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OPERATION OF MULTIDRIFT TUBES WITH DIMETHYL ETHER

R. Bouclier, G. Charpak, J. Garabatos, B. Guérard, J.C. Santiard,
N. Solomey^{*)} and F. Sauli

CERN, Geneva, Switzerland

ABSTRACT

We have built several 80 cm long multiwire drift tubes, each with 70 independent drift cells constituted by individual anodes centred in a hexagonal cell, 1.45 mm in radius, defined by six cathode wires. A thin hexagonal carbon-fibre envelope, 30 mm in diameter, supports the wire tension and provides gas tightness. Charged tracks are measured, recording drift-times on all anodes, on an average ten times on each module; the longitudinal coordinate is measured from current division at the two ends of each wire. This paper presents the results of measurements realized with dimethyl ether as gas filling in the detection of minimum-ionizing particles.

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^{*)} Permanent address: Ohio State University, Columbus, Ohio, USA.

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1. INTRODUCTION

The most difficult region to instrument in a detector for collider experiments is the one close to the vacuum tubes, where the density of tracks and the background rate are very high. This is, moreover, the most inaccessible region of the set-up; a major breakdown there has the worst consequences for the whole operation. One way of improving the reliability of a system based on gaseous wire detectors is to increase its modularity and redundancy; such an approach was originally taken by a group at SLAC with the development of cheap, mass-produced individual drift tubes or 'straws' that can be assembled to constitute a complete detector.¹ Extending this concept further, we have built several multidrift modules that have many independent drift cells packed within a thin carbon-fibre supporting tube, of hexagonal shape, which also contains the gas. Each sensitive cell consists of an anode wire centred in a hexagonal drift structure with cathode wires at the corners. Our first prototypes (called Model 1) had 128 anodes per module, with an anode-to-cathode distance (cell radius) of 1.15 mm; the method of construction and the main experimental results obtained with such a design have already been described.^{2,3} Because of the problems encountered in the manufacturing of such a high-density detector, we have redesigned the detector as Model 2, slightly increasing the cell radius to 1.45 mm (1.27 mm between wire planes); this has simplified wiring and soldering, and greatly increased the reliability of the detector, at the expense of a decrease in the information density (70 cells per tube) and a slightly longer resolution time. All results described in this note refer to Model 2. When a charged particle traverses the tube, measurements of the drift-times on all wires provide the transverse coordinates,

* Permanent address: Ohio State University, Columbus, Ohio, USA.

perpendicular to the wires; the longitudinal coordinates are provided by a measurement of the charge ratio on the two sides of each wire. On an average, ten pairs of coordinates are recorded for each track in a single tube. Several tubes can be closely packed, for example in a cylindrical geometry, to instrument the central region in a collider detector; in the case of failure, individual modules may be disconnected or replaced.

2. CONSTRUCTION OF THE MULTIDRIFT TUBE

The method of construction of a module has been described in Ref. 3, and will only be shortly summarized here. Wires are strung between two high-quality fibre-glass plates of hexagonal shape (Fig. 1), 4 mm thick and 30 mm in diameter, through a set of holes of 600 μm diameter drilled on a high-precision numerical boring machine. A 50 μm thick copper sheet is glued on one side of the plate before drilling; all pins holding the cathode wires, once inserted and kept under tension, make contact with this common electrode that distributes the high voltage. As can be seen in the figure, a short, larger diameter (1.2 mm) bore around the holes destined to receive the anodes ensures the insulation of these pins from the cathodes. Wires are soldered to metal pins inserted in the holes of the supporting plates; these pins are precision-machined brass cylinders, 0.8 mm in diameter,

Fig. 1 Schematics of the drilling geometry of the end plates. Small circles represent holes for inserting the wire-holding pins; around the anodes, a short, larger-diameter drill ensures insulation against the metallized surface of the plate.

reducing to 0.6 mm at the tip in the section inserted into the plate (Fig. 2). A V-shaped groove, cut over the full length of the cylinder, receives the wire before soldering. Because of the different diameters of the corresponding wires, anode and cathode pins have grooves with different depth to ensure proper centring; the cathode pins are also shorter, and are completely covered by epoxy in the last phase of manufacturing. A bore on the edge receives an insulating tube for the gas inlet; the high voltage is provided to the interconnecting copper plate through a miniature pin soldered on the circuit. We have used 25 μm diameter gold-plated tungsten for the anodes and 70 μm copper-beryllium wires for the cathodes, tensioned at 60 and 120 g respectively.

