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SOME CHARACTERISTICS OF

PLASTIC STREAMER TUBES

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INTRODUCTION

In recent years a new type of detector plastic tubes has been widely implemented in high energy physics experiments. Basic features of this detector are modest construction cost, separation of readout elements from an active high-voltage zone, fabrication simplicity and high reliability. The common operating principle of plastic tubes is a self-quenching streamer mode. In large physical experiments^{/1/}, particularly in detectors for colliding electron-positron beams (LEP-CERN), it is proposed to use streamer plastic tubes. For instance, plastic tubes will be used as detectors in the DELPHI hadron calorimeter. The total amount of wires in this hadron calorimeter is 200 000 with a covered area of up to 6000 m².

The distinguishing feature of plastic streamer tubes is the use of an insulator with high-ohmic conductive coverage as a cathode what makes it possible to readout information with the help of external pick-up electrodes. These electrodes are independent of the basic detector and can have a required configuration (delay lines, thin cathode strips, cathode pads).

The main advantage of the self-quenching streamer mode, large signal amplitude, allows readout electronics to be considerably simplified^{/2/}. Simplicity and adaptability of manufacturing basic parts of the detector might be also pointed out.

Some operational characteristics of the plastic streamer tubes very close to those of the DELPHI hadron calorimeter in construction are presented in this paper.

1. A SET-UP FOR TESTING OF A HADRON CALORIMETER PROTOTYPE ON A BEAM OF THE DUBNA SYNCHROPHASOTRON

According to the plans of participation in DELPHI experiments, work to prepare a mass production and test of the detectors of the hadron calorimeter is being conducted at the Joint Institute for Nuclear Research. One of the research stages is to investigate operational characteristics of a full-thickness scale prototype of the hadron calorimeter on beams of the Dubna synchrophasotron at a 10 GeV energy.

A set-up for studies of the hadron calorimeter is placed on the 36 synchrophasotron beam line. The apparatus arranged on

Fig.1. Layout of the DELPHI hadron calorimeter prototype on a beam of the Dubna synchrotron.

Fig.2. Block-diagram of the electronics for the hadron calorimeter prototype.

the set-up is schematically shown in fig.1. A primary beam of the synchrotron is extracted into this line. In the near future additional beams of $\pi^\pm$ -mesons, electrons and muons with energies of several GeV will be also used.

The hadron calorimeter prototype in the longitudinal direction fully repeats the structure of a cylindrical part of the DELPHI hadron calorimeter. The transversal cross section of the prototype is $1 \times 1 \text{ m}^2$. A radiator is constructed from iron plates 50 mm thick. In front of the radiator an electromagnetic calorimeter is placed the thickness of which is similar to that of

the DELPHI electromagnetic calorimeter. Information from the electromagnetic calorimeter, made of 3 mm thick lead plates interlayered with plastic scintillators, is also used for hadron energy determination. Pulses from the scintillators are registered by two photomultipliers with the help of wave shifters.

A block-diagram of the prototype electronics is shown in fig.2. The apparatus operates on-line with an ES-1040 computer.

2. CONSTRUCTION OF THE PLASTIC STREAMER TUBES

The construction of the streamer tubes under study has been developed due to main parameters approved for the detectors of the DELPHI hadron calorimeter.

The module of the streamer tubes consists of two profiles, inside which signal wires are stretched, covers, a container and two end caps with gas inlets and outlets and a high-voltage connector. Besides, readout of signals from anode wires is also provided. All elements of the module are made of polyvinylchloride.

The profile is composed of 8 cells $9 \times 9 \text{ mm}^2$ in size with a wall thickness of 1 mm, coated inside with a graphite layer with a resistance of $R \approx 100 \text{ kohm}$ per square. A beryllium-bronze wire $100 \mu\text{m}$ in diameter is centred inside each cell. The thickness of the top cover, also coated with the same graphite layer, is 1 mm. The container, inside which the two profiles are arranged, determines an operating gas volume. The length of the tubes varies from 25 cm to 100 cm.

To investigate the detector characteristics with external readout, pick-up electrodes with different configurations were made from a two-sided Cu-covered G10 1 mm in thickness.

Two gas mixtures, argon+isobutane (1:3) and argon+ CO_2 + n-pentane (1:2:1), were used.

3. RESULTS

For our plastic tubes the transition to the self-quenching mode initiated by a β -source, began at $U = 4.2 \text{ kV}$ what can be observed when high amplitude pulses appear on an anode wire (fig.3). The operating gas mixture for this case is argon+isobutane (1:3). The width of an anode pulse is $\tau = 20 \text{ ns}$ with its rising time about 5 ns.

