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SURFACE STUDIES OF PLASTIC STREAMER TUBES

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Abstract

The structure and chemical composition of plastic streamer tube cathode surfaces were studied. Possible causes for dark currents and continuous discharges observed earlier in these detectors are suggested.

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1. Introduction

Plastic streamer tubes [1] have been widely adopted for use as the active media in calorimeters of large collider experiments [2,3,4,5]. They are also used in underground nucleon decay experiments [6]. This study has been made within the DELPHI Hadron Calorimeter Project, a joint effort between CERN, University of Helsinki, IHEP Serpukhov, JINR Dubna and INFN Rome Sanità.

During the development of the DELPHI Hadron Calorimeter it was soon discovered that the operation of the plastic streamer tubes was not always stable in the counting plateau [7,8]. In all batches of detectors produced, there was a number of tubes which exhibited large dark currents, spurious pulses and flashes in the current. It was suspected that these problems were due to the Malter effect [9] taking place on the cathode surface.

Figure 1 gives an idea of the geometry and the materials of the cathode. The conductive layer is prepared with a mixture of graphite and an organic solvent, isobutyl-methyl-ketone. It is applied onto the surface by means of a synthetic sponge to which the conductive varnish is fed by gravity. This procedure gives a layer which by visual inspection contains streaks of varying shades of grey.

A high sensitivity to single minimum ionizing particles, especially important for the DELPHI muon trigger [10,11,12] requires the use of as high a resistivity as possible. Due to problems experienced with cathodes of $\approx 1 \text{ M}\Omega/\square$ resistivities, a brushing procedure was adopted after varnishing the DELPHI HCal cathode profiles [13].

2. Experimental set-up

We studied the surface topology and composition of the cathode profiles in plastic streamer tubes with the scanning electron microscope Philips 501B in a manner shown in Figure 2.

We were able to study the effects due to different electron penetration depths by changing the accelerating voltage. The spot size could be varied in order to change the total electron flux, and the bias voltage between the electron detector and the sample was regulated to study the energy of the electrons

scattering back from the surface. We also measured the ground current with a high-precision electrometer.

All non-conductive samples were covered by a thin (20 nm) layer of gold to make the surface visible. This was not done for partially conductive surfaces, as the blurring of the image due to charge accumulation provided us with information of the non-conductive parts of the surface.

3. Measurements

In the images given by the scanning electron microscope, it was clearly seen that most of the surface gives a well-focused view, but that it is covered with a large number of white, blurred spots. These spots were absent in samples covered with a gold layer.

We studied the nature of these spots by using a stationary electron beam. It was seen that the ground current was about 30% lower in the blurred spots than in the well-focused regions. This suggests that a number of electrons were deflected from the surface. We ascribe this to a charge accumulation, and a subsequent electrostatic repulsion. Thus, the regions with the lowest conductivity showed up in the images as blurred white spots. If the beam energy was decreased we saw a bigger difference between the ground currents from the conductive and non-conductive regions. The lower energy electrons are more easily deflected and picked up by the electron detector.

The typical size of a non-conductive region on the cathode surface depends on the average resistivity. Figure 3 gives a detail of the surface of a cathode of $100 \text{ k}\Omega/\square$ average resistivity. A non-conductive spot of about $10 \mu\text{m}$ can be seen in the lower left-hand corner.

Also a highly resistive sample ($> 1 \text{ M}\Omega/\square$) was studied, the result of which is shown in Figure 4. The surface is covered by scattered non-conductive areas with a typical size of $50 \mu\text{m}$. The structure of these white areas, hidden by the electrostatic blurring, can be seen in Figure 5 where the sample was covered by gold before exposure. The non-conductive regions appear to be large clusters of grains, scattered over the surface. A detail, in Figure 6, shows the appearance of such a grain. The typical size is $3-5 \mu\text{m}$.

The chemical composition of these grains was studied by energy dispersive x-ray analysis, with the EDAX 9100 system which is operated in connection with the electron microscope. A typical spectrum of the emission from the grains is given in Figure 7 together with that from the plastic matrix material. It can be seen that the grains contain a large quantity of calcium which is only visible in small quantities in the background. Since we know from the manufacturer that the PVC raw material used for the extrusion of the profiles contains 18 % of a filler material, CaCO_3 , we are led to suspect that the grains are of this origin. The graphite varnish does not cover all these grains, especially when the resistivity is pushed towards higher values by applying only a thin conductive layer.

We suggest that such exposed CaCO_3 grains may accumulate a charge build-up on their surface due to ions from streamers. This charge may cause a strong electric field both between the grain and the conductive varnish and through the bulk of the grains. The latter may lead to the Malter effect, emission of electrons to the gas volume, leading to additional streamers and eventually to a continuous discharge between the anode and the cathode.

The DELPHI Hadron Calorimeter group has studied the use of an anti-static liquid, BREOX B-35, for making the conductivity of cathode surfaces more uniform [14]. The effect of a treatment with BREOX can be seen in Figure 8. Although no gold layer has been applied, the image is well focused and no blurred white spots appear. The intrinsic resistivity of BREOX B-35 is about $10^{11} \Omega/\square$. This suggests that the resistivity of the non-conductive spots appearing in previous figures must be higher. It also implies that if the Malter effect only occurs in the regions which give a non-conductive appearance in the electron microscope, the BREOX treatment can eliminate this source of trouble.

4. Conclusions

This study gave us new insight into the possible sources of dark currents and continuous discharges in plastic streamer tubes. It was shown that a normal PVC cathode surface is covered by a large number of non-conductive areas which appear to be composed of clusters of grains, 3–5 μm in size. An x-ray analysis suggested that these grains are of CaCO_3 , a filler material in the PVC.

We suspect that these grains constitute a major cause for the dark currents by provoking electron emission to the gas volume through the Malter effect.

We also showed that a treatment with an anti-static liquid, BREOX B-35, helps to cure the lack of conductivity in the observed non-conductive regions.

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FIGURE CAPTIONS

1. Dimensions and structure of the detector profile in a streamer tube of the DELPHI Hadron Calorimeter.
2. The scanning electron microscope set – up. The division of the beam current is indicated.
3. A detail of the surface of a cathode of $100 \text{ k}\Omega/\square$ average resistivity. A non – conductive area can be seen in the lower left – hand corner.
4. The surface of a highly resistive ($> 1 \text{ M}\Omega/\square$) sample without a gold plating.
5. The highly resistive surface of Figure 4, covered by a gold layer.
6. A detail of Figure 5 with grains protruding from the plastic surface.
7. The x – ray emission spectra of the PVC matrix and the protruding grains.
8. A cathode surface treated with BREOX B – 35, resistivity $100 \text{ k}\Omega/\square$.

Figure 1.

Figure 2.

10μm

Figure 3.

Figure 4.

100μm

Figure 5.

10µm

Figure 6.

Figure 7.

100μm

Figure 8.