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**AGEING PROPERTIES OF STRAW PROPORTIONAL TUBES
WITH A Xe-CO₂-CF₄ GAS MIXTURE**

M. Capeáns, C. Garabatos, R.D. Heuer, R. Mackenzie, T.C. Meyer, F. Sauli
and K. Silander

CERN, Geneva, Switzerland

V.G. Bondarenko, V.A. Grigoriev, J.S. Markina and A.A. Kruglov

Moscow Physical Engineering Institute, Moscow, Russia

Abstract

Studies of the behaviour of straw proportional tubes, 4 mm in diameter, under sustained irradiation were carried out with a Xe-CO-CF₄ [50-30-20] gas mixture. No observable drop in gain has been found to affect the tubes up to reasonable doses (≤ 1 coulomb per cm of wire). The chemical modification of the gas composition, causing the formation of electronegative, relatively stable species during the avalanche processes in a highly irradiated straw tube, is suggested to be responsible for a decrease of the pulse-height in a second proportional counter (12.5 mm drift distance) operated with this (radical-enriched) gas mixture. Finally, we have observed that, for a straw tube operated at gain of a few times 10^4 , there is a contribution to the total collected charge coming from a few, very large pulses, probably due to occasional transition to a limited streamer regime.

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1. Introduction

Straw proportional tubes [1, 2], single-wire counters a few mm in diameter, appear to be good candidates for high rate tracking and transition radiation detection (TRD) in future experiments at the Superconducting Super Collider (SSC) and the Large Hadron Collider (LHC). The radiation hardness is an important condition for gaseous detectors expected to operate in high luminosity-collider experiments. In the case of LHC the total dose expected at one metre from the intersection point in one year of operation is of the order of 1 Mrad. This corresponds, for typical multi-wire chamber design and operating conditions (1 mm wire spacing, 5 mm gap, and gain 5×10^4), to a total collected charge of about 1 coulomb per centimetre of wire (C/cm). Ageing tests performed on straw tubes with Xe-CO₂ [50-50] and Xe-CO₂-CF₄ [50-30-20] gas mixtures have shown that up to doses of ≈ 5 C/cm the detector recovers its initial gas gain and energy resolution after a relatively short relaxation time (transient ageing), which is gas flow dependent [3]. In order to study both the radiation hardness and the transient ageing of these detectors under controlled conditions, some tests were carried out in the Research and Development RD-10 laboratory at CERN [4] -specifically designed to perform accelerated ageing tests- in collaboration with the project RD-6 [1].

2. Ageing studies

The straw tubes under study had a 50 μm diameter gold-plated tungsten anode wire, centred in a 11.5 cm long, 4 mm diameter tube made from 18 μm thick kapton film, coated on the inner side with 2000 Å of aluminium and a 4 μm layer of carbon-loaded polyamide as cathode [2]. The gas inlet and outlet were placed at both ends of the tube by means of brass feedthroughs on which the anode wire was soldered. The high voltage was applied to the cathode.

2.1. Test 1

Ageing tests were performed on two straw tubes in slightly different operating conditions. During the first test (test 1), the pre-mixed gas (Xe-CO₂-CF₄ [50-30-20]) was transported by a stainless-steel line, connected to the test straw by a few centimetres long plastic tube [3]. The gas outlet of the straw, through another short section of plastic tube, went into a second, RD-10 standard, stainless-steel proportional counter (12.5 mm anode to cathode distance) for monitoring [5]. A silicon oil bubbler was installed at the end of a 15 m long copper exhaust line to control the gas flow, which was kept to a small value of around 0.1 cm³/min owing to the limited amount of gas available. A Gas Chromatograph (GC*) was used to analyse the gas as it came out of the monitor chamber. The straw tube was operated at a gain of around 10^4 (at 1830 V) during the ageing test. An 8 mm long section of the wire was irradiated at a dose rate of about 4×10^6 X-

* Hewlett-Packard model 5890

rays per second (peak energy of 9 keV) coming from a Fe target X-ray generator operated at 10 kV. A second, attenuated output of the same generator was used to irradiate the monitor chamber.

