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MEASUREMENTS OF PROPORTIONAL MODE CHARACTERISTICS OF PLASTIC DRIFT TUBES

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The results of investigation of proportional mode in plastic drift tubes (PDT) are shown in this paper. The use of the proportional mode allows a high voltage of sensitive wires to be lowered and the lifetime of detectors to be increased sufficiently. PDT are a detector using an analog method of registration of coordinate information; the track coordinates in PDT are calculated by the centre of gravity of charge distributions registered by a system of external electrodes (pads). The problem of choice of an optimal pad size for the given registration precision was one of the tasks of the investigation.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

Измерение характеристик работы пластиковых дрейфовых трубок в пропорциональном режиме газового усиления

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В данной работе приводятся результаты исследования режима пропорционального газового усиления в пластиковых дрейфовых трубках (ПДТ). Применение пропорционального режима позволяет снизить высокое напряжение, подаваемое на анодные проволоки, и существенно повысить время жизни детектора. ПДТ являются детектором с аналоговым считыванием информации, координаты треков частиц в которых вычисляются по центру тяжести распределенного заряда, регистрируемого системой внешних электродов. Проблема выбора оптимального размера педа при заданной точности регистрации была одной из задач проведенных исследований.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

1. Introduction

Plastic drift tubes (PDT) are widely used in experimental set-ups at the present time what can be explained by a simple detector design. It allows one to render the manufacture process of detectors automatically and to construct a large number of such gas detectors. Besides, the presented design of detectors allows a gas volume and a high voltage circuit to be separated from a sensitive system of electrodes that register particle track coordinates. All these points simplify the detector design and raise its reliability.

A limit streamer mode is used in the operation of these detectors. This mode allows one to obtain large signal amplitudes from sensitive wires and, respectively, to induce the threshold of electronics. However, the use of the limit streamer mode imposes more rigid requirements for the design of a detector, limits particle high rates and reduces detector reliability for long-duration operation. In particular, wire burning-out [1] and the violation of high ohmic resistive cathodes are observed.

The results of investigation of a proportional mode in PDT are shown in this paper. These investigations have been made during the design and manufacture of PDT for veto chambers of the Cherenkov spectrometer in the WA-98 experiment at CERN. The use of the proportional mode allows a high voltage of sensitive wires to be lowered and the life-time of detectors to be increased sufficiently.

PDT are a detector using an analog method of registration of coordinate information; the track coordinates in PDT are calculated by the centre of gravity of charge distributions registered by a system of external electrodes (pads). It allows two event coordinates to be registered.

Certainly, this solution requires a larger number of electronic channels, and so the problem of choice of an optimum pad size for the given registration precision was one of the tasks of the investigations. The precision for the coordinate parallel to the anode wire direction should be 1 mm and it is enough to separate the wire along the second coordinate.

The precision of coordinate registration for detectors with analog readout can be estimated by the formula [2]:

$$\sigma = \left(\frac{\Delta Q}{Q} \right) \cdot W, \tag{1}$$

where $\Delta Q = \alpha \cdot \sigma_n$, σ_n is the error of charge measurement for an individual electronic channel (noise of electronic channels); α is the coefficient determined by the method of coordinate calculation; W is the distance between the centre of readout electrodes.

The coordinate of events is calculated by the centre of gravity method by the formula:

$$X_i = \frac{\sum n_i \cdot Q_i}{\sum Q_i}.$$

In this case, α is approximately equal to $\sqrt{n}$ and n is the number of channels used to calculate the track coordinate.

Formula (1) is true if distance between the centres of readout electrodes W equals in the order of the r.m.s. of the registered charge distribution ($\sigma_{\text{c.d.}}$) and σ can be written in a more general form:

$$\sigma = \left(\frac{\Delta Q}{Q} \right) \sigma_{\text{c.d.}} \,. \tag{2}$$

As seen from formula (2), the precision of track coordinate registration is determined by the ratio of the charge measurement error to the total charge registered by the coordinate electrode system. At the present time it is not a problem to realize a noise amplifier level of $\approx 10^{-15}$ C. So, requirements for signal amplitude can be reduced, and the range of proportional gas gain can be effectively used without decreasing track registration precision.

