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ON SOME FACTORS AFFECTING DISCHARGE CONDITIONS IN MICRO-STRIP GAS CHAMBERS

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ABSTRACT

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We describe the results of an investigation on the influence of geometrical parameters on the maximum gain that can be attained in a micro-strip gas chamber. Single electron emission from the cathode was confirmed to be a precursor of discharge, particularly for gas mixtures with a high fraction of quencher, confirming our previous observations. In contradiction however with the results of a theoretical model proposed in earlier work, we found that the maximum gain is obtained in a narrow range of cathode strip width. This suggests the presence of other mechanisms initiating a discharge, such as photon- or ion-initiated feedback. The influence of strongly ionising irradiation on discharge conditions has also been investigated; we have observed an increasing probability of discharge in detectors irradiated with α particles, releasing around one MeV in the gas, as compared to 6 keV X-rays. This results in a reduction by a factor of two of the maximum gain at which a MSGC can be safely operated, a concern for the use of micro-strip chambers in vertex detectors for colliders where low energy, heavily ionizing particles and thermal neutrons are produced together with minimum ionizing particles.

1. Introduction

Introduced only a few years ago [1], micro-strip gas chamber (MSGC) are today integral part of the design of high resolution tracking detectors for high rate LHC experiments [2, 3], and are finding applications in many other fields. A collaborative effort is being devoted to determine the best chamber geometry and manufacturing technology to guarantee stable and safe long-term operation, as summarized for example in the RD-28 status reports [4, 5]. One major requirement, in order to obtain good efficiency and resolution for minimum ionizing particles, is a gas gain sufficiently high to provide a good signal-to-noise ratio; on the other hand, the operation has to be safe, implying a comfortable margin between the operating voltage and the appearance of discharges or breakdown.

In high luminosity experiments, a large background of strongly ionizing particles such as low energy hadrons and thermal neutrons will be unavoidable. Recent simulations [3] show that the rate of low energy pions (less than 10 MeV) will be up to 1 kHz cm^{-2} in the inner cavity of the CMS detector; the neutron flux is estimated to be around $5 \cdot 10^5 \text{ cm}^{-2}\text{s}^{-1}$. By direct ionization, nuclear interactions or neutron activation these particles can release in the gas large amounts of ionization, and consequently induce large avalanches whose possible outcome is to increase the probability of discharges in the chamber.

In the present paper we describe recent experimental work intended to characterize gain-limiting discharge mechanisms in MSGCs. The influence of the width of cathode strips on maximum gain has been investigated, and is compared with the results of a model proposed in earlier work [6]. The effect of strongly ionizing particles on the discharge threshold has also been being studied experimentally, irradiating the chamber with heavily ionizing 5 MeV α particles and comparing the results with those obtained with soft X-rays.

2. Optimization of the cathode width

In earlier work we have proposed a model for the discharge mechanism in order to find an optimal MSGC geometry [6]. According to the model, the discharge in MSGCs can be initiated by electrons ejected from the cathode and multiplied in the regions of high field near cathode and anode edges. As shown in Fig. 1, from the quoted reference, the gain computed for electrons released in the region of the cathode edge, and following a field line near the surface of the substrate can be more than an order of magnitude higher than for those arriving from the “normal” ionization drift region. Following the procedure suggested in previous studies of breakdown conditions in wire chambers [7], we have assumed that a discharge can be induced when the total gain for a particular path exceeds a certain value, constant for all geometries in a given gas; by total gain we mean the result of the charge multiplication of an electron from the point of production all the way to the anode, taking into account the amplification near the cathode. The model predicted that with increasing cathode width and fixed pitch (a decreasing gap between cathode and anode), multiplication in the critical region between the edges of strips should be reduced by the shorter path and therefore the discharge limit will increase. This was however not demonstrated experimentally.