To assemble the module, the two end plates are inserted on temporary brackets, rigidly mounted on a connecting horizontal bar. Wires are individually pulled through facing holes in the end plates, and kept under tension by a pulley and weight system. The appropriate brass pins are inserted on each side, with the wire resting face up in the grooves; wires are then soldered with a low-melting-point alloy and cut at both ends. The assembly proceeds in layers, starting from the lowest. Once the wiring is completed, the fibre-glass plates are fastened to a coaxial support fixed to three threaded pins on the corners, insulated from the copper layer (they will be used later to fasten the connector); on one side, the support consists of a long rod on which the supporting tube has been

Fig. 2 Cross-section of the end-plate assembly. Once inserted and wired, cathode pins are completely embedded in epoxy, the common contact being provided by a pin (not shown) soldered to the copperized upper layer of the plate. The system of signal connection, which makes use of an anisotropic conducting sheath, is also shown.

previously inserted. The temporary brackets are then removed, all wires being kept under tension by the coaxial mounting, and the carbon-fibre tube is slid over the wires to its final position; epoxy is poured over the plates so as to completely cover and insulate the cathode pins and at the same time to seal the module. The carbon-fibre tube used for the prototypes is 80 cm long and 550 μm thick, with an outer diameter of 32 mm; it is composed of carbon and epoxy in almost equal proportions. Figure 3 shows a close view of one end of a completed module: one can recognize the top of the anode pins, the tube that provides the gas inlet, the pin for the high-voltage connection, and the three threaded rods used for fastening the signal connector. A contact to the anode wires is available at both ends of the module, to allow the determination of the longitudinal coordinate through a measurement of the current ratio on the resistive wire. At present, the anodes are realized with gold-plated tungsten wires that can be soldered to the pins; because of the low resistivity of such wire, the localization properties in current division are rather modest. We are currently developing an alternative method of mounting, using fast-setting conductive epoxy instead of soldering, which should allow the use of resistive wires of any material.

Because of the high density of output contacts, we have developed a special connector to bring the signals to the electronics boards. After several attempts, using various kinds of mechanical spring-loaded and conductive pad contacts that had rather

Fig. 3 One end of a finished module. Contacts with the anode pins are visible, as well as the tube for the gas and the pin for the high-voltage supply. The three threaded pins are used for assembly and to hold the signal connector in place.

poor reliability, we have adopted the solution sketched in Fig. 2. It consists in inserting an anisotropic conducting membrane between the anode pins and the printed-circuit matrix to which the cables are soldered. The membrane is a thin (0.3 mm) rubbery sheet with thousands of short metal wires, perpendicular to the surface, and insulated from each other. With our surface of contact (0.5 mm²) the serial resistivity is typically between 10 and 50 Ω ; while tolerable for time-recording electronics, such a spread is rather annoying for analogue recording as used in the current-division method. We are investigating alternative connection methods; one that seems promising consists in directly soldering the signal cables to the pins or gluing them with conductive epoxy, during the manufacturing process. This also has the advantage of reducing the amount of material in the end plates of the detector.

3. EXPERIMENTAL SET-UP

Prototype tubes with the described geometry have been installed for testing in a minimum-ionizing particle beam at CERN, together with a set of three high-accuracy drift chambers.⁴ For the beam tests, the time reference was provided by a scintillation counter coincidence. Originally intended to provide a positional reference to study the localization properties of the multidrift tube, the chambers were in fact only used for gross track selection in the analysis, because of the very good quality of the results obtained within the tube itself.

As mentioned above, all anode wires (70 in each module) can be read out on both sides of the tube; for the measurements described here, however, we have only recorded the drift-time on all wires from one side, using a system of discrete electronics elements connected to the anodes with short (50 cm) miniature coaxial cables. For the measurement of the longitudinal coordinate through current division, four anodes only were equipped with charge- and time-recording circuits on both sides; in this case, we have used a low impedance amplifier terminating the coaxial input cable, followed by a splitter providing both the analogue and the shaped signals for charge and time measurements. Discrimination and shaping were realized with a home-made circuit⁵ whose threshold could be regulated from 10^{-2} pC up, and having typically 3 ns slewing for a 40 dB variation in the input signal. The shaped output from the discriminators is sent to logical receivers in the counting room via flat twisted-pair cables, and the drift-time measured with multichannel time-to-digital converters; similarly, the analogue information from the current division was sent via coaxial cables to a set of analog-to-digital converters. Data were recorded with a small on-line computer, and analysed off-line.

