Electro Physical Ways of Creating Pressure Differential in the Course of Charged Particles Output into the Atmosphere

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Abstract – This article is focused on the issues of creating pressure differential through the systems of diaphragms by means of beam extraction, discharge and shock waves.

1. Introduction

The beams of charged particles (electrons or ions) are rather promising in plasmochemistry, medicine, synthesis of material, under certain pressure, concentration and temperature. For low-voltage (up to 100 keV) stationary beams extraction into gas we know such output devices as gas-dynamic windows. In their simplest way, the windows are the systems of diaphragms with gas pumping between them [1–20].

However, the application of output systems is retarded by the contradiction between the output holes dimensions and pumping means capacity to maintain vacuum for generating electrons. For example, for electron beam extraction from the source with the thermal cathode, operating at the pressure 10 (–3) Pa, we use 5–6 pumping stages with the holes diameter of 1–10 mm. The power consumption is 5–7 kW per 1 mm of holes area.

During the extraction of high-current electron beams there appear a number of associated problems. The high-current beams have big diameter (5 kA/sm) and probabilistic distribution of beam density at the level of output holes. Due to this there appear a problem of correlation between the beam area and the holes area.

The use of gas-dynamic effects at small pressure values becomes problematic due to the gas discharge.

The form of elements for maximum pressure differential depends on the distance between the elements and the relation of pressures between the pumping stages. Making the form more complicated has technological limitations.

With the decrease of pressure, decreases the pumping means efficiency in relation to gas flow and drops gas pumping efficiency from the output device.

2. The ways to solve the problem

In addition to gas-dynamic effects there are suggested the electro physical ways to create pressure differential. For example, the use of positive influence of output beam on the pressure differential, glow-discharge and arc discharge arrangement, shock wave arrangement.

3. The gas parameters change scheme

The scheme is based on the thermal model of beam interaction with gas and on changing the holes U flow capacity because of temperature:

$$U \sim (T/M)^{0.5}, \tag{1}$$

where T and M are the temperature and gas molecular weight respectively.

In this case, we have the momentum conservation equation [15]:

$$I = (k + 1)/2QV^2Z(\lambda), \tag{2}$$

$Z(\lambda) = \lambda + 1/\lambda$ is the tabulated function of momentum variation in the course of heating [15].

The change of gas temperature T and flow Q is connected with the change of velocity coefficient λ by the formula [15]:

$$T_h/T_c = (1+\lambda_c^2)/4\,\lambda_c^2. \tag{3}$$

$$Q_c/Q_h = [2T_h/T_c - 1]^{0.5}. \tag{4}$$

The indices "h" and "c" correspond to hot and cold gas. It is evident that the smaller is the gas velocity, the greater is its heating.

On account of the flow finiteness ($\lambda \rightarrow 2.5$) and its pulse function maximum value $Z(\lambda) \rightarrow 3$ there is the ultimate heating value of the moving gas flow. The further flow overheating only results in decrease of pressure change coefficient δ in the flow and flow deceleration.

There is the ultimate possible gas density change coefficient R:

$$R = (k + 1)/(k - 1), \tag{5}$$

where k is the factor of adiabat (for air R = 6).

4. The picture of gas flow in the output device

Figure 1 shows the one-dimensional model of gas parameters variations in the output device.

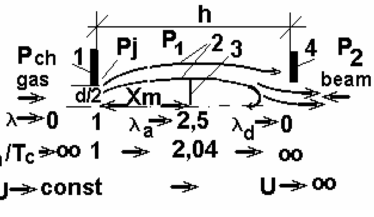

Fig 1. The scheme of changing the parameters in the beam output device

In the working chamber the flow is motionless; $\lambda \to 0$; $T_h/T_c \to \infty$.

Further, the gas flow gets into the output device through the output hole d in element 1. In the cut of the hole $\lambda \to 1$; $T_h/T_c \to 1$, so the conductivity U of the hole d remains constant.

