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NEGATIVE CORONA CURRENT PULSES IN ARGON AND IN MIXTURE ARGON WITH SF_6 [1]

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Waveforms of the first negative current pulses in a short negative point-to plane gap in pure argon and argon with SF_6 admixture have been investigated with a nanosecond time resolution at a gas pressure 50 kPa as a function of applied gap voltage and content of SF_6 in the mixture. We have made an attempt to explain the differences in the discharge development in pure argon and in argon with admixture of SF_6 based on the observed changes of the pulse shape. The experimental results obtained will be discussed in context with existing computer simulation models.

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1 Introduction

When a sufficiently high negative voltage is applied to the point of a point-plane electrode configuration in an electronegative gas, after the statistical time lag a pulsating corona current, of frequency ranging from 103 to 106 Hz is observed in the external circuit. Because of its development in a negative ion charge free space, the first pulse of the pulse train is always larger than the subsequent pulses and often exhibits a step or a peak on the leading edge. According to the streamer-based hypothesis, which was published together with the supportive experimental results by Černák *et al.* [1, 2], the stepped pulse leading edge forms as follows: The initial current rise to the step is, as suggested by Morrow [3, 4], due to a Townsend ionization mechanism fed by cathode secondary photoemission processes. After decay in the current rise due to the rapidly shrinking cathode fall region, the current begins to rise again because of the development of a cathode-directed streamer-like ionizing wave, which results in the observed complex shape of the pulse leading edge. This can be envisaged, as supplanting of the feedback-to-cathode Townsend ionization mechanism by a feed forward-to-gas streamer ionization

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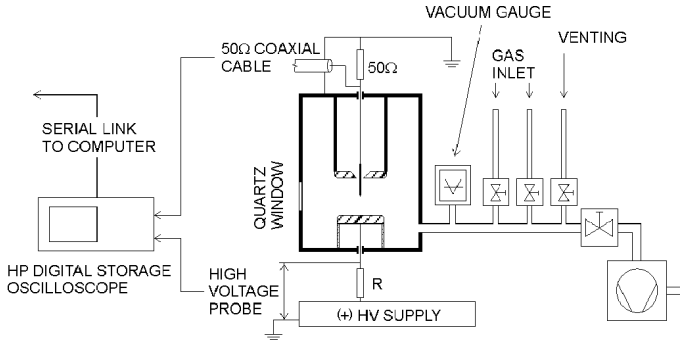

Fig. 1. Schematic of experimental set-up.

mechanism that is not governed by the cathode secondary electron emission. The pulse maximum is attained just as the ionizing wave reaches the cathode.

In this article, which extends our previous work on the negative corona mechanism in N_2-O_2 mixtures [2], O_2 [5,6], CO [7], CO_2 [8], H_2 [9], in air-SF_6 mixtures [10] and N_2-SF_6 mixtures [11], we present the results of an experimental study of negative corona current pulses in argon, serving as a basis for modifying and extending the theory. The choice of the working gas was motivated by the fact that argon is the inert gas with probably the best basic data, therefore, the results can form a convenient basis for future computer simulations of the negative corona pulses.

It is apparent that, for the current state of knowledge of the negative corona formation mechanism, the major issue is whether the pulse current growth is associated with the Townsend avalanche ionization mechanism, or whether it can be attributed to a streamer mechanism [5]. This issue is intimately connected with clarification of the exact roles played by electron photoemission and electron attachment. To clarify the role of photoemission processes, the study of negative corona current pulses was measured in working gas argon, where the photoemission is negligible compared to electron emission by positive ions [12,13]. The admixture of SF_6 to buffer gas argon provides possibility to study the discharge mechanism by changing the electron attachment.

2 Experimental set-up and procedure

The experimental arrangement is shown schematically in Fig.1. The point-to-plane electrode system consisted of two near-constant-field brass electrodes of an 80 mm overall diameter with a 90° Rogowski profile separated by 30 mm. A copper rod with a tip curvature radius $r_0 = 0.1$ mm extended 18 mm outward into the gap from the cathode. The cathode tip-to-anode plane spacing of 12 mm was measured to within approximately 0.1 mm. The discharge gap was housed in a duralumin vessel of 3.6 l capacity. The operating pressure of the gas was measured by a DVR1 gauge with accuracy better than 1 %. The vessel was equipped with a quartz window, which could be used to irradiate the discharge gap with UV light from a mercury discharge lamp.

