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TRACKS STORAGE IN OPTICAL SPARK-CHAMBERS

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A new technique in optical spark chamber pulsing is described, which allows tracks storage for a time of the order of 10^{-3} sec. The mechanism producing this effect is discussed together with tests performed with different experimental conditions. The results obtained show that storage is possible with no loss in efficiency and without significant distortion of inclined tracks.

1. Introduction

In this paper we describe a technique for storing-tracks in optical spark-chambers for a time up to one millisecond.

This storage is accomplished by applying two high-voltage pulses successively to the chamber. The first pulse is a "storing" pulse generated by an external trigger, which produces invisible avalanches containing metastable atoms but does not produce a visible spark. The second pulse is a "recording pulse" which, if applied within a time of the order of 10^{-3} sec after the storing pulse, completes the track formation process and results in a visible track.

This long-period storage capability offers many advantages and new possibilities in high-energy physics experiments. The main feature of the method is that the time available before the spark allows the use of sophisticated analysis in the triggering logic or the introduction of slow devices, for example magnetostrictive spark-chambers, whose data recording time is of the order of 10^{-4} sec. Also the selection of "good" events can be greatly simplified by performing an analysis during the storage time by means of Charpak-chambers and on-line computer before triggering.

2. Track storage process

The mechanism by means of which the storage effect is produced is not yet completely clear.

Since the storage time is very long compared with the mean life of the free electrons, the most reasonable hypothesis one can suggest is that objects with long lifetime, such as metastable atoms, are involved.

This storage effect has already been demonstrated in streamer-chambers with the same technique; in particular, the number of streamers per unit-length has been measured as a function of the "recording pulse" delay[1]).

Experimentally it is observed that this number decreases exponentially with a life-time of about 5 msec; however, this track lifetime is not necessarily the same as the lifetime of the metastable atoms involved.

When the first pulse is applied to the chamber, the number of free electrons strongly increases and metastable atoms are formed by inelastic scattering. These atoms can be deexcited only by means of encounters with atoms or photons, hence their lifetimes depend on the environmental conditions and, in particular, on the gas pressure[2]).

In our case we believe that the main process is the so called Penning effect

$$A_{\mathrm{met}} + B \rightarrow A + B^{+} + e^{-} \, .$$

This reaction is possible provided that the excitation energy of the metastable states is greater than the ionization potential of the atoms B.

For helium and neon the excitation energies of the metastable states are 19.8 and 16.6 eV respectively[3]).

Since the ionization potential of the common molecular gases such as oxygen, nitrogen, hydrogen, argon, krypton, xenon is about 15 eV or less, it is clear that very slight traces of impurity suffice for the Penning effect.

At a pressure of 760 mm Hg one metastable atom can make about 10^8 collisions during its lifetime and thus makes about 100 scatterings with an impurity molecule if this impurity is present in the gas in proportion as large as one part per million. In the absence of impurities the lifetime of metastable atoms is about 100 msec.

It is therefore evident how important our knowledge of spark-chamber gas impurities must be.

If we call τ_{m} the lifetime of metastable atoms in a well determined gas mixture and τ_{e} the lifetime of electrons in the same conditions, the number of the free electrons present at the time t is:

$$n(t)=\frac{\tau_e}{\tau_m}\,\alpha N_0\,e^{-t/\tau_m}+\left(n_0-\alpha N_0\,\frac{\tau_e}{\tau_m}\right)e^{-t/\tau_e}\,, \qquad (1)$$

where: N_0 is the number of metastable atoms initially produced; α is the Penning effect probability for a metastable atom; n_0 is the number of electrons at the initial time.

From this equation it becomes evident that increasing the gas purity and therefore increasing τ_e and τ_m results in an increasing of $n(t)$, assuming that the ratio τ_e/τ_m and N_0 remain constant. This effect has also been experimentally tested.

Due to their large mass the metastable atoms have a small diffusion coefficient and therefore their diffusion does not produce any significant distortion of the spark-chamber tracks. Indeed the mean displacement produced by diffusion in 10^{-3} sec is 0.16 mm in helium and 0.08 mm in neon.

