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ДОКЛАДИ

USING A PHASE-LEADING ELECTRICAL DISCHARGE IN PLASMA SYSTEMS WITH INDUSTRIAL FREQUENCY AT ATMOSPHERIC PRESSURE

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Abstract. There is a possibility to create a pre-heating or additional electrical discharge that will prepare the main one-atmosphere high-pressure barrier discharge as regards the elementary processes. As a result, igniting the main discharge occurs at lower voltage values or at smaller ignition angles. This affects favorably the plasma characteristics as well as the electrical characteristics of the discharge. This method represents a new approach to increasing the effectiveness of that type of discharges at industrial frequency.

Keywords: external (volt-ampere) static characteristic, low-frequency glow discharge, one-atmosphere barrier discharge, phase-leading barrier discharge, pre-heating barrier discharge, and volumetric active power density.

INTRODUCTION

The high-pressure barrier discharge or one-atmosphere barrier discharge or *OABD*, is an autonomous electric discharge that exists due to the series reactive (capacitive) ballast resistance introduced by the dielectric barrier in the external electric circuit of the discharge; this resistance limiting the discharge current. Normally, a system of diode electrodes is used, which consists of two planar electrodes placed in parallel to each other and embracing the two flat dielectric barriers (or just one of them) and the working gap. It is conditionally assumed that this is a barrier discharge with uniform electric field or *OAUBD*, that burns and creates the so-called technological plasma volume in its working gap, Fig. 1a, [1].

It is possible that the one-atmosphere barrier discharge burns only on one of the surfaces of the dielectric barrier – on the so-called technological plasma surface, if a strongly non-uniform electric field is used. This electric field emerges in the diode electrode system consisting of two electrodes that are respectively located on the two opposite sides of the barrier. This type of barrier discharge with a non-uniform field or *OANUBD*, burns on the edges of the flat (plasma) electrode built of multiple, electrically conducting strips placed in parallel, which are separated by an air gap but are not isolated electrically from one another. The opposite flat electrode covers the whole opposite side of the barrier, Fig. 1b, [2].

The technological plasma volume may be also realized by uniting the two diode electrode systems in one triode system of common electrode. Actually, this is the second diode electrode system, to which a planar electrode is added from the side of the plasma electrode in such a way that the technological plasma volume is formed between these two electrodes. In the triode electrode system built as described it becomes possible to exist two electric discharges with different values of the voltage of ignition $U_{CR,I}$ or with different time of ignition. One of these is the pre-heat barrier discharge (one atmosphere non-uniform barrier discharge) that creates the conditions facilitating the ignition of the main barrier discharge, and the other one is the main barrier discharge itself (one atmosphere uniform barrier discharge) that creates the technological plasma volume.

THE TASK of the present work consists in examining the conditions, under which a technological plasma volume containing chemically active ozone-oxygen plasma with increased volumetric density of the active power is formed in the triode electrode system described above. On its part, this plasma determines the technologically effective burning modes of the new barrier discharge, namely the one-atmosphere triode barrier discharge (*OATBD*).

CONDITIONS ENABLING THE OCCURRENCE AND EXISTENCE OF *OATB* - DISCHARGES

The one atmosphere uniform barrier discharge is an autonomous electric discharge characterized by the fact that the current is limited by the ballast reactance, i. e. by the capacitive reactance of the dielectric barrier. The dynamic mode of burning ensures a large Debye radius, which determines the presence of ideal classical plasma in relatively big technological volumes. This plasma (*OAUBDP*) is of low temperature due to the worsened impact interaction and exchange of kinetic energy between the light component and the heavy one.