The known method was used to measure the coordinate precision when the coordinate normal to the wire direction was calculated. In this instance any wire becomes a point source of induced radiation along this coordinate, and this feature allows one to check the precision of coordinate calculation and the potentialities of the centre of gravity method.

2. PDT Design and Measurment Scheme

The design of a plastic drift tube is shown in Fig.1 Each tube consists of 8 individual gas counters with a cross section of 9×9 mm^2. Cu-Be wires 80 microns in diameter placed in the centre of each counter are used as an anode counter (1, see Fig.1). The stability of anode wires is guaranteed by special support elements, which are mounted at a distance of 0.5 m between them. The surfaces of profile 3 and cover 4 coated with conductive paint are used as PDT cathodes. The profile and cover are placed in a hermetic case that has gas-filling outlets, an anode wire high voltage connector and a connector for returning the resistive cathode to ground.

The length of the PDTs used in the investigation was equal to 0.5 m. The value of cover surface resistance was 150—300 kOhm per square, the resistivity of the profile 10—30 kOhm per square. The system of coordinate elements (strips of pads, see Fig.2) was placed on the cover side.

Charge sensitive amplifiers were used to register signals from sensitive electrodes. The sensitive electrodes and the amplifier inputs were connected by twisted pairs. The signals from the amplifier outputs were registered by ACD (LeCroy Model 2249A). An ADC strobe pulse was generated by a trigger system consisting of a scintillator counter and necessary fast electronics.

An $Ar + CO_2$ gas mixture was used for filling the PDTs, and the percentage of Ar varied from 10% to 90% during the investigation. The drift time was within the limits of (80—150) nsec for different gas mixture. The strobe pulse duration was chosen to be equal to (200—400) nsec.

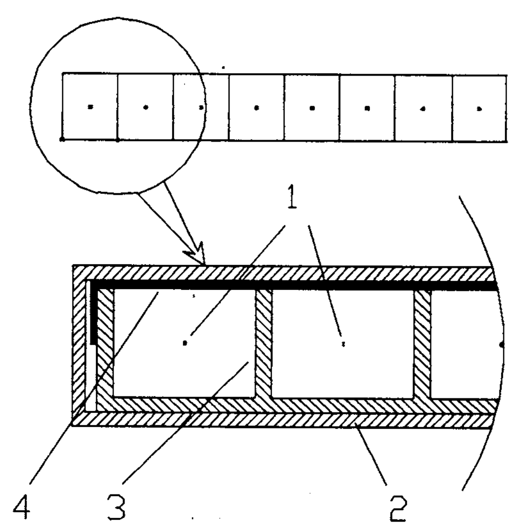

Fig.1. Design of a plastic drift tube: 1 — anode wires (CuBe, ⌀80μ m); 2 — hermetic case; 3 — profile with a surface resistivity of $10 \div 30$ $k\Omega/\square$; 4 — cover with a surface resistivity of $150 \div 300$ $k\Omega/\square$

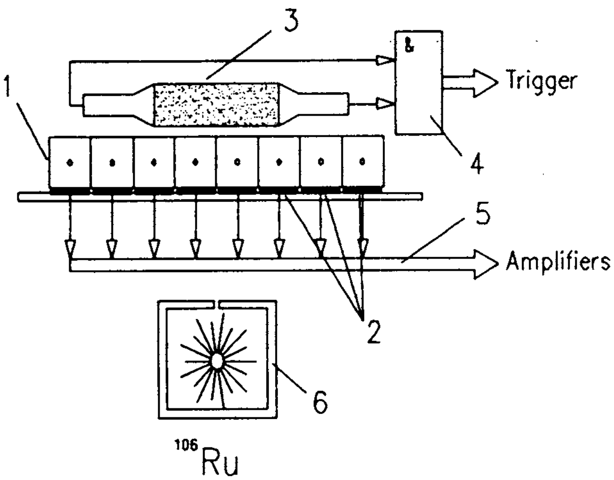

Fig.2. Layout of the set-up: 1 — PDT; 2 — coordinate system (strips of pads); 3 — scintillation counter; 4 — two-fold coincidence circuit; 5 — twisted pairs; 6 — radioactive source with a collimator

