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Section A

New advances in spark detectors

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Several experiments carried out in our laboratory during the last two years, have led to the introduction of simple techniques for the construction of highly reliable spark counters of the Chang–Rosenblum type. A systematic study on the behaviour of such counters has shown that through the use of a new electronic technique to interrupt the discharge and by a suitable choice of the filling gas, it was possible to reduce drastically the radiation damage in the cathode and to obtain plateaux of 2 kV with a slope $< 0.01\%/V$. It is shown that the techniques used have decreased the dead time of the counter by a factor 10^2 and its life was increased by a factor 10^3/cm of anode length.

1. Introduction

It is well known that spark counters undergo a severe degradation of their characteristics after a long exposure to an incoming flux of highly ionizing radiation, such as protons, alpha particles and fission fragments; a severe decrease of its efficiency and the presence of spurious pulses limits its utilization to about 10^5 particles for cm of anode length [1,2] – a circumstance which has inhibited its use for measurements during long periods of time under moderate counting rates.

Spark detectors suffer from the drawback that the strong radiation damage is undergone by its electrodes due to the hostile conditions imposed by the spark discharge, by the radiation from its streamers during the pulses and due to the effects of the steady corona discharge around the wire: these phenomena give rise to changes of the operating conditions of the detector which, sometimes, can be observed even after a few minutes after the counter exposition to the incoming radiation ceases. All such phenomena are strongly dependent on the nature of the flowing gas.

Similar problems are found in both proportional and Geiger–Müller counters, as shown by the pioneer work of Wilkinson [3]. Charpak et al. [4] also have found that, whenever hydrocarbon quenching gases are used in multiwire proportional counters, difficulties, such as an increase in noise is observed. Since then, a great deal of work has been done on these problems for several types of gaseous detectors and there is a fairly large literature on the mechanisms of the counter aging [5–10]. It must be stressed, however, that, in such cases, the working conditions of the usual detectors are more favourable and very different from what is observed in spark counters, since both the mechanisms of the gas photoionization and the disruptive discharge are avoided by the presence of a quenching agent in the gas mixture and a use of much lower wire gain, whereas in spark counters no quenching agent is used and the gaseous amplification factor attains values of the order of 10^{10}. One should expect, therefore, that the aging effect in spark counters should be stronger than in proportional counters.

Although in multiwire counters such effects can be attenuated through the use of non-polymerizing quenching agents and low gain operation [4,11], this seems to be still an open question since several observers have found that the radiation damage persists even in the above conditions.

For spark detectors of the Chang–Rosenblum type, there is no literature available on this subject and it seemed that the only way to eliminate the radiation damage effects on the counter was to proceed a thorough polishing of the cathode surface and the replacement of the anode wire.

Since the existence of a corona on the anode wire has been considered up to now as an essential condition for the operation of these counters [12–15] and since, on the other hand, the electromagnetic radiation emitted during the discharge near to the anode is the main factor responsible for the radiation damage on the cathode surface, we decided to make several experiments aiming to decrease its intensity without sacrificing the counter operating conditions. Several gases and gaseous mixtures and new quenching circuits were tried in order to improve the counter behaviour.

The modifications which were introduced in the counter operating conditions have given excellent results which led

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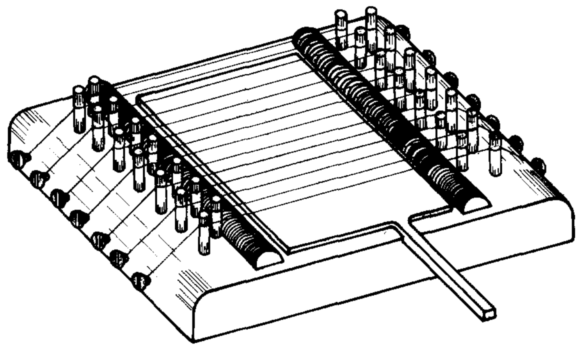

Fig. 1. The Spark Detector.

to an increase of the useful life of the counter by a factor higher than 10^3/cm of anode length, with a drastic decrease of the radiation damage on the cathode surface.

