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Space distribution of streamers in straw drift tubes

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Abstract

The appearance of a limited streamer mode in straw drift-tubes operating with a $Xe/CO_2/CF_4$ gas mixture has been investigated. The space distribution of streamers across the straw has been measured for different gas gains and anode wire offsets. Streamer mode discharges have been found to be generated when ionization from the particles occurs within a narrow zone (FWHM ≈ 400 µm) surrounding the anode wire. It was shown that the streamer contribution sharply increases with high voltage reaching almost 100% at a gas gain about of $1.2\cdot10^5$. It was found that the streamer intensity is very sensitive to the wire offset. Consequently, at a gas gain of $7\cdot10^4$ the number of streamers doubles when a wire is offset by 300 µm. This may greatly boost the aging of anode wires because streamers are an additional source of active radicals generated in the gas discharge since the total charge produced by streamer may be a hundred times larger than that from a proportional mode discharge.

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Keywords: Aging; Limited Streamer Mode, Intense Irradiation.

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1. Introduction

It was shown [1,2] that for a $70\%Xe+10\%CO_2+20\%CF_4$ gas mixture the limited streamer mode (LSM) plays an important role in the gas avalanche development starting from a gas gain of 4.5×10^4. The fraction of streamers rises extremely fast versus gas gain. The LSM is an additional strong source of space charge production since the total charge produced per streamer is around a hundred times larger than that from a proportional pulse. Moreover, such results lead us to conclude that an appearance of the LSM is a quite reasonable explanation for the effect of accelerated aging. These data prompted us to provide a thorough study of LSM development in straw drift tubes.

2. Test set-up

The set-up for investigation of the streamer mode appearance in straw-tubes is shown in Fig. 1. The measurements were carried out with straw drift-tubes [3] equipped with gold-plated tungsten anode wires with a diameter of 35 µm. These straw drift-tubes had a diameter of 4 mm. The gas flow rate during the test was 0.5 cm^3/min, or five straw volumes per hour. A ^{55}Fe X-ray source was used for the straw tests. The irradiation zone was defined by a collimator, which provided the following beam dimensions: 20 mm along and $\Delta X = 0.1$ mm across the straw.

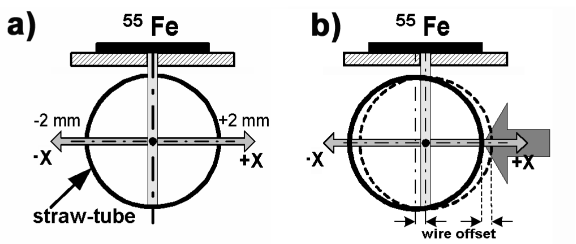

Fig. 1. Test set-up for investigation of the streamer mode contribution. To investigate the spatial structure of streamers a narrow beam passed across straw (Fig. 3a). The same scanning procedure carried out to study the streamer distribution for different wire offsets (Fig. 3b).

In order to measure the streamer contribution dependence on the particle track position, the cross-section of the straw was scanned with a narrowly collimated ^{55}Fe source. A non-collimated beam was used to study a contribution of the streamer mode.

3. Test results

3.1. Gas gain measurements

The gas gain has been estimated by measuring the peak position of the ^{55}Fe-pulse height distribution vs high voltage with subsequent calibration (Fig. 2). This shows that the LSM starts with a gas gain of 4.5×10^4. The maximum gas gain that could be achieved in proportional mode is about 1.2×10^5. As one can see, the contribution of LSM to the gas discharge quickly increases versus gas gain (Fig. 3). Pulse-height spectra obtained for different gas gains clearly demonstrated that LSM has a double-peak structure (Fig. 4). The probability for generating these streamer modes at the gas gain of 4.5×10^4 is about 0.75% (for mode I) and 0.02% (for mode II). These spectra look very similar to those obtained by M.Atac [4].

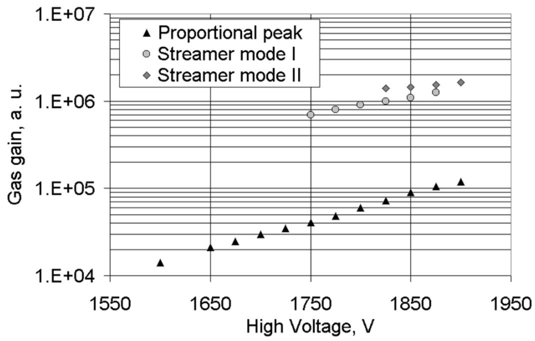

Figure 2. Gas gain (proportional mode) and LSM behavior vs. high voltage for the ^{55}Fe source.