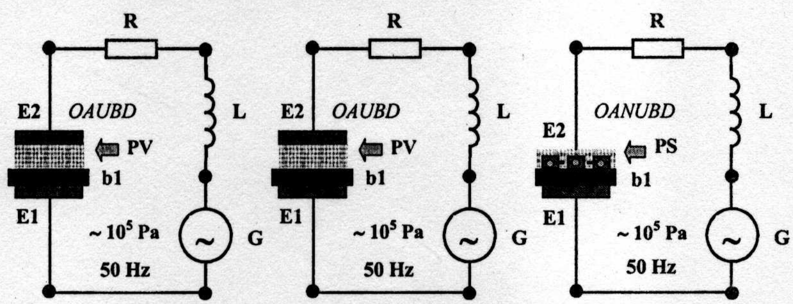


Figure 1. Types of diode barrier discharges at atmospheric pressure: **a** - one-atmosphere uniform barrier discharge; **b** - one-atmosphere non-uniform barrier discharge.

E1 and **E2** - electrodes; **b1** and **b2** - dielectric barriers; **PV** - plasma volume; **PS** - plasma surface; **G** - electric generator (50 Hz); **R** and **L** - electric parameters of the external electric circuit.

The one-atmosphere (1 atm, 760 Torr, 1.01×10^5 Pa) barrier (or capacitive) discharge is the only discharge that produces cold technological plasma at high, i. e. atmospheric pressure.

Depending on the geometry and mutual arrangement of electrodes **E1** and **E2** in the diode electrode system, it is possible to form technological plasma volumes or surfaces, Fig. 1.

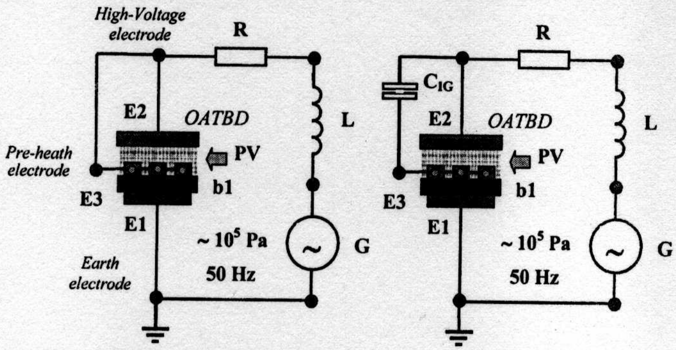


Figure 2. Types of triode barrier discharges at atmospheric pressure: **a** - one-atmosphere triode barrier discharge without any ignition capacitance ($C_{IG} = 0$); **b** - one-atmosphere triode barrier discharge ($C_{IG} \neq 0$).

E1 - earth electrode; **E2** - high-voltage electrodes, and **E3** - pre-heat electrode; **b1** - dielectric barriers; **PV** - plasma volume; **G** - electric generator (50 Hz); **R** and **L** - electric parameters of the external electric circuit.

The one atmosphere triode barrier discharge is realized by adding a third, so called pre-heat electrode, which is equivalent to the existence in parallel of two barrier discharges in the plasma volume *PV*: one of these is the one atmosphere uniform barrier discharge that burns between electrodes **E1** and **E2,** and the other one is the *one atmosphere non*-uniform discharge burning between electrodes **E1** and **E3.** Electrode **E1** represents a common electrode for the two barrier discharges.

Irrespective whether there is an ignition capacitance C_{IG} or not, the two barrier discharges burn in the common plasma volume *PV* and feature different values of the voltage of ignition $U_{CR,1}$. Considerably lower voltages of ignition characterize the one atmosphere non-uniform barrier discharge and burning compared to those of the one atmosphere uniform *barrier* discharge. This fact defines the former as a pre-heat or preliminary discharge that prepares the main discharge as concerns the elementary processes, Fig. 2.

EXPERIMENTAL RESULTS AND DISCUSSION

Because of the broad scope of the experimental investigation, the present discussion is focused on the one atmosphere triode barrier discharge that burns in the plasma volume *PV* at constant thickness $\delta = 3$ mm of the barrier (made of alkaline glass), located in the interelectrode space, and at constant size of the working air gap - $b = 3$ mm. The plasma generator idles in free or undisturbed operating mode where there is no material placed for plasma-chemical surface modification in the plasma volume.

