ANALYZE OF GAS PROPELLANT CONSUMPTION OSCILLATION WHEN THE SELF-HEATED HOLLOW CATHODE IS STARTING "COLD" STATE

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Introduction

Developed to the present time gas flowing arc hollow cathodes with an indirect heating have found broad application, both in a structure of electrojet propulsion systems, and in the technological equipment. This cathode having long time resource of activity, unfortunately, have a number of essential defects, such as long duration time of preparation to start-up and small reliability of the launching heater.

Heating of the emitter in the hollow self-heated cathodes (SHHC) implements immediately by discharge, these disadvantages are eliminated. The time of achievements nominal discharge current is minimum (from several microseconds up to same milliseconds). However output of the cathode on nominal operational mode continued much longer.

This article describes in-depth study gas flow of processes happening at start-up SHHC.

Describes of calculations.

Obviously, the breakdown discharge of an electric current in a digit circuit results in a number(series) of essential changes. At first, it is necessary to mark so-called electron pressure on the diaphragm of the cathode, with characteristic time origin 10^{-6} - 10^{-4} s is determined by electrical parameters. The value of electron pressure is a composite function from parameters of discharge, geometrical degree of narrowing and gas expenditure. It the analysis is an independent problem and will be submitted in the following publications. Secondly, the electric current results in sharp heating of gas in a cavity SHHC for the score of electron - atom collisions. The value of temperature of gas reaches 3000 ... 7000 K. The analysis of this aspect also will be submitted later.

The time of heating is determined by power of discharge and conditions of heat exchange of gas with a design of the cathode, varies over a wide range from 10^{-2} up to 1 s. Thirdly, the discharge results in gradual heating of the emitter and capsule of the cathode. Accordingly there is a second way of heating of gas in gas flow a channel - heating of gas from walls of the capsule, that results in change of hydraulic resistance of a channel and influences a general view of current.

The method of elementary balances was used for the solution of a non-stationary problem heat-mass exchange. The gas channel was divided on N of volumes, the condition of every volume was described by an equation of a condition of real gas. Temperature of gas was equally to temperature of a body of the cathode, which distribution was determined experimentally. Heating gas was taken into account in addition at the expense of electron bombardment in a cavity and in a near diaphragm area. The hydroresistance of a channel was necessary equal to zero within the limits of each selected volumes, and between volumes hydroresistance was calculated with conditions of gas flow. The solution is accompanied by the rather great mathematical calculations in the given statement of a problem, therefore we shall consider more simplified model, which, however, shows the main tendencies of behavior of a system.

The gas channel was divided into two volumes, one was equaled to volume of a cavity, and other was, so-called «spurious», all volume of a channel up to the first throttle working in a supersonic mode (see fig. 1,2). All conditions described above were taken into account.

Then set of equations can be recorded as:

1. Proceeding from an equation of a condition of actual gas

$$\frac{P}{\rho RT} = 1 + B_r(\tau) \cdot \rho \qquad (1)$$

$$B_r(\tau) = \frac{1}{\rho_0} \sum_{i=1}^{5} b_i \left(\frac{T}{T_0}\right)^{-i}$$

were Br (t) - second factor of a variation,

For every volume it is possible to record:

$$\frac{dP_i}{dt} = \frac{dm_i}{dt} RT_i + m_i R \frac{dT_i}{dt} + \frac{dB_r(\tau)}{dt} \cdot \frac{m_i^2}{V_i^2} RT_i + \qquad (2)$$

$$B_r(\tau) \frac{2m_i \, {dm_i}/{dt}}{V_i^2} RT_i + B_r(\tau) \frac{m_i^2}{V_i^2} R \frac{dT_i}{dt}$$

where R - individual gas constant;

P_i, m_i, T_i, V_i - pressure, weight, temperature of gas in volume number i.

2. The equation described gas flow through a hole section S between volumes:

For subsonic gas flow we can write

$$\frac{P_i}{P_{i-1}} > \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}} \qquad (3)$$

$$\dot{m}_i = \mu_i \cdot S_i \cdot \sqrt{\frac{2k}{k-1}} \cdot \frac{P_i}{\sqrt{RT_i}} \cdot \left(\frac{P_i}{P_{i-1}}\right)^{\frac{1}{k}} \sqrt{1 - \left(\frac{P_i}{P_{i-1}}\right)^{\frac{k-1}{k}}}$$

For supersonic gas flow at $\frac{P_{i-1}}{P_i} \le \left[\frac{2}{k+1}\right]^{\frac{k}{k-1}}$

$$\dot{m}_i = \mu_i \cdot S_i \cdot \frac{P_i}{\sqrt{RT_i}} \cdot \left(\frac{P_i}{P_{i-1}}\right)^{\frac{1}{k}} \sqrt{k \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad (4)$$

where $m^{\bullet}$ - flow coefficient;