3.2. Space distribution of streamers

The space distributions of streamers have been obtained for different high voltages (Fig. 5) as mentioned in section 1. These data definitely demonstrate that streamers are generated by particles passing through the straw within a narrow zone (FWHM ≈ 0.4 mm) around the wire. To find an explanation for the obtained results the Townsend (α) and attachment (η) coefficients have been calculated with the MAGBOLTZ program. The results of this calculation are presented in Fig.6. It is seen that a ring with electronegative properties $(\alpha-\eta)<0$ exists around the anode wire. This ring has the following geometrical dimensions: the minimum diameter is 0.36 mm and the maximum diameter is 0.9 mm. As one can see, the sensitivity of these ring dimensions

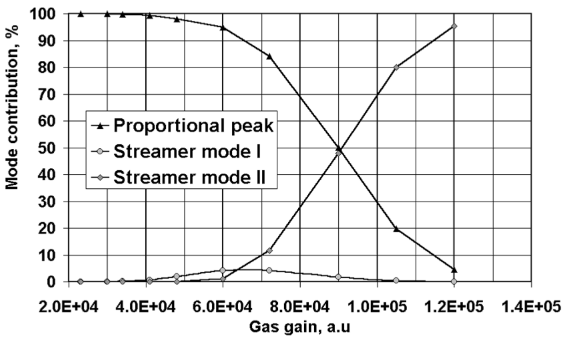

Fig. 3. Streamer mode contribution versus gas gain.

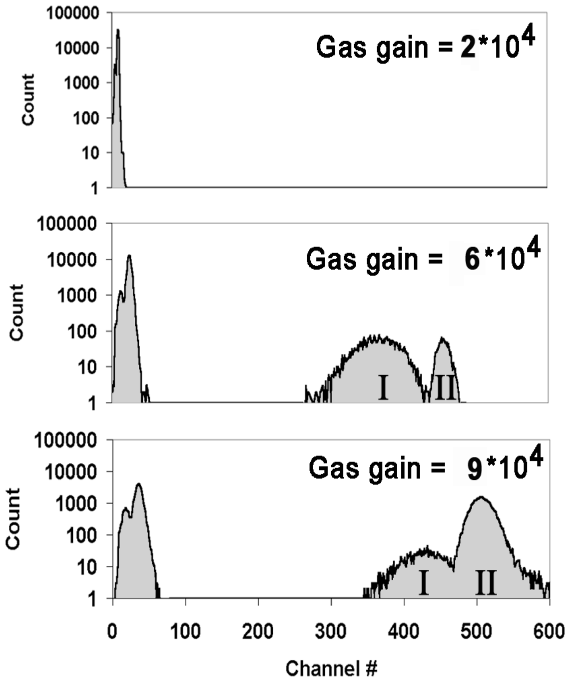

Fig. 4. Spectra from a ^{55}Fe source with 2 distinct LSM's.

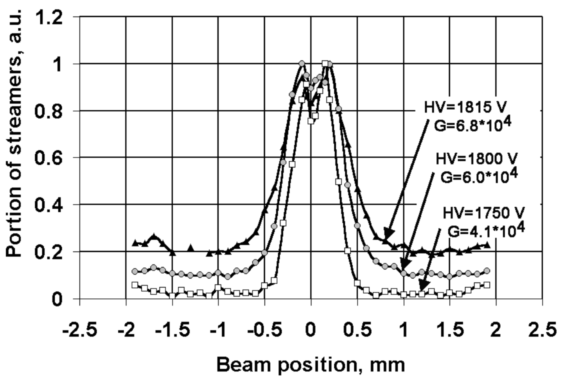

Fig. 5. Relative portion of streamers versus beam position across the straw.

to the high voltage is very small.

Comparison of the data presented in Figs. 5 and 6 gives a direct correlation between the space distribution of streamers and the ring dimensions. It leads us to the following conclusion about the mechanism of streamer generation in the straw-tube. Electrons extracted within the gas after ionization by the photons from ^{55}Fe source, which cross the straw outside of the electronegative zone, drift toward the anode wire through this zone. This causes a reduction

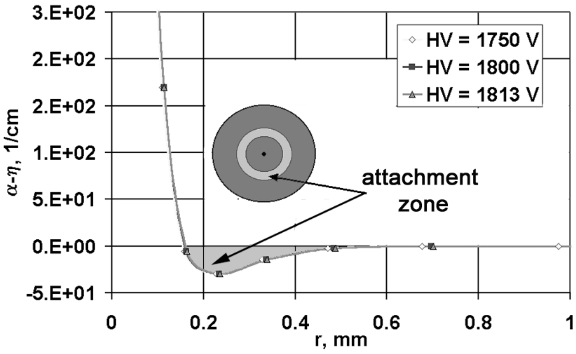

Fig. 6. Attachment zone in the straw tube.