The efficiency curve for β -particle registration as a function of high-voltage is presented in fig.4. The registration threshold is held at a 5 picocoulomb level. Curve "a" is taken for the argon+isobutane (1:3) gas mixture. A plateau starts at

Fig.3. Anode wire pulse shape.

4.3 kV, and it extends by 700 volts. At $U=5.0$ kV break-downs inside the detectors arise, and operation instabilities are observed. The average level of noise is about 10 Hz ("c" curve). The level of efficiency on the plateau is determined by the geometry of a triggering counter. Curve "b" is obtained for the argon+CO₂+n-pentane (1:2:1) gas mixture. Figure 5 shows the amplitude spectra of anode pulses for different wire voltage and the argon+CO₂+n-pentane (1:2:1) gas mixture. Here and further on the integration time was 300 ns. At 3.9 kV the detector operates in the usual proportional mode. As high voltage increases, the self-quenching streamer mode begins and the spectrum shape significantly changes, i.e., a peak of large amplitudes appears. Over a 4.2-4.5 kV range the detector operates mainly in the self-quenching streamer mode. At 4.5 kV some spread is observed in the amplitude spectrum, which is an evidence for a two-streamer regime.

Figure 6 shows the amplitude spectra of anode pulses taken at different voltages for the argon+CO₂+n-pentane gas mixture. It can be seen that the transition to the self-quenching mode begins a little earlier than in the previous case.

The transition to the self-quenching mode is easier for a cluster nature of primary ionization. Figure 7 demonstrates the amplitude (charge) spectra of signals taken from a signal wire for the argon+CO₂+n-pentane (1:2:1) gas mixture, when a ⁵⁵Fe-source is used. It is seen that the self-quenching streamer mode starts at lower voltages than for β -particles (fig.5). When operating on the plateau ($U=4.5$ kV), the shape of the amplitude spectrum is very close to the gaussian one

Fig.4. Electron counting efficiency as a function of voltage from the ¹⁰⁶Ru β -source: a) argon+isobutane (1:3) and b) argon + CO₂+n-pentane (1:2:1) mixtures. The counting rate of noises (curve "c") is shown for the argon+isobutane mixture.

Fig.6. The same as in fig.5 but for argon+CO₂+n-pentane(1:2:1).▶

Fig.5. Pulse height spectra of pulses from an anode wire at different voltages for the argon-isobutane (1:3) gas mixture. The tube was triggered by electrons from the ¹⁰⁶Ru source.

with root-mean-square deviations of 12%, i.e., there are no indications of the two-streamer regime.

We have observed an interesting peculiarity in transitting to the self-quenching streamer mode in investigations with a beam of relativistic ⁴He nuclei with 7 GeV/c. Figure 8 shows the amplitude spectra for pulses from an anode wire for this case. First, the transition to the self-quenching streamer mode

Fig.8. Pulse height spectra of pulses from an anode wire at different voltages obtained with the 7.0 GeV/c ^4He nuclear beam. Argon+isobutane gas mixture.

Fig.7. Pulse height spectra of pulses from anode wire at different voltages for the ^{55}Fe source. Argon+isobutane (1:3) gas mixture. The vertical scale indicates the charge in relative units.

begins considerably earlier than for particles with minimal ionization. Second, at 3.7-3.8 kV the two-streamer regime appears, what doubles the signal amplitude. At 4.0 kV the detector operates mainly in the two-streamer regime. One can assume that the development of streamers is based on primary ionization collection at the opposite side of a wire.

Figure 9 shows the signal amplitude as a function of voltage for ^4He beams with 7.0 GeV/c (argon+CO₂+ n-pentane gas mixture).

The possibility of readout by means of external pick-up electrodes is a useful feature of the plastic streamer tubes. Of interest is the behaviour of the induced pulse distribution as a function of the distance between the electrodes and a streamer.