In order to measure the voltage dependence of gain, counting rate plateau and background noise for different geometries, we have manufactured with the same technology and on the same support four MSGCs, each with an active area of $8 \times 10 \text{ mm}^2$. The substrate was a sheet of electronically conducting glass with a resistivity of $10^9 \Omega \text{ cm}$; electrodes were made of gold, $0.5 \mu\text{m}$ thick, with anodes $7 \mu\text{m}$ wide at a pitch of $200 \mu\text{m}$, and cathodes $170, 130, 90$ and $60 \mu\text{m}$ wide respectively in the four patterns. The technology to manufacture the chambers (galvanic growth over a titanium under-layer) has been described in Ref. [8]; it should be kept in mind that some results of this study may depend on the manufacturing technology, and in particular on the thickness and shape of the strip' edges. The common drift electrode was realized with a mesh 10 mm above the MSGC plates. All measurements were made on the signals induced by avalanches on groups of twenty cathodes, equipped with a charge amplifier and pulse height analyzer, irradiating the chamber at low rate with 5.9 keV X-rays. Absolute gain values were obtained at one voltage setting by measuring simultaneously pulse height, counting rate and anode current in the chamber during irradiation; all other measurements realized in the pulse height mode were normalized to this value [9]. The counting rate was measured with a low threshold discriminator and scaler connected to the amplifier output; the noise corresponds to the counting rate in the absence of radiation. Accuracy and reproducibility of the gain values are estimated to be of the order of 10%.

We have investigated experimentally the dependence of the discharge limit on cathode width using the four MSGC described above; Fig. 2 shows the gain dependence on anode voltage for the four plates operated with a 50-50 mixture of argon and dimethylether (DME). For each MSGC the measurement was halted by a discharge tripping the HV power supply, set at a current limit of about $20 \mu\text{A}$. The singles counting rate (Fig. 3) shows a substantial increase in the noise about 50 volts before discharge. Pulse height spectra recorded at high voltage, with the source removed, reveal the exponential characteristic of the noise (Fig. 4), as one would expect for the amplification of single electrons. Assuming each avalanche in the noise spectrum to be initiated by single electrons, we can calculate the average gain value for such events. As shown in Fig. 5, the gain computed from the noise spectrum is about 10 times higher than the gain for normal detected X-rays. This is a clear indication that the noise avalanches are initiated by electrons generated at the cathode edge; we will call this process edge-to-edge (ETE) gain, as against the regular gain for ionization arriving from the drift region. When the cathode width is increased, and the gap between anode and cathode correspondingly decreased, keeping a the normal gain fixed, the measured ETE gain drops as shown in Fig. 6; this behaviour is predicted by the model [6], but implies that if breakdown is initiated by large avalanches due to electrons ejected by the cathode, the discharge limit has to increase with the cathode width. The results shown in Figs. 2 to 5 indicate instead that the discharge limit increases with the cathode width, is maximum around $90 \mu\text{m}$, and drops rapidly with wider cathodes. This decrease of maximum gain together with the drop of ETE gain at wide cathodes (short anode-to cathode gaps) suggests clearly that a discharge in MSGC can be initiated by other mechanisms. In Fig. 7 we show the comparison between the measured and calculated discharge gain; the discrepancy becomes clear for cathode widths exceeding $100 \mu\text{m}$ (anode-cathode gap below $50 \mu\text{m}$).

Several possible mechanisms of discharge can determine such a behaviour of the gain threshold. As we have seen from the previous measurements, a discharge in MSGCs is always preceded by an increase in the rate of field emission. The intensity of emission depends on the field strength, and therefore is higher when the anode-cathode gap is smaller; individual avalanches induced by emitted electrons are small in size, but their higher rate increases the probability of a discharge.

Another possible mechanism for discharge is UV photon- or ion-mediated feedback; the probability of both effects depends also strongly on the electric field strength. For a small distance between anode and cathode strips, the solid angle offered by cathodes for secondary emission by UV photons is larger, and more electrons are expected to be produced. The relative importance of the two discharge mechanisms can be inferred from the results reported in previous work (see Fig. 2 in Ref. [6]). For small DME concentrations in argon, there is almost no noise detected before discharge, and this despite the lower gain limit; a feedback mechanism can be suspected to be a precursor for the discharge in this case. For higher quencher proportions, on the other hand, the noise rate increases considerably before breakdown, and the maximum gain is smaller despite the increased suppression of UV photon feedback. This suggests that a spontaneous emission mechanism is responsible for the discharge.

