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RECENT DEVELOPMENTS OF THE MULTIDRIFT TUBE

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ABSTRACT

We describe the latest results in the development of a tracking detector based on a modular concept using multidrift tubes. Several prototypes have been built and tested. Each module contains about 70 independent drift cell, constituted by anodes centred in a hexagonal cell defined by six cathode wires. A thin hexagonal carbon-fibre envelope, 30 mm in diameter, supports the wire tension and provides gas tightness. Using dimethyl ether as a gas filling, we have obtained radial localization accuracies of about $65 \mu\text{m}$ r.m.s. per wire and longitudinal accuracies of about 0.9% of the wire length. Ageing measurements show that we can expect good operation of the modules up to an accumulated charge density of about 1 C/cm. Furthermore, owing to the small cell size and high field, the space-charge gain reduction is less than 10% for currents up to $0.5 \mu\text{A/cm}$, about 20 times better than observed in conventional MWPCs.

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1. INTRODUCTION

The design of tracking detectors for future high-luminosity hadron colliders poses several problems, e.g. a very large number of particles per event and very high event rates, of the order of 10^8 interactions per second for a luminosity of $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$. Therefore, the detectors should have a high granularity to allow high-rate operation and the reconstruction of complex events. Furthermore, they should be able to withstand a very high radiation dose, of the order of 1 Mrad/y at a distance of 8 cm from the beam line. A few years ago, the Multidrift Module detector (MDM) was proposed as a device capable of fulfilling these requirements [1]. Now the MDM is an integral part of the LAA Project on Detector Research and Development [2] at CERN, led by Prof. A. Zichichi. Figure 1 shows a schematic layout of the multidrift tube: it consists of a thin hexagonal envelope, containing a large number of individual drift cells, also of hexagonal geometry. The distance of an ionizing particle track to the central anode wire is deduced from the drift-time of electrons released by the particle in the gas, whereas the longitudinal coordinate is measured by the charge ratio on the ends of each anode. The drift cells are made very small (1.46 mm radius in the present design) in order to minimize the total drift-time and to obtain good two-track resolution. The total drift-time of 30–40 ns, depending on the gas filling, makes it possible to operate the tubes at very high count rates. The hexagonal symmetry makes it easy to assemble modules around an intersect in order to build a complete vertex detector. An additional advantage is that each element is easily replaceable in case of failure.

The present paper briefly describes some recent measurements of localization accuracy and rate tolerance realized with various prototypes.

2. MECHANICAL CONSTRUCTION AND OPERATION

The method of constructing the multidrift tube has been extensively described elsewhere [3–5] and will only be summarized here. Anode and cathode wires are stretched between two precision-drilled fibre-glass end-plates and soldered onto miniature brass pins, which have V-shaped grooves cut along their axes. The overall radial wire positioning thus obtained is better than $20 \mu\text{m}$. The high-voltage distribution to the cathode pins is made by a copper layer glued to the outside of the end-plates, and with which all cathode pins make electrical contact. The anode pins are insulated from each other and from this copper layer, and allow readout of individual signals from both sides of the module. Several prototypes have been built with anode wire diameters ranging from 20 to $50 \mu\text{m}$ and with different wire materials. The preferred choice at present is to use $31 \mu\text{m}$ diameter ($35 \mu\text{m}$ nominal value) stainless-steel anode wires, thick enough to have good mechanical properties but still with a resistivity high enough to allow localization through charge division (about $1 \text{ k}\Omega/\text{m}$).

Figure 2 shows a completed multidrift tube with 66 preamplifier channels mounted. The high-density preamplifier cards shown use the Fujitsu MB43458 quad-charge amplifier. The rise and fall times of this preamplifier, 6 and 30 ns respectively, match the characteristics of the tube quite well, and its small size and low power consumption (50 mW per channel) allow it to be mounted without problems in the limited space available on the edge of the tube. The outputs of the preamplifier cards are connected, via miniature coaxial ribbon cables, to a remote receiver-discriminator, which provides analog and logic signals. These signals are then digitized by commercial charge-to-digital and time-to-digital converters.