The current I provided by the high-voltage power supply to the straw was measured continuously during the tests, and every hour the flux of radiation was attenuated with a thin-foil stainless-steel absorber in order to measure a pulse-height spectrum. The current drawn at this low rate was also recorded 30 seconds after the absorber was put in. It should be noted that the stainless-steel absorber filters out part of the energy spectrum of the X-ray generator. To illustrate this, we show in figs. 1 and 2 the pulse-height spectra recorded with a sealed proportional counter (having a beryllium window) when thin aluminium (fig. 1) and stainless-steel (fig. 2) absorbers are used. This difference in the detected spectrum has to be kept in mind but has no practical consequence on the results.

A total charge of about 0.9 C/cm was collected at the anode wire of the test straw in four days (8 mC/hour). Figure 3 shows the raw measurement of relative gain computed as I/I_0 , I_0 being the initial current, measured on the test straw as a function of the collected charge. Neither a gain drop nor a deterioration in the pulse-height spectra are observed. The small fluctuations of the measured current visible in the figure are due to variations in the ambient pressure, temperature and/or gas flow, which influence not only the gas density but also the anode to cathode distance ('breathing' of the thin-wall tube).

2.2. Effects observed downstream from the irradiated region

While the gain differences due to changes in ambient conditions can, in principle, be corrected using the pulse-height recorded in the monitor chamber (which experiences the same changes), the mechanical deformations due to 'breathing' do not have a counterpart in the thick-walled monitor chamber and therefore cannot be corrected. Another observation however made the standard calibration procedure meaningless: this is the surprising effect shown in figs. 4 and 5. The normal spectrum in the monitor chamber, which has already a poor energy resolution with this gas mixture when the straw tube is not irradiated (fig. 4), shows a significant suppression of the larger pulse-heights when the irradiation in the straw tube is turned on (fig. 5). Since the monitor chamber is placed in series with and downstream of the straw tube, we can admit that the gas composition is somehow modified in the avalanche plasma of the irradiated region in the straw, presumably producing some neutral but electronegative radicals. These radicals would remain stable in the gas and flow into the monitor chamber, where they capture electrons drifting through a relatively long path, thus limiting the total charge available in the avalanches that take place in the chamber. Possibly, this effect of poisoning of the gas is not visible in the straw tube itself owing to the relatively high gas flow and shorter drift distance, but indeed the 'transient' ageing effect observed before at lower gas flows [3] could well be due to the same phenomenon as the effect we observe in the monitor chamber. The larger gas volume (by factor of ≈ 30) in the monitor chamber and the quick change in the operation of the chamber as a result

of the irradiation in the straw tube suggest that the deposition of polymers on the anode wire surface in the monitor chamber is not significant.

A Mass Selective Device (MSD) connected to the GC failed to show any change in the gas composition with and without irradiation on the straw tube; this is probably due to the fact that the MSD ionizes the species that are separated in the GC column, much in the same way as the electronic avalanches do in the irradiated test module. As an example, fig. 6 shows the chromatograms of ions of mass 69 (corresponding to CF_4), 132 (Xe), and 44 (CO_2) as they are separated in the GC column. The column used is not suitable for good separation of molecules such as CO_2 . The mass spectrum of the CF_4 is shown in the same figure, below, where the different ions into which the molecule is split up in the MSD identify the compound. Since, for example, the CF_4 and the CO_2 are highly concentrated in the main gas mixture, any extra abundance of ions such as F^- , CF_3^+ , CO^+ , or O^- might be compensated for in the device.

2.3. Test 2

A second ageing test (test 2) was done with some modifications in the set-up. The monitor chamber was replaced by a second straw tube connected upstream in the gas flow from the new test straw. In order to study the ageing behaviour of the detector at a lower charge collection rate, the gain of the test straw was reduced by a factor of 10 with respect to test 1. Figure 7 shows no ageing after 0.5 C/cm, accumulated in one week (2.2 mC/hour). The measured current in the test straw is normalized in this case to the gain measured from the pulse-height spectrum of the monitor straw, to better compensate for temperature and pressure variations.

