observed (as shown in Fig. 7) that up to rates of $10^3 \text{ s}^{-1} \text{ mm}^{-1}$ along a wire of the MWPC, the energy response is not degraded for gains of 10^3 - 10^4 in the preamplifying gap and a total gain of 10^5 .

5. CONCLUSION

The use of proportional chambers for the imaging of soft X-ray radiation has many attractive features; however, it is limited in many applications by the parallax error introduced when detectors of relatively large thicknesses have to be used to keep the quantum efficiency at a sufficient level.

We have shown that by using a photon absorbing gap with moderate multiplication and transfer to a localizing multiwire chamber, it is possible to achieve accuracies better than 1 mm (FWHM) for a 2 cm deep gap.

The counters are very flexible, and using the same detector structure one can decide, according to the application, whether to use the full amplifying gap with low gains and moderate resolutions (0.7-1 mm FWHM), or a limited depth with higher gain but better resolution (0.3-0.4 mm FWHM) -- but also lower efficiency.

Measurements of the spatial accuracy in multistep chambers have shown that the centroid of avalanches can be localized to positions as accurate as 100 μm after two steps of amplification. Parallel-grid amplification has already been tested for surfaces of 0.5 m^2 .

Since the necessity to measure the pulse height over a large dynamic range introduces some limitations in the maximum rate capability of such detectors,

we may say that for moderate rates our approach should permit the construction of large-surface X-ray detectors with a high spatial accuracy and free of parallax error for X-ray beams emitted by sources within a large range of angles.

Acknowledgement

We are indebted to Dr. F. Sauli for stimulating remarks.

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Figure captions

- Fig. 1 : Principle of the parallax-free multistep counter.
- Fig. 2 : The z-coordinate resolution function versus the maximum gain of the first amplification element. The right-hand scale gives the resolution for the case $\Delta E/E = 20\%$ (FWHM) and amplification gap $L = 20$ mm.
- Fig. 3 : Pulse height recorded at the MWPC for various gains of the first amplification element, as functions of the photon conversion depth z . The error bars correspond to the energy resolution (FWHM). For all three gains, the mean energy resolution is of the order of 22% FWHM.
- Fig. 4 : Energy spectra corresponding to a 2 mm separation between two collimated beams (0.2 mm), at various conversion depths z (indicated on the figure):
a) $G_{\max} = 2.5 \times 10^2$; b) $G_{\max} = 4.2 \times 10^3$; c) $G_{\max} = 10^5$.
The energy resolution has deteriorated at the region of the anode owing to electronics noise.
- Fig. 5 : Experimental depth resolution. The FWHM is computed from the energy resolution values of fig. 3.
- Fig. 6 : Energy spectra of 8 keV photons.
a) 98.4% Ar + 1.6% propane; the escape peak is well pronounced.
b) 90.5% Ar + 8% Xe + 1.5% TEA; the escape peak has almost disappeared owing to absorption in Xe.
- Fig. 7 : Pulse-height variation versus the counting rate per millimetre of the MWPC wire. The photon beam was collimated to 0.2 mm. The photon beam penetrated the amplification element in parallel with the electrodes, near to the cathode; this corresponds to the worst case of the higher gain ($> 10^5$). The data then correspond to an *upper limit*.

Fig. 1

Fig. 2

Fig. 3

$z = 3 \text{ mm}, 1 \text{ mm}$

$z = 10 \text{ mm}, 8 \text{ mm}$

$z = 17 \text{ mm}, 15 \text{ mm}$

a) $G_{\max} = 2.5 \times 10^2$

$z = 3 \text{ mm}, 1 \text{ mm}$

$z = 10 \text{ mm}, 8 \text{ mm}$

$z = 17 \text{ mm}, 15 \text{ mm}$

b) $G_{\max} = 4.2 \times 10^3$

$z = 3 \text{ mm}, 1 \text{ mm}$

$z = 8 \text{ mm}, 6 \text{ mm}$

$z = 13 \text{ mm}, 11 \text{ mm}$

c) $G_{\max} = 10^5$

Fig. 4

Fig. 5

a)

b)

Fig. 6

Fig. 7