3. Gain limit in presence of heavily ionizing particles

To investigate the influence of heavily ionizing radiation on the discharge threshold, we have built a special MSGC with a very thin polymer window (3 μm Hostaphan). Manufactured with chromium strips on standard 300 μm thick D-263 glass, the detector had 10 μm wide anodes, 80 μm cathodes and 200 μm anode to anode distance; other operating parameters were similar to those used for previous measurements. The chamber was irradiated with collimated 5 MeV α particles from an Am^{241} source, and with 5.9 keV X-rays from Fe^{55} ; the drift voltage was fixed at -1 kV on the 3 mm gap. In both cases the rate was not higher than 1 kHz over the full active area of the chamber, about 10 cm^2 .

The measured dependence of peak position on anode voltage for the two sources is shown in Fig. 8. Since the energy loss for α particles is much higher than for x-rays, we had to use different gain settings on the pulse height analyzer, and re-normalize the data. Increasing the anode voltage from low to high values, the measurement was halted when the power supply would trip within a few minutes from application of voltage, a limit shown by the vertical arrows in the figure. During the measurement, we have monitored also the rate of pulses exceeding by a factor of two or more the largest physical signal induced by the sources; the rate of those large pulses is constant and low in absence of irradiation, while it is an order of magnitude larger and increasing with time when the chamber is exposed to the α source at a voltage close to the limit of discharge (see Fig. 9). These large pulses may be considered as precursors of radiation-induced breakdown. The difference in gain between the highest anode voltage reached before discharge with X-rays (660 V) and the highest safe voltage in presence of α particles (620 V) is about a factor of 2; this has to be taken into account when estimating the conditions for safe operation of MSGC in a presence of strongly ionizing particles.

4. Conclusions and summary

In a study made to optimize the geometry of MSGCs, we have investigated experimentally the discharge threshold of the detectors and its dependence on the width of cathode strips, and compared the results with the predictions of a model. The gain at the discharge threshold was found to increase for a decreasing anode-to cathode gap, reach a maximum at about 50 μm for a 200 μm pitch and then to drop rapidly for smaller gaps, in contradiction with the results of the model. The experimental results suggest an optimum cathode width of 90-100 μm for the pitch of 200 μm .

We have considered two mechanisms that can be responsible for the observed behaviour: high intensity spontaneous emission by field emission on cathodes, and UV-photon mediated feedback. While we expect the general dependence of the discharge threshold on geometry to be similar for different chambers, the detailed results can depend on the technology used for manufacturing the MSGC plates.

In a study aimed at assessing the stability of operation of MSGCs in presence of heavily ionizing radiation, we have found that exposure to 5 MeV α particles (releasing about one MeV in the gas) causes a decrease of the maximum gain before discharge by about a factor of two, as compared to irradiation with soft X-rays; this should be taken into account when estimating the operating conditions of MSGCs in the LHC environment.

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FIGURE CAPTIONS

- Fig. 1:** Computed equal gain contours in a MSGC, superimposed to the field map; electrons released close to the cathode edge generate avalanche sizes an order of magnitude larger than those released in the drift region.
- Fig. 2:** Experimentally measured dependence of gas gain on anode voltage in MSGCs with different cathode width. The highest point in each curve corresponds to the discharge limit.
- Fig. 3:** Counting rate plateaux (full lines) and noise rates (dashed lines) for three MSGCs with different cathode strips width (60, 90 and 130 μm).
- Fig. 4:** Pulse height spectrum of the noise (signals without sources). The full line represents an exponential fit to the data.
- Fig. 5:** Measured dependence on anode voltage of the “normal” gain for ionization released in the drift region (full lines), and computed edge-to edge gain for electrons released at cathodes (dashed lines), for three values of the cathode strips width.
- Fig. 6:** Computed edge-to edge gain for three values of normal gain, as a function of cathode strips width.
- Fig. 7:** Computed and measured maximum gain before discharge, as a function of cathode width, at fixed 200 μm pitch.
- Fig. 8:** Dependence of pulse height peak position on anode voltage for α particles and X-rays; the vertical arrows indicate the maximum voltage attainable before discharge in each case.
- Fig. 9:** Measured rate of pulses exceeding by at least a factor of two the largest signals from the sources, at an anodic potential of 630 V, in presence of α particles irradiation (open circles) and without (full points).

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