TWO TYPES of NEGATIVE CORONA CURRENT PULSATION

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Physical mechanisms of two basic types of negative corona current pulsations – Trichel pulses of relatively low frequency and high-frequency current pulsations are submitted. It is proved a responsibility of two types of ionic components (negative and positive) for a generation of these pulsations. Behaviour of pulsations has been analysed in detail under various conditions of the discharge. In particular, there were used nitrogen, argon and electronegative admixtures of oxygen over a wide concentration range.

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It is known, that under certain conditions the negative corona between a negative point and a plane anode pulses with relatively low frequency of unities - hundred kilohertz. The current pulses (Trichel, disclosed in 1938, [1]) include complicated secondary structure, in particular, high-frequency current pulsations (HFCP) with a repetition frequency of about megahertz. Untill now a consensus concerning mechanisms of the Trichel pulse (TP) and the HFCP formation is absent in the literature. Explanation of the TP was built upon a screening effect of positive ions [1] or it was affirmed [2], that the TP exists only in electronegative gases due to negative ions. Though it was declared a possibility to generate the TP in pure nitrogen, there was used an electronegative admixture (ENA) of oxygen in numerical modelling [3]. The corona pulsation in pure N_2 is attributed to the resistive anode [4]. The HFCP have not been obtained in modellings [3, 5,6]. Author has described the HFCP in argon and nitrogen for the first time in [7,8]. Afterward they were detected in other gases [9,10], and it was recognized that "the mechanism of these oscillations has yet to be understood". HFCP in nitrogen are compared [4] with the TP.

The purpose of this article is to elucidate a different nature of two types of negative corona current pulsations – the TP and the HFCP. There were carried out detailed analyses of their behaviour in N_2 and Ar at atmospheric pressure with the ENA of oxygen of a variable concentration (C%,O_2), beginning from $2*10^{-3}$%. The numerical modelling has been realized, using continuity equations for fluxes of positive and negative ions and electrons, supplemented by the Poisson's equation in a quasi-two-dimensional space. As a special case, these pulsations were investigated at "zero" ENA concentration. A clear division of ionic components (negative and positive) in respect to their implication in LF and HF pulsations of the corona current in all stages of its passing is shown.

Fig.1. The discharge device sketch and the measuring scheme

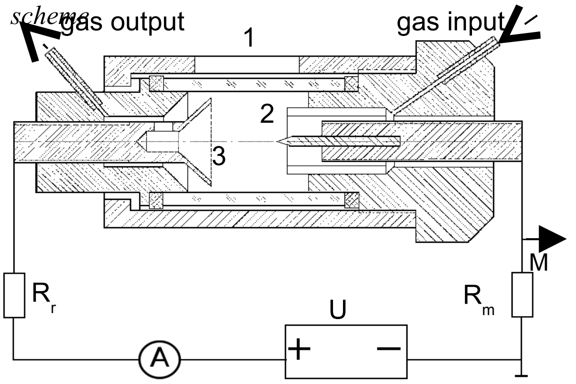
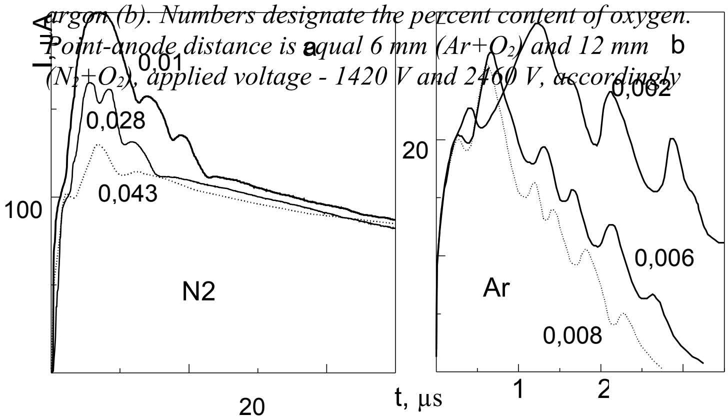


Fig.2. Oscillograms of corona current in nitrogen (a) and argon (b). Numbers designate the percent content of oxygen. Point-anode distance is aqual 6 mm (Ar+O_2) and 12 mm (N_2+O_2), applied voltage - 1420 V and 2460 V, accordingly



