STUDY OF THE ROTATING GLIDING DISCHARGE AT ATMOSPHERIC PRESSURE

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The possibility of creating a source of non-equilibrium atmospheric pressure plasma based on the rotating gliding discharge is considered in this research. Systems used for the research of the rotating gliding discharge at atmospheric pressure are described. Results, obtained during the study are presented. The possibility of creating discharge system with a bigger effective area of the discharge cathode binding to electrode than standard electric arc plasma generators is demonstrated.

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INTRODUCTION

Modern plasma technologies are big part of our lives. Low-temperature plasma is already actively used in chemistry, metallurgy, mechanical engineering and other fields of industry. The deep plasma implementation into chemical technology looks especially promising. Although, there're several factors which impede the plasma industrial use in large scale. One of them is short life time of the traditional arc plasma sources, due to severe erosion of the electrodes. This erosion occurs because these sources operate under high power and difficult environments.

The electrodes erosion is caused by local heating due to the Joule heat releasing in places, where gas discharge comes in contact with the electrode surface. One of the solutions is surface area enlargement through which the current flows, since the amount of generated heat (Q) is proportional to the second power of current density (j) which flows through the discharge ($Q \sim j^2$). Although, the size of the stationary electrode spot usually depends on the current, electrode material, its temperature and potential, carrier gas type and pressure at which the electric discharge takes place [1]. Therefore, it is often impossible to control the spot size, and, as a result, current density and electrode erosion in specified conditions. One way to solve this problem is area enlargement by discharge gliding on electrode surface. In this case, more attention should be focused on the effective area through which the electric current flows, i.e., the electrode surface area which is embraced by discharge during its operation. Such an approach suggests that prolonged action plasma source can be obtained by providing a bigger amount of material for erosion and avoiding major thermal loads on the electrode in places of its contact with a discharge, due to the rapid discharge position changing on the electrode.

In future, it is possible that plasma systems (which meet the approach mentioned above) will be managed by gas-dynamic flows. The greatest interest are the systems with axial symmetry–rotating gliding discharges, which are not enough investigated [2-5].

The aim of this research is to evaluate the possibility of prolonged plasma creation on the basis of a rotating gliding discharge.

1. THE EXPERIMENTAL SETUP

The operation of two axially symmetric systems (schematic diagram presented in Figs. 1,a,b) has been observed in order to study the rotating gliding discharge.

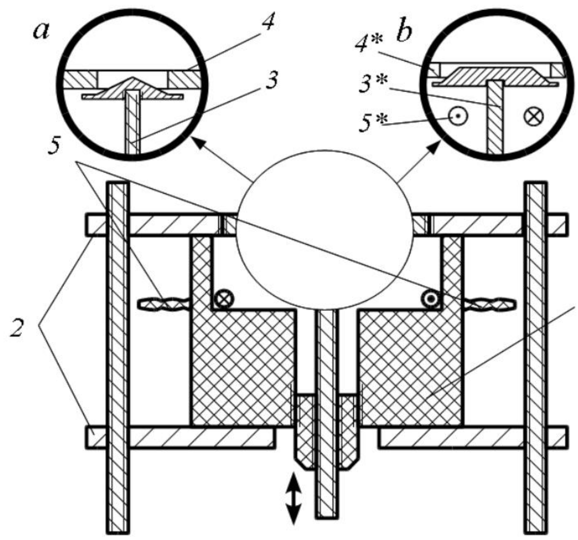

Fig. 1. Schematic drawing of the studied plasma systems

See Fig. 1,a shows a schematic diagram of the first system. The fluorocarbon chamber (1) is clamped by two metal flanges (2). The top flange has a height of 10 mm and a hole of 49 mm in diameter with thread where the block with cylindrical hole of 25 mm in diameter is screwed in (4). The combination of the top flange and the block serves as the system peripheral electrode. The pin that can move vertically along the fluorocarbon thread serves as the second electrode of the system. Various metal attachments (3) which are central electrodes of the system can be screwed onto the pin tip. In this research, a cone with a height of 10 mm served as an attachment on the central electrode. Bead of 29 mm in diameter and 1 mm in height has been placed at the cone base (which rises from the bead) with a diameter of 24 mm. Air flow, introduced to the system tangentially trough the vortex chamber channels (5) allows the gas-dynamic control of the discharge.

