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# INVESTIGATION OF PECULIARITIES OF THE DISCHARGE EXCITATION WITH HOLLOW CATHODE EFFECT IN $N_2$ IN A TUBE ELECTRODE

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**Abstract.**

The influence of some constructive discharge system elements on the electric excitation modes and stable maintaining of pulse glow discharge plasma in $N_2$ in a hollow tube cathode has been investigated. The investigation has been carried out within 50–700 Pa $N_2$ pressure range. The dependence of voltage amplitude values, exciting the discharge with a hollow cathode effect, on the pressure of plasma forming gas at various cathode positions in the quartz tube have been obtained. The experiments show that the discharge is excited and glows stably in the range of 50–660 Pa pressure when the plasma forming gas passes through the discharge system, and in a narrower 100–500 Pa range when the gas is fed past the discharge system. It was established that the influence of distance between the cathode and the counter-electrode in the range of 110–200 mm on the excitation modes and maintaining of the discharge with a hollow effect is insignificant.

**Keywords:** discharge, hollow cathode, vacuum, tube electrode.

## 1. Introduction

Numerous specific peculiarities of a hollow cathode discharge [1–3], determine its wide application in spectroscopy, microwave devices, various ion devices, for welding and metal melting, etc. [4–7].

Regarding the problems of vacuum-plasma treatment processes intensification the interest concerns the investigation and development of the method of preliminary working gas activation in a separate plasma source [8] which can be based on the use of a hollow-cathode discharge.

A great number of publications deal with the investigation of a plasma forming of glow discharge with a hollow cathode effect mode (HCE) [9–11]. But because of the specific constructive peculiarities of plasma discharge systems of such type, the definition of optimal plasma-forming modes for a definite design and a certain hollow cathode sizes turns to be impossible. Besides, the plasma-forming mode is greatly influenced by such factors as the type of a gas, the frequency and the form of the electric pulses exciting the plasma, the shape and the position of the cathode, the anode's spatial position, etc.

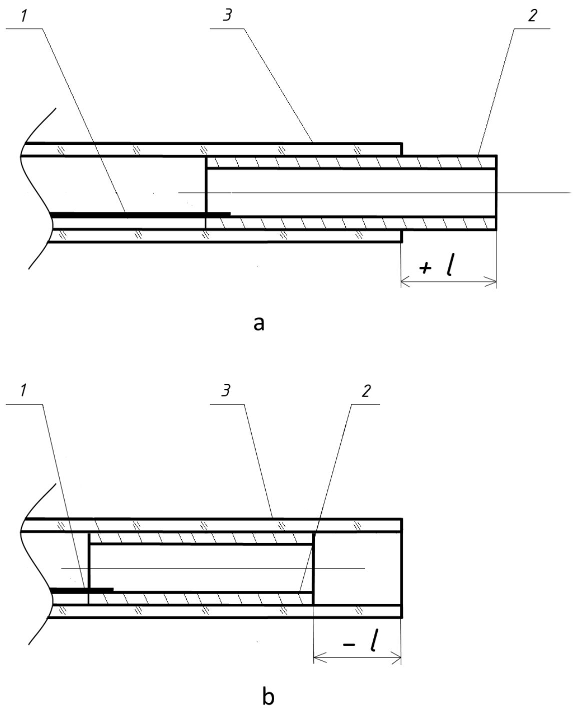


*Figure 1. The design of a plasma discharge system with hollow tube electrode-cathode extended outside the dielectric quartz tube on $+l$ distance (a) and immersed into dielectric quartz tube on $-l$ distance (b):*
*1 – current feeding wire*
*2 – hollow tube cathode*
*3 – quartz tube*

## 2. Experimental part

The investigation of some gas discharge system design peculiarities influence on the excitation of the discharge with a hollow cathode effect was carried out with the use of a cylindrical tube electrode-cathode held with a quartz tube (Fig. 1).