The spark formation process involves all the electrons produced from metastable atoms within a time given by the memory time of the chamber, typically 5 μsec: since the mean value of the displacement for an electron in 5 μsec is 1.5 mm in neon, the distortion due to electron diffusion can be very large. This produces a deterioration of the efficiency for wide angle tracks, which depends strongly on the alignment of the avalanches.

It has been found experimentally that the addition of water vapour or alcohol to the gas improves spark properties and the efficiency for wide angle tracks.

The mechanism by which these vapours act is not yet completely clear, however it seems that they operate upon electrons, producing bound groups such as $2\,H_2O^-$ and $(2\,C_2H_5OH^-)$[4]. These groups have (because of their mass) a small diffusion coefficient, and can be broken when an electric field is applied, with consequent production of free electrons.

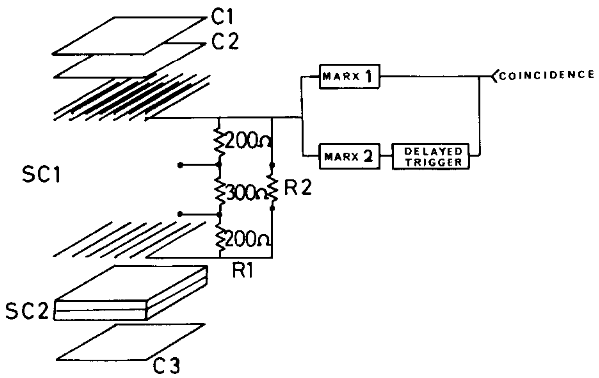

Fig. 1. Experimental set-up for wide gap tests. SC_1 is a wide-gap wire spark chamber and SC_2 is a narrow-gap reference chamber.

3. Experimental set-up

The storage effect previously described has been tested experimentally using a wide gap (10 cm) spark chamber $30\times30\times10$ cm^3 with electrodes consisting of copper–beryllium wire 100 μm in diameter, spaced at 2.5 mm.

We have chosen this particular prototype since this technique could be used in the experimental apparatus of the project "MEA" (Experiments with magnetic detector at Adone) which requires optical spark chambers with transparent electrodes.

The experimental set-up is schematically shown in fig. 1: C_1, C_2, C_3 are scintillation counters; SC_1 is the test chamber; the electrode to which the high voltage pulse is applied consists of two wire layers spaced at 1 cm. The two wire planes minimize field distortion near wires, if grounded objects are present in the surroundings. In fact, measurements previously carried out show that if the high voltage electrode consists of only one wire layer, the chamber efficiency is very critically and strongly dependent upon the location of grounded objects in the surroundings. SC_2 is a reference narrow-gap spark chamber pulsed in the conventional way.

Marx 1 is a 6 stage marx generator with output capacitance of 330 pF.

Marx 2 is a 4 stage marx generator, filled with nitrogen at a pressure of several atmospheres, with output capacitance of 1500 pF.

Marx 1 provides the storing pulse whose length depends upon the resistance $R=R_1//R_2$; Marx 2 produces after a suitable delay a recording pulse whose length is long enough for the formation of the spark.

In the following the efficiency of the test chamber is defined as the ratio between the number of tracks in the wide-gap which are aligned with the ones in the narrow-gap and the total number of tracks in the narrow-gap chamber.

The efficiency so defined is surely underestimated because of the presence of multiple sparks in SC_2.

4. Measurement and experimental data with wide-gap chamber

As outlined in the previous paragraph, the storage efficiency strongly depends upon the initial number of metastable atoms which are produced when the first pulse (storage pulse) is applied to the chamber.

However it is rather evident that these metastable atoms must be formed immediately along the trajectory of the ionizing particle and should be well aligned with it; therefore it seems to be more convenient to use a storing pulse rather large in amplitude and short in length; an other reason for doing it is that this type of a pulse also reduces the statistical fluctuation in the number of metastable atoms produced.

As we will see later, for a given length of the storage pulse the efficiency increases with the amplitude; however at a certain value, there is a worsening of the spark quality; this happens when the spark begins to be produced by the first pulse.

The early tests were carried out using a gas mixture consisting of 20% neon and 80% helium with a storing pulse time constant of 220 nsec; in this condition the amplitude of the recording pulse to produce a visible spark was about 6.3 kV/cm.

The behaviour of the efficiency as a function of the delay of the second pulse is shown in fig. 2B.

