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A NEW TWO-DIMENSIONAL X-RAY DRIFT CHAMBER FOR DIFFRACTION STUDIES WITH PULSED SYNCHROTON RADIATION

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A two-dimensional position-sensitive detector (drift-chamber) for X-ray diffraction experiments with pulsed synchrotron radiation is described. For the measurements of drift direction (x), the small drift chamber uses a reference signal generated by the electron bunches circulating in the storage ring. A flat geometry delay-line, inductively connected to the anode, detects the position of avalanche electrons on the anode wire (y-direction). The main features are: spatial resolution in drift direction (x), 100 μm for 5 keV photons; spatial resolution in y direction, 400 μm; maximum counting-rate, 5×10^5 cps; quantum efficiency ar 5 keV, 52%. The system has been successfully tested at the ADONE storage ring at Frascati by measuring the small-angle diffraction spectrum of a dry tendon collagen.

1. Introduction

In the last few years, there has been a resurgence of interest in small-angle scattering and static and dynamic diffraction experiments, motivated by the appearance of new radiation sources, especially synchrotron radiation, and by the invention of both one and two-dimensional position-sensitive X-ray detectors.

In the field of new detectors, X-ray position-sensitive detectors have been developed with good spatial resolution, good detection efficiency (which is linear with the photon intensity), suitable for direct and unambiguous identification of the reflection peaks: among these, channel plates, television-based systems, special proportional detectors, etc., can be mentioned [1]. All the specifications of such new detectors cannot be met at the same time by other conventional detectors, such as photographic plates which, for instance, are not linear with the photon intensity and are not suitable for dynamic experiments.

The most popular position-sensitive detectors are based on the position measurement of the avalanche of secondary electrons on the anode of a proportional counter. The widely used one-dimensional chamber with a delay-line readout belongs to this class of detectors. A spatial resolution of about 0.40 mm and count-rate capability around 4×10^4 Hz/mm have been achieved [2]. This type of detector is used at the storage ring DORIS [3] and in Japan [4,5] for the study of muscles and biological systems. At present, mainly multiwire chambers, using several parallel anode wires each connected to a preamplifier, are currently used. For two-dimensional measurements a multiwire chamber of this class is used at Stanford for the study of proteins [6]. In a particular version of this chamber, X-rays are absorbed in a long drift region preceding the anode wires, in order to increase the detection efficiency and the acceptance angle. At Orsay, a semispherical drift region 10 cm long and with 480×280 pixels is in use; other relevant instrumental parameters are: an acceptance angle of 81°; detective quantum efficiency at 1.54 Å of 0.6; and count-rate of 370 kHz [7].

In the present paper we describe a two-dimensional X-ray detector which may be considered to be related to the above-mentioned class of detectors. It is a small drift chamber with continuous flow of gas, scaled down from the drift chambers developed for high-energy physics, very suitable for small-angle scattering or, when used on a goniometer, for diffraction experiments. The chamber is in operation at the ADONE storage ring at Frascati, and it has been tested for a year [8] in the energy range 4–12 keV on the X-ray beam line, which gives a beam of 10^8 photon/s with $\Delta\lambda/\lambda = 10^{-4}$.

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2. Experimental set-up

One-dimensional drift-chambers were invented by Charpak and co-workers in 1968–69 [9]. The idea was to determine the position of a charged particle by measuring the intersection point of its trajectory with the detection plane of a gas-filled detector. This measurement can be done by measuring both the time t_0, when the particle reaches the chamber (for instance by a fast detector placed behind the chamber), and the time t_1 of the arrival of the ionization electrons on the anode, guided by a suitable electric field. The time interval $(t_1 - t_0)$, gives the position of the particle. In other words: when a charged particle passes through the chamber, a fast counter starts a clock which can be stopped after a time interval

$$\Delta t = \int_x^{x_0} \mathrm{d}x / w(x),$$

where x is the drift coordinate orientated from the anode at x_0 and $w(x)$ is the drift velocity of the electrons. In principle, then, if one knows the drift velocity $w(x)$, the position of the particle may be determined. Actually, by choosing an appropriate gas mixture and value of the electric field, operation conditions are obtainable in which the drift velocity is constant over the whole detecting area [10,11]. As this drift velocity can be determined with high precision for any operating chamber, the measurement of the particle position is much more precise than that obtainable with any other position-sensitive detector. On the other hand, the drift chambers require the use of fast counters to obtain an accurate measurement of the arrival time of the particle onto the detector. The original scheme of operation of the drift chambers is then inadequate for X-ray detection, because an incident X-ray is completely absorbed by the gas in the chamber during the ionization process.

