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FURTHER STUDIES OF AVALANCHE MODE OPERATION OF RESISTIVE PARALLEL PLATE CHAMBERS

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Abstract

We have investigated the high rate operation of the resistive plate chamber and have discovered that Melamine-phenolic laminates are good candidates for a plate material. We have previously shown that avalanche mode (rather than spark mode) gives a substantial improvement in the rate capability. There are two new encouraging results; the timing spectra are not affected by the rate; and particles at non normal incidence have a higher detection efficiency; these substantially increase the rate capability of this device. However there are two results that show that further R and D is needed. These are: the change in resistivity of the plate material with time; and the fall off of the efficiency with increasing high voltage. Our goal is to produce a cheap large area detector that has good spatial and time resolution and has the rate capability suitable of the muon system at a future collider. We believe that these results show that this detector is already promising and should satisfy these requirements with further R and D.

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1. INTRODUCTION

The Resistive Plate Chamber (RPC) is a very simple gaseous detector. Essentially it is a gas volume enclosed by two parallel resistive plates. A high voltage is applied to the outer surfaces of the plates, thus there is a strong electric field across the gas gap. A through going charged particle ionises the gas; the liberated electrons avalanche in the high electric field and so produce a pulse on the electrodes. A larger pulse can be produced if the avalanche initiates a spark breakdown. The high resistivity of the plates keeps this discharge local. The electrons and positive ions produced by this discharge are deposited on the surface of the plates, this reduces the electric field. The full field is restored by current flowing through the resistive plate. Obviously this mechanism leads to a fall off in the detection efficiency with rate. In our previous paper [1] we have discussed the operation of the RPC in spark and in avalanche mode, in particular we discussed the improvement in the rate capability when operating in avalanche mode. We have also shown that melamine-phenolic laminates used as resistive plates give the highest rate operation at this moment.

We have continued these studies and present here our recent results. All the results here are obtained from working in avalanche mode. The resistive plate material is a melamine-phenolic-melamine laminate 0.85 mm thick (in some cases it is 1.2 mm thick). We have found that the resistivity of melamine and phenolic vary with time and humidity; we discuss the implications of this. We also discuss the drop off in efficiency with increasing high voltage. Both these problems will need further R and D effort. However encouraging results have been obtained concerning the timing spectrum; essentially there is no time walk and no degradation of the time resolution with increasing rate. Also we have measured a substantial increase in detection efficiency with non-normal angle of incidence of the through going particles.

2. DESCRIPTION OF THE CHAMBER AND TESTS

A cross section of a typical test chamber is shown in figure 1. We have built a number of chambers using different materials for the plates. The electrodes are made by painting the surface with nickel paint; these electrodes have a resistivity of $1\sim 2 \Omega/\square$. The chambers have an active area of $22 \times 22 \text{ cm}^2$ and the signal from a single pad is read out. The spacers around the edge used to seal the gas are made from PVC, different thicknesses (between 2 and 8 mm) have been used. The gas was fed in via a small insulated tube. Usually there were no other spacers used in the chamber. The chambers described in these tests have resistive plates of melamine-phenolic-melamine laminate (more details can be found in ref. 1.). The test chambers also had two external sheets of Plexiglas for mechanical support. The rate measurements were performed in a test beam in the East Hall at CERN. The rate is the

average rate during the 400 ms spill. The beam was defocused so that the whole active area of the chamber was exposed to the beam.

3. RESISTIVITY

We have measured the resistivity of the resistive plates. This was done by painting an area of $20 \times 20 \text{ cm}^2$ on both sides of the plate with conductive paint. We applied a voltage to these pads (between 500 and 2000 volts) and measured the current. We mounted this within a gas box through which we passed bottled nitrogen. In figure 2 we show the results from a pure phenolic plate 500 micron thick, and also the results from a melamine-phenolic-melamine laminate 850 micron thick. At various times, marked on the figure, we opened the gas box and exposed the plate under test to normal atmospheric humidity. At other times we reversed the polarity (marked with arrows on the figure). When we did this the resistivity dropped, but returned to the value before the polarity change within one hour. The same effect was observed with an increase of voltage. As can be seen from the figure the resistivity of the melamine-phenolic-melamine laminate rose from $10^{10} \Omega \text{ cm}$ to $10^{15} \Omega \text{ cm}$ over a 2 month period. On exposing the plate to humid air the resistivity does not return to $10^{10} \Omega \text{ cm}$ but to a higher value of $10^{12} \Omega \text{ cm}$. This suggests that the electric field is causing some out-gassing (presumably water). The variation in the resistivity observed on the right side of the plot in figure 2 appears to follow the relative humidity of the atmosphere. More controlled tests are underway.

