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MULTIWIRE DRIFT CHAMBERS FOR THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

The design, construction, and performance of a 3360-channel multiwire drift chamber system for use in the CERN ISR is described. These chambers eliminate the left-right ambiguity problem and provide position and direction information at the drift cell level. Single wire resolutions of 0.27 mm over 50 mm drift lengths and 0.50 mm over 100 mm drift lengths have been measured with this system. Together these chambers provide three-dimensional track reconstruction capability over a solid angle coverage of nearly 1 sr.

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1. INTRODUCTION

Drift chambers have proved to be very promising high-resolution fast detectors for high-energy particle physics, both for ionizing particles and soft electromagnetic radiation. Since the original invention of the wire chamber¹⁾, the field has seen a steady increase in the development of various types of chambers, from the first operational drift chamber²⁾ to versions on a much grander scale³⁾. Intrinsic accuracies obtainable with drift chambers are typically below $60\text{ }\mu\text{m}$ ⁴⁾, where diffusion effects of the drift electrons and inherent time resolution of the electronics are the principal limitations on resolution. However, for ionizing particles passing through the chamber planes at angles as high as 45° , primary statistics⁵⁾ and electric field ripple from field-shaping cathode wires⁶⁾ become the dominant limitations on resolution. Low electronic thresholds are important for minimizing resolution loss for large-angle tracks by detecting single electrons associated with primary statistics⁷⁾.

"Left-right" ambiguity of track position with respect to the sensitized anode wire has been solved either by staggering consecutive drift chambers⁸⁾, or by placing two anodes separated by small distances⁹⁾. These solutions, however, may be mechanically redundant and technically difficult for large multiwire systems.

Two-dimensional read-out capability for drift chambers has been shown using current division techniques¹⁰⁾ and by using delay lines situated alongside the anodes. However, resolution has been limited to about 2 mm ^{9,11)}. Better resolutions of the order of $400\text{ }\mu\text{m}$ ¹²⁾ are possible, but are limited to the detection of soft electromagnetic radiation.

We describe here a 3360-channel drift chamber system which eliminates the left-right ambiguity problem, and provides position and slope information for ionizing particles with angles up to 45° . A novel electronics system accompanying the chambers is introduced; this has low threshold capability and incorporates monostable one-shots to record the drift times in a simple and low-cost way. Single wire resolutions of 0.27 mm over 50 mm drift lengths and 0.50 mm over 100 mm have been measured with this system.

2. DESIGN AND CONSTRUCTION

The basic unit within the structure of the drift chamber consists of a symmetric cell with a station of sense wires in the centre and drift field regions on each side (Fig. 1). A uniform electric field is generated by cathode wires set at uniformly graded potentials by means of a resistive voltage partition. These cathode wires define the drift region. Cathode wires placed between the sense wires create a quadrupole field configuration with electrostatic stability and confinement; potential wells surrounding these wires allow close wire spacing with high electric fields, while producing a field which falls off rapidly away from the station and into the drift region. So-called "left-right" ambiguities are also removed by the cathode wires since they impede the flow of electrons through the station from tracks originating on one side of the cell.

This multiwire configuration has two advantages over previous drift chamber design: in addition to eliminating ambiguity, the combined drift times from the four sense wires in a drift cell record the slope and intercept of tracks passing through the cell.

Each drift chamber is formed from two semi-hexagonal parts consisting of three planes (v, x, and u), oriented at 60° with respect to one another, with up to 15 cells per plane (Fig. 2). These three planes are contained within 24 cm along z (z is the normal to the chamber plane). One drift chamber determines the particle trajectory in three dimensions with eight constraints. The position and slope information is determined at the cell level within each plane with two constraints. The planes v, x and u are then matched together by demanding that the position and slope satisfy the conditions $v + u = x$ and $(dv/dz) + (du/dz) = (dx/dz)$ for fixed z; these two constraints eliminate ambiguities and accidental tracks.