2. Experimental

Several detector configurations were used: a single wire stretched alternately through the isolating spacers and single parallel wires insulated from each other; several metals were tested as cathodes (which were highly polished and were almost optically flat) and wires of different diameters and chemical composition were used in our experiments. In most tests a single anode wire (tungsten, 127 μm of diameter) and a 304-L stainless steel cathode were used. The distance between the wire and the cathode was 1.5 mm and the spacers were made of lucite. In order to avoid spurious discharges, the edges of the plate were rounded off and, in order to keep the wire-plate distances accurately, a lucite worm screw was used both as an insulator and spacer (Fig. 1). The flowing gases used were air and ultra-pure argon (99.999% purity) at atmospheric pressure; a collimated alpha-particles source of ^{241}Am (0.2 mCi of intensity), at 30.0 mm from the cathode was used.

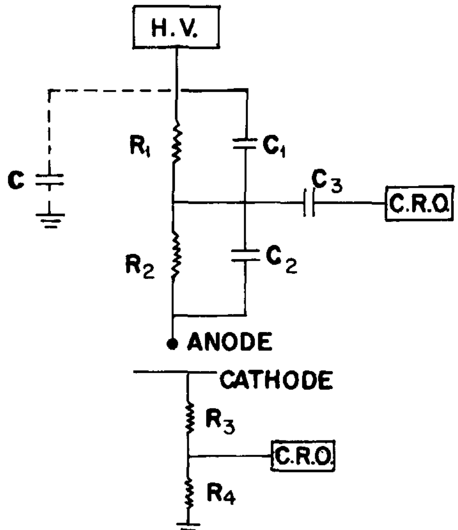

Fig. 2. Compensated voltage divider.

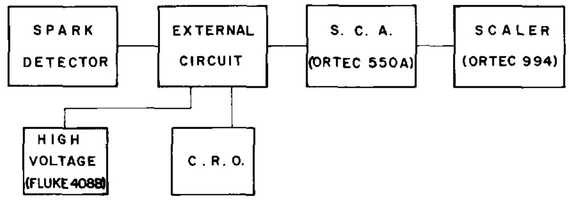

Fig. 3. Block diagram of the equipment used.

The electronics system used is shown in Figs. 2 and 3 and consisted essentially of a compensated voltage divider to avoid a deformation of the pulses and reduce its amplitude to feed a 50 Ω impedance line; those pulses were observed in a digital memory oscilloscope (300 MHz, Tektronix 2440) and were formatted by a single channel analyzer (Ortec 550A) connected to an Ortec 994 scaler which provided a record of the particles which reached the sensitive volume of the counter.

3. The radiation damage of the electrodes due to sparks and corona

The changes observed on the physical and chemical properties of the electrodes of a spark counter give rise to an alteration of its characteristics are mainly due to the violent bombardment of the cathode by positive ions and of the anode by accelerated electrons during the time duration of the discharge. Since the temperature of the discharge is of about 10000°C [16], a local crater is produced in the point struck by the discharge. A chemical alteration of the cathode surface is mainly due to the production of ozone (when air is used as the flowing gas) which oxidizes the area around the crater; when gases with organic vapours are used, microscopic deposits of polymers are observed both at the cathode and the anode of the counter.

The layer of polymers, as well as the presence of oxides or nitrates on the electrodes interferes with the discharge mechanism.

When air is used as a flowing gas a fairly high amount of ozone and nitrogen oxides are formed and, if a mixture of gases contains hydrocarbons, polymers and carbon deposits are formed during the discharges which can be observed by a naked eye. The production of thin films on the cathode surface, as described above, can give rise to the well-known mechanism of secondary electron extraction from the cathode, called thin film or Malter field emission [17] that is responsible for a large fraction of the phenomena responsible for the ageing of spark counter and

MWPCs. Another effect which is observed under these conditions is the production of an increasing number of spurious pulses which can originate an arc discharge between the electrodes.

The secondary effects discussed above can be easily observed on the cathode after a strong irradiation with ^{241}Am alpha particles in a counter filled with a mixture of air and 1.5% of methane. The wire shadow is clearly seen surrounded by a lateral oxidized region. Such a shadow cannot be attributed only to the effects of ozone and the formation of polymers because its colour is much lighter than the lateral damage zones: a microscopic examination of the surface shows clearly the presence of pits in the cathode due to its bombardment by the positive ions generated during the discharge. An enlarged picture of the anode wire shows that it is covered by an insulating layer constituted mainly by the yellow and blue tungsten oxides.

It follows unambiguously from the above that the high temperature of the discharge and the bombardment by positive ions give rise to the formation of craters (pits) and the sputtering of the cathode material (from the craters).

The above effects are considerably attenuated when external means are provided in order to decrease the discharge time and the consequent pit temperature and the metal evaporation.