The operating characteristics of the multidrift tube depend, to a large extent, on the gas filling. Several characteristics of dimethyl ether [DME: $(\text{CH}_3)_2\text{O}$] make it very attractive for use in our modules: first of all, its high primary ionization density and low electron diffusion allow good localization accuracies to be obtained. Indeed, for tracks passing close to the anode wires, the distance between primary electron-ion pairs is the major source of dispersion in the position measurement of the track. We have recently measured a primary ionization density of 55 ± 5 pairs

per centimetre in DME at standard temperature and pressure. This result was obtained by decreasing the pressure in a DME-filled cylindrical single-wire proportional counter, fully efficient for single electrons, while measuring the efficiency of detecting minimum-ionizing particles. Since the number of primary ionization clusters within a given track length ℓ is governed by a Poisson distribution, the detection inefficiency is given by $1 - \epsilon = \exp(-n \cdot \ell / p)$, where n is the primary ionization density in pairs per centimetre at standard temperature and pressure, ℓ is the track length in centimetres, and p is the pressure in atm. Figure 3 shows the measured points and the curves given by the previous formula for different values of the primary ionization density. It can be seen that the agreement is best for a value of 55 pairs per centimetre. The same measurement, made in argon, yields a value of 25 pairs per centimetre, in agreement with accepted values. Another favourable characteristic of DME is its good quenching properties, which allow very large stable gains without secondary effects. In all prototypes built so far, we have indeed obtained very comfortable efficiency plateaus, several hundred volts long. The gas gain, measured in our multidrift tubes for 31 μm diameter anode wires, is shown in fig. 4. Finally, there is confirmed evidence [6, 7] that proportional counters with a DME gas filling are able to withstand high radiation doses without damage due to polymerization. This point will be discussed further.

3. LOCALIZATION ACCURACY

To measure the localization accuracy perpendicular to the wires, we tested the multidrift tube in a charged particle beam. The gating for the charge measurements and the time reference for the drift-time measurements were provided by three scintillation counters. The tracks could be measured independently by two silicon microstrip detectors located 6 cm upstream and downstream from the MDM under test. The reconstruction accuracy using the strips was about 30 μm , essentially owing to the alignment errors between the axis of the tube and the strips. In order to calculate, from the measured drift-time, the radial distance of the track from the anodes, the space-time correlation has to be known. This could in principle be computed from the electric field geometry and the drift velocity. Since the latter is not well known for the high electric fields encountered near the wires in the multidrift tube, we have instead measured the space-time correlation using the coordinates provided by the microstrips. Figure 5 shows an example of the correlation between the drift-time measured on a single wire in the multidrift tube and the real space coordinate measured by the silicon strip detectors. It can be seen that the correlation is non-linear owing to the large field variations across the cell. Furthermore, the hexagonal geometry of the cells introduces a small angular dependence of the correlation. From scatter plots such as the one shown in fig. 5 for different wires and different angles, average correlations are computed which are then parametrized for use by the track reconstruction program. Figure 6 shows the dispersion calculated from the track fit for a single wire: the distribution peaks at a value of 51 μm and has an average value of 64 μm . A somewhat more detailed investigation of localization accuracy is presented in fig. 7: this figure shows the radial dependence of the r.m.s. deviation between the space coordinates measured by the silicon strip detectors and those obtained by the drift-time measurement on a single wire for tracks crossing the tube at an angle of 0° (i.e. parallel to one of the sides of the cell). Also shown in the figure is a curve which represents the contribution of primary ionization statistics to the resolution. As mentioned before, one can see that the large error near the anode wire is almost exclusively due to ionization statistics. Another region with rather modest resolution can be found near the edge of the cell. This is probably explained by the fact that for this particular angle, tracks near the edge of the cell pass through a region of very small electric field between two cathode wires. The smallest error obtained is about 60 μm at 1 mm distance from the wire. This corresponds to an intrinsic accuracy of about 50 μm for the multidrift tube, taking into account the errors in the reconstruction by the microstrips.