1. EXPERIMENTAL PROCEDURE AND MAIN RESULTS

In Fig.1: 1 – the discharge device; 2 – the point (W, Ni, Pt, etc); 3 – the anode; R_r - restrictive and R_m – measuring resistances; U – the high voltage source; M – the output to the oscillograph and the frequency meter. A distance between the point (with the top diameter of 40-100 microns) and the anode could be set in limits of 5 - 25 mm. A constant voltage was set in borders of 1000-3000 V with a stability of $2*10^{-2}$ - $2*10^{-1}$ %. The resistance R_r was varied in limits of 4.7 - 470 MΩ, R_m – 100-20000 Ω. To put a gas mixture in the device and to vary fluently a concentration of the ENA there was used the dynamic mixing system and model mixtures with oxygen less than 0,85%. Argon and nitrogen purity was not lower than 99,998 %. Measurements were carried out in the following order. After the pre-evacuation and the long enough expulsion by argon or nitrogen the working gas mixture was introduced in the device and the "aging" discharge was initiated during 5-10 minutes. Further, the high voltage of a level necessary for a stabilization of corona pulsations was established. The main pulse parameters were measured by the S1-93 oscillograph and the C3-34 frequency meter. For recording of the pulse secondary structure the measuring resistance was lowered up to hundred Ohm, and low signals were extra amplified.

The shape and sizes of current pulses differ essentially in N_2 and Ar (Fig.2). In N_2, current shapes the separate peak, and after it is reduced slowly. At increasing of

$C\%O_2$ its maximal value I_m rises essentially. In Ar, the current is reduced monotonically. The pulse duration in N_2 and in Ar is reduced at increasing of $C\%O_2$. When $C\%O_2$ is varied in limits of 0,002..0,06% the pulse charge Q is reduced in one order in Ar (Fig.3a), and in N_2 - in 2 times. The pulse frequency increases due to $C\%O_2$ rise, and in argon - stronger (Fig.3b).