Hollow cathode 2 was made of corrosion-proof steel in the form of a cylinder with the internal diameter 5 mm and placed at one end of the quartz tube 3. The other end of the tube was led out of the vacuum chamber through a vacuum connection. The quartz tube can perform several functions: it is an electrode-cathode holder; it provides plasma forming gas feeding through the electrode; it serves as a protection screen for the current feeding wire; it is an insulator for a part or for the whole external surface of the electrode.

The electrode-cathode was placed at the distance of more than 200 mm from the internal surface of the metallic vacuum chamber elements of which served as the distributed electrode-anode.

Several experiments were carried out with the use of a grounded counter-electrode (anode). It was made of corrosion-proof steel in the form of a disk with 100 mm diameter. The disk was placed perpendicularly to the electrode-cathode axis at different distances from it.

To excite the discharge with a hollow cathode effect, a negative polarity pulse voltage with the rectangular pulses of $f = 50\,\mathrm{kHz}$ frequency and duty factor $S = 1/4$ was applied to the cathode.

High purity nitrogen with the percent of $N_2$ greater than $99,999$ was used as the plasma forming gas.

The moments of discharge appearance and extinction were defined according to the indication of an optical plasma glow sensor connected to an oscilloscope.

Before the experiments, the vacuum chamber of the installation was pumped down to the value of the residual pressure not exceeding $P = 1\text{–}2\,\mathrm{Pa}$.

During the experiments, the ranges of plasma forming process modes were: the generator's voltage pulses amplitude was varied from -450 V to -1300 V; the pressure of $N_2$ in the vacuum chamber of the installation was varying within the range 50–700 Pa.

## 3. The results and discussion

The experiment's data on the amplitude values of discharge breakdown voltage at different cathode positions relative to the quartz tube's end face at various pressure are shown in fig. 2.

The presented dependencies show that extension of the electrode from the quartz dielectric tube within the studied values does not significantly affect the amplitude values of voltage pulses required for the discharge excitation.

With the cathode immersed into the quartz tube we observed a close to the linear dependence of increasing breakdown voltage value on the distance from the tube's end face. We assume that this effect is connected with the increase of plasma particles interaction with the internal surface of the quartz dielectric tube and respective deterioration of plasma forming conditions [12]. Note that with the increase of $N_2$ pressure, the degree of this influence increases. This is due to the fact that the breakdown voltage depends on the electron multiplication in the space between the anode and the cathode and at the cathode surface. The values of the breakdown voltages increase correspondingly with the increase in pressure in accordance with Pashen's law [13].

During the experiment, it was established that the position of the hollow tube-type cathode in a quartz