The longitudinal coordinate can be calculated from the ratio of charges measured at both ends of the anode wires. We have measured the accuracy that can be obtained by this method for a prototype with 31 μm stainless-steel wires, 400 mm long, both for minimum-ionizing particles and for soft X-rays. The resulting single-wire accuracy distribution for minimum-ionizing particles is shown in fig. 8. The width of the distribution is 3.5 mm, or about 0.9 % of the wire length.

4. AGEING AND RATE CAPABILITY

One of the most important aspects of our development concerns the ability of the detector to run at very high radiation fluxes. Gaseous proportional counters typically experience two problems in high-rate environments: first, the large amount of positive ions released in the avalanches produce a local space charge, modifying the electric field and reducing the gain of the detector. Secondly, gas molecules can break apart and recombine, forming heavy polymers that form deposits on the wires, thereby permanently changing the operating characteristics of the counter.

The very small size of the drift cells in the multidrift module, and the high electric fields, should be effective in reducing the importance of space-charge effects. As shown in fig. 9, we have indeed observed gain reductions of less than 10% for charge rates up to 0.5 $\mu\text{A}/\text{cm}$ in a multidrift tube with DME gas filling. With our operational conditions, this is equivalent to a particle flux of about 10^6 minimum-ionizing particles per square centimetre and second. In a conventional MWPC with small wire spacing, an equivalent gain reduction is observed at a rate of about 10^{-2} $\mu\text{A}/\text{cm}$ [8] or about a factor of 20 lower.

Another important result concerns the ageing properties of our detector. Results on ageing are a subject of controversy between various groups, who reported substantially different results under apparently similar conditions. This seems to imply that very small traces of impurities can dominate the ageing process. Therefore, a detailed investigation [6] of ageing in DME-filled proportional counters, including measurements of trace impurities and surface analysis of damaged wires, was made in collaboration with a group at the University of Florida, Gainesville. The results of this study were reported at this conference [7] and can be summarized as follows: with a proper choice of materials, and using high-purity DME, proportional counters survive without noticeable modification of gain up to integrated currents above 1 C/cm. It also became clear from this study that stainless steel is the only resistive wire material suitable for use in DME-filled proportional counters.

In parallel with this systematic research, we have irradiated several prototype multidrift tubes using commercially available pure DME. No special precautions were taken for outgassing, and we used a standard gas distribution system in order to simulate realistic operating conditions. As shown in fig. 10, we have observed no gain reduction up to a total integrated current of about 0.5 C/cm. At that point however, a discharge develops on one of the wires, soon followed by the other wires in the tube. We believe that this is due to a deposition of polymerization products on the cathode wires. The investigation is continuing to try to identify the ageing agents and to eliminate them by means of a suitable purification technique.

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Figure captions

- Fig. 1 : Schematic showing the geometry of the multidrift tube.
- Fig. 2 : One end of a completed module, with preamplifiers for 66 channels mounted.
- Fig. 3 : Track detection efficiency in a cylindrical proportional counter as a function of gas pressure for DME and argon gas fillings. The curves represent the theoretical behaviour for several values of primary ionization density.
- Fig. 4 : Gas gain measured in a multidrift tube with DME gas filling on a $31\text{ }\mu\text{m}$ diameter anode wire.
- Fig. 5 : Space-time correlation measured on a single wire in the multidrift module for minimum-ionizing particles.
- Fig. 6 : Distribution of the overall dispersion calculated from a straight-line track fit.
- Fig. 7 : r.m.s. deviation between the distance measured using i) drift-time and ii) the track reconstruction in the microstrip detectors. The solid line shows the effect of primary ionization statistics, combined with the reconstruction error in the microstrips (dash-dotted line). The dashed lines show the uncertainty in this model calculation.
- Fig. 8 : Localization accuracy measured from charge division in a 40 cm long multidrift tube for fast electrons.
- Fig. 9 : Rate dependence of the gain measured in a multidrift module with DME gas filling.
- Fig. 10 : Normalized current measured on several wires as a function of irradiation time, using standard-grade DME. Breakdown is observed after an integrated current of about 0.5 C/cm ; it is probably due to the deposit of polymerization products on the cathode wires.

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