Three of these chambers, types A, B, and C, with active surface areas of 2 m^2 , 3.4 m^2 and 14 m^2 , respectively, are at present being used in an experiment at the CERN Intersecting Storage Rings (ISR)¹³⁾. Types A and B have drift cells 50 mm in length (see Fig. 1), while C chambers have 100 mm long drift cells. The station

wire configuration is identical in all chambers, while C chambers have twice as many drift field wires in the direction of drift.

Gold-plated wires of 20 μm diameter tungsten and 100 μm diameter copper-beryllium^{*)} are used for the sense and field-shaping wires, respectively. For holding the system of more than 20,000 wires in place, a special technique has been developed which allows easy removal of broken or damaged wires¹⁴⁾. This technique involves crimp connections of the wires in a specially prepared pin made of a hollow copper tube^{**)} surrounded by an insulating mould of acetal^{***)} (Fig. 3a). Pins of 100 μm and 200 μm inner diameter are used to hold the sense and field-shaping wires, respectively. The cell pattern is reproduced with holes drilled in Resocell⁺⁾ with a tolerance of 30 μm (Fig. 3b); the pins are then held in place by wire tension from the pin crimped at the other end. Sense wires are put under 40 g of tension, which is already near the wire's elastic limit. Wires of 100 μm are held with only 120 g. This is to limit the resulting force from the large number of these wires (nearly 200 kg on one side alone).

The Resocell is bolted onto outer metal frames of anodized aluminium for the A and B chambers and stainless-steel Innox is used for the C chambers. Additional support from four reinforcing spokes is needed for the C chambers to prevent sag due to wire tension. An exterior 50 μm stainless-steel wire mesh⁺⁺⁾ provides the chambers' ground plane; the chamber is made gas-tight by thin outer mylar-kelel windows⁺⁺⁺⁾ (Fig. 4).

To compensate for mechanical sag and electrostatic deflection of the wires, a support grid of three adjustable vetronite planes is used to fix the wires at

*) Lumalampan A.B. (Stockholm, Sweden).

**) Minitube (Grenoble, France).

***) Vapé (Oyonnax, France).

+) Laminated Phenolic and paper.

++) Michel & Fils (Mulhouse, France).

+++) Denimex (USA).

points along the span whose distances are no more than 150 cm apart. For these maximum lengths the sagittal displacement due to mechanical sag is 40 μm for sense wires and 160 μm for cathode wires; electrostatic deflection accounts for nearly 190 μm displacement of the sense wires under normal operational voltages.

High voltage is distributed to all wires by printed circuit bus lines sandwiched with vetronite strips and araldite^{*)} to prevent voltage breakdown between the lines. The pins are connected to high voltage with AMP^{**)} connectors and teflon-coated wires soldered to the bus board. Decoronator caps^{***)} are put on unused wire ends. Both connectors are spring loaded, which eliminates the need for soldering directly on the wires. A 5 mm layer of Rhodorsil⁺⁾ covers all exterior Resocell areas in order to electrically insulate exposed high voltage, and to make the pins gas-tight.

A high-voltage protection system similar to one used in a previous experiment¹⁵⁾ is employed to protect the drift field wires against the sometimes large radiation losses experienced in the ISR. Heavy ionization between drift wires crossing adjacent planes may cause breakdown which can destroy these wires. The sense wires are individually protected by high-value resistors and current-limiting high-voltage supplies.

3. ELECTRONICS

A main advantage of the electronics for drift chambers is the considerable reduction in components for a given active surface area, as compared with conventional multiwire proportional chamber (MWPC) systems. However, in a system as large as the one described here with 3360 channels, novel design techniques must be considered. The main features in this system are the use of time-stretching devices¹⁶⁾ which expand the measured times, and a capacitive memory system¹⁷⁾

*) Araldite AY103, Ciba-Geigy (Basel, Switzerland).