Fig. 2A represents the memory curve of the chamber pulsed conventionally by Marx 2 in this way it is possible to check gas purity.

It is evident that there is a critical dependence of the efficiency on the amplitude of the storing pulse and efficiency is not completely satisfactory. Furthermore we have seen that the storing efficiency for wide-angle tracks ($\approx 30°$) is very low.

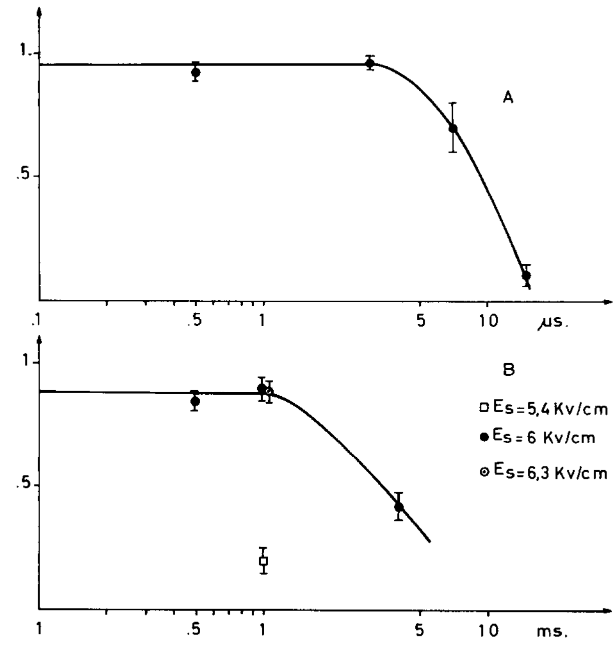

Fig. 2. (A) SC$_1$ efficiency vs Marx 2 delay, Marx 1 is off, the gas is Henogal (80% He, 20% Ne) and $E_2 = 6$ kV/cm. (B) SC$_1$ efficiency vs Marx 2 delay with Marx 1 on, for various storage pulses amplitude, in the same condition of (A). τ_1 is 220 nsec and τ_2 is 1100 nsec.

A remarkable improvement is obtained if the time constant of the storing pulse is reduced to 40 nsec; however, in this case also the efficiency for wide angle tracks remains low, even using a Neogal gas mixture (80% neon, 20% helium).

By introducing water vapour at room temperature

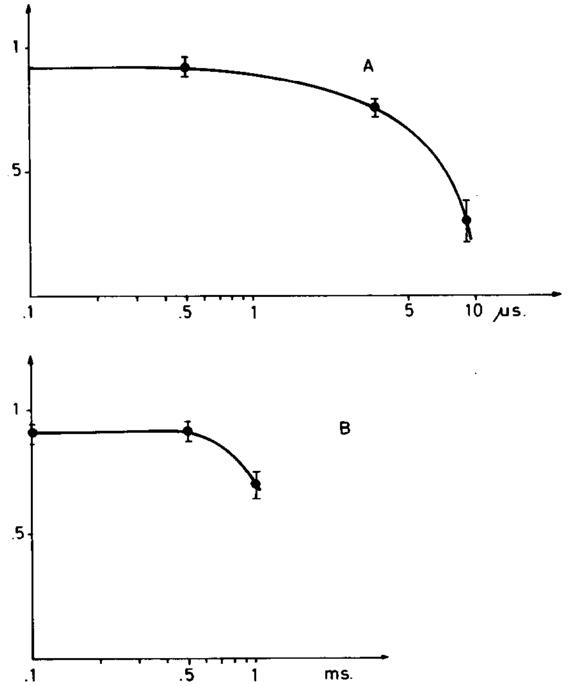

Fig. 3. (A) SC$_1$ efficiency vs Marx 2 delay with Marx 1 off; for $33° \pm 5°$ tracks the gas is Neogal (80% Ne, 20% He) saturated with water vapour, $E_2 = 6$ kV/cm. (B) SC$_1$ efficiency vs Marx 2 delay in the same condition of (A) but with Marx 1 on. $E_1 = 10$ kV/cm, $\tau_1 = 40$ nsec, $E_2 = 8.8$ kV/cm, $\tau_2 = 200$ nsec.

