TIME DEGENERACY OF MULTIWIRE PROPORTIONAL CHAMBERS

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The deterioration with time of multiwire proportional chambers using isobutane as one component of the gas mixture is studied. It is shown that by addition of methylal among others, a long lifetime can be obtained without changing the properties of the gas mixture. Irradiation tests of $5 \times 10^{10}/\text{cm}^2$ have not shown any alteration in the chamber performance.

1. Introduction

A deterioration with time of multiwire proportional chambers (MWPC) using organic gases (hydrocarbons in particular) has been observed by several groups, at CERN and elsewhere\(^1\)\(^-\)\(^3\). The evidence for the approaching death of a MWPC is as follows:

- large dark current in the chamber, up to a few hundred microamperes;
- high background counting rate, up to several kiloherz per wire;
- radiation-initiated self-sustained discharges, either localized on special regions or more or less uniformly scattered throughout the whole chamber;
- displacement of the efficiency plateau towards higher voltages;
- visible appearance of various kinds of solid deposits or coatings on the cathode as well as on the anode.

Use of magic gas\(^4\) accelerated the death of MWPC, probably because of the very high gas amplification factors that can be obtained; the same phenomenology has been observed, however, when operating a MWPC with an argon–propane mixture\(^1\) and with argon–isobutane\(^2\)\(^-\)\(^3\). The degeneration of a chamber using the magic gas has been described by Ash et al.\(^5\).

We have found evidence that the following are three main phenomena responsible for a self-sustained discharge:

1. a thin layer of insulator on the cathode; the positive ions produced in the avalanches are attached to the layer, and the strong electric field produced can extract electrons from the cathode thus producing a regenerative process; the effect was described a good while ago by Malter\(^6\);

2. a thin film or foil of grease on the anode sense wires; just because of the big electric constant of the insulator, the already very high electric field near the sense wires is locally reinforced, and the breakdown point can be reached;

3. microscopic imperfections of the thin anode wires; any sharp edge or crater will obviously generate a high localized field and possibly a constant breakdown.

When an organic gas is used in the chamber, secondary polymerization products, either solid or liquid, can be produced in the avalanches and can reach the cathode. It is clear that an existing localized discharge will have the tendency to spread all over the chamber, just because of the continuous production of oily deposits on the cathode. Even a perfect chamber may, however, follow the same evolution if very strongly irradiated.

A description of a similar phenomenology in methane-filled Geiger counters may be found in a paper by Farmer and Brown\(^7\).

In this paper we will not try to give a quantitative explanation of the phenomena, but instead propose methods of avoiding the degeneracy.

2. Experimental procedures

Most of our experience was gained with the operation of proportional chambers with hv wire planes. The operation of chambers with flat hv electrodes is described in section 4.

The characteristic parameters of the chambers are summarized in table 1.

The chambers were operated with the magic gas mixture: 0.5% freon 13B1 (CF$_3$Br),
TABLE 1
Characteristic parameters of the chambers described in the text.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber size</td>
<td>$100 \times 100 \text{ mm}^2$ to $180 \times 50 \text{ cm}^2$</td>
</tr>
<tr>
<td>Hy plane</td>
<td>$100 \mu \text{m}$ copper-beryllium wires</td>
</tr>
<tr>
<td>wire distance</td>
<td>1 mm</td>
</tr>
<tr>
<td>Sense wires</td>
<td>20 $\mu \text{m}$ tungsten, gold-plated</td>
</tr>
<tr>
<td>wire distance</td>
<td>2 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>6.6 to 8 mm</td>
</tr>
<tr>
<td>Guard strips</td>
<td>$\approx 1 \text{ mm}$ wide, at 0.7 mm from sense wires</td>
</tr>
</tbody>
</table>

24.5% isobutane, 75.0% argon; all percentages are given in respect of volume.

It was essential, in all tests, to start with a very clean chamber; the presence of grease or impurities would distort the picture.