Figure 10 presents the induced charge distribution against the distance between a pick-up strip and a fired wire when operating with the β -source. The pick-up strips were arranged parallel to the signal wires. The width and step of the strips were 3 and 4 mm, respectively. The FWHM of the distribution is about 12 mm, and the recorded shape of the distribution well enough corresponds to the expected one for the cathode with infinite resistance. Figure 11 shows the induced charge distribution as a function of the distance between pick-up electrodes 10x10 cm² in size and the collimator centre of the β -source. The induced pulse amplitude is normalized to the value corresponding to the streamer placed at the pad centre. The source is moved along the direction parallel to the wires. The dotted and solid lines correspond to a 300 ns and 1000 ns integration time, respectively. It can be seen that the amplitudes of induced pulses as a function of the distance between streamer and electrode decrease much slower along the wires than in the direction perpendicular to the wires. This observation can be quite probably explained by cathode resistance anisotropy caused by profile walls coated with a resistive layer. Apparently, the effect of charge spread-out, induced on the resistive cathode directly in proximity to a streamer, takes place, and a remote pick-up electrode "feels" this process by capacitive coupling with the cathode.

At large distances from the centre of the pick-up electrode the charge amplitude changes its sign, reaches (in absolute value) about 2-3% and does not decrease more with distance. For better understanding this effect, we have investigated the shape of an induced pulse at different distances of the β -source from the pad centre. Figure 12 demonstrates the shape of an induced pulse at different distances between the β -source and pad centre. It is seen that, except the main induced pulse with positive polarity caused by spatial separation of the electron and ion avalanche components which decreases with

Fig.9. Pulse height spectrum from an anode wire as a function of voltage from the 7.0 GeV/c ^4He nuclear beam. Argon+isobutane (1:3) gas mixture.

Fig.10. Transverse distribution of the induced pulse.

Fig.11. Induced charge as a function of the distance between the collimated source and the centre of the $10 \times 10 \text{ cm}^2$ pad.

growing the distance between a streamer and the pad, a negative pulse propagates along the wire direction the amplitude of which is practically independent of the β -source location. We assume that a negative pulse on the pick-up pad is caused by the induction of an anode signal, which propagates along the cell containing a signal wire and having a coaxial structure. To check this assumption, we have conducted comparative studies of the shapes of pulses from an anode wire and of negative pulses induced on the remote pick-up pad. Figure 13a depicts the signal shape from a wire and from the remote pick-up pad for the case when a signal wire 8 m long is open from one side. The wire end, at which a signal is observed, was terminated by a 280 ohm resistor through a 10^4 pF capacitor. The wire 8 m in length was arranged by consecutive connection of 8 module wires. The shape of a signal from the remote pick-up pad is shown in the lower sweep (the signal is inverted by an ampli-

Fig.12. Pulse shape of a signal induced on the 10x10 cm² pad:
a) ¹⁰⁶Ru collimated source aligned with the pad geometrical centre, b), c), d), e) 5 cm, 7.5 cm, 10 cm, 20 cm, from the pad centre, respectively.

Fig.13. Pulse shape of an anode pulse and a pulse from the pick-up electrode for the cases: distant end of the wire is a) open, b) terminated, c) grounded.

fier). It is seen that an anode pulse really propagates along a cell as in a line with distributed parameters with a delay of 4 ns per meter, and it is reflected from the open end of the wire. A signal from the pad remoted from the point, where a streamer originates, follows the signal shape on the anode wire. Figure 13b shows the case when a distant end of the wire is terminated in the same manner as a close one. Figure 13c presents the case when the distant end of the wire is grounded by a capacitor.

Fig.14. Scheme of wire connection for oblong cross-talk minimization.

Fig.15. Charge induced on the 16x16 cm² pick-up pad depending on the number of active wires.

Fig.16. Pulse height spectrum of pad signals when 12 wires are fired.

The described effect, called "oblong cross-talk", can lead to considerable difficulties in measuring energy in the DELPHI hadron calorimeter for e^+e^- -events with high multiplicity. This problem requires thorough consideration and careful Monte-Carlo analysis.

Noises, caused by oblong cross-talk, can be minimized by appropriate connection of the signal wires, when the direct and reflected signals compensate each other (fig.14).

When a streamer tube operates with external readout, the induced pulse amplitude should be proportional to the number of particles having passed through the area of the pick-up detector. It is of importance to determine this dependence for hadron calorimeter calibration. To investigate the induced amplitude as a function of streamer numbers under a pick-up electrode, a series of measurements was made using the He beam 7.0 GeV/c. The size of the external pad was 16x16 cm². The numbers of streamers were changed by disconnecting some wires.

For these investigations the 16-wire module was used. With increasing the multiplicity of firings, the induced pulse amplitude rises linearly (fig.15). Figure 16 shows the amplitude spectrum for the case when 12 wires are fired.

CONCLUSION

The investigations have shown stable operation of the plastic streamer tubes, their simplicity and convenient use.

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