3. Results of Measurments

In addition to the determination of possible sizes of pads, a maximum length of twisted pairs between the amplifiers and the pads has been investigated. A parasitic input capacitance increases with increasing the length of a twisted pair. As a result, the conversion gain of the charge sensitive amplifiers and the signal-to-noise ratio decrease. The results of track registration precision dependence in the PDTs on twisted pair length are presented in Fig.3. As seen from the Figure, the registration precision is equal to 0.3—0.4 mm for a twisted pair length of 2 m what completely meets the requirements for the veto chamber accuracy. The measurements were performed using the strip system. The length of strip was 95 mm; and the distance between the centre of strips, 15 mm. The measured capacitance of a strip was 60 pF; and the twisted pair capacitance, 35 pF per meter.

The type of gas mixture chosen for filling PDT is an important parameter and determines the efficiency plateau width verus anode wire high voltage, PDT is a detector using the centre of gravity method for the calculation of track particle coordinates, and respectively, track coordinates can be calculated by the analysis of analog information from the detector. So, we should provide a necessary input signal dynamic range of the amplifier-ADC system. Thus, gas mixture should be chosen taking this condition into account.

Figure 4 shows the results of efficiency plateu width measurements for an $Ar + CO_2$ gas mixture for a different ratio of gas components. The end of the plateau was estimated by a (3—5)% level of limit steamer mode pulses. The registration efficiency on the plateau equal

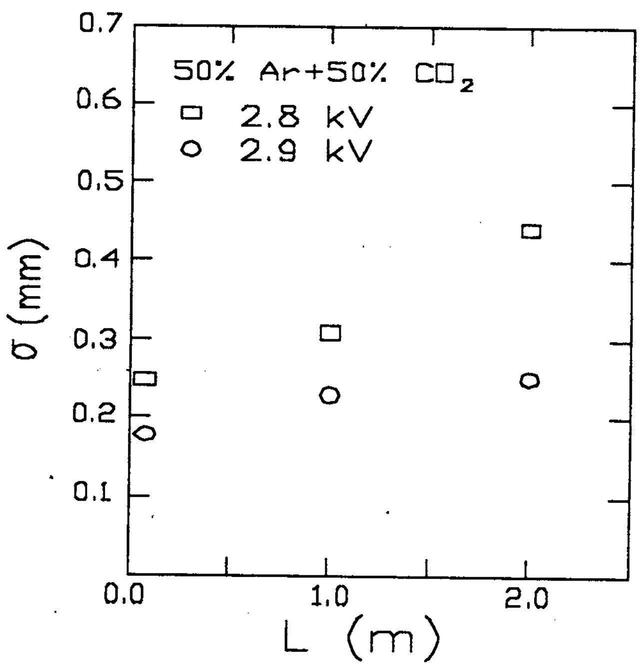

Fig.3. Dependence of PDT registration precision on the length of twisted pairs between the strips and amplifier inputs

to (0.92—0.95) was determined by the tube geometric and trigger system efficiencies. The plateau width was 300—350 V for an Ar + CO_2 (50:50) gas mixture what was enough for reliable operation of the PDTs in the set-up.

The total charge distribution is presented in Fig.5. It was measured by strips 90 mm in length at a 10 mm pitch for an Ar + 50%CO_2 gas mixture and an anode wire high voltage of 3 kV. The level of limit streamer mode pulses was ~ 5%, and the width of their charge distribution was limited by the overflow of the ADC channels. The proportional mode signals were separated quite well, and their average charge was $Q_{tot} = (0.7 \div 0,8)$ pC.

