# Multi- Channel Devices for Transportation of Electron and Ion Beams into Gas

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**Abstract - The extraction of focused electron beams via the system of funnels is discussed. The increase of efficiency is achieved with the use of gas-discharge electron an ion sources, improvement of a funnel shape and consideration of beam effect upon the pressure differential.**

## The present state of the problem

Electron and ion beams, injected into gas, can find wide application in material machining, metallurgy, quantum electronics, medicine and microelectronics. The devices with beam removal usually consist of an electron source and an output window that separates its vacuum volume from a chamber filled with a gas. For extraction of low-energy continuous focused electron beams the gas-dynamic windows consisting of supersonic gas jets, metal vapor jets and liquid jets can be used. Besides, jet gates for extraction of focused beams some systems of aligned diaphragms can be used with differential gas pumping between them [1-19]. The pressure differential obtained with such means increases with a number of stages and pumping capacity but drops with the increase of output hole dimensions. Gas-dynamic windows parameters can be improved by a better design of the gas-dynamic windows itself and also pumping means. The decrease of the incoming gas pressure can be achieved by overlapping of holes in case of beam absence, e.g. using a rotating cylinder with a channel for beams extraction, or with a disk of holes at its edge for the same purpose. With advances in vacuum techniques instead of mechanical pumping means, cryogenic and ejector means can be used currently.

Now existing means for extraction of stationary (up to 100 kV) beams through the system of diaphragms allow extracting beams into atmosphere from electron sources with a thermal cathode operating at pressures of the order $10^{-3}$ Pa using 5-6 pumping stages, through holes with the diameter of 1-10 mm, and power consumption about 5-7 kW per 1 mm of the hole area and current losses up to 75%.

Despite growing interest to application of continuous beams, their use retarded by a number of problems evolved in the process of electron sources operation with gas-dynamic windows. The most important one is a contradiction between hole dimensions for beam extraction and the capacity of pumping means to maintain vacuum for electron generation.

In most cases, the beam is extracted with probabilistic forecasting as to a pressure differential and removed power. However, in some cases a form and mutual arrangement of gas-dynamic windows elements together with the passing beam modes can define a pressure differential and beam losses but not the capacity of pumping means. One of the reasons of probabilistic efficiency of beam extraction is the fact that well-known calculation methods based on relationship of vacuum techniques can not reveal the conditions of efficiency increase but only establish a tentative correlation between the hole diameter and the necessary gas pumping rate.

## Problem solution

The increase of beam extraction efficiency related to a solution of a number of problems that can be subdivided according to the following directions: an electron source, pressure differential system, electro physical events, current passage, correlation.

## The Order of system

Electrons heat the material. For modification of surfaces by ions they need a high voltage source. For phase conversions we can advise a multi - charge monochrome low - voltage ion source. For operations of ion pickling, ion waxing, ion peelings it is necessary to neutralize an ion flow.

## Electron and ion source

The employment of gas-discharge and vacuum arc sources, operating in a for vacuum, is rather promising. The advances in electron - beam and plasma technologies of electron guns based on gas - discharged source with a cold aluminum cathode and a high-voltage glow discharge operating in forvacuum under conditions of lesser requirements to gas-dynamic windows parameters allows using only mechanical pumps. The development of multi-channel electron guns as electron sources that can generate electron beams at pressures of 80 Pa and more [14] has many advantages.

For ion sources this pressure is limited by origin of a high-tension glow discharge at pressures about 1Pa. It is most advantageous to use light inert gases with high potential of ignition (helium and its mixtures).

**Electrophysical phenomena.**
**The Reflected particles**

Reflection of particles from elements of a device includes desorbtion and decomposition of molecules, ionizing and change the voltage-current feature of a source. The method to overcome – it is to make the elements of complex form.

**Neutralization of ion beam charge**

The absence of neutralization leads to ionizing of gas and spilling of beams. Neutralization of pulsed beams is performed by pulsed magnetic field ~2 TL for current 40 kA. The Neutralization of stationary ion beams is performed by an electron flow obtained, from heating or from electron source.

**Losses on gas**

The existing theories [15] describe dissipation of particles through pulse *I* of particles:

$$I = [(k+1)/2k]QFZ(\lambda) \quad (1)$$

*Q*- flow of gas, *F*-area of flow, *k*- factor adiabatic; λ- factor to velocities of flow [15].

Under λ=0 gas is still, under λ=1 a flow reaches the velocity of sound, under λ>1 a flow reaches the supersonic velocity.

Z(λ)- is a function of pulse. $Z(\lambda)\to\infty$ at the velocities of flow to zero and $Z(\lambda)\to 3$ under maximum flow velocity. The velocity of flow in holes is close to subsonic velocities, so $Z(\lambda)\approx 2$.

The changes of gas temperature from its heating by beams are expressed [15]:

$$T_h / T_c = Z^2(\lambda)/4 \quad (2)$$

The indices "h" and "c" correspond to hot and cold gases.

