HIGH FREQUENCY PULSATION OF HIGH-VOLTAGE GAS DISCHARGES

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Physical mechanisms of high frequency current pulsations of high-voltage discharges at negative needle - flat anode and flat cathode - flat anode geometry are presented. It is shown for the first time that their nature is the same as a nature of negative corona HF current pulsations.

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A transition of low-frequency Trichel pulses (TP) of the negative corona [1] in the high-frequency current pulsation (HFCP) has been recently recorded in hydrogen [2]. At a length of the point-to-plane gap d = 20 mm, gas pressure of 12,5 kPa and the point radius r_0 = 0,15 mm at the TP finishing the HFCP with a frequency of 1-10 MHz arises (Fig.1a). It was recognized [2] that “the mechanism of these oscillations has yet to be understood”. The similar phenomenon has been observed by the optical method earlier [3]. The HFCP have been registered also in [4] (Fig.1b,c). A complete theory of the HF pulsation of the high-voltage discharge plasma is not known in a literature. We have first disclosed [1] that under certain conditions the corona HFCP can accept three shapes – the 1-st after-peak type, the 2-nd tail type and the 3-rd outside of the TP type. In this work, to clarify a nature of the HF pulsation the detailed analysis of a behavior of the space-temporal distribution of charges and field in the discharge plasma in N_2 of atmospheric pressure with O_2 in a wide region of the concentration (C%,O_2) is carried out.

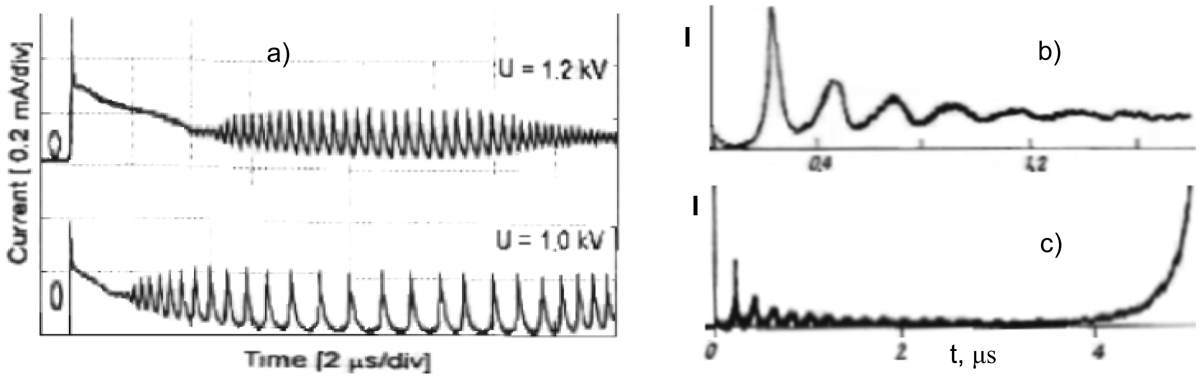

Fig. 1. Temporal dependences of gas discharge current with HF pulsations measured in a) [2] and b,c) [4]

1. CHARACTERISTICS OF MEASURED HFCP

The shape of the HF pulse (Fig.1a) is similar to the shape of the TP pulse [1] with the considerably short duration. Temporal dependences of the discharge current measured in nitrogen and in nitrogen-methane mixture [4] include the HF pulsation with amplitudes damped to the constant current (Fig.1b) and with the current exponential increase right up to the breakdown (Fig.1c).

2. MODELLING RESULTS AND DISSCUSION

A simulation basis is the solution of continuity equations for three types of charges, supplemented by the Poisson’s equation for an electrical field in a quasi-two-dimensional space [1]. Typical temporal current dependences of the point-to-plane corona and the transition discharge in nitrogen are submitted in Figures 2-5. One can see that under certain conditions the calculated HFCP are similar to measured ones (Fig.1). Strong HFCP dependences on the O_2 concentration (Fig.2a,b, 3, 4a), the applied voltage U (Fig.2b) and the external resistance R (Fig.2d, 4b) are evident. The 3-rd type of the HFCP appears outside of the peak part of the TP at a lowering C%,O_2 up to 0.25% (Fig.2a), 0.5% (Fig.2b) and 0.352% (Fig.3). Lower C%,O_2 lead to the breakdown (Fig.2 - <0.05%, Fig.3 - <0.35%, Fig.4 - <0.3%). A transition to the breakdown can occur immediately after the first TP peak (Fig.2,3) and without the last (Fig.4). An increase of the C%,O_2 slows down an appearance of the HFCP and reduces its frequency (Fig.4a). An increase of the R delays this process as well and smoothes the HFCP (Fig.4b). Fig.4c demonstrates weak initial amplitudes of the HFCP (0-8,5 µs) and their sharp increase in the next short time interval (9,6–10 µs). Numerals 1-6 indicate extremums for which the correspondent spatial distribution of positive charges in the cathode plasma are depicted in Fig.4d,e. Apparently, a decrease of the positive ion density in its tail distribution (Fig.4e) at the moment 5 of the pulse maximum is much higher in comparison with its decrease at the initial moment 2 (Fig.4d). So, a screening efficiency of positive ions in the corona plasma increases essentially in course of time.