Since the purpose of this paper is to propose a way of saving the magic gas, let us summarize the prominent features that made us very reluctant to abandon it:

1. Very high gas amplification factors can be obtained. At the beginning of the efficiency plateau, a single ion pair can be detected with a $-5 \text{ mV}$ threshold on 2 k$\Omega$ of terminating resistor. This has been demonstrated measuring the pulse amplitude spectrum given by the single photo-electron produced by an ultra-violet light source. The corresponding gas amplification factor ranges between $10^7$ and $10^9$ (fig. 1). This results in a large efficiency plateau, even with high thresholds on the sensing electronics [fig. 2; see also Bouclier et al.4] and Dumps et al.9].

2. The pulse amplitude spectrum at high voltage is almost independent of the energy of the ionizing particle. In fig. 3, the amplitude spectra for a 5.9 keV X-ray from $^{55}\text{Fe}$, and for single electron photo-production with ultra-violet light are compared. This uniformity greatly reduces the cross-talk and overloading problems in the electronics (small dynamic range of input pulses). It also means that the gas amplification factor is largely independent of the primary specific ionization.

3. Because of the electronegativity of freon, the sensitive region can be limited around the sense wires; this means a shorter occupation time in the gap for any track, and a reduction of the mean number of triggered wires on very inclined tracks (better multiple-track resolution and simpler read-out logics). In a magnetic field, a smaller lateral displacement of clusters is also expected.

4. Complete protection is obtained against sparks; no sparks have been observed in our chambers during the operation with magic gas, even at the higher voltages. This property has been found in no other gas mixture. It not only avoids the destruction of the thin wires, but also allows the elimination of the diode protection circuit on each amplifier.

The chambers were irradiated with a collimated

![Fig. 1. Gas amplification factor of a MWPC operating with the magic gas, as a function of the hv. The measurement has been performed using the chamber described in table 1 (see text) and a $\beta$-source.](image)

![Fig. 2. (Upper curve): Efficiency plateau for fast electrons, measured in the MWPC described in table 1, operating with the magic gas and with the following parameters: resolution time, fixed by a gate generated by scintillation counters: 60 nsec; discriminator threshold on each wire: $-5 \text{ mV}$; 32 wires connected to read-out. (Lower curve): Background counting rate, in singles, of the chamber. Mean value of the rate, in counts/wire sec, averaged over 32 wires each with a threshold of $-5 \text{ mV}$.](image)
$^{90}\text{Sr} \beta$-source. Two scintillation counters, placed behind the chamber, were used for measurements in coincidence; requiring the triple coincidence, only fast (minimum ionizing) electrons were selected. There is, of course, quite a flux of slow electrons detected by the chamber only, and the total flux was estimated from the singles counting rate of the chamber.

The quantities measured for the different gas mixture were:

- the pulse amplitude spectrum on 2 kΩ on a single wire;
- the efficiency curve for a collimated source, with a $-5 \text{ mV}$ threshold, in coincidence with the scintillators;
- the noise rate, without source, and given in single counts per wire per second, with the same threshold;
- the single counting rate of the chamber, for different radiation levels.

Our figure of merit was the expected radiation level at the CERN Intersecting Storage Rings:

max. instantaneous rate $10^3/\text{cm}^2 \text{ sec}$,
max. annual rate for continuous operation $3 \times 10^{10}/\text{cm}^2$.

3. Degeneration and conservation of MWPC

The degeneration of a chamber operated with the magic gas mixture is demonstrated in fig. 4, where the single counting rate for several radiation levels is shown before (full lines) and after (broken lines) a strong irradiation. The breakdown point clearly depends on the radiation level, and displaces to lower voltages after irradiation. The chamber was irradiated uniformly with an integral flux of about $10^7/\text{cm}^2$, and at 5.7 kV.