A stabilized dc HV supply was connected to the anode via a charging resistor R

= 10 MΩ. The gap voltage U was measured at the anode using a Tektronix P6015A capacitive-resistive HV divider with a rise time of 10 ns. A 50 Ω coaxial measuring resistor R_0 was used to measure the discharge current. Signals from both voltage divider and measuring resistor were fed to an HP54616B digital oscilloscope with an analogue band width of 500 MHz and 2 Gs/s sampling rate. The RC time constant of the detection circuit was of the order of 0.1 ns. The experiments were carried out static in mixtures of commercial (99.99%-pure) argon and SF_6. Before the start of experiments, the chamber was evacuated by rotary pump to basic pressure and the gas mixture was admitted into the system. To detect the first corona current pulse the oscilloscope was set to the single shot storage mode with the high voltage switched off. Then, simply by switching on the HV supply, the anode was charged via the resistor R to a high positive voltage U. Because the high-field region of the point cathode was so limited in area and volume that there was a large statistical lag, we initiated the discharge after the stabilization of the anode voltage by a very faint irradiation of the gap with UV light. The oscilloscope was then triggered by the first corona current pulse. In this way an overvoltage could have been applied to the discharge before the discharge ignition by UV light. At higher gap voltages, the discharge occasionally started after a delay time without UV light irradiation. The discharge current waveforms measured at the same gap voltages, however, did not differ in the presence and absence of UV light.

3 Experimental results

Figure 2 illustrates the development of current peak with increasing gap voltage in pure argon. Close examination of the pulse leading edges shows that the pulse leading edge become shorter and steeper as the gap voltage was increased. For $U > 4$ kV, beyond the initial current growth, the discharge went into a spark, so that periodical Trichel pulses did not formed. For $U < 3.5$ kV the initial peaked current signal was followed by a steady negative glow corona current.

Figure 3(a) shows a waveform of the first negative corona current pulse measured at a gap voltage of 3.4 kV together with the temporal development of the gap voltage. A decrease of the gap voltage was caused by the high value of the charging resistor R = 10 MΩ. However, as it is indicated by Fig.3(b) the gap voltage remained constant during the recording of the initial part of the current pulse.

To illustrate the effect of increasing electron attachment rate on the pulse shape, Fig. 4 shows current growth waveforms for a pressure of 50 kPa at gap voltage values of 3.6 kV in argon containing various admixtures of strongly attaching gas SF_6 .It can be seen, that the pulse in pure argon exhibits a inflection on pulse leading edge. With the higher content of SF_6 the inflection on the leading edge of the pulse becomes a formation of the step on the leading edge.

Figure 5 (a) - (b) illustrate a typical development of the first negative corona current pulses with increasing gap voltage at a pressure of 50 kPa for 5 % and 10 % admixtures of SF_6. It can be seen that the SF_6 admixtures resulted in a reduction of the current pulse maximum. At higher gap voltages the formation of a step preceding the main current was observed. At SF_6 content higher than 5 %, a remarkable result was observed - the

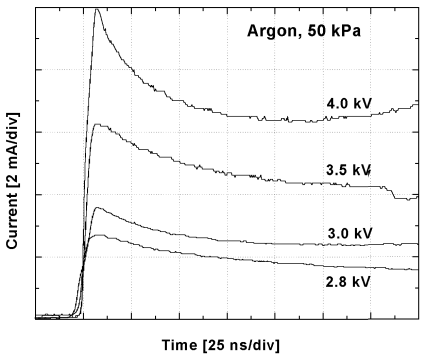

Fig. 2. Development of the first corona current pulses in argon at a pressure of 50 kPa with increasing gap voltage.

step on the pulse leading edge was found to develop into a new peak, i.e., the waveform has the form of a double peak.

4 Discussion

Our results presented in Sec. 3 are related to the stepped form of the first negative corona pulses. The stepped pulse waveforms measured for 5 % and 10 % SF_6 admixtures in argon (see Figs. 5(a) -(b)) agree well with the characteristics of the stepped negative corona current pulses observed in oxygen [5,6], CO [7], CO_2 [8] and in mixtures N_2-SF_6 [11] and air - SF_6 [10].