Variety of the blocks geometry in the flange (4), attachments (3) on the pin, their relative position towards each other and different air flows, this makes this system the general-purpose equipment for the generation and study of the atmospheric pressure gas-discharge plasma.

The research review on several geometries of the central and peripheral electrodes in this system can be found in [6].

Fig. 1,b shows the central part of the second system. There are no fundamental differences from the first, but it has a more complex structure and is bigger in size. (3*) – central electrode of the system (the cut cone with a bead; the cut cone parameters are: the base diameter is 89,5 mm, the cut part diameter is 57 mm; the bead parameters are: the diameter is 96.2 mm, height is 2 mm; the height of the whole figure is 12 mm); (4*) – peripheral electrode, flat circular flange (10 mm in height) with a cylindrical hole (90 mm diameter); (5*) – direction of the air vortex flow in the system.

The electrodes polarity of the systems under consideration was always the same: the central electrode-positive one (anode), and the peripheral one is grounded with negative potential (cathode).

The air flow is ensured by the FIAC Cosmos compressor and controlled by the rotameter. БП-150 served as a source of power supply from the magnetic-discharge pump (NORD type).

The schematic of the plasma system connection to power supply and compressor presented in Fig. 2.

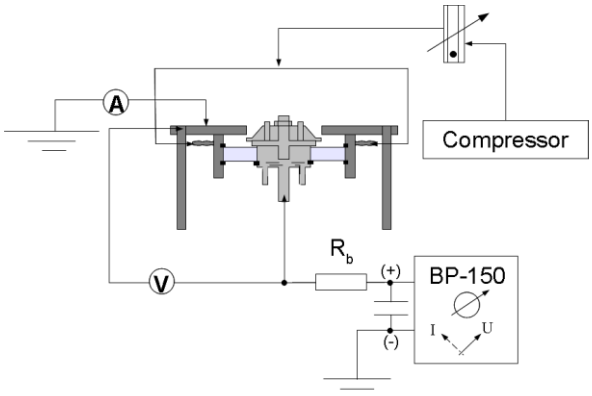

Fig. 2. The schematic of the plasma system connection to the power supply and compressor

It shows: the system under consideration; Power Supply BP-150, which contains the built-in ammeter and voltmeter; capacitor bank, which serves for additional smoothing of the power supply output voltage; ballast resistance R_b to confine the discharge current; external ammeter and voltmeter to measure current and voltage directly on the discharge; compressor and rotameter to introduce and control the air flow into the system, respectively.

2. THE EXPERIMENT DESCRIPTION AND THE MAIN FIXED PARAMETERS

When system electrodes from high voltage power supply are energized, the discharge lights up between central and peripheral electrode. Air vortex flow with channels tangentially directed to the vortex chamber wall, sustains the discharge outwards, causing it to slide across the two electrodes.

Current voltage characteristics (CVC) of the discharge and emission spectra of glow discharge plasma, effective area (total area of traces left by a gliding discharge on the electrodes) have been measured during the experiments with rotating gliding discharge, depending on the different geometries of these systems, electrodes configuration and air flows. Also, many discharge pictures and videos have been obtained, and its visual observation has been performed during the experiment.

Therefore, the main output parameters fixed during the experiments were: current (I) and voltage (U); airflow amount (G); distance from the lower edge of the upper flange to bead (d) (in the case of the central electrode with the bead) or immersion depth of the central electrode (l) the distance from the upper surface of the flange to the upper surface of the central electrode (in the case of the central electrode without the bead with flat surface that could easily enter the hole in the peripheral electrode); overall geometry of the system. After the end of the experiment, the following parameters have been recorded: time (t), the temperature of the electrodes (T) and effective area (S_{ef}).

3. THE EXPERIMENT RESULTS

Fig. 3 shows typical images of the discharge obtained from the system with geometry, which is shown in (see Fig. 1,a), at the air flow of 80 *l/min* and different times of camera exposure.

