Dielectric Resistive Plate Chamber
as a detector for time-of-flight measurements

A. Akindinov¹, V. Golovin², A. Martemianov¹, V. Petrov², A. Smirnitskiy¹, K. Voloshin¹,*

¹Institute for Theoretical and Experimental Physics (ITEP),
B. Cheremushkinskaya 25, Moscow, 117218, Russia.
²Center of Perspective Technologies and Apparatus (CPTA),
Preobrazhenskaya pl. 6/8, Moscow, 107076, Russia.

Abstract
Principles of operation, construction and first test results of a Dielectric Resistive Plate Chamber (DRPC) are described. The detector has shown stability of operation in the avalanche mode of gas amplification within a wide range of applied voltages. Double-gap DRPCs have demonstrated the MIP registration efficiency of 97% and the time resolution of 180–200 ps. No changes in DRPC operation have been observed with test beam intensities up to $10^3$ Hz/cm².

1 Principles of operation and construction
The first beam test results for a new time-of-flight (TOF) gaseous detector — Dielectric Resistive Plate Chamber (DRPC) [1] — were obtained in the slopes of R&D program for TOF gaseous detectors intended to be used in the proposed nuclear experiment ALICE at LHC.

DRPC was developed as a frontier detector between PPC and RPC. The basic idea is to avoid large energy resolution in spark cases (RPC feature), keeping high time resolution altogether with fast response provided by PPC [2]. A dielectric layer introduced between the electrodes is covered with a surface resistivity on the gas side which lets, in case of a breakdown, to decrease or limit the spark energy by charging an elementary plate condensor, which then discharges through the resistive surface. The detector has shown stability of operation in the avalanche mode within a wide range of applied voltages. Time response and energy resolution in spark events may be adjusted by varying the main electric parameters of the detector: the dielectric layer capacity and the surface resistivity.

The basic detector construction used in the tests is shown in Fig. 1. A plate condensor has external dimensions $50 \times 50$ mm², corresponding to the required dimensions of a single detecting cell in the ALICE TOF system, and is several millimeters thick. One of the electrodes is made of a conducting material, the other has a resistance-dielectric-metal structure. The gas gap has been chosen

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*Corresponding author. E-mail: Kirill.Voloshin@itep.ru
to be 0.6 mm wide basing on the PPC experience as this value provides high MIP registration efficiency altogether with a rather good time resolution. The gap is formed by means of ceramic spacers. Accuracy requirements are similar to those for the traditional PPC: the electrodes and spacers are kept flat and parallel within the several micrometers of accuracy.

The layer electrode is the crucial part of the detector. The dielectric thickness $d_d$ is determined from the condition $d_d \leq \epsilon_d \cdot d_g / \epsilon_g$, where $d_g$ is the gas gap width, $\epsilon_d$ and $\epsilon_g$ are the dielectric and gas dielectric constants correspondently. We used 1 mm thick Al$_2$O$_3$ with $\epsilon / \epsilon_{air} \approx 10$. The dielectric was covered with a thin layer of resistant material SiC or TiC with the volume resistivity $\rho = 10^2 - 10^3 \ \Omega \cdot cm$. The outer side of this electrode was metallized through evaporation, and actually appeared to be the second condensor electrode producing the electric field responsible for the gas amplification.

In the tests double-gap detectors formed of two identical single gaps were investigated.

Fig. 2 shows other possible options of the detector assembly.

2 Time measurements with DRPC

DRPC has been studied as a detector for high precision and efficient time measurements on PS beams at ITEP and CERN. $\pi^-$-beams with 2–7 GeV/$c$ momenta, $10^2-10^5 \ s^{-1}$ intensities, and several cm$^2$ cross-section at the detector position were usually used.

Trigger and start counters, made of scintillators of different sizes and modifications, and adapted for time measurements, were positioned on the same beam line. The trigger consisted of 6 to 10 counters, including those situated on precise movable platforms, which determined the space position of the beam ahead and behind the target, important for efficiency measurements, as well as the crossing point between the beam and the detector plane. The time measurement scheme included 2 start scintillation counters (each with 2 PMTs), it was always possible to measure their time resolution continuously during the data taking. A typical resolution of the start system equaled to 150 ps.

The signal from the detector was used as the stop in the scheme. The resolution of start counters was quadratically subtracted from the time of particles flight along a fixed base. In this way the detector resolution was measured.
Figure 2: Various options of DRPC construction: 1 — conducting layer (anode), 2 — dielectric, 3 — resistive layer, 4 — cathode, 5 — gas gap, 6 — spacers.
Figure 3: Sample result of the DRPC time resolution and efficiency measurements: 

- **a** — amplitude spectrum,
- **b** — polynomial T(A) correction,
- **c** — time resolution at different amplitudes,
- **d** — total time resolution.

All trigger and timing electronics were assembled in the NIM and CAMAC standards.

Specially designed fast and low-noise electronics, consisting of a preamplifier, a main amplifier and a discriminator, were used for registration of signals from the gaseous detector. The scheme comes as a development of ideas previously described in [3] and lies beyond the slopes of this paper.