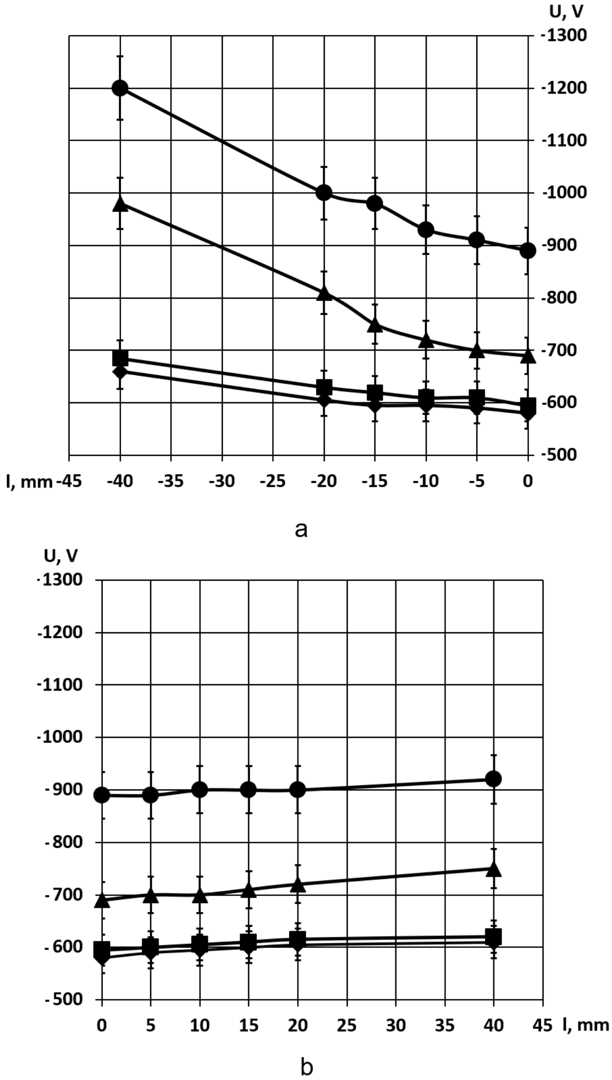


*Figure 2. Dependence of discharge breakdown voltage values on the cathode's position in the quartz tube at different pressure values (gas – $N_2$) when immersed into the quartz tube (a), when moved out of the quartz tube (b):*

♦ – $P = 50$ *Pa*
■ – $P = 80$ *Pa*
▲ – $P = 225$ *Pa*
● – $P = 330$ *Pa*

tube affects the range of pressure at which the discharge with hollow cathode effect is excited and stably maintained.

The discharge is excited and stably maintained in the range of pressure equal to 50–700 Pa, when the position of the end face of the cathode with respect to the end of the tube was in the interval from $l = +40$ mm to $l = -15$ mm. When the cathode is immersed to more than 15 mm, the range of pressure decreases significantly, particularly its upper bound. The discharge begins to behave unstably or does not excite at pressures exceeding 350 Pa.

It should be noted that the instability, in this case, manifested itself in a quick decay (about 2–3 sec) of discharge and in the difficulty of the objective registering its characteristics by oscillogram.

According to the results of the performed experiments, the way of gas feeding into the plasma-formation zone affects the characteristics of exciting and maintaining the discharge with a hollow cathode effect.

Fig. 3 shows the dependence of voltage amplitude values, exciting the discharge with a hollow cathode effect, on the pressure of plasma forming gas at various cathode positions in the quartz tube. The values of Fig. 3a have been obtained for the conditions of gas feeding into the quartz tube not through the discharge system. The data of Fig. 3b have been obtained when the gas passed in the quartz tube through the discharge in the hollow electrode-cathode.

The experiments show that the discharge is excited and glows stably in the range of 50–660 Pa pressure when the plasma forming gas passes through the discharge system, and in a narrower 100–500 Pa range when the gas is fed past the discharge system.

Note that when the gas is fed through the discharge system, somewhat higher values of pulse voltage are required to excite the discharge with a hollow cathode effect. We assume that it can be explained by the following factors: 1. when the plasma forming gas is fed through the electrode of the discharge system, the pressure in its cavity is higher than in the vacuum chamber; 2. the discharge is formed in the stream of the non-activated gas and the area of plasma afterglow does not significantly affect the process of plasma excitation.

Concerning possible variations of the design variants and the position of discharge system elements, the influence of the distance between the hollow cathode and the grounded counter-electrode on the value of voltage exciting the discharge with hollow cathode effect was studied.

The obtained data are presented in Fig. 4.

The results of measurements show that the influence of distance between the cathode and the counter-electrode in the range of 110–200 mm on the excitation modes and maintaining of the discharge with a hollow effect is insignificant. In this range of distances and at 50–500 Pa pressures the discharge behaves stably. The electric characteristics of plasma-formation change insignificantly.