There is a significant difference between capacitance values in the two electrode systems: in the ignition electrode system consisting of comb-shaped electrode **E3** (strip width - 4 mm, distance between strips - 4 mm) and planar electrode **E1** (area – 480 cm^2) - $C_{1\text{-}3} = 0.536$ nF, and in the main electrode system involving the two planar electrodes **E1** and **E2** (area – 480 cm^2) - $C_{1\text{-}2} = 0.718$ nF. This conditions their different types of electric behavior, Fig. 4.

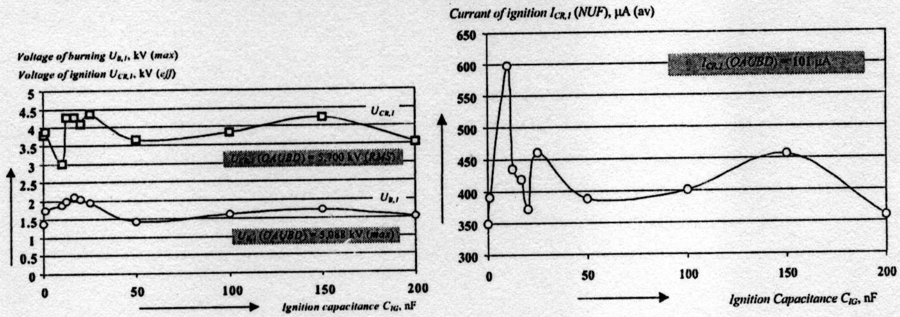


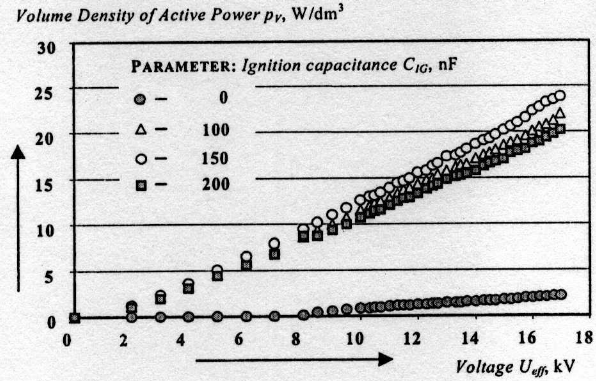
Figure 3. Variation of the critical ignition parameters of the one atmosphere triode barrier discharge: voltage $U_{CR,I}$ (**a**) and current $I_{CR,I}$ (**b**) of ignition, and burning voltage $U_{B,I}$ (**a**) of the discharge with capacitance C_{IG} of the ignition capacitor.

Moreover, the ignition electrode system **E1** - **E3** has a second working sector that manifests itself at a voltage of ignition $U_{CR,2} = 14$ kV (*max*) and burning voltage of the barrier discharge $U_{B,2} = 2{,}87$ kV (*max*), or it can also operate in the plasma region that contains nitrogen oxides (NO_x). The joint operation of the two electrode systems prevents the occurrence of this plasma region – the triode plasma system creates plasma volume containing chemically active oxygen and ozone.

The burning voltage $U_{G,I}$ of the one atmosphere triode barrier discharge decreases considerably with respect to that of the one atmosphere uniform barrier discharge – from 5.088 kV to 1.379 kV (at $C_{IG} = 0$), and at certain values of the ignition capacitor - $C_{IG} < 10$ nF and 200 nF $> C_{IG} > 25$ nF it also falls below the burning voltage of the one atmosphere non-uniform barrier discharge, Fig. 3a.

The critical voltage of ignition $U_{CR,I}$ of the one atmosphere triode barrier discharge decreases considerably from 5.700 kV (*max*) to 3.813 kV (max) with respect (at $C_{IG} = 0$) to that of the *OAUB* - discharge. At certain values of the ignition capacitor - C_{IG} : 10, 50, 100, 200 nF, it falls even below this value, although this fall is not very essential – the minimal value is 3.014 kV (*max*) at $C_{IG} = 10$ nF, Fig. 3.