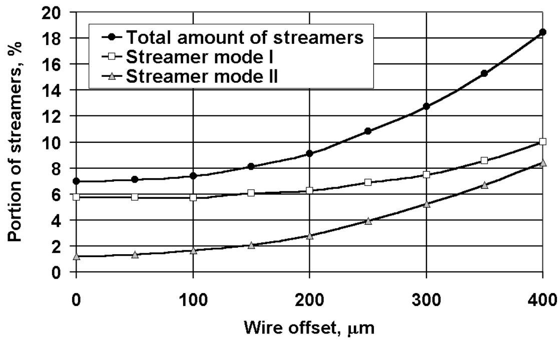

Fig. 7. Streamer contribution versus wire offsets. (HV = 1.8 kV) obtained with non-collimated beam.

of the electron number due to the high attachment in this zone. Finally, the total charge generated near the anode wire decreases a few times, which results in a strong suppression of the probability for LSM generation.

3.3. Influence of a wire offset on the streamer generation

To study the contribution of the streamer mode we used both non-collimated (Fig.7) and collimated beams (Fig.8). The LSM contribution versus a wire offset is presented in Fig. 7. It shows that the increase of a wire offset results in a rise of the total amount of streamers. Moreover, this effect becomes more pronounced for higher gas gain.

The spatial distributions of LSM obtained for different wire offsets are presented in Fig. 8. It is seen that the probability to generate streamer mode II is higher on the side where the cathode is closer to the anode wire (see Fig. 1b – to the right of the anode wire). In other words, the area with both higher electric field strength and higher field gradient provokes the creation of streamer mode II. Correspondingly, the probability for generation of streamer mode I is higher on the left of the anode wire due to the lower field strength.

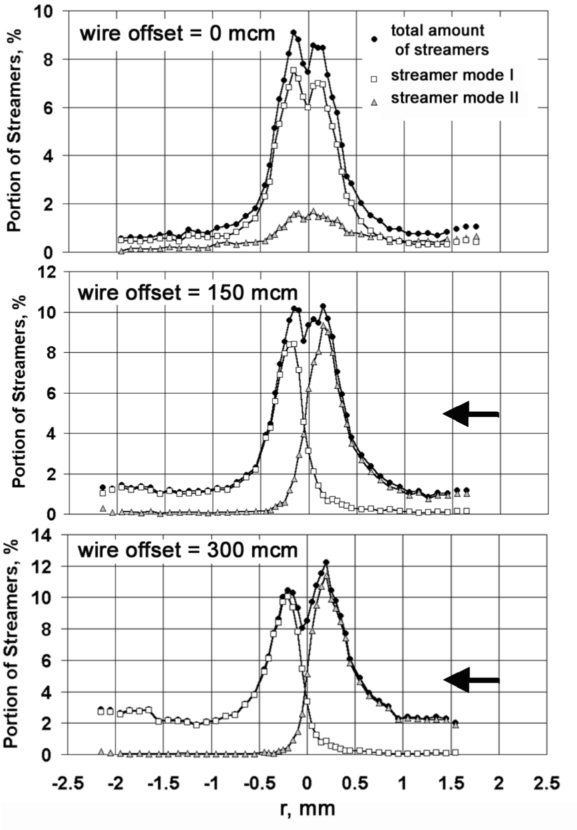

Fig. 8. Space distributions of streamers for gas gain of $6{\cdot}10^4$ (HV=1.8 kV) obtained with collimated beam.

4. Conclusion.

1. It was observed that straw-tubes operating with a $70\%Xe+10\%CO_2+20\%CF_4$ gas mixture are very sensitive to the appearance of the Limited Streamer Mode which starts at a gas gain of 4.5×10^4 contributing about 0.8% to the total number of events. The number of streamers rises extremely fast with the high voltage and reaches up to 50% for a gas gain of 9×10^4.

2. Two limited streamer modes (I and II) have been observed. Mode II becomes dominant starting at a high voltage of 1.825 kV (corresponding to a gas gain of 7.2×10^4).

3. It was demonstrated that the Limited Streamer Mode is generated only by those particles, which pass through the straw drift-tube in a narrow zone (FWHM ≈ 400 μm) surrounding the anode wire. The space structure of this streamer generation zone closely matches the space dimensions of an electron attachment zone. We assume a direct correlation between the LSM generation zone and the attachment zone in the straw.

4. It was shown that the streamer contribution is very sensitive to the wire offset. A wire offset of 300 μm almost doubles the streamer contribution (from 7% to 13%) for a gas gain of 6×10^4. This is mainly a consequence of the generation of the streamer mode II. It must be taken into account in the design of detectors that are based on straw-tubes.

5. The process of the streamer generation depends on an electric field structure. In the case of a 300 μm wire offset, two streamer modes (I and II) exist with equal probability of appearance of about 11%. The modes are well shared in the space. These generation zones are located 0.2 mm away from the center of the straw. The streamers of mode II have higher amplitude and are located on the side of the straw that has higher electric field strength.

6. Our results do not present clear evidence that LSM accelerates the aging process. This problem needs more study. However, the comparison of the data presented above with the results from [1,2] give us some hints supporting such a conclusion.

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