The stepped negative corona current pulse leading edge was first calculated theoretically by Morrow [3,4]. Morrow's 1.5 - dimensional model is based on the numerical solution of Poisson's equation in conjunction with the continuity equations for electrons, positive ions, and negative ions. The ions and electrons are assumed to be limited to a cylindrical channel with fixed radius and the field was computed using the method of disk. The model presumes Townsend's ionization fed by two secondary emission mechanisms: emission due to the impact of photons produced in the discharge and emission due to positive ion impact.

More recent works by Rees and Paillol [14,15] and Napartovich et al. [16] are based on similar computer simulation models to that by Morrow [3,4]. The basic difference with Morrow's work [4] is that the authors have attempted to simulate the stepped form of negative corona current pulses in air at atmospheric pressure for sharp cathode points with radii less than 0.1 mm, where the role of photoemission can be neglected. Such simulations are misleading, however, in that the step on the pulse leading edge usually are not observed experimentally when a sharp cathode is used.

According to Rees and Paillol [14,15] the stepped form of the pulse can be simulated even when secondary emission processes at the cathode are neglected. They, in an

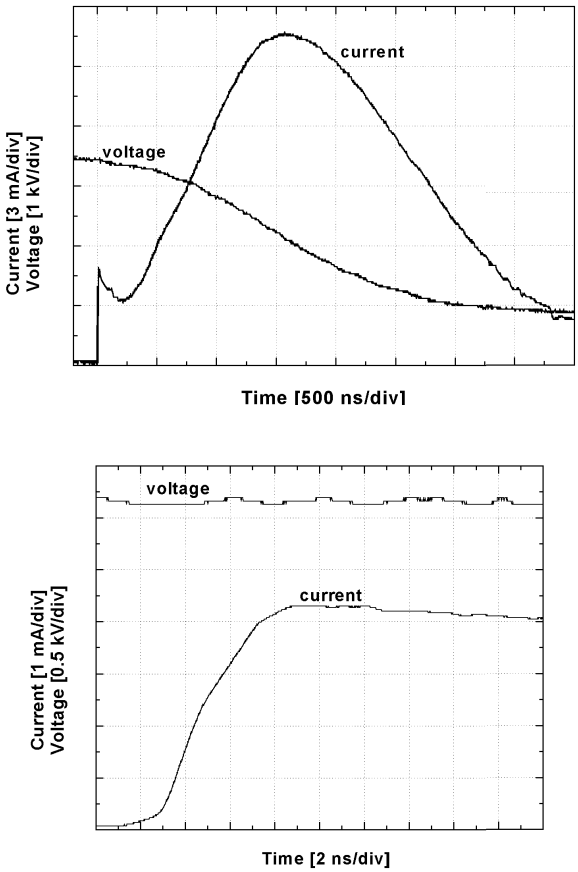

Fig. 3. a) (upper panel) and b) (lower panel) Development of the first corona current pulses in argon at a pressure of 50 kPa together with the temporal development of the gap voltage taken with the time resolution (a) 500 ns/div and the time resolution (b) 2 ns/div.

agreement with the suggestion by Laan and Perelygin [17], explain the step formation in terms of cathode-sheath formation leading to a large increase in the number of electrons released at the cathode by field emission.

Napartovich et al. [16] have suggested that the initial rise to the step might be explained by a positive-streamer-like ionizing wave and the subsequent current rise to the maximum is fed by γ_i-emission from the cathode. This is the only computer simulation model that in a qualitative agreement with the works by Černák et al. [1,2] indicates the existence of a positive-streamer-like ionizing wave associated with the negative current pulse formation. This is apparently because the authors in they 1.5-dimensional model

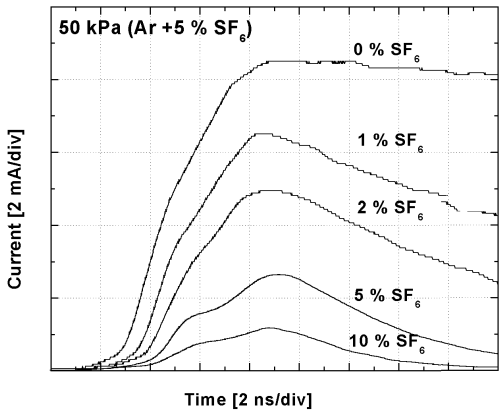

Fig. 4. Development of the first corona current pulses at a pressure of 50 kPa for various SF_6 admixtures to argon at gap voltage values of 3.6 kV.