Nevertheless, in the case of synchrotron light emitted by the electrons circulating in short bunches in a storage ring, the reference time can be obtained directly from the bunches *. Our drift chamber uses this technique to obtain the reference time for the measurement of the time interval $(t_1 - t_0)$ in the drift direction; whereas the second coordinate of the incident X-ray is obtained by measuring the position of the avalanche electrons on the anode wire, a measurement which can be performed as described in the following section.

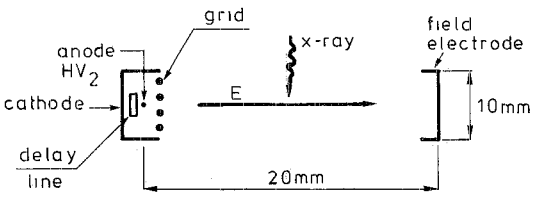

Fig. 1. Scheme of the drift chamber.

The basic scheme of the drift chamber is given in fig. 1 and a schematic view is shown in fig. 2. The chamber has a drift region along which the electrons, which are produced by the incident photons absorbed at the time t_0 in the position (x, y), can travel guided by the constant electric field E; an amplifier–discriminator for the detection of the signal received on the anode at the time t_1; a delay-line placed along the longitudinal direction y perpendicular to the drift direction x. The chamber is operated in the well-known gas mixture of argon–isobutane–methylal (67%, 30%, 3%) at 1 atm.

For ADONE in single-mode operation, the electron bunches have a duration time of 1.2 ns

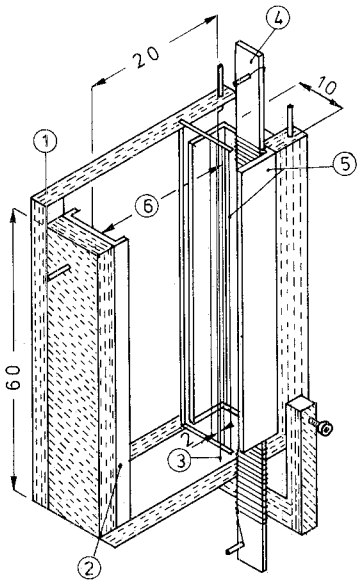

Fig. 2. The two-dimensional drift chamber. (1) Fiber-glass frame; (2) field plate at 3.8 keV; (3) anode wire, $\Phi = 20\mu$m, at 1.70 keV; (4) delay-line: 12 ns/cm; (5) cathode and grid wire; (6) drift region. Mylar windows are not shown.

* In the case of continuous sources, it is also possible to extract this information by exploiting other physical mechanisms [12].

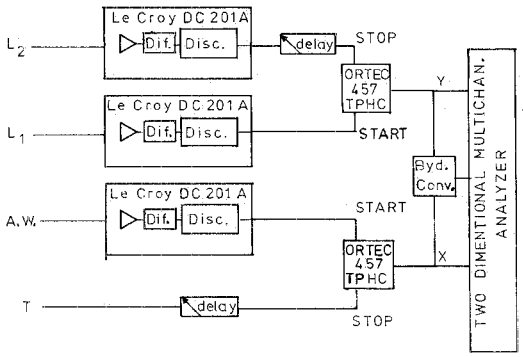

Fig. 3. Scheme of the read-out system. T, trigger from bunch; A.W., anode wire; L_1, L_2, delay-line ends.

and a periodicity of 351 ns. As the drift velocity in our chamber is 50 μm/ns, the maximum drift length useful experimentally is 17.5 mm. This is the case because the position on the detector area of photons originated from a bunch can only correctly be determined by using the reference time obtained from the same bunch. The maximum drift time along the whole length of the chamber must then be less than the bunch periodicity.

