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of the Helical Delay Line Type**

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DESIGN AND CONSTRUCTION TECHNIQUES
FOR ONE-METER POSITION SENSITIVE PROPORTIONAL COUNTERS
OF THE HELICAL DELAY LINE TYPE

by

S. D. Orbesen, J. D. Sherman, and E. R. Flynn

ABSTRACT

A description is given of the techniques involved in the construction of a one-meter long helical proportional counter which produces excellent position accuracy of 1 mm while yielding particle identification through a measurement of energy loss and total energy.

I. INTRODUCTION

This report describes the design and construction techniques of a one-meter helical cathode proportional chamber developed for use in Q3D spectrometer. Principal features of this counter are high-spatial resolution for a long detector, 1 mm or 0.1% of its length, energy loss measurement sufficient for separating light ions of medium velocity, and a total energy measurement for protons up to 50 MeV (or heavier particles with equivalent range or less). The counter is designed to operate in a high vacuum environment, 10^{-6} Torr, and at internal pressures from 50 Torr to 550 Torr depending upon experimental conditions. Details of the use of such a counter are given in Ref. 1. The theoretical design for helical delay lines has been suggested by Lee et al.,² and their use in nuclear physics applications by Flynn et al.³

II. PRESSURE VESSEL

The detector consists of an inner assembly which contains the active elements for position and energy measurement, and an outer pressure vessel which separates the counter gas from the surrounding vacuum.

The pressure vessel (see Fig. 1) was constructed of 12.7-mm 6061 aluminum with full inside

weldment and removable front and back plates. The overall dimensions of this vessel are 114 cm long by 23.3 cm high by 16.6 cm wide. In the front plate is a slot 107.5 cm long by 3.3 cm high which forms the entrance window. The window structure is constructed so that the window is as close to the detector assembly as possible to minimize energy loss of particles passing through counter gas in front of the detector. This gap was 8 mm without a pressure differential but an additional 3-5 mm was added due to the bowing of the window under pressure. This window consisted of 25 μ m Kapton sealed by a 2.6-mm O-ring and held in place by a 3.2-mm thick stainless steel clamp forming a pressure barrier up to 800 Torr. To prevent a failure of the pressure window in a vacuum, along with its disastrous consequences, all surfaces in contact with the windows are polished to a high luster, and the window tested to 1-1/2 times its standard working pressure. The back plate of the pressure vessel holds all of the feedthrough connectors to provide electrical connections between the detector and external electronics. These include both BNC vacuum connectors for signals and high voltage (HV) vacuum feedthrough for the detector voltages (up to 2 kV). Two gas feedthroughs are located at opposite ends of the back plate as are the support brackets to which

the inner detector assembly is mounted. Slide assemblies mounted on the ends of the pressure vessel and connected to the back plate facilitate removal of the delicate detector assembly for maintenance. The entire detector assembly must also be remotely driven along the focal plane of the spectrometer, thus requiring lightness in weight and flexibility in cabling. The detector travel in the vacuum section of the QSD detector chamber is 1.4 m. An additional feature of the one-meter helix box is a remotely controlled "finger" which can be driven along the detector by stepping motor control. This finger can be used to block the detector window at any desired location from high fluxes of particles associated with elastic scattering. These intense lines of particles could otherwise produce excessive count rates in the detector.

111. HELIX ASSEMBLY

The inner detector assembly, as shown in Fig. 2, has an active (i.e., sensitive to radiation) length of about 100 cm and height of 2.7 cm. This active region forms a parallel plate gas proportional counter whose limits are defined by the front cathode plate consisting of 25- μ m aluminized Mylar stretched tightly over a G-10 frame and the helix winding in back. Proportional counters of this type are discussed by numerous authors (see, e.g., Refs. 4 and 5) and achieve a gas gain of several thousand produced by avalanche conditions on narrow diameter anode wires (see below). The helix winding, acting as the back cathode of the proportional counter, has a pulse induced on its windings for every proportional pulse. This pulse, which is actually induced on several windings simultaneously and whose centroid actually produces the position information, travels down the helix winding in both directions near the speed of light. The helix is wound at 1-mm pitch with 50- μ m-diameter copper wire on a frame constructed of an aluminum ground plane and G-10 insulator. This frame is 17.8 cm high and 3.4 cm thick, resulting in a circumference per turn of 42.4 cm. Assuming that the signals travel at the speed of light, then each turn represents 1.4 nsec of delay for the signal. The top and bottom of the frame have G-10 strips, 3-mm-thick, epoxied together in a T-shaped configuration, to reduce the

amount of dielectric in contact with the helix winding. After the general helix frame dimensions were established, some minor changes were necessary in order to achieve the correct pulse propagation along the delay line. This was done on a trial and error basis by changing the distance of the cathode winding to the central ground plane or by adding to or removing metal from the ground plane. These tests were performed with a pulser by observing the risetime at the ends of the helix on an oscilloscope and did not require the use of radioactive sources. This technique saves considerable effort in the helix construction by assuring that the helix has the proper delay line characteristics independent of the actual counter operation. To do this a pulser is connected to one end of the helix through a pulse splitter while the other end is terminated. Observation of the reflected pulse in the pulse splitter is then done by an oscilloscope. The desired features of the reflected pulse are minimum risetime and a slightly negative undershoot before the positive rise. This latter feature results in a minimum of time jitter for low-level discriminators. The pulse shape for the present helix is shown in Fig. 3.