In the time region A (Fig.5a) the inter-pulse current rises above zero, and in the region B the HF pulsation is discontinued and the current increases sharply to the break-down. Correspondent to the region A the density of positive ions in the tail distribution (Fig.5b) is essentially reduced in points 3,4 of the current maximum – in anti-phase with an increase of the density near the surface. In a transition to the break-down (region B, Fig.5a) the density of positive ions and electrons approaches one to other in the full cathode region (Fig.5c,d), creating a homogeneous plasma medium before the breakdown.

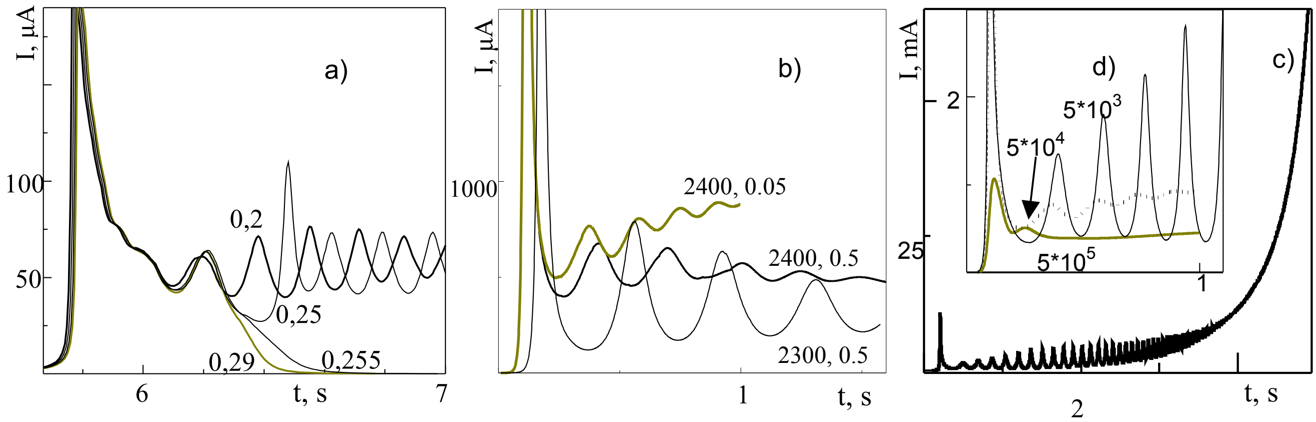

Fig.2. d = 0.6 cm: a) r_0 = 0.0035 cm, U = 2200 V, R = 1×10^6 Ω, C%,O_2 - numerals; b,c,d) r_0 =0.004 cm: b) R =5×10^4 Ω, U and C%,O_2 - numerals; c,d) U = 2400 V, C = 0, c) R = $5*10^3$ Ω, d) R – numerals, Ω