4. Methods to decrease the electrodes radiation damage

4.1. The response of a spark counter with a LRC cathode circuit

In order to decrease the number of positive ions that reach the cathode during the duration of the spark, a 1.2 μH coil was connected between the counter cathode and ground (Fig. 4).

The analysis of the pulses produced across the coil show some important facts:

a) The pulse amplitude (between cathode and ground) is practically the same as observed with the conventional circuit.

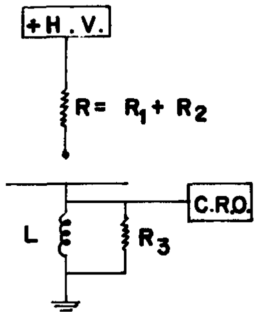

Fig. 4. The LRC cathode circuit.

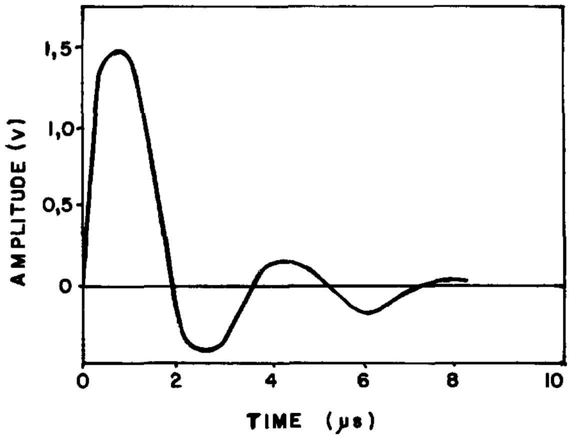

Fig. 5. Shape of the damped pulses observed at the coil terminals.

b) An examination of the pulse shape shows a shape which is characteristic of heavily damped oscillation (Fig. 5). When compared with the pulses produced by the conventional RC circuit, the main difference is the much smaller recovery time of the counter, as compared with the pulses observed with a RC quenching circuit.

c) The streamers observed during the passage of the current practically disappear and the recovery time of the detector decreases from about 200 μs to 2 μs.

As one would expect, the e.m.f. which appears at the coil terminals due to the spark current creates an electric field which is opposite to the motion of the positive ions towards the cathode; those ions penetrate into the electron cloud and recombine. This process limits severely the intensity of the spark as a consequence of the absence of the electromagnetic radiation due to the bombardment of the cathode by the positive ions. This decrease of the energy liberated by the spark decreases considerably the production of the streamers and their secondary effects as one would expect by Meek's theory [18]: the sparks became almost invisible and there is a remarkable decrease on the erosion produced at both the cathode and the anode of the detector.

The life of the counter is thus considerably increased (as observed for an irradiation of 14 h with the ^{241}Am alpha source of 0.2 mCi, without collimator), by a factor of 10^2/cm of anode length when air is used as the flowing gas. When ultra-pure argon is used, a factor of 10^3/cm of anode length is obtained for the counter life: no chemical reactions were observed on the electrodes and the corona on the anode wire practically disappears. This is an important consequence since it allows the construction of gas sealed counters with a life about 10^3 larger than that observed with flowing air. As can be observed in Fig. 6, an increase of the detector counting rate of about 40% is observed and is due to the decrease of its recovery time, as mentioned in item (b).

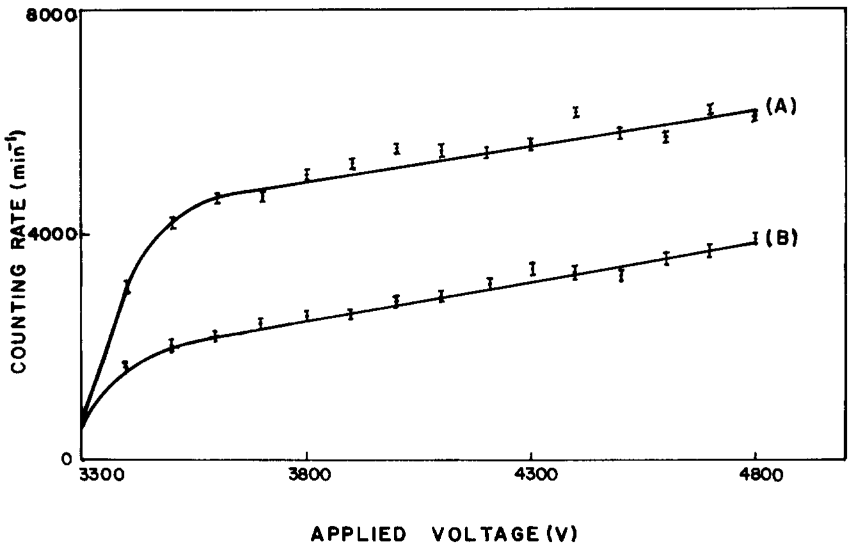

Fig. 6. Characteristic curve of the detector: (a) with cathode series inductance; (b) with the RC conventional circuit (flowing gas: air ntp).

