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Modeling of Trichel pulses in negative corona

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Negative corona - low current discharge between a cathode (a wire or a point) and a plane anode - is a quite common object widely used in industry. While studying the negative point-to-plane corona in air G. W. Trichel revealed the presence of regular relaxation pulses [1] Qualitative explanation given by him included some really important features like shielding effect produced by a positive ion cloud in the vicinity of the cathode. The role of negative ions was practically ignored. In the following work [2] it was stated that the Trichel pulses exist only in electronegative gases, and a particular emphasis was put on the processes of electron avalanche triggering. It was stressed also that, usually, the time of the negative ion drift to the anode is much longer than the pulse period. More detailed measurements of the Trichel pulse shape demonstrated that the rise time of the pulse in air may be as short as 1.3 ns [3] and a step on a leading edge of the pulse was observed [4]. Later, the systematic study of the electrical characteristics of the Trichel pulses was undertaken [5], and some empirical relationships were found for the pulse repetition frequency, a charge per pulse and so on.

Among attempts to give theoretical explanation for discussed phenomena the work of R. Morrow is most known [6], where the preceding theories are reviewed also. Continuity equations for electrons and positive and negative ions in a one-dimensional form were numerically solved together with the Poisson's equation computed by the method of disks [7]. It was supposed that the electric charges occupy the cylinder of a given radius. One of electrodes, cathode, was spherical. The negative corona in oxygen at a pressure 50 Torr was numerically simulated. Only the first pulse was computed, and extension of calculations on longer time showed only continuing decay of the current. In Ref. [6] the shape of the pulse was explained while practically ignoring the ion-secondary electron emission. In the following paper [8] the step on the leading edge of the pulse was attributed to the input of the photon secondary emission, and the main peak was explained in terms of the ion-secondary emission. This explanation was criticised later in [9] pointing at the importance of an ionization-wave-like evolution of the cathode layer on early stages. To authors' knowledge, up to now the detailed analysis of the nature and mechanism of the Trichel pulses based on numerical simulations is absent. In this paper, the results of detailed numerical studies on the Trichel pulses formation for dry air in short-gap (<1 cm) coronas are reported. The numerical model capable to reproduce the established periodical sequence of the pulses is formulated for the first time.

We developed the quasi-one-dimensional numerical model. To derive equations of this model we supposed that all the physical quantities are constant in every cross section of the discharge current. The same approximation was used for example by R. Morrow [6]. However, it is well known from numerous experiments that the discharge current is concentrated near to the point and occupies comparatively large area in the anode surface. If to introduce the current channel width, this width grows strongly from the cathode to the anode. The ratio of the current spot radii on the anode and cathode is on the order of 10^4. Here, we took the radius of the current channel to be a function of the axial distance, x. Continuity equations for electrons, positive and negative ions, and Poisson's equation averaged over the current cross section were solved numerically. The boundary conditions for positive and negative ions are self-evident: their number density is equal to zero at anode and cathode, respectively. For electrons we, in contrast to R. Morrow, include only the ion secondary emission. In the current channel two different regions can be discerned: one corresponding to the active zone of the negative corona, and the second corresponding to the unipolar ion drift zone. The shape of each of pointed zones is determined by quite different processes, hence should be chosen almost independently. The shape of the active zone was taken as a paraboloid of revolution. This paraboloid was characterised by three parameters: 1. the radius at the cathode surface, R_c; 2. the radius at the boundary between two zones, R_b; 3. the length of this zone, x_b. All three parameters were varied in calculations seeking the best agreement in the Trichel pulse parameters with the experiment. The shape of the ion drift zone was taken also as a paraboloid of revolution, parameters of which are fitted to make the current channel radius a continuous function of x. The radius at the anode, R_a, served also as a fitting parameter. The resulting parameters of the current channel are following: for the point curvature radius $R_p = 0.008\ cm$ and the point to plane distance $0.7\ cm$ the chosen values are $R_c = 0.004\ cm$; $R_b = 0.0046\ cm$; $x_b = 0.02\ cm$, and $R_a = 0.517\ cm$.

Solving the system of equations with the boundary conditions the development of the negative corona current was simulated. It was found that after interval not greater than 80μs the continuous sequence of pulses was established with good reproducibility of all parameters of each pulse. Comparison of a computed pulse with the experimentally measured one is demonstrated in Fig. 1. The calculated and measured shapes of the pulse are rather close each to other. The computed amplitude of the current pulse is *1.5 mA* in comparison with experimental *1.3 mA*. The computed charge per pulse is *57.4 pC* in comparison with *60 pC* measured. However, the agreement between the repetition frequencies is not so good: $f = 160$ *kHz* in experiments against $f = 254$ *kHz* in calculations. As a result, the calculated average current is also higher than experimental one (*15.1 μA* and *10 μA* respectively). In fact, the calculated fine structure of the pulse waveform shown in Fig. 2 with a high time resolution is much more complicated. In the leading edge of pulse the very sharp peak can be observed associated with the displacement current. This peak has no relation to the