The read-out scheme is shown in fig. 3 and uses, for the drift coordinate, an amplifier–discriminator with a very low threshold of 200–300 μV (Le Croy DC-201 A) a TAC (ORTEC BTPHC, model 457) which measures the time interval $(t_1 - t_0)$, and a multichannel-analyzer (LABEN 1024) which accumulates and records the voltage outputs from the TAC. The spectra recorded by the multichannel-analyzer give the spatial patterns of the events along the drift direction. The electronic system, with the exclusion of the multichannel-analyzer, has a time precision of 0.5 ns, better than the time duration of a single bunch, 1.2 ns. Therefore it is the bunch duration which limits the precision of the measurements of the time interval $(t_1 - t_0)$, and thus the precision of the measured position of the incident X-ray, which is found to be 60 μm. The latter figure is better than the intrinsic spatial precision of the detector, which is determined by the range of the photoelectrons in the gas. For instance, at 5.0 keV, the photoelectron range is 100 μm [13].

The noise level measured on the multichannel analyzer is flat and very low, around 10^{-2} counts/s. This is the case because a signal on the anode (START) can originate a voltage output from the TAC only when it is related to the trigger signal from a bunch (STOP). This mode of operation gives a drastic suppression of noise signals and a flat distribution of their counts along the chamber length.

The longitudinal coordinate (y) of the incident photon is obtained by measuring the time difference at the two ends of the delay-line of the signal induced on the line by the anode signal. The delay-line is placed behind, and close to, the anode. This time difference is obviously determined by the position y on the anode of the avalanche discharge produced by the incoming electrons. The final spatial resolution in the longitudinal coordinate is limited by the range of the avalanche discharge, which in our case is typically 400 μm [11].

The electronics of the detection line of the coordinate y consists of two amplifier–discriminators which detect the signal at the two ends of the delay-line, and by the TAC. The detected events are accumulated and recorded on the same multichannel-analyzer, operated in the two-dimensional mode, which records the events related to the drift coordinate (x).

3. Chamber performances

The final efficiency of the detector is determined by the conversion efficiency of the X-rays in the gas, and by the collection efficiency of the anode. The former is given by the X-ray absorption efficiency in the argon–isobutane–methylal mixture at 1 atm. For instance, at 5.0 keV the absorption coefficient is 52%/cm; and this number gives the conversion coefficient of our chamber, whose thickness is 10.0 mm, at this energy. The collecting efficiency of the anode is shown in fig. 4, and turns out to be ~ 1 under our operating conditions. In addition, the response of the chamber along its whole length is linear, as shown in fig. 5.

The measured count-rate capability is 5×10^5 cps. Here it may be worthwhile to comment that, in the case when the detector area is impinged on by an X-ray beam whose intensity is lower than the space-charge limit of the ions produced in the avalanche amplification at the anode, the count rate capability of a drift chamber is better than that of a multiwire chamber. This is because in a

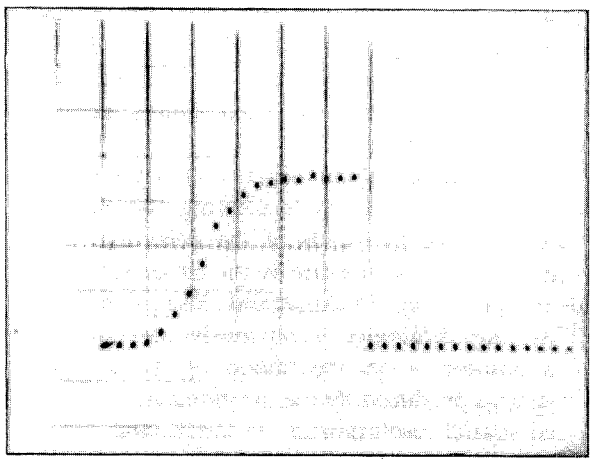

Fig. 4. Detector efficiency versus anodic voltage by steps of 20 V in the range $HV_2 = 1440–1840$ V. The drift field is constant.

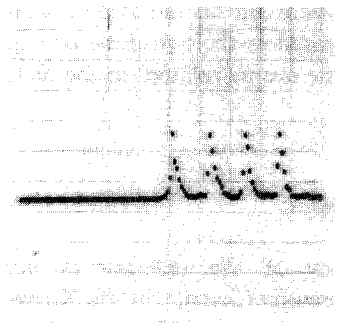

Fig. 5. Linearity test of detector response along the drift direction (x) by 4 mm steps.

