Performance of straw proportional tubes under high gas gain, transition to self-quenching streamer mode and corona discharge

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The straw operation under high gas gain in proportional mode is always accompanied by self-quenching streamer (SQS) discharges, with a probability which rises very quickly with the gas gain.

Further increase of the applied high voltage leads to corona discharge or breakdown. Transition from proportional mode to SQS and corona sparking was studied for straw tubes filled with the following mixtures: Xe/CO\textsubscript{2}/CF\textsubscript{4}, Xe/CO\textsubscript{2}, Xe/CO\textsubscript{2}/O\textsubscript{2} and Xe/CO\textsubscript{2}/H\textsubscript{2}O. Streamer discharge probabilities as a function of applied high voltage and temperature were determined.

Special attention was paid to show how the pulse height distribution varies as a function of the applied high voltage with a $^{55}$Fe source. It was found that there exists a state of counter operation, at a certain high voltage, in which SQS mode (dominating), proportional mode and corona discharge occur simultaneously.

1. Introduction

Straw detectors have been chosen as detec-
ing elements for the transition radiation detectors in the ATLAS Experiment and for the enhanced tracking detector at the ZEUS Experiment. For this reason there has been a large activity aimed at the development of straw tubes. The difficult operating conditions of the straws in HEP experiments, especially those expected at the LHC, impose strong restrictions on the choice of the straw gas.

When ionizing radiation passes through the working gas filling the proportional counter, free electrons and ions are liberated. The number of created electrons, $n_0$, can be calculated from equation:

$$n_0 = \frac{E}{W}$$

where: $E$ – energy deposited in the gas, $W$ – energy required for electron-ion pair production.

In a high electrical field, the electrons created may have sufficient energy to ionize further and create secondary electron-ion pairs. The total number of electron-ion pairs, $n$, divided by number of primary electrons $n_0$ gives the so-called gas gain coefficient, $A$,

$$A = \frac{n}{n_0}$$

The range of gas gains for which the straws will operate stably is determined by several considerations. One of them is the minimum threshold for the front-end electronics discriminator. To keep the threshold to noise ratio at a reasonable level (4:1 in the ATLAS experiment) [1], a high drift time measurement efficiency and the required drift time accuracy, the straws should work at a gas gain of $\sim 10^4$. For higher values of the gas gain, self induced space charge effects lead to significant non-linearity in the straw response, which also depends on the deposited energy. The straw operation under high gas gain in proportional mode is always accompanied by self quenching streamer (SQS) discharge [2,4], with probability which rises very quickly with the gas gain. Further increase of the applied high voltage leads to corona discharge [3] or breakdown (Fig. 1). SQS produce big pulses, few times higher than those corresponding to the proportional mode, and deposit more charge which affects the efficiency leading to overloading of the front-end electronics. The large signals from SQS discharges would also lead to faster aging of the detectors.

In this paper the transition from proportional mode to SQS and corona discharge was studied for straw tubes filled with Xe-based gas mixtures.
2. Experimental setup

The ATLAS straw tubes of diameter \(2r_k = 4\) mm with an axially located gold plated wolfram anode of diameter \(2r_a = 30\) µm were used for the measurements. The entrance window for the bombarding radiation, practically mono-energetic \(X\)-rays (MnK\(_\alpha\) from a \(^{55}\)Fe source) of 5.9 keV, is a 4 mg/cm\(^2\) beryllium foil.

The straws were connected to a gas system, enabling flushing them with pre-mixed (in steel cylinders) \(Xe/CO_2/CF_4\) \((70/10/20)\) mixtures. All the other straws were filled with a gas composition achieved by mixing pure \(Xe\) with \(CO_2\) \((70/30)\) and either \(H_2O\) \((70/28.5/1.5)\) or \(O_2\) \((70/27/3)\).

Measurements of the charge characteristics of the chambers were done using a conventional electronic system consisting of a low sensitivity charge preamplifier, amplifier and a multichannel analyzer.

3. Experimental results

The proportional and self-quenching streamer charges were measured as a function of the anode voltage, \(V\), of the straws, for different \(Xe\)-based mixtures. In the transition region, either the proportional state or the streamer state occur with no intermediate pulse height observable. At the voltage of 1820 V, proportional, SQS and corona discharge are observed simultaneously, Fig. 1, for \(Xe/CO_2/CF_4\) \((70/10/20)\).

The probability of streamers versus high voltage for all the mixtures investigated is shown in Fig. 2.

A high voltage increase above a given value, which depends on the type of mixture, leads to a fast rise of the SQS count rate, until this type of discharge becomes the dominant one.

Streamers (SQS I, SQS II) and corona discharge pulse count rate was compared with the proportional rate for a wide range of applied high voltage, Fig. 3. Increase in the number of registered pulses is observed due to corona discharge. SQS II and corona discharge were observed only for the mixture with the addition of \(CF_4\).

Different positions of the straws inside the experiment introduce the temperature gradients along a straw or across a group of straws working at the same high voltage. The temperature dependence of the streamer probability has also been measured, see Figs. 4, 5.

4. Conclusions

- Mixture \(Xe/CO_2/CF_4\) \((70/10/20)\) – very stable, SQS starts at 1700 V, corona discharge for \(HV \geq 1820\) V, no sparking observed up to 2 kV.
- Mixture \(Xe/CO_2\) \((70/30)\) – low operation stability, SQS starts at 1620 V, no corona discharge observed, sparking below 1800 V.
- Mixture \(Xe/CO_2/H_2O\) \((71/27.5/1.5)\) – similar to \(Xe/CO_2\).
- Mixture \(Xe/CO_2/O_2\) \((70/27/3)\) – intermediate operation stability, SQS starts at 1660 V, no sparking observed up to 1880 V.
- For fixed applied \(HV\), streamer probability depends on temperature.
- For fixed gas gain, streamer probability is temperature independent.

REFERENCES

Figure 1. Pulse height spectra illustrating three different working modes (proportional, SQS and corona discharge) appears simultaneously, for applied HV = 1820 V, for the $\text{Xe}/\text{CO}_2/\text{CF}_4$ (70/10/20) gas mixture, under atmospheric pressure and at 20°C.

Figure 2. SQS probability as a function of applied high voltage for all investigated mixtures.

Figure 3. Contribution of different types of discharge modes to the overall number of collected pulses for straw tube as a function of applied high voltage for (a) $\text{Xe}/\text{CO}_2$ (70/30), (b) $\text{Xe}/\text{CO}_2/\text{H}_2\text{O}$ (71/27.5/1.5), (c) $\text{Xe}/\text{CO}_2/\text{CF}_4$ (70/10/20) mixtures.
Figure 4. SQS probability as a function of gas gain for three different temperatures for the Xe/CO$_2$/CF$_4$ (70/10/20) mixture at a pressure of 1025 hPa.

Figure 5. SQS probability as a function of applied high voltage for three different temperatures for the Xe/CO$_2$/CF$_4$ (70/10/20) mixture at a pressure of 1025 hPa.