For the tests of the chambers with cosmics and the test beam, generally we have used dry gas (by dry we mean that the gas is from standard gas bottles available at CERN, no special precautions were taken to remove the traces of water). Thus we expect that the resistivity of the chamber plates undergoes a similar change in resistivity as measured above. In figure 3 we show a selection of efficiency plateau curves for an RPC with a 5 mm gap. The curve marked 'A' is taken in the test beam with a freshly made chamber. The chamber was then left on the shelf for some months (sealed) and then the plateau curve remeasured with cosmics (the curves marked 'B' and 'C'). The chamber needed an extra 1000 volts. We then added 1% water vapour to the gas mixture; this change in gas mixture had the immediate effect of increasing the operating voltage by 600 volts (curve 'D'). The operating voltage then dropped by 1400 volts over the next 3 days (curves 'E' and 'F'). We discuss these observations below.

We have discussed in a previous paper [1] our belief that the resistivity of the plates is not the critical parameter governing the rate capability of these chambers. The resistivity is the product of charge carrier mobility and the density of these charge carriers; as we discuss below we believe that mobility is one of the governing parameters. It is possible to have substances that have high charge carrier mobility which also have high resistivity (diamond

for example), thus a material with low resistivity may not have the best rate capability. In the original understanding of the behaviour of the RPC the rate dependence was thought to depend solely on the resistivity and dielectric constant of the plate material. The reason for this is that the avalanche/spark process deposits charge on the surface of the resistive plate and this area of charge has to be recharged. This element of the plate material has a particular resistance (which depends on ρ) and capacitance (which depends on ϵ) associated with it. Thus if one makes the analogy with an RC circuit, one finds a rate dependence that varies as $\epsilon\rho$, where ϵ is the dielectric constant and ρ is the bulk resistivity of the resistive plate. However as we showed in our previous paper this can not be considered as a simple RC circuit, as, for example, the charge moves through the plates themselves. There may also be another factor; this is that the avalanche/spark process may inject charge carriers into the plate itself. Since the resistivity depends on the product of the charge carrier density times the drift velocity, the resistivity at this place may be locally reduced. We believe that the recharging of the surface of the plate (and thus the rate capability) may depend more on the mobility of charge carriers and the thickness of the plates, essentially one has to pass this charge from one surface of the resistive plate to other surface.

However the resistivity of the plates does play a role in the chamber operation (however this does not directly affect the rate limit). There is a small leakage current through the spacers keeping the two resistive plates apart. If the resistivity of the plates is very high, this small but finite leakage current causes a large voltage drop across the resistive plates. This will reduce the electric field across the gas gap. As can be seen from the figure 3, this can be compensated by increasing the applied high tension. If the resistivity is a principle factor controlling the rate dependence of the RPC, we would expect that the rate dependence of our chambers should degrade with time as the resistivity of the plates increased. We show in figure 4 the rate dependence of a chamber, taken 24 hours apart. In this period the working voltage had to be increased from 9.1 kV to 9.4 kV (presumably due to an increase in resistivity (of a factor 2 or 3 according to figure 2)), however there is not a marked difference in the rate behaviour; this lends credence to our belief that the avalanche process injects charge carriers into the plate and that the static resistivity may not strongly influence the rate capability. However more systematic tests are needed to clarify this point. Before these measurements the chamber had been sealed and left on a shelf for a month, so one assumes that the resistivity is high.

Obviously such large changes in operating voltage would be unacceptable in experimental conditions where many thousand of square metres of RPC would be used. However, probably stable operation can be obtained by adding a small quantity of water vapour to the gas mixture. Current tests in the laboratory show that indeed this is true.

