THE PAD TPC: A TPC WITHOUT SENSE WIRES

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A time projection chamber (TPC) is proposed in which the gas amplification is obtained in a single parallel gap between a transparent cathode grid and an anode plate. The anode is segmented into circular pad rows for $r\phi$ measurement by centroid finding and into circular strips for dE/dx sampling. This technique offers (a) higher $r\phi$ resolution (up to a factor 2) due to the suppression of the major error source, the combined effect of ionization fluctuations and $E \times B$ and track angle smearing, (b) better two track resolution (up to a factor 4, in principle), and (c) substantially reduced positive ion feedback. In addition, there results a simpler construction, less dead space and slower ageing by deposit formation. With Ar/CH_4 (80/20%) a maximum gain above 10^5 was obtained in a single amplification gap. Positive ion feedback was found smaller than 4%. The properties of this detector and first test results will be discussed.

1. Introduction

The time projection chamber (TPC) has proven to be a very powerful tracking device, providing excellent pattern recognition and good dE/dx information for particle identification [1]. Many modifications to the original design [2] have been discussed over the past years, including the use of parallel plate counters as endcap chambers. The principal aim was to improve the two track separation in $r\phi$. It was, however, felt that the additional development work and especially the additional cost in electronics were not justified by this goal alone. Recent developments raised the author's interest again in this technique. Several groups started or are planning to operate a TPC at ambient pressure. It was soon realized [3] that at 1 atm. the major error for the $r\phi$ measurement is caused by the so-called "tg α effect": the induced pulse on the cathode pads is smeared out due to the track angle α [fig. 1(b)] and $E \times B$ modifications to the electron trajectories near the grid and sense wires. Ionization fluctuations along the track then lead to an error in the centroid determination.

We will demonstrate, that the introduction of a parallel plate counter can effectively suppress this "tg α -effect" as well as improve the two track separation in $r\phi$, and strongly reduce positive ion feedback. The suppression of the sense wires, in addition, simplifies the construction and reduces dead space (fewer support frames) and ageing effects due to deposits on the anode (because of much larger anode surface). Only improved two track separation requires more electronic channels *.

* Some of these points are also discussed by A. Peisert in these Proceedings [8].

We will discuss the principle and properties of the parallel plate geometry and pad anode design and describe the experimental work carried out on gas amplification, positive ion feedback and on a full scale prototype.

The Pad TPC will be compared to a 1 atm "standard TPC" with the following characteristics [fig. 1(b)]: sense wire pitch = 4 mm (with field wires in between); grid pitch = 2 mm; gap = 2×4 mm; pads = 8×8 mm; driftfield = 0.1 kV/cm, magnetic field = 1.2 T.

2. Principle of Pad TPC

2.1. Pad TPC design

The design of the Pad TPC is sketched in fig. 1(c). A parallel plate geometry is set up between the cathode mesh (terminating the drift volume) and the anode plane. All information is taken from the anode plane, which is segmented into circular strips (for dE/dx sampling) and circular pad rows for $r\phi$ measurement by centroid finding. The Pad TPC measures only direct avalanche signals. Thus, the Pad TPC offers two advantages:

- A signal which is narrower in $r\phi$ (the avalanche widening in the amplification gap is < 1 mm rms [4], whereas the induced cathode pulse in the standard TPC has a 4 mm rms width for a 4 mm gap;
- and a circular arrangement of the pads.

The narrow signal helps the two-track separation, the circular symmetry plus parallel plate amplification reduces ($E \times B + \text{tg}\alpha$) distortions.

The circular pad geometry had been considered for the standard TPC [5], but was rejected because the

The major contribution is from W_{ind} , which is strongly reduced in the Pad TPC:

$$W' = W_{aval} + W_{diff} + W_{tg\alpha}$$

$$\sim < 1 + 0.1 - 0.8 + \sim 0 < 1.4 \text{ mm.}$$

We see, that a three- to four-fold improvement in track separation is possible.

The only drawback is, that to achieve this improvement, the pad size has to be decreased to $< 3 \text{ mm}$ and three times more amplifiers are required. However, this may often be justified at small radii, where the tracks are closest.

For larger radii one may couple resistively several pads and read out only each third, fourth or more [fig. 1(c)]. In this case, the pad pitch should be smaller than the avalanche width [6].