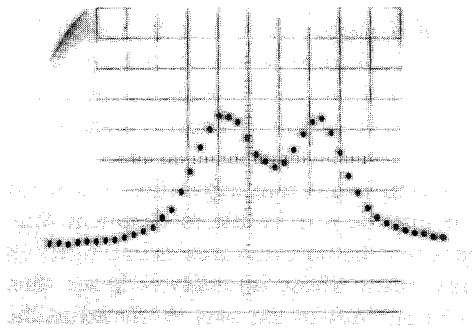

Fig. 6. An example of spatial resolution along the drift direction (x). Two beams separated by 400 μm are well resolved. Beam dimension: 100 μm; accuracy = 100 μm.

multiwire chamber any signal induces effects on the neighbouring wires. These induction signals limit the frequency of the detection electronics by not permitting a good differentiation of the signal [10].

As mentioned above, in the drift direction (x), the spatial resolution, limited by the range of photoelectrons, at 5.0 keV is 100 μm. This value is actually the measured resolution, as shown in fig. 6. Such spatial resolution can be compared with that of a multiwire chamber which is of the order of the semi-distance between two nearby wires, typically 1.0 mm. Moreover, it may be useful to report the following experimental observations. In the first version of our drift chamber, similar to the Charpak chambers [10], the electric field was produced by two parallel planes of wires, with the anode placed almost at the end of these planes. The distance between the wires was 2.0 mm. The spectrum of a beam of X-rays emitted by a non-collimated source and detected by the chamber, appeared as having a modulated structure with a periodicity of 2.0 mm (fig. 7a). Obviously, this effect of efficiency modulation along the detector length is not acceptable for most diffraction experiments, where small structures of the spectrum are to be observed. For this reason, we have replaced the two planes of wires with a [-shaped electrode (fig. 1) obtaining the total suppression of the modulation effect (fig. 7b).

The spatial resolution in the longitudinal direction (y) is determined by two effects: the range of the avalanche discharge on the anode, which is typically 400 μm in our case, and the time resolution of the delay-line. We have chosen a delay-line with flat geometry to obtain a high coupling coefficient with the anode [14,15], (fig. 8). The experimental values are 12 ns/cm for the delay-line, and 80% for the coupling coefficient. The measured spatial resolution is 0.5 mm, which is comparable with the ultimate intrinsic resolution of 0.4 mm due to the range of the avalanche discharge.

Fig. 9 shows the two-dimensional pattern of the beam of the X-ray line at ADONE collimated by a hole of diameter 1.0 mm. The photograph is taken on the multichannel-analyzer operating in the two-dimensional mode.

The drift chamber has also been tested by measuring the small-angle diffraction spectrum of a dry tendon collagen. In order to have a well-collimated parallel beam of X-rays incident on the

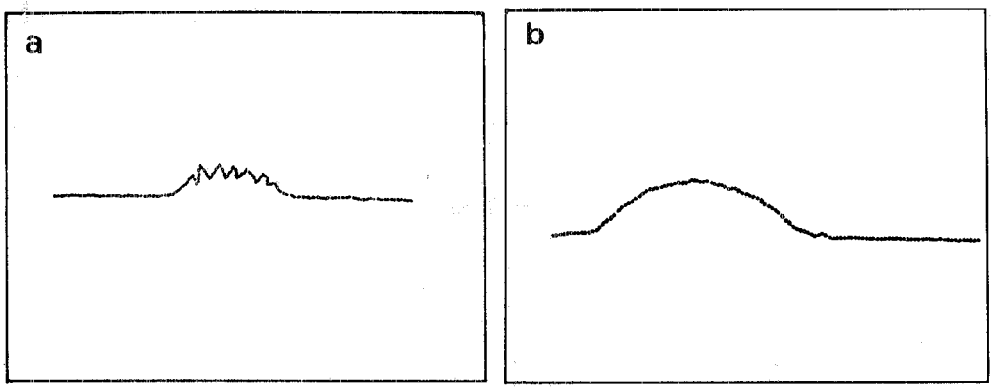

Fig. 7. Modulation effect in the first version of the chamber with a non-collimated beam; periodicity, 2 mm. Modulation effect is suppressed by using the present version of the chamber with a [-shaped electrode.