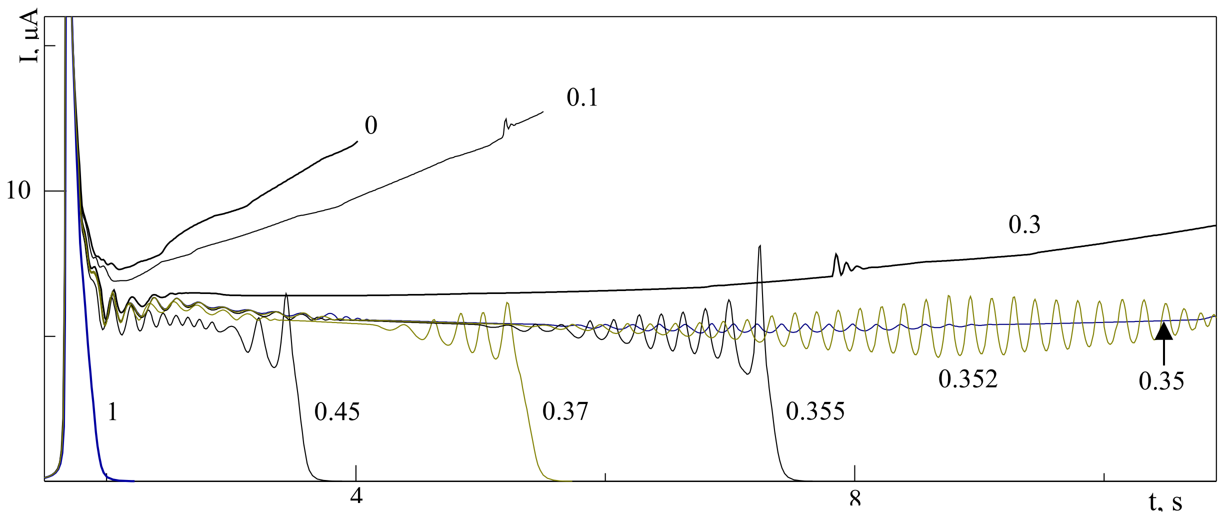

Fig.3. d = 0.6 cm, r_0 = 0.004 cm, U = 2300 V and R = 1 MΩ ; C%,O_2 is designated by numerals

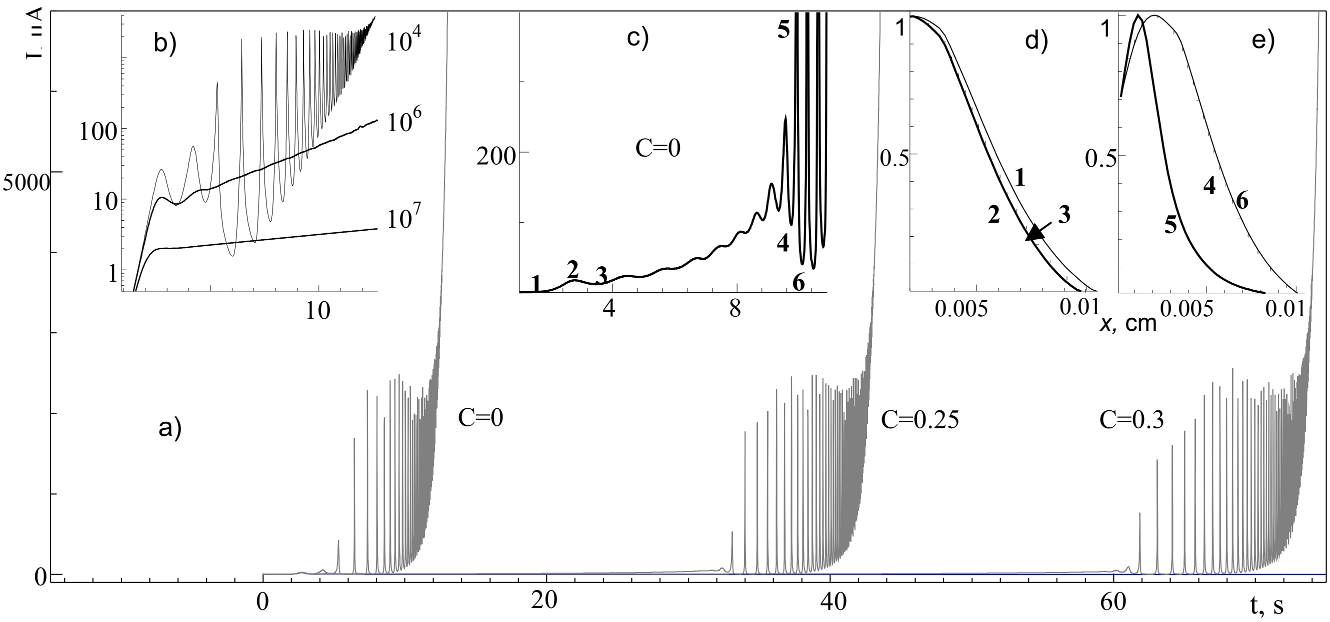

Fig.4. d = 0.6 cm, r_0 = 0.004 cm, U = 2300 V; a,c) R =1×10^4 Ω, b) C = 0; d,e) dependences of relative positive ion density $n_p(x)/n_p(0)$ on the distance x from the cathode

Based on obtained results, we can assert that a reason of an origin of the HF current pulsation in transition discharge stages in the non-uniform high-voltage field is its periodic screening in the cathode area by positive ions, in other words, mainly by a “self-screening”. A feed-back of the ion density on the cathode surface and the electric field in a tail of their distribution creates the negative current-voltage characteristic of the cathode layer. Such picture exists at the low current, when in the surface layer the ionization region is very thin. At an increase of the current the ionization layer gradually expands in a direction of the drift space and conditions for the plasma origin are created (Fig.5c,d), so the HF current pulsation disappears. Further, depending on a relation of internal electrical and gas parameters, the applied voltage and the external resistance, earlier or later the break-down arises (Fig.2-5), or the current is restricted by the constant value (Fig.2,3). A maintaining of the glow discharge in pure electropositive gases is complicated (Fig. 2-5, C=0). A presence of the slow negative component in the discharge space can change this HF process of screening, slow down the break-down (Fig.4a) or lead to a complete