The critical current of ignition $I_{CR,I}$ of the one atmosphere triode barrier discharge increases significantly with respect to the current of the one atmosphere triode barrier discharge – from 101 μA to 350 μA (at $C_{IG} = 0$), and for all selected values of the capacitance of ignition capacitor $C_{IG} \neq 0$ it remains above that value and reaches 599 μA at $C_{IG} = 10$ nF.



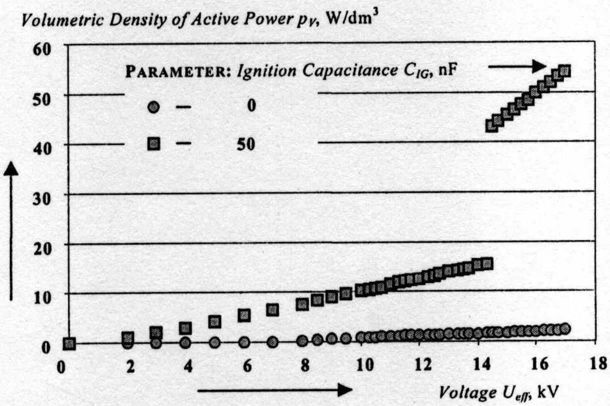


Figure 4. Variation of the volumetric density of the active power p_V for the *OATBD* - plasma with the value of capacitance C_{IG} of the ignition capacitor placed between ignition electrode E3 and high-voltage electrode **E2**.

The integral parameter permitting to forecast the effectiveness of the technological plasma-chemical process is the volume (and area) density of the active power p_V. It depends on both the burning voltage $U_{G,I}$ and the critical current of ignition $I_{CR,I}$ of the discharge, Fig. 4, [1].

The volumetric density of the active power p_V attains its maximal value at $C_{IG} = 50$ nF and boundary voltage of discharge 17 kV (*RMS*), namely 54 W/dm³. The volumetric density remains of high value already at C_{IG} : 1, 100, 150, 200 nF, namely ca. 22 ÷ 24 W/dm³. This is about tenfold greater density of the active power compared to that of the one atmosphere uniform barrier discharge, i. e. the process of plasma-chemical modification may be the same number of times more intensive than the classical solution used in creating a technological plasma volume.

CONCLUSION

Experimental investigations conducted on one-atmosphere triode barrier discharges permit reaching the following principal conclusions related to the technological potentials of the three-electrode plasma reactor:

1. The one-atmosphere triode barrier discharge without ignition capacitor ($C_{IG} = 0$) features a working region that begins at about 3.813 kV (*RMS*) and provides maximal volumetric density of the active power $p_V = 2.2$ W/dm^3 for the boundary voltage of 17 kV (*RMS*).

2. In the low-value range of capacitance $C_{IG} \propto 1 \div 10$ nF of the ignition capacitor, good technological results should be expected for one-atmosphere triode barrier discharge: ♦ at $C_{IG} \approx 1$ nF, as for the boundary voltage of 17 kV (*RMS*) the volumetric density of the active power p_V attains 24 W/dm^3, and ♦ the value of 2.2 W/dm^3 is obtained already at a voltage of about 3 kV (*RMS*).

3. In the high-value range for capacitance $C_{IG} \propto 25 \div 200$ nF of the ignition capacitor, good technological results should be expected for one-atmosphere triode barrier discharge: ♦ at $C_{IG} \approx 50$ nF – the maximal volumetric density of the active power p_V attains 54 W/dm^3 for 17 kV (*RMS*); ♦ at $C_{IG} \approx 150$ nF this density has a lower value but is of the order of that at $C_{IG} \approx 1$ nF, namely 24 W/dm^3. In both cases the value of 2.2 W/dm^3 is obtained for low voltages, ca. 3 kV (*RMS*).

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