The idea that, under stable conditions, the deposition of polymers on the anode surface is a continuous process [6], balanced by the etching properties attributed to the tetrafluoromethane [7, 8], supports the compatibility of the present results with those previously published [3].

3. Gain and collected charge

Figure 8 shows a typical X-ray pulse-height spectrum obtained with a straw tube operated at 1830 V. The overflows at the rightmost bin correspond presumably to large pulses, produced by a streamer mechanism, which occur about 1–2% of the times at this gain and with the Xe- CO_2 - CF_4 [50–30–20] gas mixture. Since the total charge produced per streamer is around hundred times larger than that of the proportional pulses, the total charge collected by the anode wire after a given dose, as measured by the current meter, will be higher than would be expected if all the avalanches were limited to the proportional mode and computed as the product of rate times gain. In fig. 9, the measured currents in the straw tube are plotted as a function of the irradiation rate, for two values of the gains which differ by a factor of 10 as estimated from the pulse-height in each case. Apart from the saturation of the curves at high rates, presumably due to a space-charge effect, the ratio of the currents at a given dose is of the order of 15. This could be explained by an increase in the number of streamers with gain, but not with rate. The behaviour of the

current measured at the anode wire as a function of the voltage applied on the cathode, shown in fig. 10, also suggests an increase in the relative number of streamers with gain.

4. Conclusions

The good tolerance of straw tubes operated with a Xe-CO₂-CF₄ gas mixture to high radiation doses has been confirmed up to collected charges on the anode wire of 0.9 and 0.5 C/cm for two different gains, after which no deterioration in the pulse-height spectra was observed. In addition, it is suggested that neutral, stable but highly electronegative species created in the avalanche plasma during irradiation might be responsible for the so-called transient ageing that has been observed at lower gas flows. The consequence of such dynamic modification in the gas composition due to high avalanche rates for the conception of a large detector (where the gas flows through regions exposed at different radiation rates) needs to be properly analysed.

On the other hand, it has been shown that the total charge collected by the straw tubes for a given dose and a gain of a few times 10⁴ is higher than what can be computed as the product of the dose by number of electrons in a proportional avalanche, owing to occasional transition of a fraction of the events to the limited streamer mode.

References

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Figure captions

Fig. 1: Pulse-height spectrum of the energy spectrum of the Fe target X-ray generator obtained with a proportional tube with an aluminium absorber. The spectrum peaks at ≈ 9 keV.

Fig. 2: Pulse-height spectrum of the energy spectrum of the Fe target X-ray generator obtained with the same proportional tube as in fig. 1 but using a stainless-steel absorber. The spectrum peaks now at 6.4 keV.

Fig. 3: Relative gain (current drawn by the HV supply divided by the initial one) as a function of the collected charge per centimetre of wire, for a gas gain of a few times 10^4 in the straw tube.

Fig. 4: Pulse-height spectrum of the X-ray radiation obtained with the monitor proportional counter when the straw tube, placed upstream relative to the gas flow, is not irradiated.

Fig. 5: Pulse-height spectrum of the X-ray radiation obtained with the monitor proportional counter when the straw tube is highly irradiated.

Fig. 6: Top curve: ion chromatograms, along the retention time, of one of the characteristic ions of each of the components of the Xe-CO₂-CF₄ gas mixture used during the tests, obtained with the Gas Chromatograph (GC). Bottom curve: The mass spectrum obtained with the Mass Selective Device (MSD) at the retention time corresponding to maximum abundance of the tetrafluoromethane. The characteristic ions in which the molecule is split up are labelled.

Fig. 7: Relative gain as a function of dose, corrected by the position of the peak of the monitor straw, for a test straw tube operated at a gain of a few times 10^3 .

Fig. 8: Pulse-height spectrum obtained with a straw tube operated at 1830 V. The overflows correspond probably to streamer pulses.

Fig. 9: The measured currents in the straw tube as a function of the incoming dose, for two values of the gain (a few times 10^4 and a few times 10^3) whose ratio is exactly 10 as measured from the preamplifier signals.

Fig. 10: Current measured on the anode wire of the straw as a function of the applied voltage on the cathode.

Fig. 1

Fig. 2

Fig. 3

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Fig. 10