Then the gas flow expands into vacuum and accelerates proportionally to pressure differential. Expansion is accompanied by forming zones of pressure condensation 1, 2, 3. The flow acceleration is characterized by the velocity coefficient λ, equal to the relation of the flow velocity in the stream to the sound velocity:

$$\lambda = V/V_a. \quad (6)$$

The maximum expansion of the flow is achieved at the distance X_m (in Mach disk):

$$X_m = 0.7d\sqrt{kP_J / P_1}, \quad (7)$$

P_J, P_1 are the pressures on the hole d cut and between the output elements.

The flow in the space between the output elements (up to Mach disk) is accelerated from λ = 1 to a in a supersonic region, and decelerated from $\lambda_d = 1/\lambda_a$ to λ = 1 in a subsonic region (after Mach disk). In the absence of the beam the gas temperature decreases with the increase of velocity, and under the action of the beam it increases. Chart 1 shows the total pressure change function values in the course of gas heating $f(\lambda)$ for subsonic and supersonic regions of the stream [15]

$$f(\lambda) = (\lambda^2 + 1)[1 - (k - 1)/(k + 1)\lambda^2]^{1/(k-1)}. \quad (8)$$

Chart 1. Some flow parameters

λ	0	0.528	1	2	2.5
$f(\lambda)$	1	1.1	1.2	0.32	0

From this chart you can see that the total pressure change function value $f(\lambda)$ in the supersonic region decreases by more than two orders. Before the element 4, the nearest to the particles source, the flow is encumbered and heated, which results in the increase of hole flow conductivity ($U \to \infty$).

The coefficient of total pressure change is expressed as:

$$\delta = [f(0)/f(1)][f(1)/f(\lambda_a)][f(\lambda_d)/f(1)] \approx f(\lambda_d)/f(\lambda_a) \approx$$
$$\approx f(0.46)/f(\lambda_a).$$

So, total pressure change during the beam pass is determined by the relation of function of total pressure change on Mach disk. I.e. the limiting change of pressure parameters ranges in one order; in terms of consumption – 1.75; in terms of temperature – 2.04. In the most output devices, in power considerations, the pressure differential in output elements does not exceed two orders, i.e. λ ≤ 2.15. So δ ~ 7.85.

5. The influence of the output beam on the pressure differential

The beam heats the gas. It is considered, that the output beam increases pressure differential. But, reducing the distance between the elements, for reducing beam losses at the output, the beam deteriorates the pressure differential being created. Positive or negative influence of the output beam on the pressure differential is explained by the dependence of the holes conductivity U and gas consumption Q on the temperature.

Figure 2 shows the beam influence on the gas consumption change.

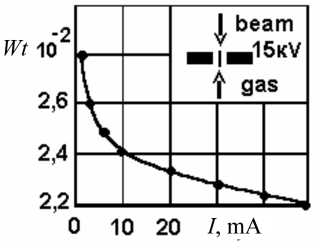

Fig. 2. The dependence of gas consumption on electron beam flow

At the small distance between the elements the gas flow consists mainly of subsonic region, where the gas heating value is big.

Eventually, depending on the beam parameters and output devices pumping modes, output beam can either leave the pressure differential without influence or change it by nearly one order either increasing or decreasing it.

The gas flow Q, pumped by the beam out of the electron source, is described by the expression

$$Q = cWdP / dt \quad (9)$$

where c is the constant value which depends on a beam power and gas emission from the elements, W is the gas volume in electron source.

6. Glow discharge in the output device

The charge ignition changes flow parameters. (The flow becomes wider, forward pressure in it decreases).

In the case of discharge, taking thermal model, there is termobaroeffect, during which the difference in temperatures causes the difference in pressures ($\Delta T \sim \Delta P$). In this case the momentum conservation equation is true [15]:

$$I = (k + 1)/2QV^2Z(\lambda_1) = (k + 1)/2QV^2Z(\lambda_2). \quad (10)$$

Figure 3 shows theoretical 1, 3 and experimental 2 graphs of temperature and gas consumption change.

One of the ways of increasing gas-discharge output devices efficiency is stimulating the local zones of flow change parameters. The main mechanism of gas removal during the discharge in the output device is considered to be termobaroeffect, during which the difference in temperatures causes the difference in pressures.

