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EXPERIMENTAL STUDY OF SOME PROPERTIES OF THE SPARKING DISCHARGE IN ATMOSPHERIC AIR

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ABSTRACT:

The current experimental study investigates some aspects of the electrical discharge properties between two planar electrodes. These properties involve the relationships of the minimum sparking potential to the electrode separation, the spark repetition rate, and the distribution of discharge pulse height concerning both the applied voltage and electrode separation. These discharge parameters tend to show nonlinear relationship with both applied voltage and electrode separation.

KEYWORDS: Spark discharge, Micro discharge, filaments, atmospheric discharge, PACS: 52.80.-s, 52.80. Mg

1. INTRODUCTION

The study of electric spark discharge in atmospheric air dates back to the late nineteenth and beginning of the twentieth centuries [1]. Even so, this kind of plasma discharge continued to attract researchers for over a century. This object was and still driven by the wide many applications related to this type of discharge. Some of the early applications include prevention of undesired explosions of ammunitions, and combustible dusts and vapor atmospheres [2,3], and engines spark plugs [4,5,6,7]. One of the main experimental tools used in particle physics research is the wire spark chamber [8]. Atmospheric micro discharges have also been used in medical and biological sterilization processes [9,10,11] With the last three decades advances in microchip and nanotechnology, atmospheric micro discharge studies have acquired ever-increased interest [12-16].

The electrodes configurations used to generate micro discharges vary widely depending on the particular application. These include the simple parallel plate [17,18,19], multi-needle to cylinder, [20], wire to plate, and wire to cylinder [21,22] configurations are very common.

In line with other plasma physics studies, micro discharges are produced using different types of bias voltage supplies. In addition to the simple DC biasing, pulsed [23,24, 25], 50 Hz [26], radio frequencies [27,28] and microwave frequencies have also attracted interests [29,30]. Many aspects related to works on micro discharged are covered in a recent review paper presented by Brandenburg et al (2023) [31].

The types of research sited in literature are mostly of the experimental type. Even so, some modelling and simulation works have been carried out [32,33,34]. However, and in spite of the large volume of experimental works on spark gaps in general, there seems to be no general theory, and only few experimental works related to the evolution of micro discharges in the sub millimetre gaps at atmospheric pressure [35]. This may be due to the lack of interest by industry in this range of discharge gaps compared to the more attractive microns, and several millimetre ranges on the two sides. Under the circumstances, the case for further experimental works attempting to throw more light on the subject can be regarded as a justified one.

One further point is worth stating. From observation of all above listed literature works and others, one may notice that a large percentage of these works are concerned with studying optical properties and spatial distributions of micro-discharges, and some macro electrical properties like voltage_ current characteristics rather that the electrical nature of the pulses produced. It is the purpose of this work to present experimental data on the later aspect of this subject.

2. EXPERIMENTAL SETUP

The experimental setup is shown in Figure (1-a). It consists of two circular well surface polished Aluminium electrodes 5.5 cm radius and 1 cm thick. One of the electrodes is fixed. The upper electrode is vertically movable using a micrometre screw moving mechanism. The inter-electrode distance between the electrodes is fixed using the required number of stacked circular

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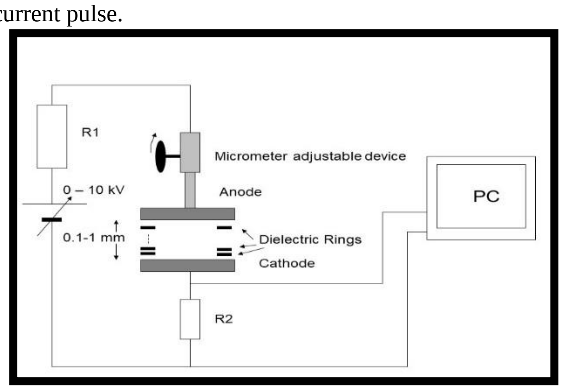
plastic rings with inner and outer radii of 5 and 6 cm respectively as shown in Figure (1-b).

The thickness of each ring is 0.1 mm. Discharge measurements were carried out using between 1 and 10 such rings allowing variation of inter-electrode spacing between 0.1-1 mm. Each inter-electrode spacing is further checked using the micrometre reading in addition to the number of stacked 0.1 mm dielectric rings. The two electrodes are connected to 10 kV dc power supply via the 200-kilo ohm, one-watt power rating ballast resistor R1. Due to the very nature of electric discharge in air at atmospheric pressure, electric discharge current cannot sustain itself for long periods. This will result in ON and OFF discharge current pulses when the applied voltage is sufficient enough. This results in discharge current fast pulses rather than continuous discharge current as it is the case in glow discharge. These current pulses are sampled from the 10 ohms sampling resistor R2. The value of R2 was set such that the maximum voltage pulse does not exceed the maximum one-volt input rating of the computer sound card used as the data acquisition device.