Fig. 7 illustrates a microphotograph of two anode wires under the same irradiation of alpha particles: the upper wire when the cathode was connected to ground through a series inductance and the lower wire when the cathode connected directly to ground. The influence of the inductance on the decrease of the corrosion of the anode can be clearly seen.

The response of an LRC circuit submitted to a vertical pulse of short duration followed by an exponential decrease of the potential (observed when the cathode is grounded) is a classical problem studied by Moullin [19] in his researches on the pulses due to atmospherics ("static pulses" in USA) in radio receivers. His analysis can be applied in our case (rise time of the pulses of the order of 2 ns).

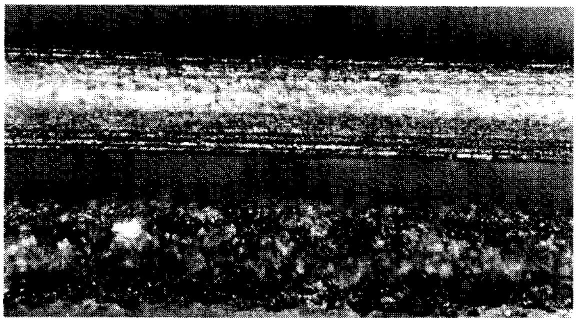

Fig. 7. Microphotograph of two anode wires: the upper wire when the cathode was connected to ground through a series inductance and the lower wire when the cathode was connected directly to ground.

We can then represent the e.m.f. developed between the circuit terminals by a function of the type:

$$V = V_0 \, e^{-\alpha t} \sin(\omega t)$$

where: V = e.m.f. across the coil, V_0 = observed voltage surged when the circuit is excited by a spark through the air gap (wire-plate distance), α = damping coefficient of the pulses, ω = angular frequency of the pulses; $\omega = 2\pi f$, with f the frequency associated with the pulses.

With a careful choice of the parameters, one can make V practically coincident – in shape and duration – to the genuine pulse observed on the oscilloscope during the passage of the particle through the counter. Alpha (α) was taken as $\omega/2$ in order to have a heavily damped circuit. Since the duration of the pulse is 2 μs, ω is of the order of 3.14×10^6 rad/s.

4.2. Choice of the flowing gas

Our measurements with ultra-pure argon show that, in disagreement with the results of Colli and Facchini [20] (for Geiger–Müller counters) with the same gas, there is no corona effect for ultra-pure argon at pressures of the order of one atmosphere. Whenever ultra-pure argon is used, the counter shows a very large plateau (≥ 2 kV, as in Fig. 8), even in absence of a corona; since the corona is not observable, its destructive effects on the electrodes are negligible and it is noteworthy that the detection efficiency is six times larger than that observed when air is used.

It is observed that, with the geometry used in spark counters (a fine wire of small diameter parallel to a metallic surface at a distance of about 1.5 mm), the corona effect depends exclusively on the nature of the gas.

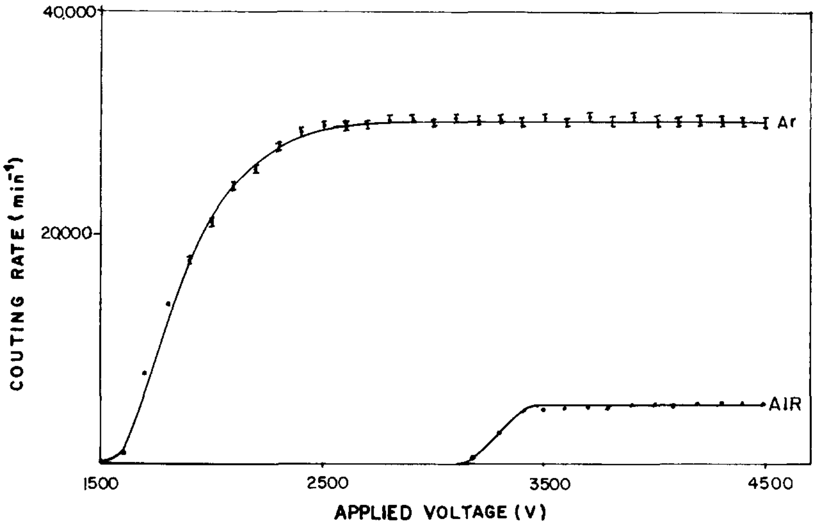

Fig. 8. Characteristic curve of the detector with ultra-pure argon (the data for air are represented for comparison).