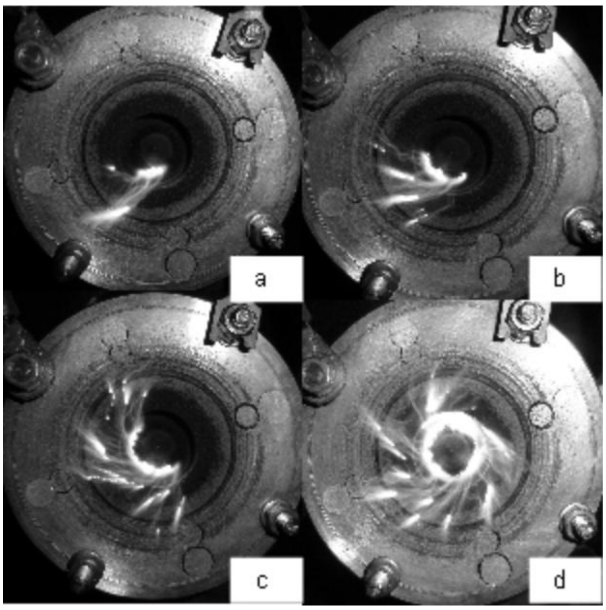

Fig. 3. Photos of discharges obtained by the system, shown in Fig. 1.a, top view. The frames sequence is from left to right and top to bottom. d=1.5 mm, I=400 mA; U=0.6 kV, G=80 l/min. Exposure time: a), b), c), d) is 1/250 s, 1/125 s, 1/60 s, 1/30 s, respectively

Also Fig. 4 shows typical images of the discharge at different air flow (long exposure).

As it is possible to see, the discharge is a cord that moves in a circle under the impact of gas-dynamic flow.

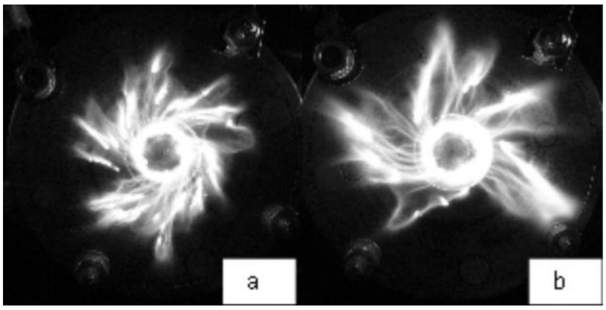

Fig. 4. Photos of discharges obtained by the system, shown in Fig. 1.a), top view: d=1.5 mm, I=400 mA. Left is U=0.6 kV and G=80 l/min. Right is U=0.65 kV, G=50 l/min. Exposure time: 1/15 s and 1/10 s, respectively

As several discharge columns and sequence of discharge bindings of one discharge column (not just blurry glow area) can be clearly seen on the photo (see Figs. 3, 4.), it is clear that the life of the discharge column can be divided into several stages: discharge initiation, movement of the discharge binding on the electrodes, and discharge breaking when it reaches its critical size. After that the cycle repeats again. It should be noted that the distance between two consecutive discharge life cycles is kept the same (on average). The bigger amount of the air flow is blown through the system (see Fig. 4.), the more correct this statement is. So as the airflow increases, the more order and axial symmetry of the discharge is seen on the photos. Angular velocity of the discharge binding movement across the central electrode has been estimated from the pictures shown see on Fig. 3. For the first three photographs (see Fig. 3) at exposures of 1/250 sec, 1/125 sec and 1/60 sec, angular velocities have been~174 *rad/s*, 196 *rad/s*, 167 *rad/s*, so on average– 179 *rad/s*.

Interesting photo of the discharge has been also obtained at the twice smaller discharge currents and little interelectrode gap (Fig. 5).