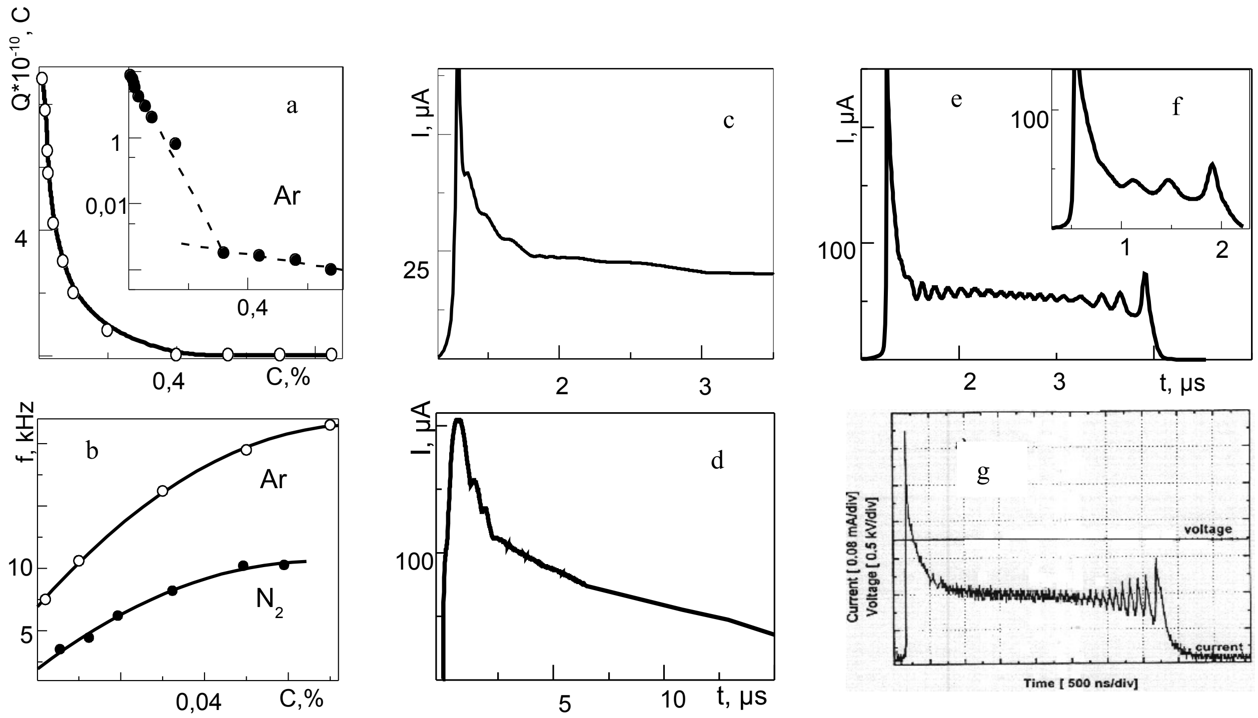


Fig.3. a,b) Measured dependences of charge Q and frequency f of the corona pulse in argon and nitrogen on the oxygen concentration. c,e,f) Calculated pulses with the HFCP of the first type in N_2 at the point radius of 0.004 cm, the point-anode distance of 0.6 cm and U = 2300 V: c) at $R_r = 5*10^6\ \Omega$, C = 0.4%; e,f) $R_r = 1*10^6\ \Omega$, C = 0.4% and 0.6%, accordingly. d,g) Measured pulses with the HFCP: d) of the 1-st type, C = 0.043% (data - Fig.2a), g) of the 2-nd type in hydrogen [10]

It is revealed, that the HFCP are clear distinguished at the low concentration of the EDA (Fig.2), the small radiuses of the coronal point and the low impedance of the measuring circuit. An increase of the point-to-anode distance leads to a decrease of the TP size and to a worsening of the HFCP clearness. At a use of thin wires (Ni, Pt, etc.) in a role of the corona electrode the HFCP are more legible and prolonged - the axial symmetry of the generating area is maintained longer. Duration of the high-stable corona generation can reach hundred hours at use of some special materials. Due to microanalyses it was detected, that the "working" surface area of the point is much greater than geometrical area of its top.

2. MODELLING OF NEGATIVE CORONA

The numerical computation basis is the continuity equations for positive and negative ion and electron fluxes, supplemented by the Poisson's equation for an electrical field in a quasi-two-dimensional space:

$$\frac{\partial n_e}{\partial t}+div(w_e n_e)=\alpha n_e w_e-\eta n_e w_e+k_d n_n n_0 \quad , \tag{1}$$

$$\frac{\partial n_p}{\partial t}-div(w_p n_p)=\alpha n_e w_e \quad , \tag{2}$$

$$\frac{\partial n_n}{\partial t}+div(w_n n_n)=\eta n_e w_e-k_d n_n n_0 \quad , \tag{3}$$

$$divE=4\pi e(n_p-n_e-n_n)\ . \tag{4}$$

Here n_e, n_p, n_n - the electron, positive and negative ions density, w_e , w_p , w_n - their drift velocity, respectively, α , η , k_d - ionization, attachment and detachment coefficients for main gas moleculas of the density n_0. Boundary conditions: positive and negative ion densities are equal to zero at an anode and cathode, respectively; the electron density at a cathode is formulated in terms of secondary ion emission coefficients. The current was calculated by $I_k = I_p + I_d$ using the charge flow current I_p and the displacement current I_d. Numerical data for kinetic coefficients were taken from the literature [10].

3. MAIN RESULTS AND DISCUSSION

An increase of a near-surface size of the current tube has allowed to simulate the TP with the superimposed HFCP for the first time (Fig.3.c,e,f) (in against to [3]). Dependences of the pulse charge and frequency on C,% of oxygen are close to the measured (Fig.3a,b). It is ascertained the quite clear separation of a near-cathode region into layers of predominantly placing of one type charge (*p*, *n or e),* which is kept during full pulsation period and determinates a feature both the TP, and the HFCP.