Strips were oriented along the direction of anode wires, and so the registration precision of the drift tube could be measured. Figure 6 shows the coordinate registration precision versus the measured charge. The investigation was performed for the charge distribution of Fig.5. As seen from the Figure, the precision is equal to $60 \div 70$ microns for charge amplitude 1 pC (1250 arbitrary units which corrspond to ADC channel units). The level of noise in the electronic channels estimated as r.m.s. of the channel pedestals was $10 \div 12$ of the AC channels. The estimation of a possible registration precision by formula (2) gives $50 \div 60$ microns. This result agrees well with the measurement results.

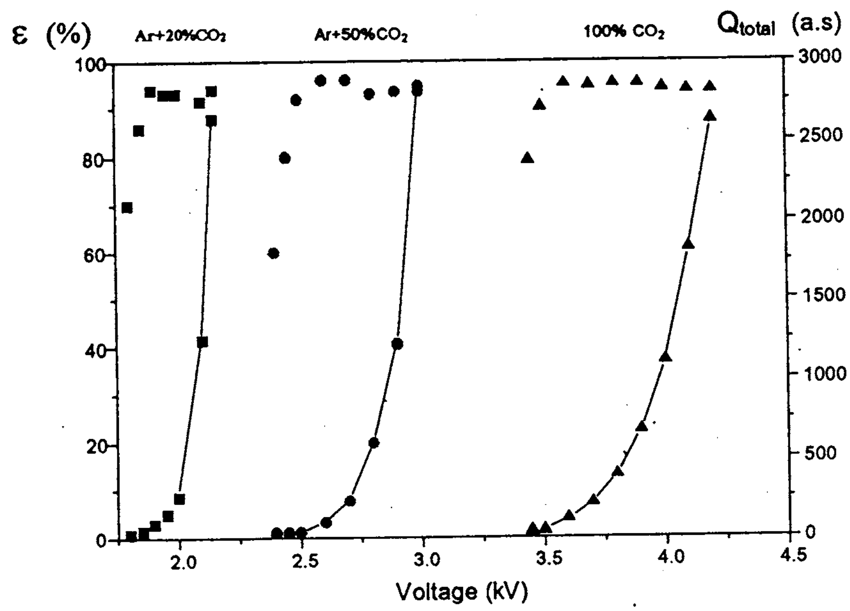

Fig.4. Dependence of particle registration efficiency (left scale) and average charge collected by strips (right scale) on anode wire voltage for gas mixture $Ar + 20\%CO_2$, $Ar + 50\%CO_2$ and CO_2 pure

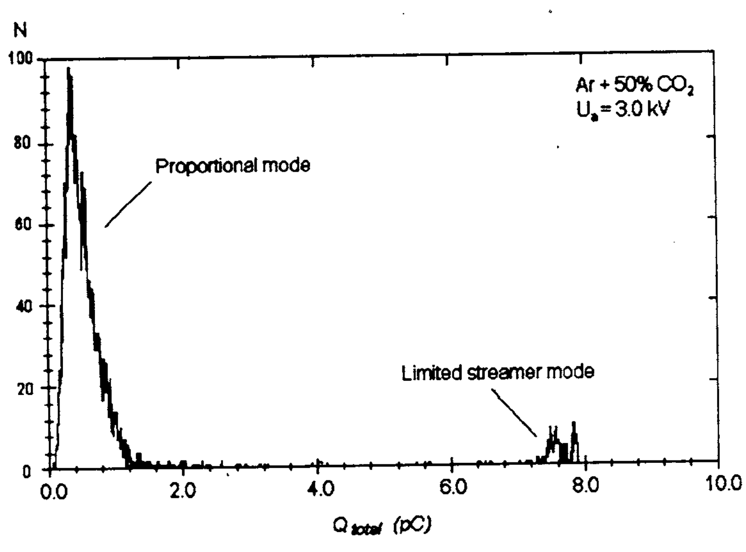

Fig.5. Charge distribution registered by the strip system

The results shown in Fig.6 illustrate the possibilities of the centre of gravity method. The relative error in measuring the total charge was 1 ÷ 1.5% for the above case. This circumstance allows one to realize so high a registration precision. However, it is necessary to assure the stability of the detector and electronic parameters at a level of 0.3 ÷ 0.5% over all the area of the detector. Of these parameters a mechanical precision of manufacturing detector components, high uniformity of cathode resistivity and calibration precision of electronic channels are the main ones.