Conclusion. This signifies that with increase of heating temperature the function of losses in gas is final. A beam is to surround, by heating the loss of beams will be less.

The experiments show that dissipation of electrons in gas below pressure of 133 Pa (1 torr) is low.

The path of ions decreases with the increase of materials Z or its density. Energy losses are proportional to the mass of ions and straight proportional to the gas density. The beam light mass scatters much less.

**Recharge**

At transportation the ions can change the charge degree, negative, neutral, or mylty charge ions. For high energy ions (> 100 кV) the losses on recharge are small. For low - energy ions with the mass more than 16 the loss can reach 40%.

**Interaction of ion beams and electronic beams**

An interaction with electrons does not give rise to dissipation of an ion beam due to small value of sent pulse. We know the characteristics of reduction of electron beams diameter under its encirclement by ions.

**Channels**

It is known effect of focusing of electrons at passing trough channels of small diameter of ~30 μm (Channels) because of accumulation of charge on walls. At present, the most spreading have been found with three channel models. They are: accumulation of load on wall, effect of lens in asymmetric channel, forming the virtual charged lattice around the ion passing channel. The last model explains the fluctuations and increase of ion beam current by 4-5 times.

**Contragirung**

The reduction of losses of beams at conclusion can be reached lighting of the discharge by taken out beams in longitude magnetic field (contragirung). This brings about the multicharge and expansion of spectrum of ions mass.

**Gas-dynamic output windows**

The most promising means for provision of a pressure differential is the system of aligned diaphragms of different shapes. There is an optimum distance that corresponds to the maximum pressure differential. To optimize the element shapes and the analysis of gas-dynamic effects a jet supersonic model of a gas flow has proved its efficiency. At the pressure differential above two orders at a hole an element shape does not effect pressure in an electron source, which is related to compliance of the principle of independence of flow parameters on a body shape.

The purpose of the output window is to deflect a gas flow. Swing of pressure does not depend on forms of window elements. This allows decreasing the distance from 10 to two diameters of the output holes without a loss in pressure swing. The deflection is reached by execution of elements under corner. Under local heating of gas, the temperature difference causes the difference of pressures (termobaroeffect).

**Influence of beams**

At pressures less that 1 torr, the capacity of vacuum pumps decreases.

To provide a pressure differential it is useful to apply the pumping effect produced by an extracted beam, or by a discharge ignited between elements [16].

However, an extracted beam and a discharge in some cases can impair a produced pressure differential. The influence of an extracted beam on the pressure differential can be analyzed using the scheme of a gas flow and changes of its parameters at a pressure differential. The gas, flowing into the vacuum, is accelerated into the region of supersonic velocities, and expands in the form of a hollow jet with formation of the pressure compacting zone (Mach disk) in front of the output elements. Following the Mach disk the flow decelerated and its pressure increases.

Positive or negative influence of beams on the pressure swing depends on the velocities of flow. The subsonic flow speeds up at heating, but the supersonic one is held up at heating. In a subsonic flow, the pressure decreases at heating. In a supersonic flow, the pressure increases at heating.

The scheme of gas parameters changing is based on the temperature dependence of the holes capacity *U* and also on a thermal model of beam interactions with a gas, according to which the greater is a coefficient of flow velocity, the lesser is its ability to be heated and pressing pressure in a gas flow. The gas temperature change is related to the change of the flow velocity coefficient $\lambda$ with the relation:

$$T_h / T_c = (1 + \lambda_c{}^2) / 4\lambda^2{}_c \qquad (3)$$

The indices "h" and "c" correspond to hot and cold gases. It is evident that the lesser is the gas velocity, the greater is its heating. The gas flow rate change *Q* in the course of heating can be defined by the expression:

$$Q_c / Q_h = [2T_h / T_c - 1]^{0,5} \qquad (4)$$

In the interelement space the velocity coefficient $\lambda$ can take the limiting values from 1 to 2.5. Correspondingly the limiting temperature changes can take values from 1 to 2,04. Thus, a limiting gas flow drop due to gas heating by a beam can not exceed 1,75 time for the air.

Table 1 gives the values of the total pressure change function $f(\lambda)$ for gas heating in subsonic and supersonic jet regions in an output facility, taken from paper [15]:

$$f(\lambda) = (\lambda^2 + 1)[1 - (k-1)/(k+1)\lambda^2]^{1/(k-1)} \qquad (5)$$

Table 1. Some parameters of a gas flow

| $\lambda$ | 0 | 0,528 | 1 | 2 | 2,5 |
|---|---|---|---|---|---|
| $f(\lambda)$ | 1 | 1,1 | 1,2 | 0,32 | 0 |

The table shows that the value of the total pressure change function *f* in a supersonic region decreases by more than 2 orders. In a subsonic jet region the total pressure almost does not change during gas heating. In an operating chamber a flow is motionless $\lambda \to 0$; $T_h / T_c \to \infty$

In the region of a beam input into a chamber

$$\lambda \to 1;\ T_h / T_c \to 1$$

Consequently the hole capacity remains constant.

$$U \sim (T / M) \qquad (6)$$

Where *T* and *M* are temperature and gas molecular weight.