4. GAS GAP

The ‘standard’ RPC (built by Santonico et al.[2]) has a gas gap of 2 mm. It appears from the literature that this value is a compromise. In spark mode the most precise timing is measured with a small gas gap. However one needs a gas gap of a certain size to produce sufficient primary ionisation so that the device will operate with a reasonable efficiency. Thus 2 mm has been chosen which gives an efficiency of around 95% for the ‘standard’ RPC. As discussed in our previous paper [1] and by others [5,6] there is an alternative mode to operate these devices, the avalanche mode. Since the pulse is much smaller, less charge is produced and one can work at higher rates. The avalanche is a precursor to the spark, a spark immediately follows (or can be delayed by up to 200 ns). Working in avalanche mode one needs to suppress the spark mode as much as possible; sparks produce big pulses that produce multiple hits for strip readout, and also deposit more charge on the resistive plates which affects the efficiency. We believe that increasing the gas gap should decrease the spark probability, increase the efficiency and not affect the timing very much. This is borne out by our tests. The efficiency plateau curves of chambers with a 2, 3 4, 5 and 8 mm gas gap are shown in figure 5. We operate in a mode where the avalanche pulse is typically 2 pC and the spark mode is 50 pC. The efficiency is measured by setting the threshold as low as possible (we estimate that we trigger on pulses of 0.5 pC). We have a second discriminator with a higher threshold which triggers on sparks; this we record as the probability for a spark. The plot in the lower right hand corner of figure 5 shows the voltage corresponding to the maximum of the efficiency, a linear relationship is observed. There are some minor differences in the construction of these chambers, the 3 and 5 mm gap chamber have Melamine-phenolic plates 0.85 mm thick while the others have 1.2 mm thick plates. The 4 mm gap chamber has a spacer (12 mm diameter PVC) close the centre of the chamber. The same gas mixture is used for all and is 71% Argon, 11% isobutane, 10% CO₂ and 8% CF₄.

There are several things clearly shown in this figure. The first is that the probability of forming a spark does indeed decrease with increasing gap width. One can operate a chamber with an 8 mm gap in avalanche mode at full efficiency with a very low probability of a spark. There is a drop of efficiency with increasing voltage. The reason for this is unclear. The 4 mm chamber has an unexpectedly small drop off (compared with the 5 mm). Whether this is due to the difference in resistive plate thickness or due to having this extra spacer, we do not know at present. Naively one would expect the spacer to have a detrimental influence on the performance of the RPC, however we have found that the spacers (around the edge) are necessary for the chamber operation. From this figure we also see that a variation in gap width of 60 μ m corresponds to a change of 100 volts in working voltage. Thus if we consider that the plateau is 400 volts long (e.g. the 8 mm gap chamber voltage can be increased by 400 volts before the onset of sparks), we have to control the gap with a precision

of $\pm 120 \mu\text{m}$. If we can work with a lower threshold, or with a different gas mixture this tolerance will change. The shape of the plateau curve, the probability of sparks and the variation of gap width to working voltage will change according to the gas mixture. We have started an extensive series of measurements with the aim of finding an optimum that will give a mechanical tolerance as large as possible.

We show in figure 6 the rate dependence for a 2 mm and 4 mm gap chamber. If we use 90% as the lower value of useful efficiency we see that there is a five fold gain in rate; this is essentially due to the increase in efficiency for the larger gap.

The construction of large areas of RPC will necessitate the use of spacers to maintain the two plates parallel to one another. This spacer will disturb the field in the chamber. We performed a test using a 12 mm diameter spacer made from PVC. We found that the dead area introduced by this spacer was exactly equal to its geometrical size independent of rate. As we previously stated, spacers appear necessary to the operation of the chamber. The study of the effect of spacers continues.

5. GAS MIXTURE

Our goal is to find the best gas mixture with which to operate the RPC. Ideally one wants a non-flammable, environmentally friendly gas. Thus the hydrocarbon content should be kept low. CF_4 is not excluded by the Montreal convention as it does not harm the ozone layer, however all other freons are banned. RPCs in spark mode require a gas mixture that includes a high fraction of quencher (usually about 40% isobutane is used) and also about 5% of freon. The role that the freon plays is unclear: it is possible that it acts after the spark breakdown to remove free electrons or actually limits the intensity of the spark. We have found in spark mode that we could not obtain high efficiency without adding freon-12. A good example of this is shown in figure 5 where one reaches a maximum of 40% with a 2 mm gap in spark mode for this gas mixture (which does not include freon-12). For avalanche mode the case is different. One still needs a quencher to stop photon feedback from initiating multiple avalanches, however one does not need freon-12.