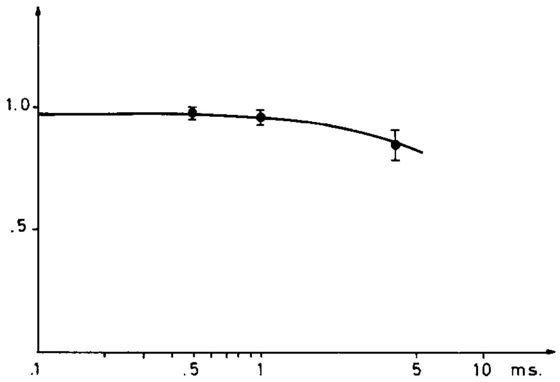

Fig. 4. SC$_1$ efficiency vs Marx 2 delay in the same condition of fig. 3B but with $\theta = 0°$.

TABLE 1

Results of measurements made with the set-up described in the text.

E_1 (storage pulse; kV/cm)	E_2 (kV/cm)	Delay (msec)	Clearing field (V/cm)	Efficiency for at least one gap	Efficiency for two gaps
4	7.5	1	0	96% ± 2	66% ± 6
5	7.5	1	0	97% ± 2	85% ± 7
5	7.5	1	50	97% ± 2	83% ± 6
5	7.5	0.5	50	96% ± 2	87% ± 6
5	7.5	0.5	0	98% ± 2	84% ± 6
5	7.5	0.2	0	99% ± 1	75% ± 5
5	7.5	0.2	50	98% ± 1	77% ± 5
5	7.5	0.2	120	100%	82% ± 5
		0.2	240	97% ± 2	80% ± 6

vapour pressure a further increase in storing efficiency and working stability has been achieved.

In fig. 3B is shown the behaviour of the track storage efficiency for tracks inclined to the electric field by 33°, as a function of the delay of the second pulse. Fig. 3A represents the memory curve obtained with the same condition, but using only Marx 2 (with no storage pulse). In fig. 4 is shown the behaviour of the storage efficiency for tracks parallel to the electric field as a function of the recording pulse delay.

We have also measured effects of track distortions as a function of the recording pulse delay and compared these with tracks produced in the conventional mode. The results of the measurement can be seen in fig. 5. It is clear that distortions for storage times up to 0.5 msec present no problems.

The method of distortion analysis is that of ref. 5. These measurements are made with somewhat poorer optical conditions so the best track distortion is twice that of ref. 5.

As we pointed out in paragraph 2 there is a correla-

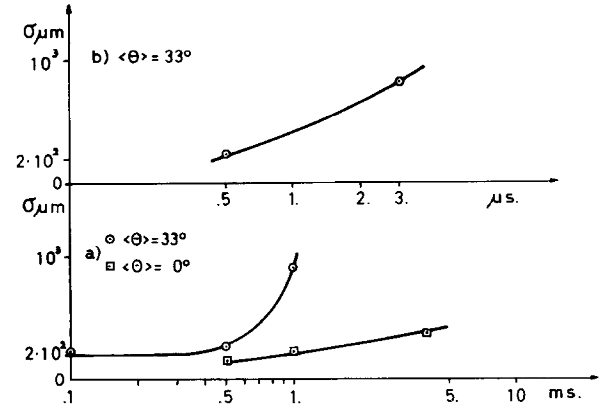

Fig. 5. Spark distortion. (a) vs Marx 2 delay in the same condition of 3B, (b) vs Marx 2 delay with Marx 1 off. These numbers are averaged on about one hundred sparks for every point.