2.3. Single track resolution in $r\phi$

The single track resolution is given as the accuracy of the centroid computation. In the standard TPC, one

obtains typically:

$$\sigma = \sigma_{el} + \sigma_{diff} + \sigma_{tg\alpha} + \sigma_{var}$$

$$\sigma(\mu\text{m}) \sim 100 + (20-160) + (100-300) + 100$$

$$\sim 175-370 \mu\text{m}$$

$$\Delta z = 0-1 \text{ m} \quad -30^\circ < \alpha < 30^\circ$$

with σ_{el} = electronics error, proportional to noise/signal, σ_{diff} = error from diffusion and σ_{var} = sum of various errors like mechanical tolerances, alignment, etc.

Actually, $\sigma_{tg\alpha} \sim 100 \mu\text{m}$ for $-30^\circ \leq \alpha \leq 0^\circ$, and rapidly rises for $\alpha > 0$. This effect is very strongly dependent on chamber geometry. We observe, that – especially for shorter drift length – $\sigma_{tg\alpha}$ is the major contribution.

This error can be reduced strongly in the Pad TPC.

Fig. 2(a) shows the electric field lines in a standard TPC. Electron trajectories have a component perpendicular to the magnetic field in zone A and zone B, which results in a deflection along the wire and pad row. This smearing of the avalanche combined with the fluctuations in the ionization causes the error $\sigma_{tg\alpha}$. Several

Fig. 2. (a) Electric field lines in the standard TPC (1 atm). S = sense wire, F = field wire, Gr = grid, G = ground plane: 1 atm, $E_{drift} = 0.12 \text{ kV/cm}$, $V_{sense} = 1500 \text{ V}$ (Lindner [3]). (b) Contribution $\sigma_{tg\alpha}$ to $r\phi$ -error from track angle α and $E \times B$ forces in zones A and B (Hilke [3]).

authors have studied this effect [3]. For our standard TPC, the result is shown in fig. 2 (b) (Hilke [3]). Note the strong asymmetry around $\alpha = 0^\circ$. The deflection in zone A is more important because of the lower electric field. Reducing the grid wire spacing, therefore, reduces the effect, but a pitch below 1 mm is impractical. A mesh (0.5 mm pitch) would reduce the $E \times B$ effect even further. But, in a standard TPC, two effects remain: the deflection near the sense wires and the smearing due to $\text{tg } \alpha$. At best, one obtains $\sigma_{\text{tg}\alpha} \sim 75\text{--}180 \mu\text{m}$.

The Pad TPC with circular pad rows, on the other hand, reduces both these effects: $\alpha \sim 0^\circ$ (at least for most tracks) and very small deflection near the mesh. Therefore, for a Pad TPC

$$\sigma(\mu\text{m}) \approx \sigma_{\text{el}} + \sigma_{\text{diff}} + \sigma_{\text{var}} \\ \sim 100 + (20\text{--}160) + 100 = 140\text{--}210 \mu\text{m}.$$

As can be seen, one obtains an appreciable improvement, especially at large angles.

This improvement can be achieved without more electronics, using resistive charge division [6]. Pads of 1.5 mm pitch may be resistively coupled and only each forth pad connected to an amplifier as long as better two-track resolution does not require more channels [fig. 1(c)]. With 8 mm long pads, $R = 35 \text{ k}\Omega$ and $C = 1.5 \text{ pF}$ between amplifier connections, and gas amplification of 2×10^4 , one obtains $\sigma_{\text{el}} = 100 \mu\text{m}$ (fig. 8 in ref. 6). Ideally, the pad row would just consist of a continuous resistive layer ($35 \text{ k}\Omega/\text{square}$). Homogeneity of about 1% would be required only locally (over 1 cm).

3. Test results

3.1. Gas amplification

Throughout the tests, Ar/CH_4 (80/20%) has been used. This gas offers a unique combination of high electron drift velocity at low electric field ($\sim 5 \text{ cm}/\mu\text{s}$ at $0.1 \text{ kV}/\text{cm atm}$), small transverse diffusion in a magnetic field ($80 \mu\text{m}/\sqrt{\text{cm}}$ at 1.2 T) and good dE/dx

Fig. 4. Gas amplification as a function of high voltage. Gap = 3 mm, $\times$: solid cathode, $\circ$: mesh cathode; $\text{Ar}/\text{CH}_4 = 80/20\%$.

resolution. Its quenching properties in a parallel plate counter were, however, unknown to the author.