One problem that we have already discussed is the drop in efficiency with increasing high voltage. This drop does depends on the gas mixture in use. At present our favourite mixture is 11.5% isobutane, 10% CO_2 and 78.5% Argon. We will continue these studies, especially as we have to consider the effect of water vapour.

6. ANGLE EFFECT

We have measured the efficiency as a function of the angle of incidence and rate. For increasing angle the particle traverses an increasing effective gas gap, however this effect is

small as it varies as $1/\cos\theta$, an increase of 15% for a particle at 30° . However there is another possible effect, this is the effect of space charge. If one considers the case where the primary ionisation consists of two electron clusters, one close to the anode (cluster A) and one further away (cluster B); cluster A initiates an avalanche which produces a cloud of positive ions close to the anode, cluster B also initiates an avalanche however the electrons leading the avalanche feed into and are neutralised by the cloud of positive ions remaining from avalanche A. As the angle increases these two avalanches will project to separate areas on the anode so that this shielding effect is suppressed; thus the avalanche pulses become larger and thus are easier to detect. In figure 7 we show the rate dependence of a 5 mm gap chamber with the chamber rotated to 10° , 20° and 30° with respect to the beam axis. As the chamber is rotated the effective rate is reduced by the factor $1/\cos\theta$. We measured the rate in a $10 \times 10 \text{ cm}^2$ scintillator normal to the beam and corrected the flux through the chamber accordingly. The results are shown in figure 7. It is apparent that there is an increase in efficiency for relatively small angles, and then this effect saturates.

Another possible cause for the increased efficiency could be a decrease in the spark probability. However we observe no decrease in spark probability with increasing angle.

7. TIMING

In spark mode operation of the RPC, there is a severe time walk with increasing rate, and an increasing late tail of pulses (up to 60 ns late) [3,4]. With avalanche mode there should be no time walk as the avalanche mechanism starts immediately, however with our chambers (as we previously stated [1]) the rise time of the pulse is rather slow ($\sim 10 \text{ ns}$). We believe that this is caused by reading out a single large pad ($25 \times 25 \text{ cm}^2$). Given this we assumed that the timing spectrum would be improved (compared to our previous measurement) if we used a constant fraction discriminator. We have now done this measurement. We show in figure 8 the time spectrum for 0, 11, 50 and 300 Hz/cm^2 . The 0 Hz/cm^2 data was generated by using only the first 10 events of each beam spill. The beam spill is 400 ms in duration. We divided the data into bins of 50 ms, after the first 50 ms there was no observable change in the spectra (even at the highest rates we measured). However to be certain that our results are not biased to be better than they are in reality, we plot the data for the last 200 ms of each spill for the 11, 50 and 300 Hz/cm^2 . One hopes that we will not need the complexity of a constant fraction discriminator when we read out strips (rather than a pad) as the rise time should be faster. Also there are other techniques based on measuring both rising and falling edges of the pulse which should give comparable results. One can see from these plots that good timing information exists, the tail of late pulses at 300 Hz/cm^2 is associated with small pulses.

8. CONCLUSIONS

Currently we are building electronics so that we can read out a chamber with strips. Some of the fall off in efficiency with rate we believe is induced by reading out a single large pad. We therefore have hopes that RPC's can operate at higher rates than we have published; it should be noted that we are already approaching 1 kHz/cm^2 for inclined tracks. We also stress that our rate measurement is performed by using a defocused beam that covers the whole of the sensitive area of the test chamber. Other authors [6,7,8] quote a rate measurement when the beam is localised to a small fraction of the surface area; by this technique they quote rate figures which we suspect can be up to two orders of magnitude greater than the chamber can operate if the flux impinges on the whole surface.