An anode bindings form ordered structure on the central cone-electrode and white line of cathode binding, which remained on the side of the cylindrical hole in the flange during photo exposure can be seen on the presented photo. Strokes of anode bindings are clearly visible on the central electrode, but on closer examination, it can be noticed that strokes consist of dots. If to count the number of strokes (N_{stroke}~21), and the average number of dots in one stroke (N_{dot}~20), and knowing the photos exposure, the average characteristic time spent on one stroke (τ_{stroke}) and one dot of anode binding (τ_{dot}) can be estimated.

$$\tau_{stroke} = \frac{t_{\text{exposure}}}{N_{stroke}} = \frac{4 \cdot 10^{-3}}{21} = 0.19 \cdot 10^{-3} s = 0.19 \quad ms,$$

$$\tau_{dot} = \frac{\tau_{stroke}}{N_{dot}} = \frac{0.19 \cdot 10^{-3}}{20} = 0.0095 \cdot 10^{-3} s \approx 10 \mu s .$$

It should be noted that, every time the discharge has gone off, it has gone not in the narrowest point of interelectrode gap, but on some distance from it. That means it hasn't died completely, but reconnected to the electrode in new location. This phenomenon (very well described in the literature related to plasma generators) is called an electric arc shunting [1]. Shunting can be also explained by the presence of discrete strokes and their dot structure (shown see in Fig. 5).

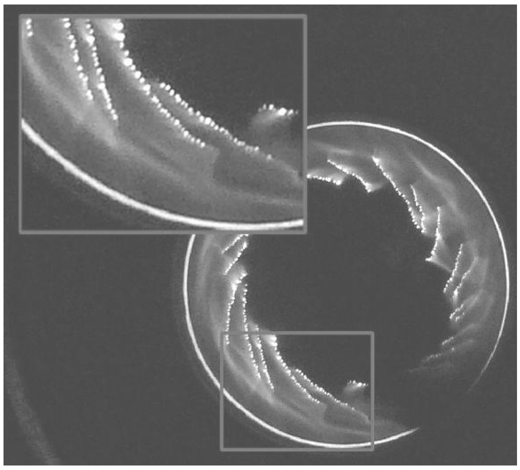

Fig. 5. Photos of discharge obtained by the system shown in Fig. 1.a), top view. d<0.5 mm, I=240…260 mA; U=0.9…1.1 kV, G=50 l/min. Exposure time 1/250 s

As, the ultimate goal of the study is to examine the possibility of obtaining the prolonged action non-equilibrium plasma source from a rotating gliding discharge, great attention has been paid to evaluation of effective area covered by the discharge on electrodes (see Introduction).

Effective areas have been discovered using autographs method. The technique is quite simple: at first the electrode surface is polished up, then, the discharge is switched on, for the time which is enough for discharge to fix its trace, and then after the power is turned off, linear size of the trace ("autograph") left by the discharge is measured and the area covered by it is counted.

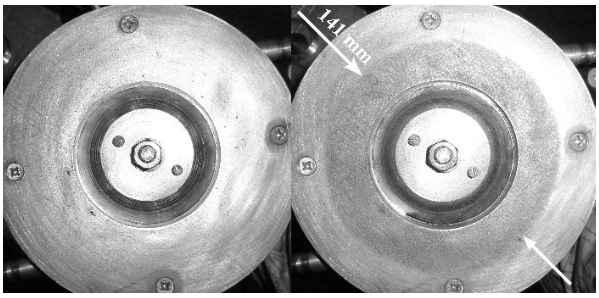

Fig. 6. Systems photo (see Fig. 1,b), before operating (on the left) and after one hour of operating (on the right). I=320 mA, U=1000 V, G=50 l/min

The photo of the system shown see in Fig. 2,b) is presented in Fig. 6 (before and after one hour of operation, respectively). The system has been operating at a current of I=320 mA, the voltage at the discharge is U=1000 V and the air flow of G=50 *l/min*.

The electrodes temperature has been measured using a thermocouple after the system has been turned off. The anode temperature in place of erosion trace has been ~90°C, and the cathode temperature has been

~80°C. The erosion trace of dark brown color has been clearly noticeable, the upper border of the erosion trace had a diameter of 63 mm, a bottom border had a diameter of 72 mm, generatrix trace has 5 mm in length. Therefore the area has been counted $S_{ef.anode}$~1050 mm^2. After operating, part of the cathode on which discharge has been gliding, has been of yellow-brown color, and the trace diameter has been 141 mm, thus the effective area covered by the discharge on the end surface of the flange $S_{ef.catode}$~9200 mm^2, and taking into consideration the side area of the cylindrical hole (as it has the same color as the end face of working cathode) total effective area of the large system cathode is $\Sigma S_{ef.catode}$~12000 mm^2, which is bigger than any cathode assemblies known area of standard electric plasma generators which is ≤100 mm^2 [1, p. 117], and require additional erosion protection systems.