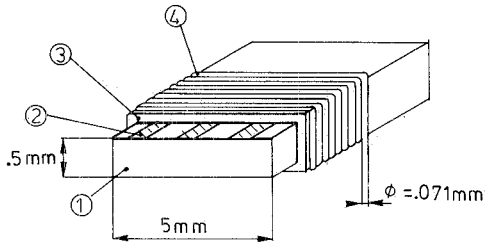

Fig. 8. Schematic cross-section of delay-line. (1) Fiber-glass frame; (2) earthed copper strips; (3) thermoplastic film; (4) coil. Electrical characteristics. (1) length 8 cm; (2) characteristic impedance Z_0, 2.2 kΩ; delay, 12 ns/cm, delay/rise-time, 13.

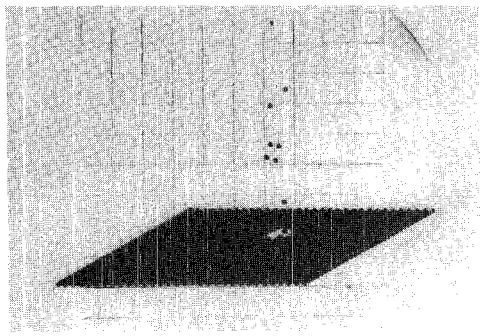

Fig. 9. Two-dimensional spectrum of a collimated beam (diameter = 1 mm).

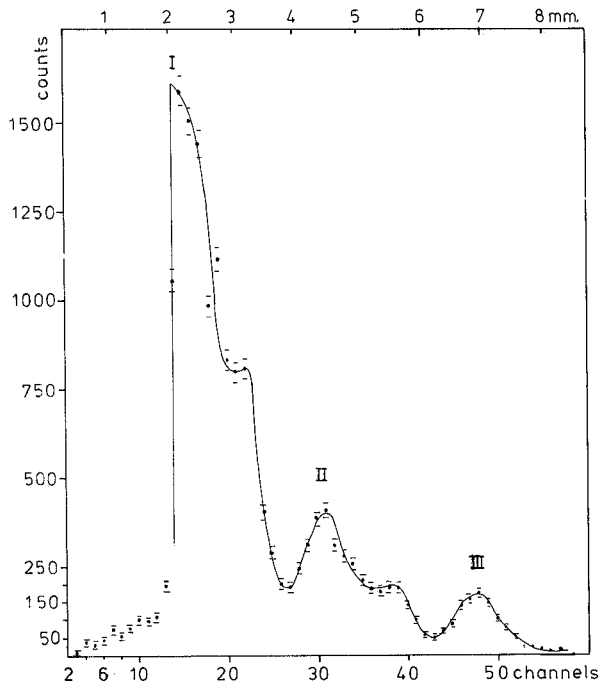

Fig. 10. Small-angle diffraction pattern from dry tendon collagen. Diameter of the collimator pin-holes: 0.5–0.7 mm; λ = 3.44 Å; recording time, 180 min; 1 channel = 0.144 mm; collagen spacing obtained from these data, 640 Å.

collagen, a two-dimensional collimator was used between the monochromator and the sample. The collimator, designed for negligible parasitic scattering from the windows, is formed by two pin-holes of diameter 0.5 and 0.7 mm respectively, at a distance of 500 mm. The pin-holes were perforated in thin lead foils, 0.5 mm thick. The primary beam is suppressed by a lead trap on the mylar window of the detector. The specimen–detector distance is 910 mm. Fig. 10 shows the spectrum obtained in the drift direction (x) of the chamber. The results obtained in the longitudinal direction (y) (not reported here) have fewer details because the spatial resolution in this direction is lower. The background in the spectrum of fig. 10 is low. The collagen spacing, measured from the

position of the peaks, is 640 Å, as expected. Peaks following those measured in fig. 10 could be detected by moving the detector by means of a goniometer. A three-dimensional goniometer which allows for measurements of scatterer spacing in the range 4–1000 Å, will be used in the near future for diffraction experiments on biological samples and liquid crystals.

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