***) Amphenol (USA).

***) MP 380598.2, EGLI Ficher (Zürich, Switzerland).

+) RTV 121, Rhône Poulenc Industries (Paris, France).

which stores these expanded drift times until they are ready to be read out, encoded, and transferred as data.

Pulses arriving on the sense wires are amplified, discriminated, and then time encoded in an analog fashion directly on the chamber with the chamber card. The Start defined by pulse detection on the sense wires precedes the Stop generated by an external trigger. Drift times from all chamber cards are capacitively stored in parallel in an analog memory whose data are read out serially with time-to-digital converters (TDC) under the control of the computer.

The chamber card receives signals from eight sense wires for a given station (see Fig. 1), processes them, and transfers two data per wire for a total of 16 outputs; each wire channel has double event capability with a time resolution of 35 nsec. The current signal across $330\ \Omega$ generates an input voltage which is magnified about 80 times by a front-end video amplifier, type 733 (see Fig. 5a and Table 1). The threshold adjustment of the input current is done by a discriminator made with an ECL amplifier stage and a potentiometer made common to all eight channels. A flip-flop acts as a signal shaper for the dual one-shots and selects the first and eventually the second pulse in time.

For a typical drift velocity of 0.05 mm/nsec, the drift time range has been chosen to be 1.5 μ sec and 3 μ sec for the A(B) and C chambers, respectively. Monostable one-shots, type SN74LS221N, are used as time-stretching devices¹⁶⁾ to expand this drift time range into the range defined by an eight-bit time encoder and by a workable frequency of 10 MHz (25.6 μ sec). The drift time is stored as a charge in a timing capacitor and is extracted by converting it into a new, longer time interval obtained by discharging the capacitor with a much smaller current. The expansion (stretch) factor of the drift time interval, is determined by the ratio of two precision resistors R_1 and R_2 (Fig. 5a). The expanded drift times are rigorously proportional to the actual drift times, in spite of the exponential charging law of the capacitor¹⁶⁾. For the A(B) chambers, 1 TDC clock count corresponds to about 6.4 nsec drift time, and 13.5 nsec for the C chambers. The use of the dual one-shot as a time stretcher allows a considerable reduction in the number of

components required on the chamber card. Here, the signals leaving the chamber cards are no longer fast pulses, but relatively slow, shaped signals which are easy to handle, of length up to 25.6 μ sec (see Fig. 5b).

The expanded drift times from all 3360 channels coming from the chamber cards are capacitively stored in an analog memory with the Hold system. Data from the Hold system are read out with only eight 16-channel TDCs ¹⁸⁾ (128 channels), which encode the timing information and pass it on to the computer via standard CAMAC dataways. This read-out cycle is repeated 27 times to read all 3360 channels.

This intermediate memory, the Hold system, operates as follows: 3360 channels of stretched drift time pulses from the chamber cards are simultaneously transferred to the Hold system. At the trailing edge of each pulse, a capacitor linked to a one-shot, as for the time stretcher, is charged (Fig. 6a). At this moment the charge is extracted by discharging the capacitor through a resistor controlled by a diode. (The values of the capacitor and resistor are chosen so that the one-shot period is nearly 25.6 μ sec). The Hold command, synchronized with the trigger, switches the diodes off and holds the voltage across the capacitor to a value which is proportional to the stretched drift time. At the same time, the computer starts the read-out cycle sending a Read command to the first series of 128 channels; the diode is switched on and the remaining charge is converted again into a pulse whose width is proportional to the drift time (Fig. 6b). As soon as these pulses are encoded by the TDCs and read out by the computer, a Read command is sent to the second series of 128 channels, and so on for a total of 27 cycles. The read-out time for this system varies from a minimum of 4 msec to a maximum of 12 msec with data in all 3360 channels (two pulses from each wire).

The capacitors used in the Hold system are high-stability ceramic capacitors. The leakage currents across the capacitors and diodes and internal leakage currents in the one-shots may distort the linearity of the system for long holding times. The measured variation is less than 1 TDC clock count after a holding time as long as 10 msec.