CONCLUSIONS

The following can be concluded as results of investigations:

The discharge in the system is the single rotary discharge, which occurs near the area of minimal interelectrode gap. Electrode discharge bindings start movement to the axis of the system at the central and from axis at the peripheral the electrodes under the impact of gas dynamic flow. At the periphery the discharge is going off and subsequent breakdown is shifted along the azimuth air flow direction.

If the air flow is reduced through the system, the single discharge with low rotation speed becomes visible on the photographs. If the airflow is increased, certain order (discharge channel length, distance between discharge channels does not significantly change in the picture area) becomes visible on the discharges photos. It should be noted that all photos are taken with exposures much higher than existence time of a single discharge.

Also presented the possibility of creating discharge device based on atmospheric pressure rotating gliding discharge with an effective contact area of the anode and cathode binding of a plasma column with electrodes $S_{ef.anode}$~10.5 cm^2 and $\Sigma S_{ef.catode}$~120 cm^2, respectively, which is significantly bigger than in any standard arc plasma sources.

ACKNOWLEDGEMENTS

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REFERENCES

1. M.F. Zhukov. Foundations of linear circuit plasmatron calculation // *Operational and informational material* / Уdited by Corresponding Member of USSR Academy of Sciences M.F. Zhukov, Novosibirsk, 1979.
2. C.S. Kalra, A.F. Gutsol, A.A. Fridman. Gliding arc discharges as a source of intermediate plasma for methane partial oxidation // *IEEE Trans Plasma Sci*. 2005, v. 33.
3. J.M. Cormier, I. Rusu, A. Khacef. On the use of a magnetic blow out glidarc reactor for the syngas production by stem reforming // *16th International symposium on plasma chemistry*, Taormina, 2003.
4. V. Chernyak // *Proc. 3rd Czech-Russian Seminar on Electrophysical and Thermophysical Processes in Low-temperature Plasma*, Brno, 1999, p. 94-99.
5. O.A. Nedybaliuk, V.Ya. Chernyak, E.V. Martysh, T.E. Lisitchenko. System with plasma injector of hydrocarbons with high viscosity // *Proc. of the VIII International Conference "Electronics and Applied Physics"*. Kyiv, Ukraine. 2014, p. 148-149.
6. D.L. Chernolutsky et al. Study of the gliding rotating discharge of atmospheric pressure // *7th International Symposium on Theoretical and Applied Plasma Chemistry*. Ples, Russia. 2014, p. 306-309. URL: http://www.isuct.ru/istapc/images/stories/istapc2014.pdf (in Russian).

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ИЗУЧЕНИЕ ВРАЩАЮЩЕГОСЯ СКОЛЬЗЯЩЕГО РАЗРЯДА АТМОСФЕРНОГО ДАВЛЕНИЯ

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Рассматривается возможность создания долгоживущего источника неравновесной плазмы атмосферного давления на основе вращающегося скользящего разряда. Описываются системы, на которых проводились исследования вращающегося скользящего разряда атмосферного давления. Представлены результаты, полученные в ходе исследований. Показана возможность создания разрядной системы с эффективной площадью катодной привязки разряда к электроду большей, чем в стандартных электродуговых генераторах, плазмы.

ДОСЛІДЖЕННЯ ОБЕРТОВО-КОВЗНОГО РОЗРЯДУ АТМОСФЕРНОГО ТИСКУ

Д.Л. Чернолуцький, В.В. Колган, В.Я. Черняк, О.А. Недибалюк, В.В. Юхименко, В.О. Шаповал, Ол.В. Соломенко, М.О. Якимов, Т.Є. Лиситченко

Розглядається можливість створення довгодіючого джерела нерівноважної плазми атмосферного тиску на основі обертово-ковзного розряду. Описуються системи, на яких проводились дослідження обертово-ковзного розряду атмосферного тиску. Представлені результати отримано під час дослідження. Показана можливість створення розрядної системи з ефективною площею катодної прив'язки розряду до електроду більшої, ніж у стандартних електродугових генераторах, плазми.