Volt-ampere characteristic of two-electrode gap at high pressure and an arbitrary emission of current carriers

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Abstract. The problem of calculation of the volt-ampere characteristic of a two-electrode gap at arbitrary emission of current carriers moving in the mode of mobility is solved.

1. Introduction
In recent years, there has been an increasing interest to the corona discharge. Corona discharges continue to be widely used in traditional areas such as air and industrial gas treatment by means of electric filters in thermal power plants, cement plants, etc., for water treatment with a high degree of its disinfection, in electrogrography and electrostatic printing. Surface treatment by means of corona discharge of polymeric materials increases wettability of the surface, which improves its ability to form bonds with solvents, coatings, adhesives, etc. Effectively corona discharge is used in the field of non-destructive testing, for example, to study the state of the surface of the steel rope. Corona discharge can also be used to strengthen the metal-cutting tool, when the surface of the tool is treated in the field of positive corona discharge before deposition of coating. The synthesis of ozone in plasma chemical reactors with using of corona discharge has been brought to industrial scale. Recently, the corona discharge of atmospheric pressure is used in nanotechnology to produce nanotubes. Corona discharge is used to excite the active medium of gas lasers, etc. [1].

2. Simulation of volt-ampere characteristic
In a number of cases, three – electrode systems are used as an ion source, in which the discharge is ignited between the electrode and the grid, and the ions are extracted into the grid-collector interval using the electric field of collector. Testing of the design and operation modes of such systems is carried out mainly by experimentally. To develop a method of calculating such systems, it is necessary to calculate the volt – ampere characteristic of the grid-collector interval at an arbitrary ion source performance. Considering the grid electrode as an equivalent emitter, it is possible to reduce the task to the calculation of the volt-ampere characteristic of a two-electrode interval at an arbitrary emission of current carriers moving in the mode of mobility, that is, when the speed of their directional motion $v_n$ is determined as follows:

$$v_n = \mu E,$$  \hfill (1)
where $\mu$ – is the mobility coefficient of charged particles and $E$ – is the local value of the electric field intensity.

For the selected model, the expression for the current-voltage characteristic is known for the mode when the current density $j_0$ is completely limited by the volume charge [2]:

$$ j_0 = 9\varepsilon_0\mu U_a^2 / 8L^3, \quad (2) $$

where $\varepsilon_0$ – is the permittivity of the atmosphere, $U_a$ – is the voltage between the electrodes of the gap, $L$ – is the distance between the electrodes (grid – collector).

For the case of arbitrary emission of current carriers to the gap is known [2]:

$$ E_0 = \varepsilon / 4\mu(j_0 / j_0 - 1), \quad (3) $$

where $\varepsilon$ – the arithmetic mean value of the thermal speed, $E_0$ – the electric field at the emission surface, $j_e$ – emission current density.

It is shown, in particular, that the electric field intensity on the emission surface can be calculated by another way:

$$ E_0 = \beta_0(j_e / j_0)U_a / L, \quad (4) $$

where $\beta_0 = j_e / j_0$ – is a dimensionless function characterizing the degree of shielding of the emission surface by the volume charge, $j$ – is the density of the current flowing between the electrodes of the gap. In figure 1 are shown the graphs of the values of functions $\beta_0 = j_e / j_0$.

**Figure 1.** For determine the electric field intensity on the emission surface: 1 – for a weak field, 2 – for a strong field.

Equating to each other equations (3) and (4), we obtain an equation that allows us to calculate the required volt-ampere characteristic. This equation can be conveniently represented as

$$ j_e = \phi \left( \frac{j_e}{j_0}, A \right). $$
where

\[ \varphi \left( \frac{J}{J_0}, A \right) = \left[ 1 + \frac{A}{\beta_0 \left( \frac{J}{J_0} \right)} \right] \frac{J}{J_0}, \quad A = \frac{\varepsilon L}{4 \mu U_a}. \]

Equation (5) allows to find \( j \) depending from \( L, U_a \) and \( j_e \) as a result of graphical or numerical analysis. The value of \( j_e \) in the considered conditions is found through the current density in the ion source and the optical transparency of the grid electrode. In figure 2 presents the calculated and experimental volt-ampere characteristics.

![Figure 2](image-url)  
**Figure 2.** Calculated and experimental volt-ampere characteristics: 1, 2 – calculation and experiment at \( L=3 \text{mm}, j_e=160 \mu \text{A}; 3, 4 – calculation and experiment at \( L=11 \text{ mm}, j_e=160 \mu \text{A}. \)

### 3. Results and discussion

The experimental test was carried out on a device that used a corona electrode consisting of \( 10\times10=100 \) needles with a step between them \( b=3 \text{ mm} \). The distance between the electrodes \( L \) could be changed from 3 to 11 mm. The mobility of negative ions in atmospheric conditions is taken \( \mu=1,8\cdot10^{-4} \text{ m}^2\text{V}^{-1}\text{s}^{-1} \). The step between the needles and the distance from the needles to the grid \( H \) were chosen such that the current density distribution over the section of corona discharge in the grid area was uniform. The uniformity of the current density across the corona discharge section from the many-needle electrode depends on the dimensionless parameter \( b/H \), and with the ratio \( b/H=0.5 \), the unevenness of the current density distribution over the cross section in the grid area did not exceed 7%.

The total corona discharge current is distributed between the grid and the collector:

\[ I = I_g + I_{kol} \]

To increase the efficiency of three – electrode devices based on the corona discharge, it is necessary to increase the current of the grid-collector interval. This device is a kind of ion triode. As the grid-collector distance decreases, the current extracted from the corona discharge through the grid increases. As shown by the study, when changing the distance of the grid-collector from 2 to 10 mm,
the uneven distribution of ions across the flow section practically did not change and was about 2%. At the same time, a grid with a step of 0.5 mm was used. These results were obtained in the study of the uniformity of the charges on the dielectric film with a thickness of 50 microns, which was uniformly stretched on the surface of the collector. Measurements were carried out with using a dynamic electrometer with a vibrating probe.

The collector current value also depends on the grid step. As the grid step increases, the current extracted from the corona discharge through the grid is increase. With the change the grid step, the current density distribution over the ion flow cross section of the gap collector-grid changes slightly. So, if you change the grid step from 0.5 to 2 mm and with the distance of the grid-collector is equal to 3 mm, the uneven distribution of current density in the region of the collector varies from 2 to 4%. Additionally, you must consider that when the current of corona discharge changes, changes and the current through the grid. On the figure 3 the dependence of the current extraction coefficient to the collector from voltage on collector at three values of the corona discharge current is presented.

Figure 3. Coefficient of current extraction versus voltage on the collector for three values of corona discharge current: 1 – 500 µA, 2 – 1000 µA, 3 – 1500 µA.

4. Conclusion
A comparison of experimental and calculated data shows that the theoretical dependences describe both the regime of current limitation by the volume charge and the output to the saturation mode.

References
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