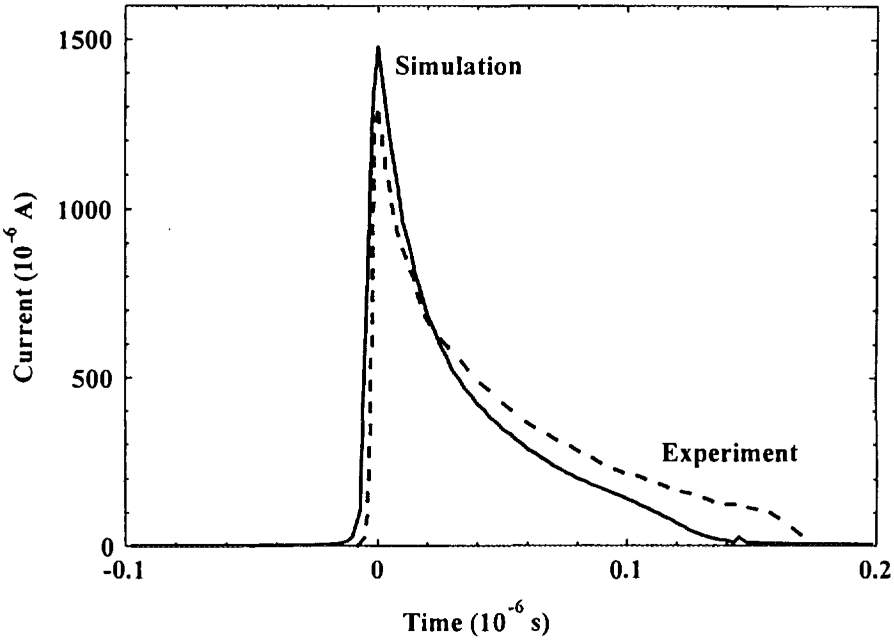

Fig. 1. Comparison between experimental (dashed curve) and calculated (solid curve) waveform of Trichel pulse for negative corona in dry air at atmospheric pressure, $h = 0.7\ cm$, $R_p = 0.008\ cm$, $V = 4.5\ kV$

photon secondary emission, as it was supposed by Morrow in [8] because this mechanism is ignored in our model at all. More detailed analysis shows that the first peak in the leading edge of Trichel pulse is due to formation of the cathode layer in a way of propagation of ionization wave in direction to the cathode. The results of numerical simulations allow us to analyse in detail the trailing edge of the Trichel pulse and inter-pulse pause responsible for the value of the of Trichel pulse is due to formation of the cathode layer in a way of propagation of ionization wave in direction to the cathode. The results of numerical simulations allow us to analyse in detail the trailing edge of the Trichel pulse and inter-pulse pause responsible for the value of the period between pulses. In particular, the variations of the total number of negative ions in the corona spacing occurring for typical conditions of pulsating corona are quite insignificant. Comparison with experiments demonstrated a reasonable agreement as in the shape of the pulse, as in average characteristics of the negative corona.

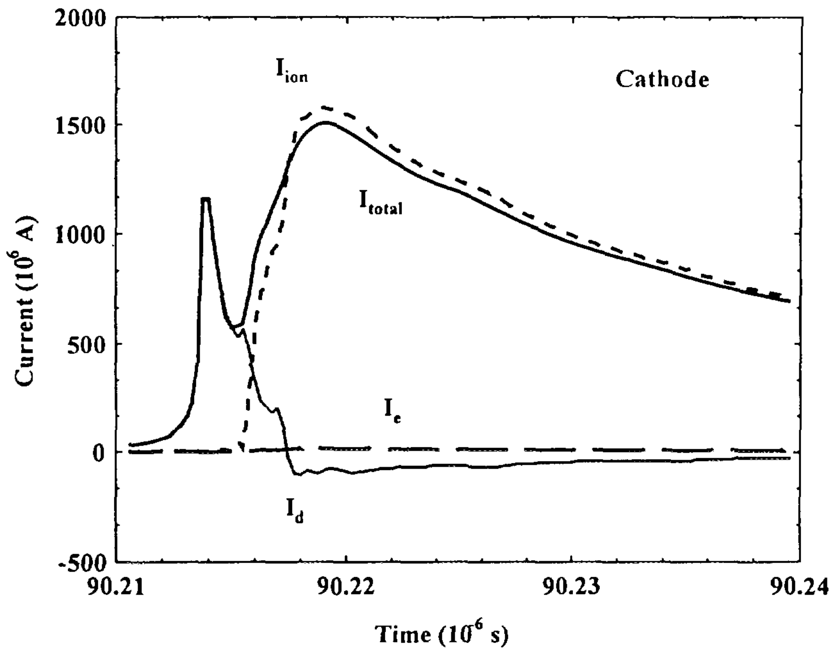

Fig. 2. Calculated current waveform the same as in Fig. 1, with high time resolution. The components of total current at the cathode are shown also

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