Looking back to fig. 2, i.e. the efficiency plateau of the same chamber, made at very low source intensity and in coincidence with two scintillation counters,
operating at working voltages as large as 5.7, 5.8 kV may be considered safe, where indeed at higher radiation levels the chamber will stay at full discharge. After a short time of irradiation a permanent increase of the dark or leakage current without source is seen. A more or less uniform whitish deposit appears on the hv wires; at the same time, a black deposit, possibly carbon, appears on the sense wires, and the efficiency plateau is displaced to higher voltages. This may simply be due to the increased thickness of the sense wires, if the deposit on them is a good conductor. The damage to the wires is, however, not permanent; after careful cleaning, the chamber was properly operating again; a cleaning procedure is suggested, for example, in ref. 7.

In the darkness, one can really see the self-sustained discharges due to the photon emission in the regions of big avalanches; the fantastic set of "constellations" of fig. 5 showed up in a large prototype chamber, similar to the ones described in table 1, after a long irradiation.

If the positive ions of the isobutane, or any of its polymers reaching the cathode, are responsible for the degeneracy in chambers operating with the magic gas, an obvious way of solving the problem is to introduce in the chamber a sufficient amount of a new quenching agent, non-polymerizing, and with an ionization potential (i.p.) lower than that of isobutane (i.p. 10.6 eV). An exchange process will then take place by collision during the trip of the ions to the cathode, and most of the ions reaching the hv electrode will be those of the additive. We then tried several quenchings, and very satisfactory results were obtained with propylic alcohol (or a-propanol, \( C_3H_7OH \), i.p. 10.1 eV) and methylal \( [(OCH_3)_2CH_2 \), i.p. 9.7 eV]. First of all, the addition of small quantities (up to 4%) of alcohol to the magic gas mixture does not change its "magic" properties; only a small shift of the efficiency plateau to larger hv is seen. But the very immediate effect of the addition is to eliminate almost completely the breakdown knee proper to the magic gas alone for high counting rates: fig. 6 (magic gas + 4% methylal) should be compared with fig. 4 (magic gas alone).

It is clear from fig. 6 that even a strong irradiation does not induce secondary discharge breakdowns. One has to prove, however, that this is sufficient to keep a chamber alive for long irradiation periods. This has been done in the following way: a 10 mCi \( ^{90} \text{Sr} \beta \)-source was used to irradiate uniformly about 100 cm\(^2\) of the test chamber as described in section 2, with a rate of about \( 10^5/\text{sec cm}^2 \). Before the start, and at fixed time intervals during the irradiation, the more interesting parameters of the chamber were measured (efficiency plateau, background rate, singles rate for several intensities, leakage current). Any change in these parameters would suggest a time degeneracy.

As mentioned in section 2, we took as a reference for the lifetime study, one year of operation at the ISR. With the quoted \( 10^5/\text{sec cm}^2 \) we then accelerated the lifetime test by a factor of 100. The results are summarized in fig. 7 for magic gas + 1% of propylic alcohol, and in fig. 8 for magic gas + 4% methylal. For the first quenching, there is a clear change in the background curve; however, at the normal working voltage (5.5 kV), the background rate stays the same. There seems to be no change at all for the methylal quenching; of course, owing to its higher vapour pressure, a larger

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**Fig. 5.** Visible localized discharges in a large MWPC after a long period of irradiation. Each glow consists of several small bright dots, whose position corresponds to the crossing of the sense and high-voltage wires.

**Fig. 6.** Same conditions as in fig. 4, but operating the MWPC with magic gas + 4% of methylal.
Fig. 7. Comparison of efficiency plateau, background rate, and singles rate for a chamber before (left) and after (right) irradiation. Total flux $3.3 \times 10^{10}$/cm$^2$ electrons from a collimated $\beta$-source. The irradiation was done operating the chamber with magic gas +1% propylic alcohol, at 5.5 kV.

Fig. 8. Same conditions as for fig. 7, but operating the MWPC with magic gas +4% methylal, at 5.7 kV.

Fig. 9. Behaviour of a chamber with flat, gold, high-voltage electrodes, before and after irradiation. The chamber was filled with magic gas.