Although particular care has been taken in the choice of the passive electronics components used, they can produce variations in the time-stretching factors and internal delays by as much as $\pm 1.5\%$ and $\pm 3\%$, respectively. For this reason, a test pulse system was devised to provide an accurate calibration of these stretch factors and delays, and to provide a reliable method for monitoring all channels throughout the duration of the experiment.

For each channel, two parameters (the stretch factor SF and time zero T_0) are obtained with a linear least squares fit to TDC clock counts for different given delays: $\text{TDC count} = \text{Delay} \cdot \text{SF} + T_0$. These two parameters completely define each electronics channel. The linearity of the system has been measured to be better than 0.5% over the entire drift time range.

4. PERFORMANCE

Tests were performed on a prototype A drift chamber at the CERN Proton Synchrotron (PS) with a 1 GeV pion beam to determine the chamber's operational characteristics. Efficiencies and cross-talk effects due to drift electrons originating on one side of the cell and passing through the station to opposite-side wires were first optimized as a function of sense and cathode wire voltages; spatial resolution was determined in the PS tests and in the ISR under actual running conditions with the use of MWPCs of 1 mm wire spacing.

A gas mixture of 55% argon and 45% ethane is used in the chambers¹⁹⁾. Argon-isobutane mixtures are typically accompanied by quenching agents such as methylal to inhibit polymer deposition on the cathodes²⁰⁾, while argon-ethane mixtures do not need a solvent additive. The velocity saturation properties of argon-ethane are also better suited to the chambers' operation: saturation varies only slightly as a function of mixtures, and occurs at lower values of the electric field²¹⁾. For the same percentage mixture of argon, these chambers can be operated about 200 V lower in sense wire voltage with ethane as compared to isobutane. The positive ion mobility for ethane is nearly twice as large as that for isobutane²²⁾; argon-ethane mixtures allow operation of the chambers at higher rates.

The cathode and sense wires are used to shape the drift field near the station, thus minimizing focusing effects and other possible field distortions. The two outermost sense wires (S1) nearest the drift field wires, which are not read out, are operated about 200 V lower than the eight innermost sense wires (S2 and S3) which are read out. S2 and S3 sense wires are operated at the same voltage (see Fig. 7). Computer simulation studies²³⁾ indicate that the optimum field configuration occurs for a mean station voltage, $\frac{1}{2}$ (cathode + sense), of +200 V with respect to the drift field ground (see Fig. 1). Using this mean as a reference point, efficiencies and cross-talk effects can be determined.

Particles passing through MWPCs placed before and after the chamber define a track monitor for a given drift cell side. The single wire efficiency is then defined with respect to this track monitor. Inasmuch as the drift electric field affects gas multiplication on the sense wires and therefore efficiency, the drift field is first set at a value already in the saturation range for argon-ethane (820 V/cm). The high-voltage efficiency plateau of the chamber is given in Fig. 10. Note that S2 sense wires reach their plateau nearly 100 V earlier than the S3 wires. This is because of the higher electric field at these wires, as a result of their closer proximity to the drift field wires. The operating voltages are chosen so that single wire efficiencies are greater than 99% and single wire cross-talk is less than 4%. With these voltage values, cathode wires eliminate cross-talk and therefore left-right ambiguity (Fig. 8), while preserving the straightness of electric field lines coming into the station (except near the sense wires where field lines meet). No loss of efficiency was observed as a function of distance from the station. The accidentals rate due to random noise from corona discharge is negligible in the operating voltage range of the chambers.

Throughout the PS tests, the chamber cell was illuminated with a ^{90}Sr source to simulate the high ionization rates experienced in the ISR. For sufficiently high rates, positive ions produced in the cell create space charge, which decreases the drift velocity as well as lowers the efficiency by reducing the gas amplification on the sense wires. No change in either the efficiency or the drift velocity was observed under these conditions.