The gas flow rate into the system of pressure differential near a beam decreases at the expence of the gas density decrease applied to the chamber out of the beam output region.

The flow in the inter element space up to Mach disk is accelerated from $\lambda = 1$ to $\lambda_a$. In a supersonic region and decelerated from $\lambda_d = 1/\lambda_a$ to $\lambda = 1$. In a subsonic region after a shock wave. Without a beam effect the gas temperature decreases with velocity increase, but it increases being effected by a beam. At the maximum flow (air) velocity we have:

$$M \to \infty, \lambda \to 2{,}5;\ T_h / T_c \to 2{,}04;$$

$$\delta = (1) / f(\lambda_a) \qquad (7)$$

Approaching the element of the second pumping stage in a subsonic region the jet flow is decelerated. $\lambda_d \to 0$; $T_h/T_c \to \infty$ which increases the capacity ($U \to \infty$).

As a whole, the influence of beams on the pressure swing depends on the parameters of beams and modes of rollout. The beams cannot influence the pressure swing, or change its nearly on order aside increase or reduction.

**Pumping action of a beam**

In a limiting case after an initial vacuum the pressure differential can be provided only at the expense of a beam. With the increase of a beam energy or a discharge current, this effect increases reaching the maximum value. The gas flow *Q*, pumped out of a chamber with the volume *V* by a beam, can be determined from the analysis of a pressure change in time with the relation:

$$Q = cVdP / dt \qquad (8)$$

where: c - constant accounting for a beam power and element gas emission.

In experiments the equivalent efficiency was equivalent to the pump NL-1 capacity.

However, the absence of a beam effect leads to pressure increase in the source almost by an order. The time of beam realignment consists of the structure rearrangement time and pressure change time in the source volume at the expense of in leakage change. Besides, the flow realignment amplifies capacity changes due to focusing properties of a jet. Under experimental conditions the admissible pause time is about several seconds. In this case the pressure in a source increases from 30 to 80 Pa. Under experimental conditions the pressure rise value is as follows:

$$\delta = f(0,46)/f(2,15) = 7,85 \quad (9)$$

It is evident that a calculated pressure change value correlates with the experimental one.

**Results**

The source is presented in Fig.1 with breakdown surface for conclusion of power full current electronic beams in atmosphere. The device of conclusion by height 65 mm and 40 mm diameter is equipped with 26 channels of 1 mm diameter. The cut corner of the elements forms $30^0$. The additional channels are executed between the excretory channels for deflection of gas. The rollout of the device steps is conducted by pumps BBH-3 and BH-7 below pressure 20 kPa and 10 Pa. The efficiency increase of the rollout from the vacuum system of reached by a pump (vacuum cleaner the Tornado). The accelerating voltage of the source is 80 - 100 kV, current is 40 кA, the pulse duration is 4 mks.

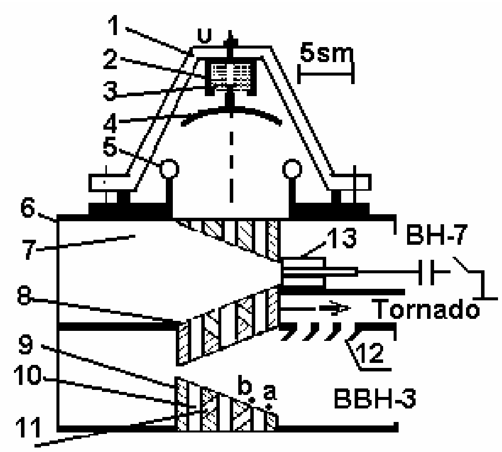


Fig 1.
1,3 –insulator; 2,4-catchode; 5-anode; 6,7- camber; 8,9,10,11,12- windows elements, 13- Arc source

**Conclusion**

A new gas-dynamic method for calculation of systems for beams transfer was developed that allows to optimize calculations of the required parameters together with new multi-channel and multi-functional gas-discharge electron sources at the operating pressure up to 80 Pa and higher. The power consumption of pumping means was reduced in the source of beams output into atmosphere from 10 to 1.5 kW/mm per 1 mm of a hole area at the distance between diaphragms from 2 to 5 diameters of output holes.

The Pressure in an ion source forms 5 Pa

The Pressure in a working camera with ion beams removed, is 300 Pa. The ion current is 12 kA

In the course of conversion program realization the means for extraction of low-energy beams can find use in polymerization of paint coatings, in production of laminated-polymer fireproof materials, for dry sterilization of soils, seeds and medical instruments.

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