An NE 110 plastic scintillator 103.5 cm long by 6 mm thick is inserted through the middle of the detector frame to act on a stopping detector. Light pipes with 170° bend are epoxied to both ends of the scintillator and coupled to RCA 6199 photomultiplier tubes mounted on the back plate with optical coupling compound.

The helices are wound on a lathe equipped with a slip clutch for smooth starting and a lead screw driven compound rest to provide the correct winding pitch (1 mm in the present case). A positioning and tensioning device mounted on the compound rest holds the copper wire spool. The helix is wound at a speed of 19 rpm. The wire is maintained at a tension of 50 gm during the winding. It is not necessary to notch the frame preceding winding as this tension holds the wire correctly in place.

IV. PROPORTIONAL CHAMBER CONSTRUCTION

Nine gold-plated tungsten wires, 20 μ m in diameter, form the anode structure, along with two 127- μ m-diameter guard wires. The anodes are stretched across two G-10 bridges containing notches to

receive the anode wires and these are located at opposite ends of the detector frame. The bridges are machined to high precision and inspected on an optical comparator before installation. This precision is necessary because they control the anode wire spacing both from wire to wire and from anode wire to both cathode planes. Deviations in this spacing are magnified a factor of ten in deviations of gain between wires.

The wire spacing in this case is 3 mm, both from wire to wire and wire to cathode plane. The bridges are epoxied in place along with solder tabs which are used for attaching anode wires. The method used to connect the anode wires is to solder one end of the wire to a solder tab, place the wire in the correct notch of the bridges, then hang a weight to the other end of the wire and solder this end in place. The amount of tension produced by the weight on the wires is most critical and care is taken that it does not vary from wire to wire in order to get uniform electrical signals. The amount of weight used for the 20- μ m anode wires is 50 g, which is very close to the breaking point of the wire. In soldering the wires to the solder tabs, emphasis is placed in getting a smooth and clean solder joint as sharp points and solder flux may cause corona and subsequent high-voltage breakdown.

The front cathode plane proved to be one of the most difficult parts of the detector construction. The front cathode in this case consists of 25- μ m aluminized Mylar stretched to a mirror-like finish across a 3-mm-thick G-10 frame and held in place with 3 M Brand 77 spray adhesive. In order to get uniform signals from the anode wires for good dE/dX resolution for the entire 1-meter length of the detector, the front cathode must run parallel and at a distance of 3 mm to the anode wires. The original scheme was to attach the Mylar film to the clamp that holds the pressure window in place; however, this proved to be impractical as the pressure vessel was found to expand away from the detector when gas pressure was applied. The frame on which the Mylar is stretched must, by the necessity of the small space between the helix and pressure vessel, be thin-rigged and flat. Even when these requirements are met, the process of stretching the mylar on the frame causes the frame to twist and distort. The final solution was to place two 100- μ m-diameter

stainless steel aircraft cables so they run over the tops of the bridges and are stretched very tightly with miniature turnbuckles. Mylar screws with a bevel cut in the head were screwed into the backside of the G-10 frame so that when they are in contact with the cables, radial tension is applied to the frame, thus holding the frame close to the cables and keeping the Mylar tightly stretched.

The principal problems that have developed after construction are an occasional anode wire breaking or the presence of foreign materials such as lint. Lint attracted by the electrostatic field to the anode wires destroys the symmetry of the anode geometry; consequently, all reasonable steps are taken to keep foreign material out of the pressure vessel.

V. GAS SYSTEM

A gas handling system, shown in Fig. 4, was built to insure the correct gas mixture, 70% argon-30% CO_2 , and also to provide a wide range of well-regulated operating pressures. Standard-grade gas regulated at 500 Torr flows through silica gel dryers and filters to calibrated flow meters equipped with a mixing tube; the combined gases are then routed to a Moore Products Co. Model 44-50 subatmospheric pressure regulator capable of providing a constant pressure of $\pm 1\%$ over the entire operating range of the detector. Detector pressure is measured locally by a differential pressure gauge and is also remotely indicated by readout of a differential strain gauge transducer. A continuous flow of gas is maintained through the detector during operation in order to minimize the buildup of contaminants in the gas.

VI. RESULTS OF X-RAY STUDIES

The operating characteristics of the counter may be determined by the use of a collimated x-ray source. The use of this technique permits rather detailed knowledge of the counter's detection properties while minimizing the use of expensive accelerator time. The source used for the measurement is a ^{55}Fe source which emits a 5.5-keV x ray. The material is deposited on a thin wire and collimated by a set of slits to approximately 0.15 mm (the source was fabricated by New England Nuclear).