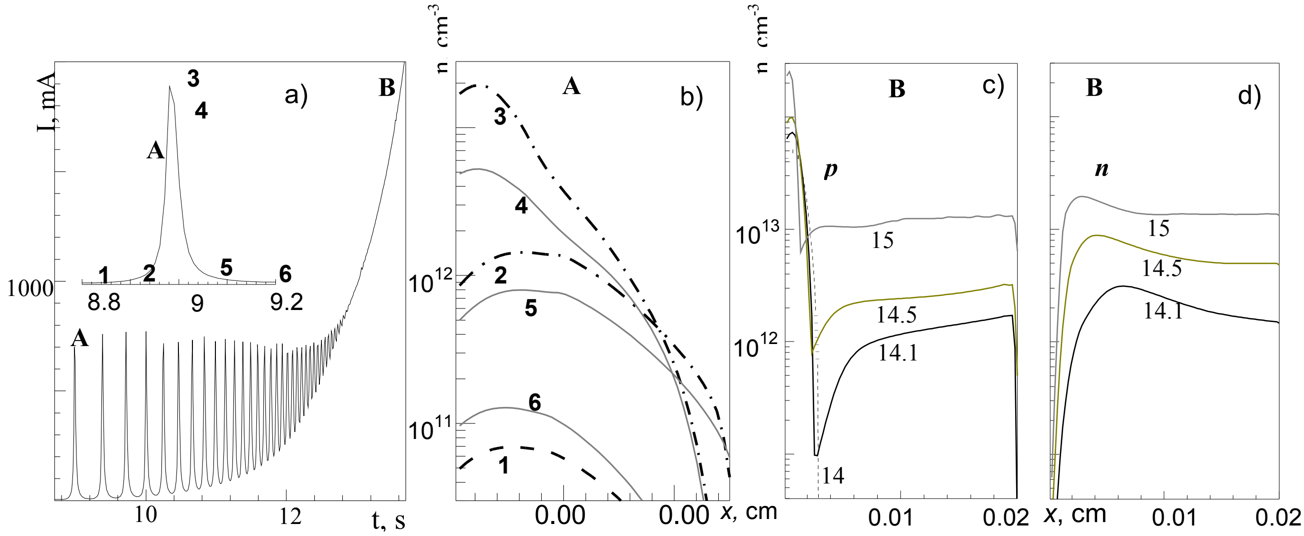

Fig.5. Data is the same as in Fig.4, C=0

blocking of the discharge (Fig.2b - >0.5%, Fig.3 - >1%).

An appearance of the HFCP in the plane discharge geometry (Fig.1b,c) was considered [4] solely due to avalanches reached an anode or positive ions - a cathode. In our opinion, a relative comparison of these results is possible at a consideration of the corona cathode field as homogeneous concerning an influence on dynamics of avalanches. In both cases their development is stopped in the end of the compared region – the anode [4] or the corona plasma sheath. Then, it is possible to consider a series of avalanches [4] as pulsations of the ion stream to the surface with corresponding current change in the circuit.

Summing, it is possible to emphasize that the HFCP of discharges are satisfactorily described by Townsend’s mechanisms without attracting of additive volumetric streamer processes. The offered theory and numerical model of the HFCP enable to increase essentially a reliability of an ascertainment of the high-voltage discharge plasma nature, in particular, of the corona, the glow and the break-down.

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ВЫСОКОЧАСТОТНЫЕ ПУЛЬСАЦИИ ВЫСОКОВОЛЬТНЫХ ГАЗОВЫХ РАЗРЯДОВ

В. Чигинь

Представлены механизмы высокочастотных пульсаций тока высоковольтных разрядов при геометрии отрицательное острие – плоский анод и плоский катод – плоский анод. Впервые показано, что их природа есть той же, что и природа ВЧ пульсаций тока отрицательной короны.

ВИСОКОЧАСТОТНІ ПУЛЬСАЦІЇ ВИСОКОВОЛЬТНИХ ГАЗОВИХ РОЗРЯДІВ

В. Чигінь

Представлено механізми високочастотних пульсацій струму високовольтних розрядів при геометрії негативне вістря – плоский анод і плоский катод – плоский анод. Вперше показано, що їх природа є тією ж, що і природа ВЧ пульсацій струму негативної корони.