4. EXPERIMENTAL RESULTS USING DYMETHYL ETHER

The first measurements confirmed the relative ease of operating the counter in many gas mixtures; the results realized with argon-hydrocarbon mixtures at atmospheric pressure, together with a theoretical analysis of the various sources of dispersion, indicated that an overall intrinsic limit in localization accuracy of around 100 μm r.m.s. had to be expected, mostly determined by the primary ionization statistics, i.e. the large

average distance between primary ionizing interactions ($300\ \mu\text{m}$ in argon). Better localizations can be obtained only by increasing the gas density (using xenon or increasing the pressure, both rather inconvenient), or finding a gas in which the primary ionization density is higher. This is indeed expected to be the case of dense gases with low atomic number; dimethyl ether [DME: $(\text{CH}_3)_2\text{O}$], with a density at STP of $2.34 \times 10^{-3}\ \text{g/cm}^3$, is expected to have twice the primary ionization density of argon (indeed, higher than xenon). Originally proposed for use in gaseous counters because of the very low electron diffusion and drift velocity at high fields⁶ DME proved also to be impervious to radiation damage, and indeed holds one of the world records of endurance in a multiwire proportional chamber (MWPC) under avalanche conditions.⁷ Very good localization accuracies ($30\ \mu\text{m}$ and better) have been obtained in drift chambers operated with this gas.⁸ Because of the very high electric field in most of our drift region, due to the close wire spacing, we did not expect to profit from a reduction in electron diffusion, but the other advantages remain. Provided straight from the bottle, DME is also a rather convenient gas to use since it does not require mixing; its vapour pressure at STP of more than 4 bars makes it easy also to operate at pressures larger than atmospheric.

The counting characteristics of the tube operated with DME at 1 bar are illustrated in Fig. 4, which shows both the efficiency in detecting minimum-ionizing particles and the single wire noise (without particles) as a function of applied voltage. Both measurements were realized with a discrimination threshold of around $5 \times 10^{-2}\ \text{pC}$ at the wires. As compared to similar measurements realized with conventional argon-hydrocarbon mixtures (see for example Ref. 3), one can observe that full efficiency is reached at higher voltages (2.1 kV instead of 1.5 kV), with a very wide efficiency plateau (more than 500 V; the upper limit was indeed determined more by natural caution than by any sign of instability, as monitored through the singles counting rate). Dimethyl

Fig. 4 Efficiency plateau for minimum-ionizing electrons (○) and singles (●) counting rate on one wire without radiation, measured in a fully instrumented module with DME gas filling.

ether appears to be a gas with remarkable quenching properties, a fact confirmed by other authors, who reported reaching the limited streamer operation in other chamber geometries.^{1,9} Presumably because of the small drift space, we did not observe any sign of electron capture on impurities, a problem encountered by most authors using DME in drift chambers. Most of the beam data were recorded operating the tubes at 2.2 kV, conveniently above the beginning of the plateau; all results described here refer to this condition.

As indicated above, we recorded the drift-time on all wires, the time reference being provided by scintillation counters. The origin of the measured coordinate for each channel, or time zero, was deduced off-line from data histogramming the drift-time spectra for individual wires; after subtraction of this quantity and multiplication by a slope constant (also specific for each channel and determined from a previous electronic calibration), we obtained the drift-time as measured event per event by the hit wires.

It appeared soon in the data analysis that the assumption of a constant drift velocity resulted in rather poor localization accuracy. Data are unfortunately not available to allow computation of the space-time correlation in the very large range of fields across a cell in our gases; we have therefore directly measured the correlation with the following set-up. A special multidrift detector with a reduced number of cells (12) was built within a transparent glass tube; two openings facing the wires, and closed with ultraviolet (UV) transparent quartz windows, allowed a laser beam to traverse the structure. Using a pulsed N₂ laser, collimated and focused within the detector by UV lenses, we were able to produce an ionization trail, simulating charged-particle tracks, at a known and variable distance from the anodes; the width of the trail was below 100 μm , thus allowing very accurate measurements of the average drift-time. The space-time correlation measured in this way for several gases is shown in Fig. 5; the estimated error in positioning is around 10 μm for each point. Note that, because of the symmetric behaviour of the measured correlation on the two sides of the wire (not shown in the figure), both the time zero and the wire position reference can be deduced from the data themselves. The curve corresponding to the 'magic' gas mixture used in the measurements described in Ref. 3 (full dots) is indeed rather linear (except very close to the wire), as was deduced from the data analysis; for DME instead there is a definite change of slope at about half of the drift distance. This is unfortunate, since it implies a different influence of various electronic dispersions (e.g. the time binning) on the resulting accuracy. We are currently investigating if addition of small percentages of other gases to DME can straighten the correlation.