Various gas mixtures, based on either DME or different types of freons with normal quality, were used as working gases in the detector. A simple gas system allowed to mix gases at rather small fluxes of about several litres per hour. No special control of quality and other gas parameters was undertaken.

The mixture DME + 5%CF₃Br was most thoroughly studied as a working gas for DRPC. The best results were obtained with C₂H₂F₄ + 15%DME and C₂H₂F₄ + 5%isobutane + 10%SF₆.

Fig. 3 represents a typical result of the DRPC efficiency and time resolution measurements.

Plot in Fig. 3 shows the amplitude distribution measured with ADC. A very narrow pedestal, corresponding to noise characteristics of both the detector and the electronic channel, may be clearly seen. Efficient signals have a wide non-exponential distribution. Such a shape allows to achieve high efficiency (98% in
Distribution of \textit{start} minus \textit{stop} time versus amplitudes is shown in Fig. 3b. One can clearly see that the mean time changes with the amplitudes for about 1 ns (this value must correspond to the signal rise time), since a constant threshold discriminator produces different times for jitters with different amplitudes. The solid line shows a polynomial approximation of this correlation.

Taking into account $T(A)$ dependence leads to the time resolution being dependent on amplitudes in the way presented in Fig. 3c. It may be seen that the time resolution is close or even better than 200 ps in a wide range of amplitudes, excluding the lower region close to the discriminator threshold of 15 mV.

Finally, the DRPC time resolution at a fixed efficiency is shown in Fig. 3d. Better than 200 ps time resolution may be reached at a high registration efficiency (95% in this case).

All the data shown in Fig. 3 were obtained at a fixed high voltage applied to the chamber. The fact that the time resolution does not depend on the applied voltage in its wide range is demonstrated in Fig. 4. Amplitude distributions and timing characteristics are plotted for several values of applied voltages starting from 3.7 kV with 100 V increment from plot to plot. Time resolution remains almost the same at different voltages (0.5 kV plateau) and approximately equals to 200 ps. The detector efficiency stays high as well.

DRPC time resolution of 200 ps is close to the same value measured for PPC with the 0.6 mm gas gap. It has been seen that the PPC time resolution decreases approximately in a linear way as the gap becomes narrower, and 0.6 mm is a minimal value still giving high efficiency of MIP registration with double-gap detectors. In this sense, one can expect that, similar to PPC, the DRPC time resolution of 200 ps may be significantly improved by decreasing the gap width.

3 Limited energy resolution in breakdowns

It has been known so far that one of the main disadvantages of PPC is its high energy resolution during spontaneous breakdowns, which is limited only by energy acquired during the discharge. Despite the very low probability of such a breakdown ($10^{-6}$ if modern freon-based gases are used), the energy resolution is about 6 orders of magnitude higher than in ordinal avalanche cases. Besides harming the detector and electronics, such a huge energy resolution leads to cross-talks between different cells of the big module and to a large dead time of the detector after breakdowns.

DRPC is suggested as a principal solution in the task of suppressing the energy resolution during breakdowns.

Oscillograms in Fig 5 show breakdown signals from DRPC without further amplification and with 50 Ω resistor at the output. Signal shapes have two bumps (seen with PPC as well), very short total duration of about 20 ns, and small amplitudes of 100–200 mV. Summarized energy resolution is about 1 nC which is 2 orders of magnitude lower than in the PPC case.

Fig. 6 represents the reaction of fast sensitive electronics on such a limited breakdown signal. One can see that the amplifier becomes saturated, but only
Figure 4: Result of the time resolution and efficiency measurements at different applied voltages (100 V high voltage increment from plot to plot).
Figure 5: Oscillograms of breakdown signals measured directly from the detector with 50 Ω output resistor.

Figure 6: Oscillograms of fast electronics response for breakdown signals.

for a short time period of about 200 ns, which cannot influence the total dead time of the detector.

4 Admixture of streamer signals

As in the PPC case, the avalanche evolution inside DRPC may lead to a streamer formation. The streamer probability depends primarily on the chosen gas, and may be either strongly suppressed, or released to let the detector work in the streamer mode.

We were not aimed in choosing or optimising working regime of DRPC but have seen a small admixture of streamer signals, rising to a $10^{-2}$ level at the end of the counting plateau, with DME + CF$_3$Br as a working gas.

Oscillograms in Fig. 7 show the single streamer signal from DRPC (a), and mixture of avalanche and streamer signals obtained at the upper region of the counting plateau (b) without amplification.
All streamer signals have same shapes with fast rise times and large amplitudes. Such working regime seems to be very attractive and must be additionally investigated.

5 Cost estimations of a large TOF system based on DRPCs

The cost of a large TOF system built of many DRPC cells may be estimated supposed that the single channel price is about $40–50, including the cost of development of new front-end and readout electronics, prototype construction, etc. This price is more than an order of magnitude less, than that which might be required for TOF based on scintillation counter technique.

Moreover, it is obvious that timing measurements are not the only possible employment of such a simple and cheap detector.

References

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