have assumed the discharge development in a channel with a variable radius contracting sufficiently near the cathode surface: It is known, for example from computer simulations in Refs. [18], that there is an upper limit of the discharge channel above which ionization occurs rapidly in the channel without the formation of an ionizing wave. Thus, we can speculate that the use of too wide discharge channel with a fixed radius of 17 mm is the reason that Morrow in his computations did not revealed the formation of a cathode-directed streamer. Support for this speculation is to be found also in theoretical and experimental investigations made at low pressures (∼2.6 kPa) by Sigmond [18], indications that negative corona current pulses formation is invariably accompanied by discharge contraction.

From the foregoing we can conclude that detailed quantitative theories capable of explaining the complexity of the phenomena are not available at present. However, we believe that the streamer-based hypothesis is in good agreement with the stepped pulses observed using SF_6 admixture to argon (Figs. 4,5).

A close examination of the pulse leading edges measured in pure argon (see Figs. 3(b), 4) reveals an inflection on the pulse leading edge. It is reasonable to suppose that the inflection is due to the same mechanism as the step on the pulse leading edges. However, if it is so, than such a photoemission-based contribution is in contrast to assumption, that in argon the photoemission is negligible [12,13]. One from explanations of the physical mechanism that generates these phenomena is that possible impurities in argon were probably the source of photoemission processes. However, we believe that for a satisfactory understanding more experimental observations of the elementary processes active in the argon plasma for the same conditions in which these experiments were performed and theoretical work is needed.

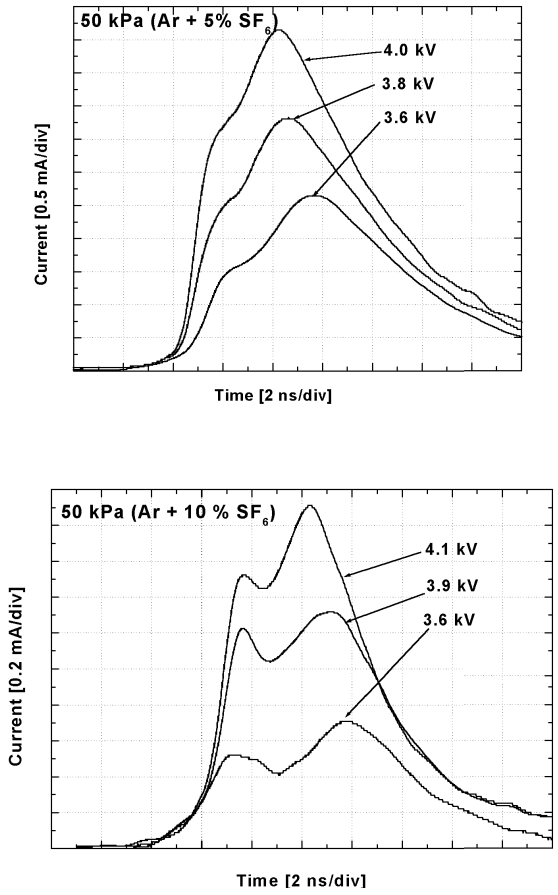

Fig. 5. a) (upper panel) b) (lower panel) Negative corona current pulse waveforms measured with increasing gap voltage at a pressure 50 kPa, in a gas mixture argon with (a) 5 % SF_6 and (b) 10 % SF_6.

5 Conclusions

Current waveforms of the first negative corona pulses have been studied experimentally in argon at a pressure of 50 kPa using point-to-plain electrode geometry. The effects of electron attachment on the first negative corona pulse waveforms were assessed by changing the relative concentration of SF_6. Experimental results are in good qualitative agreement with our recent works [1,2,6,7,8,9,10,11]. For the given conditions, the most significant conclusions, which may be reached through the analyses of the experimental results, are the follows: The streamer-based model for negative corona current pulses

[1,2] has successfully reproduced the observed complex shape of the negative corona pulse measured in the mixture argon with SF_6. The initial current rise to the step is due to the Townsend ionisation fed by the photoemission processes. The pulse maximum is attained just as the ionising wave reaches the cathode and is not critically dependent on secondary electron emission processes at the cathode. This work presents the results of experiments designed to test existing theories for the negative corona pulse formation and for future computer simulation studies in argon and mixture argon with SF_6.

Acknowledgements

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