The RPC remains a very simple gaseous detector to build as there are no thin stretched wires common to other gaseous detector - this simplicity also removes the 'broken wire' problem. In avalanche mode the pulses are small thus an amplifier is needed (this is not needed if one works in spark mode). We will be performing tests with strip readout in the near future; one assumes that our results will be similar to limited streamer wire chambers with cathode strips readout since the pulse size is similar.

We are following two approaches with manufacturing large chambers. The first is to produce resistive sheets and then apply pick-up strips; the second is to produce a board (glass-epoxy) which has pickup strips laminated and etched onto the surface (i.e. standard printed circuit board) - and then to laminate the melamine resistive layer onto these pickup strips. The first method seems cheaper, especially as we have found a cheap aluminium self adhesive strip that gives good results. The second method may be more suitable for industrial production; we are building prototypes at present.

It appears that using this Melamine-Phenolic-Melamine laminate we can build RPCs that operate at a rate sufficient for LHC even in the presence of a large neutron background. The timing spectrum makes these an ideal candidate for use for a muon trigger. There are still outstanding problems related to the long term stability and the fall off in efficiency with increasing high voltage, but we are confident that we will understand the causes and solutions in the near future.

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References

1. I. Crotty, J. Lamas Valverde, G. Laurenti, M.C.S. Williams and A. Zichichi, Nucl. Instr. and Meth. A337(1994)370.
2. R. Cardarelli, A. di Biagio, A. Lucci and R. Santonico, Nucl. Instr. and Meth. A263 (1988) 20.
3. I. Crotty, J. Lamas Valverde, G. Laurenti, M.C.S. Williams and A. Zichichi, Nucl. Instr. and Meth. A329(1993)133
4. M. Iori and F. Massa, Nucl. Instr. and Meth. A306 (1991) 159.
5. The Transition from Proportional to Streamer Mode in a Resistive Plate Chamber, I. Duerdoth, S. Clowes, J. Freestone, F.K. Loebinger, J. Lomas, S. Snow, R. Thompson. MAN/HEP/93/7, Sept. 6 1993; presented at 3rd London Conf. on Position-Sensitive Detectors Sept. 1993.
6. High Counting Rate Resistive-Plate Chamber, D.F. Anderson, S. Kwan, V. Peskov, Fermilab -Conf-93/215, Sept. 1993; presented at 3rd London Conf. on Position-Sensitive Detectors Sept. 1993.
7. M. Bertino et al., Nucl. Instr. and Meth. A283 (1989) 654.
8. Study of Resistive Plate Chambers for Muon Detection at Hadron Colliders, M. Andlinger et al. (RD5 collaboration) Nota Interna n° 1015 (CERN-PRE 93-038) and submitted to Nucl. Instr. and Meth.

FIGURE CAPTIONS

- Figure 1. Cross Section of a typical test RPC.
- Figure 2. The change of resistivity with time. The top plot shows the resistivity of a Melamine-Phenolic-Melamine laminate 0.85 mm thick; the lower plot shows the resistivity of a Melamine layer 0.5 mm thick. See text for details of the test.
- Figure 3. Plateau curves of an RPC showing variation of working voltage with time. See text for details of the test.
- Figure 4. The efficiency versus rate for an RPC, the data were taken 24 hours apart. During this period the working voltage had to be increased by 300 volts.
- Figure 5. Efficiency curves of five RPCs with a 2, 3, 4, 5 and 8 mm gas gap. The spark probability is also shown. The plot in the lower right hand corner shows the relationship between working voltage and gap width. The error bars are not shown for clarity, the efficiency and spark probability were measured using 100 cosmic ray events.
- Figure 6. Rate dependence of two RPCs, one with a 2 mm gas gap, the other with a 4 mm gap.
- Figure 7. Rate dependence of an RPC with a 5 mm gap for various angles of incidence.
- Figure 8. Time spectrum of an RPC using a constant fraction discriminator. Each TDC bin is 1.1 ns.

FIGURE 1

FIGURE 2

A	○	29-Oct-93	Test Beam	Dry gas
B	□	8-Dec-93	Cosmics	Dry gas
C	+	13-Dec-93	Cosmics	Dry gas
D	△	13-Dec-93	Cosmics	1% water vapour added
E	×	14-Dec-93	Cosmics	1% water vapour added
F	◇	16-Dec-93	Cosmics	1% water vapour added

FIGURE 3

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8