Fig. 10. Behaviour of a chamber with flat, silver, hv electrodes; the magic gas was quenched with 4% of methylal. The figures on the left side correspond to a MWPC having 20 $\mu$m stainless steel sense wires and a 6 mm gap. On the right, the same measurement was done in a chamber having gold plated wires and a 8 mm gap.
amount of quenching was possible than would be safe with propylic alcohol*.

4. Chambers with flat hv electrodes

There is evidence that the lifetime of chambers depends on the structure of the hv electrode. Actually, with the pure magic gas mixture, the following qualitative observations were made:

1. Irradiating chambers with hv electrodes made of Cu–Be 100 μm wires, as described in section 2, a permanent discharge could be initiated by integral doses of ≈ 10⁶/cm².

2. Chambers with a thin stainless-steel wire mesh as the hv electrode had a lifetime ranging from one to ten hours, with a radiation flux of ≈ 10³/cm² sec, corresponding to integral doses between 10⁷ and 10⁸/cm². The large range may depend on differences in the chambers (some had already been operated for more than one year in low fluxes).

3. Radiation tests were made on honeycomb chambers with flat hv electrodes made of aluminium, silver, and gold. The main parameters of these new chambers, which are of the construction to be used in the Split Field Magnet (SFM detector⁹), are given in table 2.

In fig. 9 we show the characteristics of a chamber with gold electrodes before and after an irradiation of 10¹⁰/cm², using the magic gas alone. As can be seen from the single plateau, there is no real breakdown point before irradiation, even without additional quenching. However, after an irradiation of 10¹⁰/cm², the typical features of deterioration appeared, namely breakdown knee in the singles rate, shift in efficiency plateau, and increase of background rate. Indeed, the chamber can still be safely operated between, say, 4.5 and 4.8 kV.

After another irradiation, however, corresponding to a total dose of 1.5 × 10¹¹/cm², the chamber must be regarded as “dead”; even at 4.5 kV, there is now full discharge with dark currents of the order of 20–30 μA. Opening the chamber, deposits on both hv and sense wire electrodes can be seen.

Adding now, for additional quenching, about 4% of methylal to the magic gas (see section 3), we strongly irradiated two other test chambers. The first chamber had stainless-steel sense wires, silver hv electrodes, and a 6 mm gap; the second one, normal gold-plated tungsten wires, silver hv electrodes, and an 8 mm gap.

As can be seen from fig. 10, the performance of these two chambers is still very good even after a total irradiation with 3 × 10¹¹ and 5 × 10¹¹/cm², respectively. Indeed, if compared to the characteristics of the gold chamber before irradiation (fig. 9), no actual difference shows up. We conclude that using methylal for additional quenching, chambers with flat electrodes may be safely operated in radiation fluxes corresponding to a 1–2 y continuous ISR operation.

5. Conclusions and summary

In the present paper we prove that the degeneration process observed in proportional chambers by several groups using hydrocarbon quenching can be avoided adding some appropriate additives to the gas mixture. In particular, with the addition of methylal to the magic gas we did not see any change in the main parameters of several test chambers after an irradiation period corresponding to one year of operation on the ISR in the worst condition (10³/cm², i.e. a total of 3 × 10¹⁰/cm²). Moreover, the remarkable properties of the magic gas are not noticeably modified by the additive.

References
1) H. Verweij and G. Petrucci, CERN (private communication).
3) J. Steinberger, CERN (private communication).

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TABLE 2
Parameters of honeycomb chambers with flat hv electrodes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber size</td>
<td>200 × 130 mm²</td>
</tr>
<tr>
<td>Hv plane</td>
<td>≈ 1 μm aluminium, silver or gold evaporated on flat honeycomb sandwich</td>
</tr>
<tr>
<td>Sense wires</td>
<td>20 μm tungsten, gold-plated or 20 μm stainless steel</td>
</tr>
<tr>
<td>Wire distance</td>
<td>2 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>6 or 8 mm</td>
</tr>
<tr>
<td>Guard ring</td>
<td>≈ 1 mm wide, at 0.5 mm from sense wire plane</td>
</tr>
</tbody>
</table>