It follows from our measurements that the corona effect only exists when the used gas does not present metastable states, in full agreement with Weissler [21] results on corona discharges. When a fine wire is immersed in air (NTP), it is possible to observe the corona effect, even when the distance wire-plate is large, by using a large potential difference because the metastable states of nitrogen are inhibited by the oxygen molecules.

When air is used as a quenching gas, the corona current reach values of the order of 100 μA for an applied potential of 4 kV. As our experiments show, the low efficiency of the counter, observed when the corona is present, is due to the corona and that the counter operates in far more favourable conditions when the corona is absent. The decrease of efficiency under these conditions is a consequence of the corona plasma, present around the wire, which increases the rate of recombination of the ions produced by the incoming particle, inhibiting, in some cases, the production of the spark along the original path and decreasing, therefore, the counter efficiency.

5. Conclusions

1) The circuit used in the cathode, constituted by an inductance shunted by a resistor adjusted to a critical damping of its oscillations, plays an important role in the working conditions of the detector by decreasing the radiation damage on the electrodes and diminishing the dead time of the counter – with a consequent increase in the counting rate for strong sources.

2) When ultra-pure argon is used no corona effect is observed and the counter has a much longer life showing plateaux with 0.01% slope and 2 kV of extension and the detection efficiency shows a sixfold increase.

3) Our measurements show that the efficiency of detection of spark counters decreases when the corona current increases.

4) The corona effect which appears in a wire-plate spark counter depends on the existence of metastable states of the flowing gas and it is not only due to the existence of an electrode (carrying a high voltage) of small radius (asymmetry of the electrodes) – as was considered up to now. The breakdowns in the anode avalanches are related to both to the nature of the gas and the anode wire diameter.

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References

[1] E. Andreeschchev and B.M. Isaev, Sov. Phys. JETP. 1 (1955) 212.
[2] Yu.N. Pestov, Nucl. Instr. and Meth. A 265 (1988) 150.

[3] D.H. Wilkinson, Ionization Chambers and Counters (Cambridge Univ. Press, 1950).
[4] G. Charpak et al., Nucl. Instr. and Meth. 99 (1972) 279.
[5] J. Va'vra, Nucl. Instr. and Meth. A 252 (1986) 547.
[6] I. Juricic and J.A. Kadyk, IEEE Trans. Nucl. Sci. NS-34 (1987) 481.
[7] J. Va'vra, IEEE Trans. Nucl. Sci. NS-34 (1987) 486.
[8] S.P. Beingessner, T.C. Meyer and M. Yvert, Nucl. Instr. and Meth. A 272 (1988) 669.
[9] A.V. Zarubin, Nucl. Instr. and Meth. A 283 (1989) 409.
[10] J. Va'vra, Nucl. Instr. and Meth. A 323 (1992) 34.
[11] M. Atac, IEEE Trans. Nucl. Sci. NS-34 (1987) 476.
[12] W.V. Chang and S. Rosenblum, Phys. Rev. 67 (1945) 222.
[13] R.D. Connor, Proc. Phys. Soc. 64 B (1951) 30.
[14] L. Daddi and L.D. Franceschi, Rev. Sci. Instr. 30 (1959) 419.
[15] A. Roberts, Rev. Sci. Instr. 32 (1961) 482.
[16] J.J. Thomson and G.P. Thomson, Conduction of electricity through gases vol. II (Dover, 1969).
[17] L. Malter, Phys. Rev. 50 (1936) 48.
[18] J.M. Meek, Proc. Phys. Soc. 52 (1940) 547.
[19] E.B. Moullin, Journal IEE 62 (1924) 353.
[20] L. Colli and U. Facchini, Phys. Rev. 88 (1952) 987.
[21] G.L. Weissler, Phys. Rev. 63 (1943) 96.