The most important feature of the counter to be determined is the risetime at the ends of the helix. Figure 5 is a photograph of an oscilloscope trace for signals resulting from placing the x-ray source near the center of the detector. The detector was operating at 1970 volts with a pressure of 550 Torr of 70% argon, 30% CO₂ gas mixture. The risetime indicated in the figure (10%-90%) is approximately 40 nsec. The slight negative undershoot preceding the main pulse is considered desirable because the discriminators fire on signals going positive from zero. Thus, minimal time jitter is achieved for this condition, and indeed, the time resolution for the situation illustrated is better than 1 nsec. The pulse height shown is on the order of 40 mV (the preamplifier gain is 10 and the discriminators fire at 1.0 mV). These conditions are quite adequate for the entire range of the detector and represent minimal operating conditions since the smallest energy deposition when operating with low-energy accelerators will be 18 keV.

Figures 6 and 7 are photographs of the anode pulses which correspond to the helix cathode pulses given in Fig. 5. This information is used to indicate the energy loss of charged particles passing through the detector and hence serves to identify the type of particle. Figure 6 indicates the initial rapid rise of the pulse due to the electron avalanche (see Ref. 4 for details of this phenomenon). These pulses rise in several hundred nanoseconds and may be employed for fast timing purposes to give time jitter less than 10 nsec. This result is used in a fast coincidence with the scintillator located within the helix to reduce background events. A resolving time of typically 20 nsec is used for this purpose, resulting in substantial background discrimination against neutron and γ rays. Figure 7 indicates the slow part of the anode pulse, which is due to the positive ions being repelled by the anode wires. It is seen that on the order of one hundred μ sec is required to fully collect the charge. This is, in general, an impractical amount of time, and amplifier time constants are usually adjusted for 2-8 μ sec depending upon the accuracy of the energy loss information required. The longer the time constant, the more charge collected and the better the energy loss resolution. A compromise

between desired resolution and count rate capabilities usually determines this setting.

The energy loss information from the x-ray source is shown in Figure 8. Use of this source to establish the energy loss characteristics is only partially indicative of the resolution because of the single initial photoelectron associated with an x ray in contrast to the continuous track of ionization of a charged particle passing through the detector. The lower peak, which is an escape peak, illustrates this difficulty. Nevertheless, this photograph, which is a multianalyzer spectrum of the summed anode wires amplified with a 2- μ sec time constant, does suggest the resolving ability of the energy loss system. Here the resolution (FWHM) is about 20-25%, which is typical of the results achieved with the counter for light-charged ions. Heavy ions, which leave many more ion pairs in their track, yield better results, about 7%.

Finally, a position spectrum obtained by placing the x-ray source at 10-cm intervals along the counter is shown in Figure 9. This figure is a photograph of a 1024 channel multianalyzer array. The gain of the TAC connected to the discriminators at each end of the helix was adjusted to give the full one meter across these 1024 channels. Thus each channel represents approximately one mm. It is seen that each peak falls into nearly one channel, indicating that the spatial resolution is less than one mm across the entire length of the detector. An expansion of these peaks by using a biased amplifier shows that the resolution is about 0.6 mm in the center of the detector and degrades to about 0.8 mm near the ends. The efficiency of the detector may be found by summing each of the peaks, and it is found to be constant within 3% across the entire detector.

VII. SUMMARY

The one-meter-long detector described here has now replaced the shorter one mentioned in reference 1. It not only affords an energy range of more than twice as great, but, because of its design permits detection of heavier ions and lower energy-charged particles. This is due to the recessed front window and the location of the scintillator within the helix structure. It is currently the principal detector system of the QSD spectrometer.

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3. E. R. Flynn, S. Orbesen, N. Stein, H. A. Thiessen, D. M. Lee, and S. E. Sobbotka, Nucl. Instr. and Methods 111, 67 (1973).
4. D. H. Wilkinson, Ionization Chambers and Counters (Cambridge Press, 1950).
5. G. Charpak, Annual Review of Nuclear Science 20, 195 (1970).

Fig. 1. Photograph of detector pressure vessel

Fig. 2. Photograph of exposed detector. The helix winding can be seen running from left to right with the photomultiplier tubes below it. Within the right hand side of the helix may be seen the scintillator and above this at each end are the bridges supporting the anode wires.

Fig. 3. Photograph of the reflected pulse induced by a pulser input at one end of the helix. The horizontal scale is 50 nsec/cm and the vertical 10 mV/cm.

Fig. 4. Schematic of the counter gas flow system.

Fig. 5. Cathode signal induced by an x-ray source after preamplification. The horizontal scale is 20 nsec/cm and the vertical 10 mV/cm.

Fig. 7. As in Fig. 6, except the horizontal scale is 10 μ sec/cm.

Fig. 6. Anode signal induced by an x-ray source after preamplification. The horizontal scale is 100 nsec/cm.

Fig. 8. Multichannel analyzer spectrum of amplified anode signals induced by x-ray source.

Fig. 9 1024 multichannel analyzer position spectrum for x-ray source at 10-cm positions.
Each channel represents approximately 1 mm.