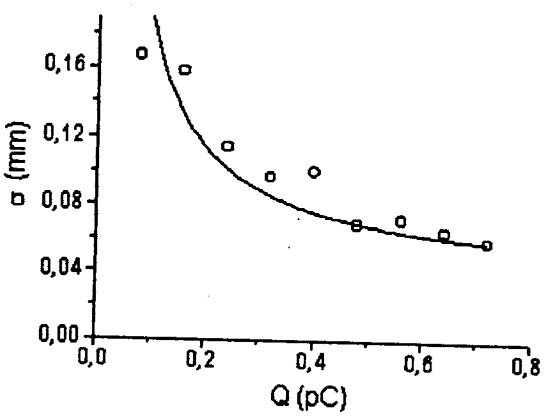

Fig.6. Dependence of PDT registration precision on the value of charge collected by strips

The shape of the registered charge distributions depends on the uniformity of the resistive cathode surfaces, and these parameters significantly affect the precision of event coordinate calculation, especially the level of systematic errors of the calculated coordinates. The surface of the resistive cathodes is not flat and has a complex form. Besides, there is no connection between the cathodes of different tubes. All these factors distort the shape of the registered charge distributions. Additional distortions are determined by a limited frequency bandwidth of the amplifiers.

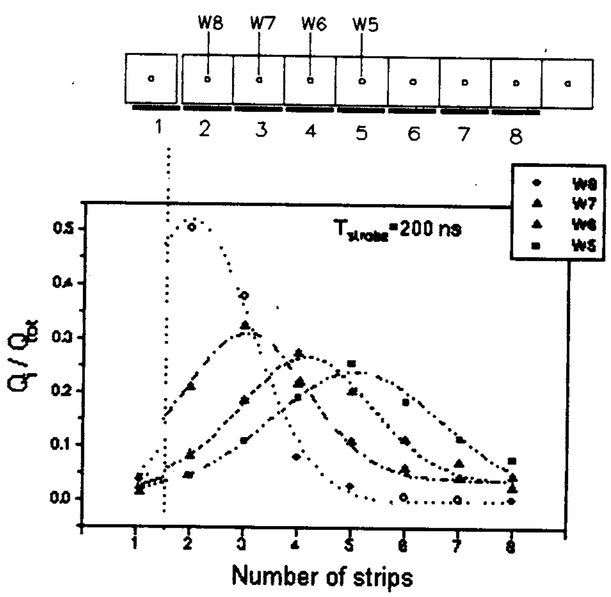

Fig.7. Shape of the registered charge distributions for different PDT wires

The results of measuring the charge distribution shape for a 10 mm strip pitch are shown in Fig.7. The measurements were made for different wires of the tube. The second tube was used to estimate the effects due to the absence of direct contact between the cathodes of the tubes. Strip 1 was placed under the last wire of the adjacent tube.