The straight-track finding proceeds then as follows. A first-level linear fit is attempted using only the hit-wire location (disregarding the actual value of the drift-time). On the perpendicular to the fitted track from the hit wires, the shorter distance is selected using the drift-time measurement (this solves the right-left ambiguity intrinsic in the detector); points having a distance from the initial track exceeding a given tolerance (2 mm) are discarded as background. The fit is then repeated with the new set of coordinates. The procedure converges in two or three steps to provide the best estimate of the track, as shown in the example of Fig. 6.

Fig. 5 Space-time correlation in various gases, measured in a dedicated drift tube with a pulsed laser beam.

Fig. 6 Example of a single-track reconstructed event. The circles represent the measured drift-time on the hit wires.

The distribution of the difference between fitted measured coordinates on a wire is shown in Fig. 7; it has a standard deviation of $70\text{ }\mu\text{m}$. This does not represent the true localization accuracy of the wire, since other wires contribute also to the dispersion; it is, however, rather close to the intrinsic accuracy because of the large number of points on each track (8 on an average). One can compute the average true single wire resolution σ from the expression

$$\sigma^2 = \Sigma(r_{\text{meas}} - r_{\text{fitted}})^2 / (N - 2) ,$$

which takes into account, for each track, the number N of hit wires participating in the fit with two degrees of freedom. The distribution of σ for a typical run is shown in Fig. 8 and has a most probable value of $80\text{ }\mu\text{m}$. This includes all statistical and systematic sources of error, such as wire positioning and errors in the time zero determination.

Fig. 7 Distribution of the difference between fitted and measured coordinates on a wire for a typical run; it has a r.m.s. of $70\text{ }\mu\text{m}$.

Fig. 8 Distribution of the overall variance from the fit σ , computed from the expression given in the text. Its most probable value, $80 \mu\text{m}$, corresponds to the average intrinsic resolution of the wires.

For a reduced number of wires (four) we have recorded both charge and time to attempt longitudinal localization using the current-division method. The quality of the results was rather modest, as expected, because of the low resistivity of the gold-plated tungsten wire used in the prototype detector ($180 \Omega/\text{cm}$). Since we expect a great improvement in the next models with the use of a resistive wire, not much effort has been invested in the present measurement. Figures 9a and b show the pulse-height spectra for minimum ionizing particles as recorded from the two sides of an anode wire, for a beam positioned at around 10 cm from one end of the module; Fig. 9c is a plot of the corresponding localization accuracy as deduced from the charge ratio, without any correction and including the beam width (10 mm); it has a r.m.s. of 30 mm (3.7% of the wire length). Other authors have reported,¹⁰ in very similar conditions but using a resistive wire, localization accuracies better than 0.4%.

Fig. 9 Charge distribution for a collimated beam of minimum-ionizing particles, recorded on the right (a) and left (b) sides of an anode wire. c) Resulting localization accuracy distribution, deduced from the ratio of charges. It has a standard deviation of 30 mm, which includes the beam size (10 mm).

5. FUTURE DEVELOPMENTS

We are continuing the development work on the multidrift tube with the aim of improving its performance and reliability. A way of improving the transverse localization accuracy is to increase the operating pressure; as mentioned, DME has a vapour pressure of 4 bars at room temperature; however, we expect already a substantial gain at 2 bars, because of the corresponding reduction of the average distance of primary ionization clusters. Tubes were indeed mechanically tested up to 12 bars, without major problems (except a deformation of the carbon-fibre envelope); however, the general layout of the output connectors and the insulation of the high-voltage pins have to be improved to allow safe operation at higher voltages.

We are also testing alternative ways of holding the wires to the pins that would allow the use of resistive wires (these have very poor soldering characteristics); fast-hardening conductive epoxies seem very promising for this purpose. In order to reduce the material in the end plates of the modules, we are also considering a direct connection of the signal miniature cables to the anode pins, by gluing or soldering: this will also improve the reliability and decrease the serial resistance of the contacts.

The success of this approach to the realization of a high-rate, high-resolution detector will depend, of course, on the finding of cheap and reliable construction techniques, as well as on the development of high-density electronics.

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