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The angular dependence of the space-time relation for each wire in the cells was measured by making a plot of the position determined by the MWPCs versus the physical drift time measured by the wire. These relations were obtained after applying the electronics calibration transformation of stretch factors and T_0 's. Figure 9 shows these plots for a sample wire for 0° and 45° tracks passing through the chamber (defined by the direction z normal to the chamber planes). For inclined tracks the resulting curve is nearly linear, and can be approximated piece-wise with two straight lines⁹⁾. The first line takes into account the deviations from a uniform electric field in a region a few millimetres from the sense wires; the slope of the second line defines the drift velocity. The angular dependence of the drift velocity for a sample wire is shown in Fig. 10.

A system of moveable MWPCs of 1 mm wire spacing was also installed in the CERN ISR to continuously monitor the behaviour of the chambers during actual running conditions. The resolution of the MWPCs was ≤ 0.5 mm, corresponding to half the wire spacing. The difference between the measured coordinates corrected for the slope of the track and the line fitted to all measured points was computed. The slope was taken from the MWPC tracks. A distribution of the residuals for the A chamber is shown in Fig. 11; the resulting width is $\sigma = 0.25$ mm. The average σ over A and B chambers is 0.27 mm. For the C chambers whose digitized time interval is nearly twice as large as the A(B) chambers, $\sigma = 0.50$ mm. Table 2 summarizes these resolutions for all chambers. As a check, a straight line was fitted through the A and B chambers using only the drift chamber coordinates calculated with the constant drift velocity and electronic offsets. The widths of the resulting distributions are consistent with the values quoted above. The limiting space resolution due to digitization of the drift times and the uncertainty in the stretch factors is 0.19 mm for the A(B) chambers and 0.39 mm for the C chambers.

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Table 1

Electronics performance

Input impedance	300 Ω
Sensitivity	1 μ A
Time slewing from 6 dB to 20 dB over threshold	< 6 nsec
Drift-time range	1.5 or 3 μ sec
Encoding time	25.6 μ sec
Maximum holding time	12 msec
Word size of the encoding time	8 bits
Linearity	$\sim$ 0.5%
Multiplicity of encoded signal per wire	2
Power dissipation of one cham- ber card with eight wires	8 W

Table 2

Single wire resolution

Chamber	23° tracks (ISR) (mm)	Conversion factor $\left(\frac{\text{nsec}}{\text{clock}} \right)$ $\left(\frac{\text{count}}{\text{count}} \right)$
A	0.25	6.39
B	0.29	6.39
C	0.50	13.50

Figure captions

- Fig. 1 : Detailed view of a drift cell. The two outermost sense wires nearest the drift field wires are not read out.
- Fig. 2 : Perspective drawing of the drift chamber spectrometer.
- Fig. 3a) : Detailed view of a wire support pin. Dimensions in millimetres.
b) : Exterior view of drift cells with exposed pins.
- Fig. 4 : Cut-away view of the C drift chamber module.
- Fig. 5a) : Schematic drawing of one channel of the eight-channel drift chamber card.
b) : Timing diagram of the chamber card.
- Fig. 6a) : Schematic drawing of one channel of the dual 16-channel Hold card.
b) : Timing diagram of the Hold card.
- Fig. 7 : Electric field configurations of the A, B chamber drift cell.
- Fig. 8 : Plateau and cross-talk efficiency as a function of station voltage. Wires are labelled from S2 inwards: S2, S3A, S3B, S3C (see Fig. 7).
- Fig. 9 : Drift time versus position, as determined by MWPCs. (Electronics T_0 offset not unfolded).
- Fig. 10 : Drift velocity as a function of angle for a sample wire.
- Fig. 11 : Distribution of residuals for A chamber for a mean track inclination of 23° .

DRIIFT - CELL OF CHAMBER

Fig. 1

Fig. 2

a)

b)

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

Fig. 11