In a parallel plate counter the real gas amplification is $G = e^{\alpha d}$, with d = gap width and α = 1st Townsend coefficient, if all charges enter at the cathode, as is the case in the TPC. However, only the fast electron signal with $G_{\text{effective}} = e^{\alpha d}/\alpha d$ may be used, the positive ion signal being too weak ($\sim G/60$ in 100 ns for a 3 mm gap). To obtain a reasonable $r\phi$ resolution (see above), we require for 8 mm pads a minimum

$$G = 2 \times 10^4 \rightarrow \alpha d = 10, \quad G_{\text{effective}} = 2 \times 10^3.$$

It turns out that the same real gain produces approximately the same signal on the pads in this Pad TPC as in the standard TPC, where pad signal in the first 100 ns = total charge in avalanche on wire/ $4 \text{ mm} \times \frac{1}{4}$.

Fig. 3. Various test chambers. (a) Solid cathode (Cu or Cu plated with Pt). (b) Mesh (wire diameter = $50 \mu\text{m}$, pitch = 0.5 mm, stainless steel). (c) Double gap chamber for measuring positive ion feedback. $U_1 = -4300 \text{ V}$, gap 1 = 3 mm, $U_2 - U_1 = -45 \text{ V}$, gap 2 = 4 mm, S = source, P = anode pad (diameter = 1 cm).

For 4 mm wide dE/dx strips, however, the signal is only one fifth that on the sense wires of a standard TPC. Because of large Landau fluctuations this is acceptable.

In a first series of tests, the gas-amplification was measured with various electrodes (fig. 3): flat copper cathode, same cathode plated with Pt, stainless steel mesh (0.5 mm pitch, 50 μm wire diameter) and same mesh plated with Pt.

In a single gap of 3 mm a maximum real gain of $> 10^5$ was measured (fig. 4) with all electrodes except the copper (which has the lowest work function). This electrode showed afterpulses at lower gain.

For a real gain of 5×10^4 , we find $E/p = 4600 \text{ V/3 mm/730 Torr} = 21 \text{ V/cm Torr}$.

This value is – according to Heylen [7] – close to the minimum for the 2nd Townsend coefficient η , which is desirable for stability. In this E/p region, electron emission from the cathode by photoeffect and positive ions defines η : the afterpulses observed with the copper cathode (at $t_0 + \text{drift time for positive ions}$) indicate, that positive ion collisions are the predominant factor.

It has, therefore, been demonstrated, that sufficient gain may be obtained with the standard TPC gas (Ar/CH_4) in a single parallel gap.

3.2. Positive ion feed-back and gating

With the set-up shown in fig. 3(c), an upper limit was obtained on the positive ion feed-back: $< 4\%$ (from $J_2/J_1 < 8 \text{ nA}/200 \text{ nA}$). The accuracy was limited by the sensitivity of the nA-meter.

We expect the ion feed-back to be only about 1%: the ratio $E_{\text{drift}}/E_{\text{amplification}} \sim 1/150$ should determine the transparency of the mesh for the positive ions, which follow closely the field lines (ion diffusion $\sim 10 \mu\text{m}$ in 3 mm; electron avalanche radius $\sim 1 \text{ mm}$).

Thus, the ion feedback is probably only $\frac{1}{8}$ that of a standard TPC. Higher particle flux may, therefore, be tolerated without the need for gating. If, however, gating should become necessary, the same technique may be applied as for the standard TPC: a second grid with alternative wires pulsed to $\pm 20 \text{ V}$, the mesh acting as an efficient screen.

3.3. Full-scale prototype

A prototype, 1.20 m wide, 0.9 m high (fig. 5), was constructed to gain experience with large scale problems. The pad configuration is our old standard, as it was the only one readily available. The grid is stretched with 100 kg/m and supported each 20 cm to reduce the sagitta due to electrostatic forces. With the anode being flat to $\pm 15 \mu\text{m}$, we expect a maximum sagitta of 30 μm to be acceptable. The resulting long range gain variation of about 25% can be measured and easily corrected for.

Fig. 5. Prototype 1.2 m $\times$ 0.9 m for large scale tests, with mesh and supports each 20 cm (standard pad configuration for historical reasons).

4. Conclusion

It has been shown, that the parallel plate counter is superior to the multiwire proportional chamber as detector in a TPC. For a Pad TPC, the performance is limited essentially by the signal error from the long drift volume. This technique certainly deserves more attention. Many aspects require further study, especially those related to large scale implementation.

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