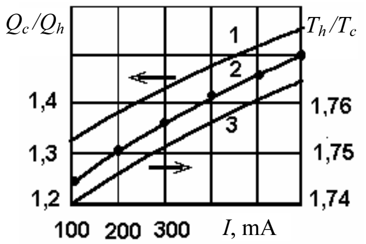

Fig. 3. Change of temperature and gas consumption due to discharge current

In multi-channel systems the gas interaction with barriers and with each other as well creates conditions to local irregularity of gas flow density. Local change of pressure occurring when gas interacts with the barrier breaks the conditions of current existence. The charge is transferred onto the other channels, where local pressure corresponds to the conditions of its existence according to Paschen law. The difference between ignition and combustion voltages is input into ionization processes and high-frequency fluctuations. Maximum gas fluctuations are observed in the modes of flow rearrangement in the range of Reynolds numbers 150–200. While increasing the distance $h > 10d$ between the elements, the discharge combustion instability decreases. If the area of discharge exceeds the area of output holes, the efficiency of glow-discharge input into pressure differential increases.

7. Arc discharge in the output device

The arc in the channel acts as a solid state and is able to hold some gas flow [4]. In addition, the arc discharge heats the gas, which increases the holes conductivity. Besides, arc combustion tends to be instable and cause discharge closure in undesirable places, which causes local gas emissions and electrododes erosion.

With the increase of arc current by more than 5 A, pressure differential is almost absent. It is explained by the fact that with the increase of current increases the percentage of losses spent on the heating of electrodes and gas emission (20–25%), on radiation (20%), on ultra-frequency plasma and acoustic fluctuations (18–25%). Working with big diameters (6–10 mm) at atmospheric pressure we can observe the instability of combustion, pressure and temperature fluctuations, which result in arc extinction.

The pressure differential through the stationary arc does not exceed the differential through the systems with glow-discharge. This is connected with the increase of overheating and flow deceleration.

8. Creating pressure differential by the shock wave

The electric rupture from the capacitance over the surface of dielectric fuse, which is situated across the gas stream, stimulates the pulse high-current arc. Local gas overheating forms the shock wave with the duration of several microseconds, deflecting gas flow. The output hole is found outside the gas stream and the pressure in electron source decreases.

The change of pressure is determined by the formula for the shock adiabat [15]:

$$P_1/P_2 = [\lambda^2 - b]/[1 - b]\lambda^2, \qquad (11)$$

where $b = (k - 1)/(k + 1)$ with $\lambda = 2\,P_1/P_2 > 5$.

While realizing this method it is important to take into account the velocity of gas fronts pass through the output holes and the velocity of plasmo-dynamic shock wave fronts formation, which is 7–10 mcs.

9. Results

Using glow-discharge (600 V, 400 mA) together with the output beam (20 kV, 50 mA) allows one to keep vacuum in gas-discharge electron source at the rate of 10–80 Pa without its pumping in the course of beam output into the atmosphere through the hole with 0,8 mm in diameter and pumping between the elements with the pump BH-1. As an example of peculiarities of such system we consider the necessity of starting vacuum in the particle source. While output beam pass through the plasma of glow or arc discharge, the losses on beam shielding do not exceed 5–20%.

10. Conclusions on electrohpysical ways of creating pressure differential

Electro physical ways of creating pressure differential are realized at the pressures less than 1 mm of mercury column.

The opportunities of electro physical phenomena for improving parameters of beam output systems have finite potential. The finiteness of creating pressure differential on the basis of electro physical phenomena originates from the finiteness of pulse transportation function value ($Z(\lambda) \to 3$). The action of the discharge in the output device is similar to the action of the output beam.

The limiting change of pressure parameters is about one order; in terms of consumption – 1.75; in terms of temperature – 2.04. Theoretical limit of gas density change under the action of shock wave from the pulse high-current discharge is limited by the factor of adiabat. For the air at $k = 1.4$ theoretical change of density can achieve 6 times. For plasma at $k = 1.1$ the limit of change tends to 11. The output beam can improve or deteriorate the pressure differential by one order. During the beam pass, the output device parameters, its frequency and operational properties change.

To sum up, electro physical ways of creating pressure differential are the prospects of atmospheric beam output systems development.

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