Mechanisms and feature of TP. In an initial phase of the current rise the avalanche reproduction of charges (*e* and *p*) in a cathode region takes place simultaneously with the "wavy" displacement of the *p*-density maximum to the cathode. At this time the surface *E*-field and, as consequence, the current I_d sharply increase. At an arrival of a main amount of ions to the surface, the conductivity current I_p increases. Simultaneously, the summary field *E,* shielded by these ions, is essentially reduced behind the "*p"* layer, and therefore, the ionisation of molecules is sharply reduced. Consequently, the current, having achieved the peak value I_m, sharply drops. Further three types of following processes can pass. (1) In absence of the electronegative admixture the current can decrease to zero - at the week external field, or (2) increase right up to break-down of a gas space - at higher fields sufficient for maintaining of the discharge. At a presence of the ENA just behind the "*p*" layer an intensity of the electron attachment rises and the *n*-concentration increases - the negative ion "*n*" layer is formed. The last controls values *E* and n_p in the near-surface region and therefore, currents I_d, I_p and I_m. At this time, the process (1) is only amplified and the primary pulse damps faster. At higher fields the process (2) is modified – a transition to a breakdown is delayed, or there is a gradual extinction of the discharge and the current temporal dependence takes the Trichel pulse shape – it is a process (3). The last is accelerated at a rise of the ENA concentration. In particular, an increase of the C%,O2 in Ar leads to a week drop of the peak current I_m (Fig.2b). Besides a decrease of the multiplication integral to a critical value, stopping the discharge, is accelerated, that is, the pulse duration is reduced (Fig.2). Thus, if a current rise to the TP peak value is formed by both under-surface Townsend's ionisation processes, the shape and parameters of the tail part of the pulse are set by dynamics of a formation and a destruction of admixture negative ions.

Mechanisms of HFCP. HF current pulsations are superimposed on the TP curve and can accept two shapes – near-peak damped ones (Fig.3c,d) or with the increasing amplitude in the pulse tail (Fig.3e,f,g). Calculated HFCP shapes depend essentially on the ENA concentration (Fig.3c,e,f) and they are close to measured ones (Fig.3d,g). Parameters of the HFCP are essentially influenced by the resistance R_r. It is revealed a stationary direct correlation between the current and such functions as the surface field strength, the near-surface concentration of positive ions and secondary emitted electrons, the multiplication integral. The field minimum, its coordinate and the second part of the integral (in limits of the minimum – the region end) are in a stationary antiphase with the HF current. Such connections result from the following cycle of physical processes. At a moment of the current maximum the enlarged layer of near-surface ions increases a self-screening and the field at the generation region end is reduced. Thus, the reduced amount of new-born ions comes in a half-period to the cathode and calls a relevant drop of the current – that is the next HFCP minimum. Changes of the field in the minimum and its coordinate entail the relevant oscillations of the voltage drop in this region. In this way the negative current-voltage characteristic of the corona near-cathode region is created - it is other shape of the HFCP source. At the same time the total voltage drop in the discharge varies no more than of 1% - thus the HFCP can not be considered as a result of an exterior "triggering".

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ДВА ТИПА ПУЛЬСАЦИЙ ТОКА ОТРИЦАТЕЛЬНОЙ КОРОНЫ

Васыль Чигинь

Представлены физические механизмы двух основных типов пульсаций тока отрицательной короны – относительно низкочастотных импульсов Тричеля и высокочастотных пульсаций тока. Доказана причастность двух типов ионных компонент (отрицательных и положительных) к генерированию этих пульсаций. Детально проанализировано поведение пульсаций тока при разных условиях разряда, в частности, при использовании азота, аргона и электроотрицательной примеси кислорода в широких пределах концентрации.

ДВА ТИПИ ПУЛЬСАЦІЙ СТРУМУ НЕГАТИВНОЇ КОРОНИ

Василь Чигінь

Представлено фізичні механізми двох основних типів пульсацій струму негативної корони – відносно низькочастотних імпульсів Трічеля і високочастотних пульсацій струму. Доведена причетність двох типів іонних компонент (негативних і позитивних) до генерування цих пульсацій. Детально проаналізовано

поведінку пульсацій струму при різних умовах розряду, зокрема, при використанні азоту, аргону та електронегативпої домішки кисню в широких межах концентрації.