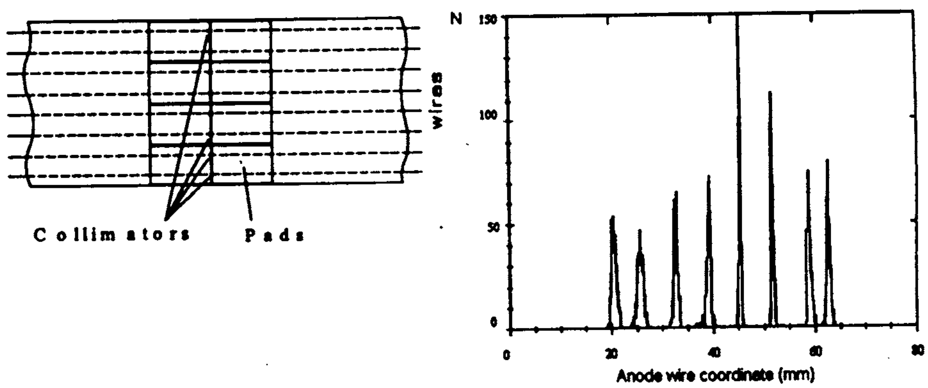

Fig.8. Distributions of the calculated coordinate for different PDT wires

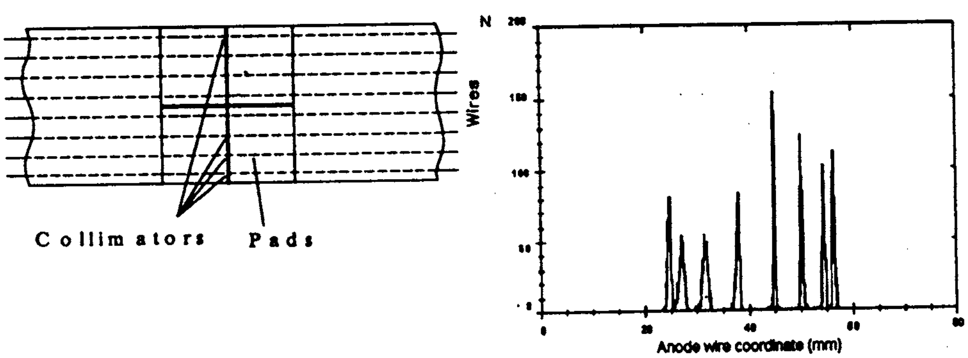

Fig.9. Distributions of the calculated coordinate of different PDT wires for pads 40×40 mm^2 in size

As seen from the Fig.7, four mirror-symmetric distributions are formed on the resistive cathode of the tube. The registered shape of the charge distributions depending on the position of the hit wire relative to the centre of the tube is substantially distorted for the last wires. These distortions are due to the absence of adjacent tube cathodes and lead to systematic errors for the calculated coordinates.

The level of signals registered from strip 1 shows that the induced radiation of electron avalanches makes a small contribution to the amplitude of the registered signals (~ 5%). The main part is determined by the diffusion of the charge on surface resistance. The influence of frequency bandwidth shows up here; the rise time of an output amplifier signal was ~ 50 nsec which was longer than the time of avalanche development.

As was said above, the coordinates normal to the anode wire direction are measured by the number of the hit wire. The coordinate drift time is not taken into account. The precision of measurement of this coordinate is determined by the distance between the wires equal to 10 mm. However, although requirements for measurement of this coordinate are soft enough, it is necessary to provide a reliable separation and determination of the hit wire number. The results of measurement of different wire positions are given in Figs.8 and 9. These measurements were carried out using the pad system with sizes of 20 mm (Fig.8) and 40 mm (Fig.9) along this coordinate. As one can see from the Figures, the number of wires is determined quite reliably even for a pad size of 40 mm.

Conclusion

The following conclusions can be drawn from the investigations of proportional mode signals in the PDT described above:

- it is possible to realize a noise-to-signal ratio of $1 \div 2\%$ for the proportional mode in the PDTs. This allows one to obtain a track registration precision of $\sigma < 1$ mm for the coordinate along the direction of anode wires, to determine reliably the number of a hit wire for another one. This precision can be obtained for pad sizes of 40×40 mm^2;
- a two-component gas mixture ($Ar + 50\%CO_2$) can be used for filling PDT. This gas mixture makes it possible to obtain the efficiency plateau width from 2.6 kV up to 2.9 kV at a level of limit streamer pulses no more than 5%;
- the shape of the registered charge distributions depends on the hit wire position and affects the value of the calculated coordinate systematic error;
- the method of wire position measurement can be used to correct systematic errors for the calculated coordinates and to calibrate the electronic readout channels;
- the absence of direct contacts between the cathodes of individual tubes leads to sufficient deformations of the registered charge distributions. However, this effect allows one to separate coordinate systems for different tubes and to simplify the manufacture and mounting of detectors with PDT.

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