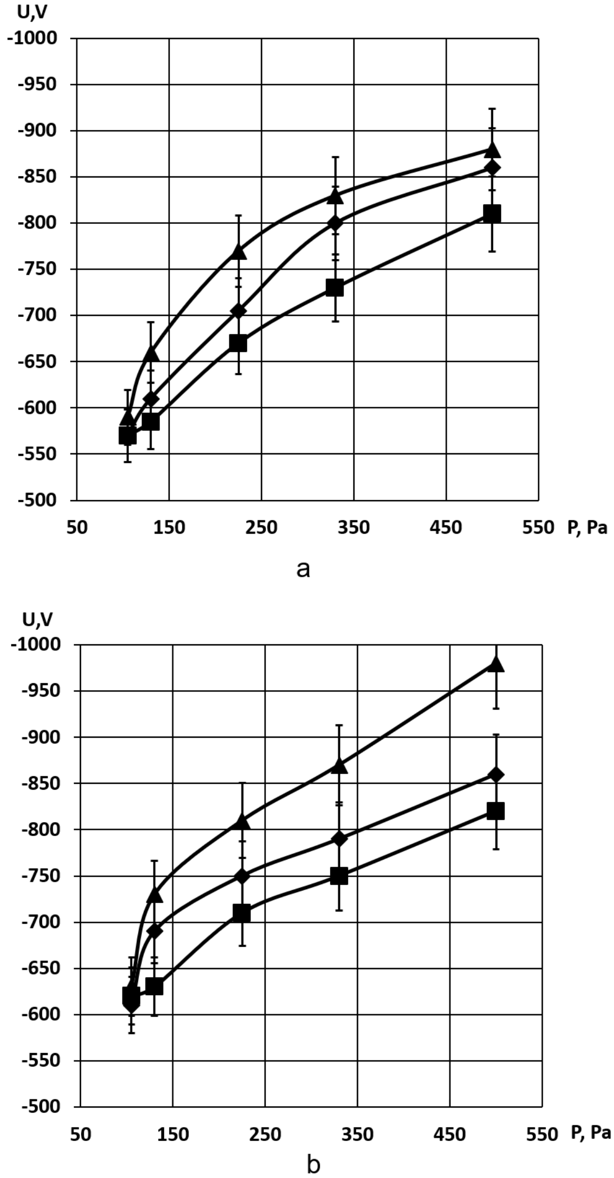


*Figure 3. Values of breakdown voltage of the discharge with hollow cathode effect in $N_2$ when the gas was fed past the discharge system (a), through the discharge system (b):*
■ – $l = +15$ *mm*
♦ – $l = 0$ *mm*
▲ – $l = -15$ *mm*

## 4. Conclusions

The influence of some constructive discharge system elements on the electric excitation modes and stable maintaining of pulse glow discharge plasma in $N_2$ in a hollow tube cathode has been investigated. The following discharge system changes have been performed: the position of a hollow electrode-cathode in the dielectric tube-holder; the method of plasma forming gas feeding to the discharge area; the distance between the electrode-cathode and counter-electrode (grounded anode). The investigation has been carried out within 50–700 Pa $N_2$ pressure range. The obtained results may be used in the design of gas discharge systems with a hollow cathode effect.

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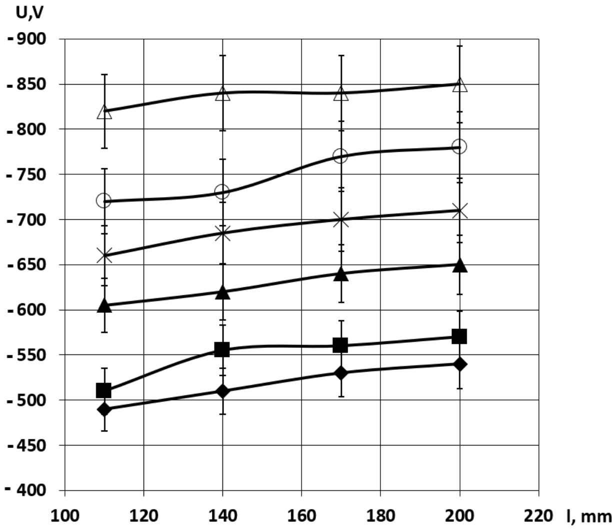


*Figure 4. Values of breakdown voltage of the discharge with hollow cathode effect when the distance between the cathode and the counter-electrode changes at different pressures:*
◆ – $P = 50$ *Pa*
■ – $P = 80$ *Pa*
▲ – $P = 130$ *Pa*
× – $P = 225$ *Pa*
◯ – $P = 330$ *Pa*
△ – $P = 500$ *Pa*

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