This corresponds to about 100 mA of pulse electric current, which is much higher than current pulsed observed during the experiment. Consequently, and in spite of the high DC voltages present within the circuit, voltages across R2 never exceed few tenth of one volt. The use of the sound card in conjunction with MATLAB software as our data acquisition system allows for 44000 Hz sampling rate that represent a time resolution of about 20μ sec. The voltage is increased between zero to several kV in steps of 0.1 kV, and discharge current data are acquired over a one second period each time. The acquired data are saved on hard disk for further analysis. The electrodes are cleaned after each run with a particular discharge cap.

The experiments were performed in a dry atmosphere with almost zero humidity. Typical data obtained just at, and after the full evolution of the discharge are shown in Figures (2-a) and (2-b) respectively. Figure (2-c) shows a magnified micro discharge current pulse.



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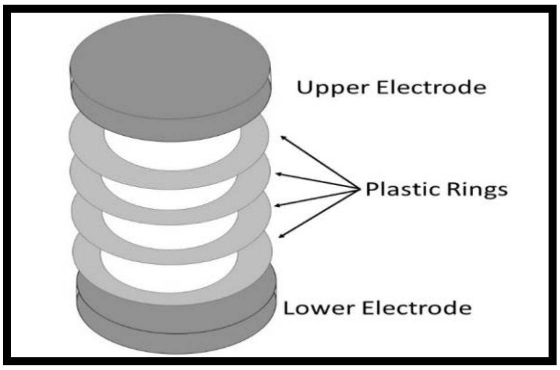

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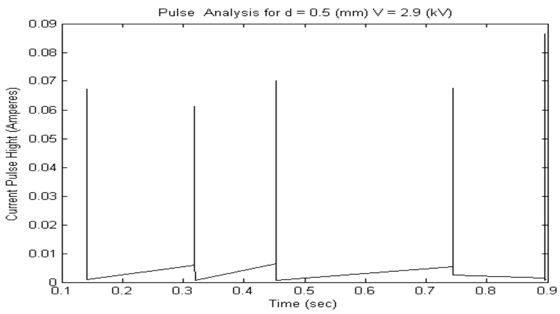
Figure 1: Experimental setup (a) General setup. (b) Electrodes and plastic rings configuration



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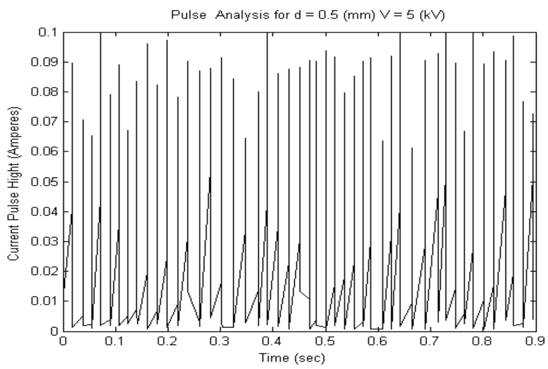

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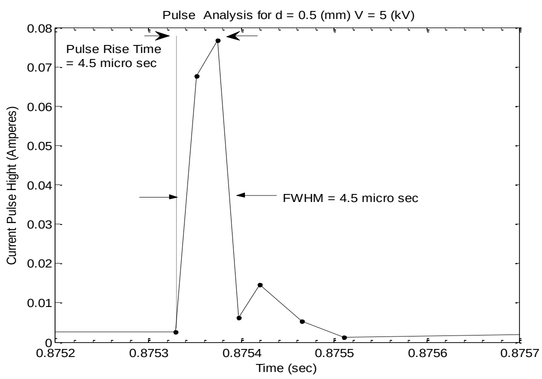


c

Figure 2: typical current pulses obtained for discharge cap of 0.5 mm (a) at voltage of 2.9 kV, which is slightly above the start of breakdown. (b) At 5 kV. (c) One typical pulse magnified.

3. RESULTS AND DISCUSSION

3.1 Breakdown Voltage

It is reasonable at first to present the results related to the breakdown voltage to the electrodes separation distance (d). The criterion used here to define the breakdown voltage is the minimum voltage at which we registered one current pulse at least over a period of one second. This is measured by repeating the pulse data acquisition process several times at each voltage value below the breakdown voltage in 0.1 kV steps. This puts an experimental error on the breakdown voltage of 100 Volts. The results are shown in Figure (3). The data tend to show an almost linear relationship between breakdown (V_{BK}) voltage in kV and spark gap length (d) in mm. Furthermore, this linear relationship extrapolates well to describe the experimental data for post one-millimetre spark gap published by Fujita et al. [36]. This linearity relation can be well described by the fitted equation