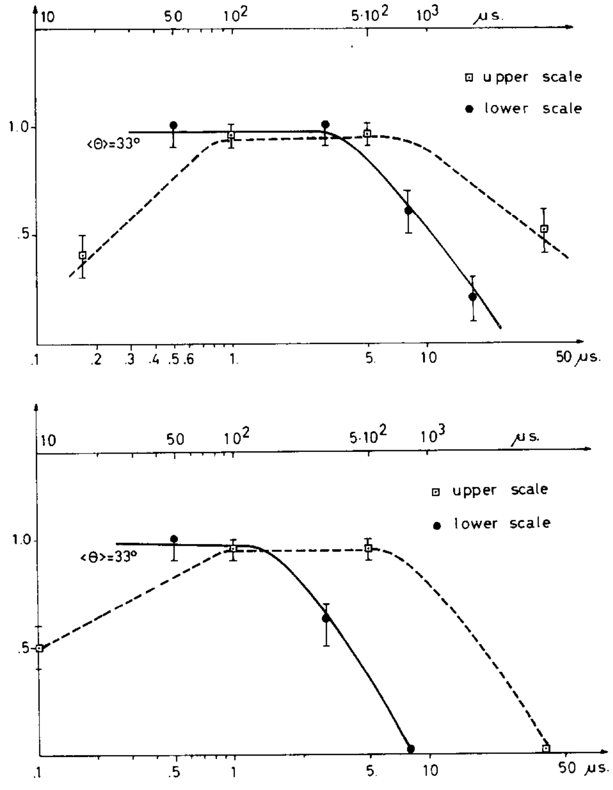

Fig. (6). Comparison of storage and memory curves. Fig. (a) shows the memory curve (solid line) and storage curve (dashed line) with a gas flow of 3 l/h; (b) shows the same curve but with a gas flow of 1.5 l/h. However all other conditions are the same as in fig. 3.

TABLE 2

Results of measurements made in the conventional manner.

E_2 (kV/cm)	Clearing field (V/cm)	Efficiency for at least one gap	Efficiency for two gaps
7.5	0	98% ± 2	98% ± 2
7.5	120	95% ± 3	90% ± 3

tion between chamber memory and track storage efficiency (see fig. 6a and 6b).

It is interesting to notice that for very short delays the storage efficiency is low.

5. Narrow gap test

We have also checked the storage capability of the narrow gap chamber using the cylindrical spark chambers which have been designed for the MEA experiment.

These chambers have a very high electrical capacitance, about 7 nF; even so, by using the pulsing system which is chematically shown in fig. 7, we have obtained pulses with no more than 60 nsec rise time. This is very important because we have previously pointed out that the pulse must have a high amplitude and narrow width.

We also expect that the presence of a Penning effect on the electrode itself will change the storage mechanism in the case of a narrow gap chamber.

The results obtained in this set up of measurements are shown in table 1, where E_1, E_2 are the peak values of the pulses.

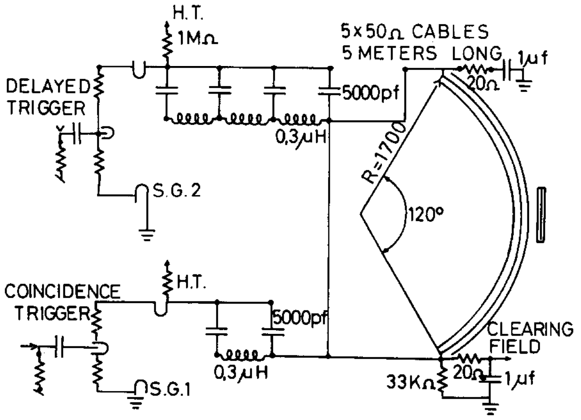

Fig. 7. Experimental set-up for narrow gap tests.

These numbers are to be compared with the efficiencies quoted in table 2 which refers to a test performed in the conventional way.

In all these measurements the gas used was Henogal (20% Ne, 80% He) and the memory time was about 10 μsec. The efficiency for at least one gap remained high also when a clearing field was applied. The two-gap efficiency was, however, a bit lower. This effect can be dependent upon small differences between the two gaps because of asymmetries, always present when dealing with very large chambers.

These asymmetries become more important because there are two high voltage pulses. We believe that chambers with gaps a bit larger than the standard (0.8 cm) would function better since the relative asymmetry would become smaller.

6. Conclusions

Our measurements show that it is possible to store tracks in optical spark chambers using standard gases. The operating conditions are not critical for storage times less than 0.5 msec.

In the best case we have obtained for the wide gap chamber an efficiency of 92%, with no significant track distortion, for tracks inclined (33 ± 5)° with respect to the electric field.

In our tests on narrow gap chambers we have obtained an efficiency for two tracks of about 85% with a recording pulse delay of 1.0 msec. This efficiency does not change upon the application of a clearing field.

We hope to achieve improvements on the narrow gap efficiency, by reducing the asymmetries between the two gaps and shortening the rise time of the triggering pulses.

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