$$V_{BK} = 3.1 \times d + 1.1 \quad (1)$$

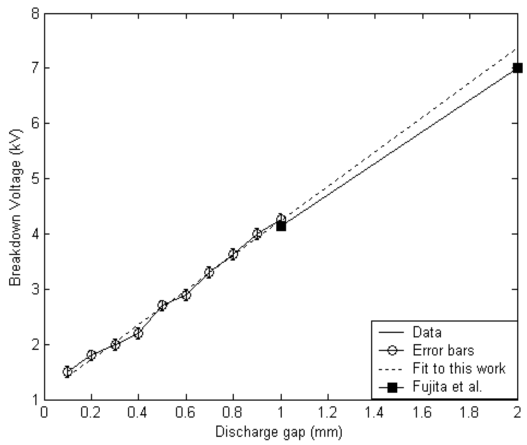


Figure 3: Micro discharge breakdown voltage versus discharge gap

3.2 I-V Characteristics

The relation between applied voltage and mean sparking discharge current is studied for all discharge gaps. For clarity reason, and space considerations, results for only four discharge gaps are presented in Figure (4). In this figure, the mean discharge current is defined as the total charge transfer (Q) during the one second of data acquisition. If the pulse height across the 10-ohm current sampling resistor is (H) volts, pulse width at half maximum is (τ) and number of pulses registered during one second is N, then the current is given by;

$$I = \frac{H}{10} \tau N \quad (2)$$

The results for all discharge gaps indicate that after the discharge threshold voltage, the discharge current tend to follow almost linear relationship to the applied voltage. This is in contrast to the case with ordinary self-sustained glow discharge where a fast rise in current is usually observed.

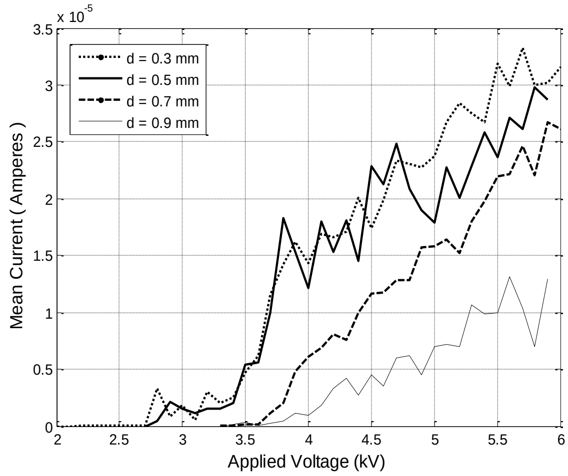


Figure 4: Current – Voltage characteristics of micro spark discharge for inter-electrode distances 0f 0.3, 0.5, 0.7, and 0.9 mm

Assuming almost constant pulse widths (τ), the value of discharge current is the result of the combined effect of changes in the number of pulses per second and the pulse height. In order to investigate which of the two effects is predominant, these two properties are studied separately for all discharge gaps. Figure (5) shows the effect of increasing applied voltage on the number of pulses per second for the four discharge gap values presented in Figure (4). Results for all other discharge gaps are much similar. Results indicate that after the initial setup of the discharge, the pulse repetition rate tends to show an almost linear increase with applied voltage

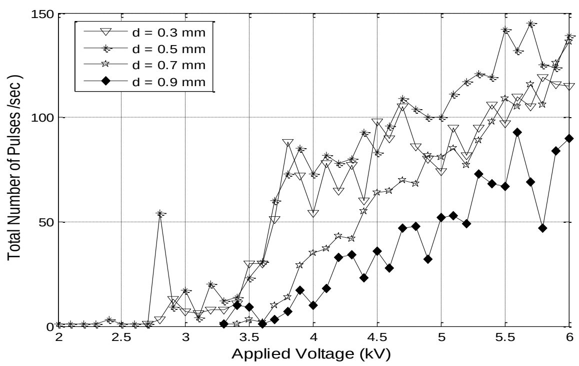


Figure 5: Total number of pulses per second for the discharge gaps in figure (4)

Figure 6 shows the results of the effect of applied voltage upon the mean pulse height. It is clear that the mean pulse height shows only a slight increase with applied voltage compared to that of the pulse rate dependence. This leads one to conclude that the increase in the overall discharge current in mainly due to the increase in the number of pulses rather that the individual pulses amplitudes. More detailed pulse height analysis is presented in the following section.

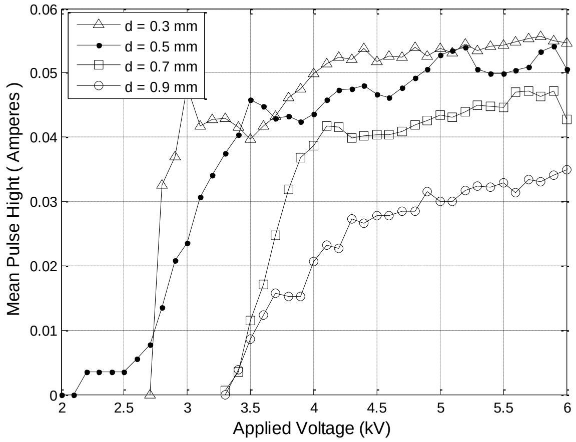
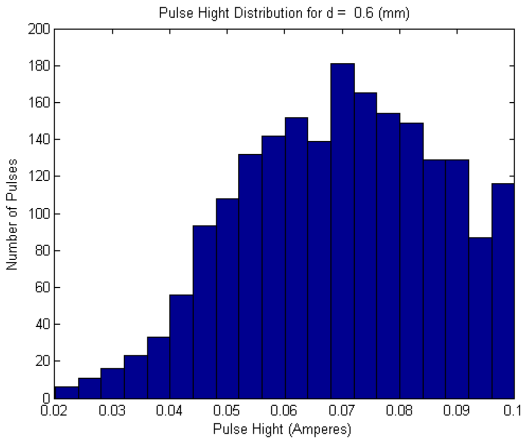


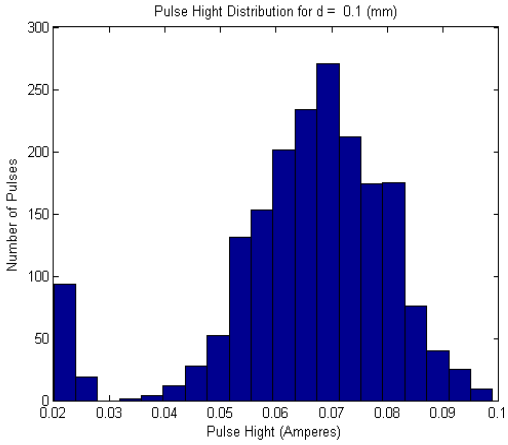
Figure 6: Mean pulse height dependence upon applied voltages for the discharge gaps presented in figure (4).

3.3 Pulse Height Analysis

In order to gain more insight about the properties of pulses, the pulse height distributions for all spark gaps and all voltages are studied using histogram plots. for all voltages and electrodes spacing. However, the smaller number of pulses at lower voltage values does not allow performing a full assessment of the voltage dependence. Even so, there does not seem to be a significant voltage dependence at higher voltage values. For this reason, the data for all voltages for every discharge gap are pooled and plotted. Typical examples of results for four discharge gaps are presented in Figure (7). It is clear from these and other similar plots that the pulse height seems to have an almost Gaussian distribution centred around 0.07 amperes. The discharge gap does not seem to have any significant effect on pulse heights.



(a)



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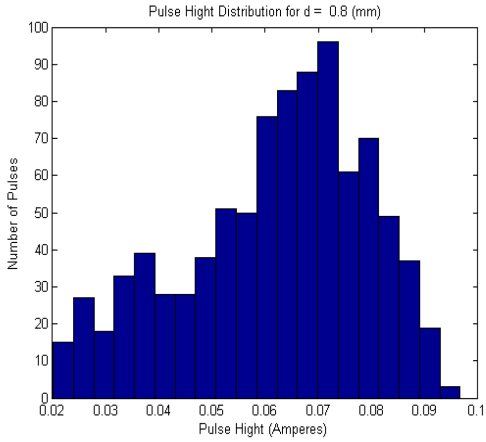
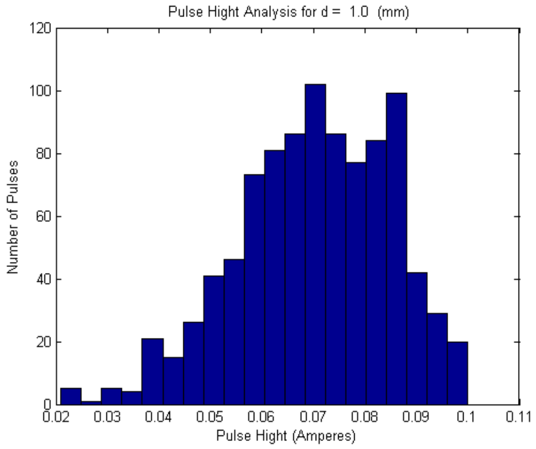


(c)



(d)

Figure 7: Pulse heights distribution for discharge gaps (a) 0.1, (b) 0.6, (c) 0.8 and (d) 1 mm

CONCLUSIONS

From the above analysis, it can be concluded that the pulse height of micro spark discharges across sub-millimetre spark gaps is independent of the spark gap separation. The increase in overall discharge current after reaching the threshold discharge voltage is mainly due to the increase in the number of pulses (pulse repetition rate). It is also demonstrated that the threshold micro spark discharge voltage is linearly related to the discharge cap.

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