P_i, T_i - parameters of gas referred to specific volume;

At the gas flow through holes of the diaphragm and strip is obtained estimated values for Reynold's numbers:

$$Re = \frac{\rho u d}{\eta} = \frac{4\dot{m}}{\pi d \eta} < 1200 \qquad (5)$$

I.e. the mode of the efflux will be laminar for all realizable temperatures and consummations. In this case for calculation of a flow coefficient it is possible to use the data, approximated by a piecewise linear function of a kind

$$\mu = \begin{cases} a \cdot \ln Re + b, 10 < Re < 100 \\ c, 100 < Re < 1200 \end{cases} \qquad (6)$$

The change of gas temperature in a cavity of the cathode was approximated by expression

$$T_2 = T_{2max} - (T_{2max} - T_0) \cdot \exp\left(-\frac{t}{\tau}\right) \qquad (7)$$

where T_{2max} - maximum temperature of gas in a cavity;

T_0 - temperature of gas at the beginning;

t - characteristic time of heating.

Temperature of the capsule a composite function of time, but with a sufficient degree of accuracy it is possible to approximate by expression of a similar type

$$T_{max}(t) = T_{1max} - (T_{1max} - T_0) \cdot \exp\left(-\frac{t}{\tau}\right) \qquad (8)$$

Where T_1 = 1000 T_o - maximum temperature in the field of a strip;

t - Characteristic time of heating of a design.

The formula Sazerland determined the viscosity of gas

$$\eta = \eta_0 \left(\frac{273 + C}{T + C}\right) \cdot \left(\frac{T}{273}\right)^{3/2} \qquad (9)$$

At the solution has appeared that the sharp heating of gas in a cavity results in sizeable recompression in a cavity. It results in outflow of the heated up gas, as through the diaphragm of the cathode, and back in «spurious» volume and as a corollary to heating gas in «spurious» volume. For the registration it the system was supplemented by an equation circumscribing heating of gas in «spurious» volume at the expense of mixing of cold gas, going from throttle and hot gas, going from a cavity:

$$T_1(t + dt) = \frac{[\dot{m}_0 T_0 - \dot{m}_{12} T_2(t)]dt + \frac{P_1 V_1}{R}}{(\dot{m}_0 - \dot{m}_{12})dt + \frac{P_1 V_1}{RT_1}} \qquad (10)$$

where m_0, m_{12} - gas flow rate through the diaphragm and strip;

P_1, V_1, T_1 - parameters of gas and volume of a «spurious» cavity.

In a fig 3-6 the versions of calculation for m_0 = 0,4 mg/s, d_d = 0,5 mm and various values of diameter of a strip are shown.

It is visible, that at small holes of a strip the sharp increase of the consumption through the diaphragm, and then gradual lowering up to fixed is observed. At increase of diameter of a strip the throw of the consumption of a gradually decreases on size and at d> 0,35 increases of the consumption are not observed. There is only fall of the consumption through the diaphragm. Thus the size of the minimum consumption achieves 0,3 - 0,4 from fixed.

The conducted numerical analysis of a system shows the following outcomes:

1. The availability of electron pressure introduces sizeable disturbances to a gas dynamics of start-up only on short on time during of start-up.

In some cases occurrence of a current and, accordingly, the occurrence of electron pressure on the diaphragm completely locks the consumption through the diaphragm. But in any case the occurrence of electron pressure results in sharp lowering of the consumption, which was fixed and in experiments.

2. The rather sharp process of heating of gas in a cavity for the score electron-atom collisions results originally in a less sharp falling of the consumption, and also to more long duration, then, time of recovery of the fixed consumption through cathode.

3. At beforehand certain diameter of the diaphragm D the great influence of diameter of a transient segment) to time of recovery of the consumption is remarked.. So, at reduction of diameter between volume of a cavity and «spurious» volume **d** up to some critical the sharp decreasing of launch time is observed. After reaching critical value **d** the launch time begins again to be increased. Such behavior is possible to explain by availability of two gears of formation of launch time. Originally for large diameters **d** the necessary pressure P, for maintenance of the specific consumption, is reached for too long time because of a wide margin of pressure P_1 before start-up and P_2 on stationary mod. Reducing diameter **d** we achieve a pressure buildup in a cavity P_2 before occurrence of a critical difference on diameter **d.** From this time, at start-up, the concavity does not feel development of discharge, on some segment of time. But during achievement of stationary mode the difference decreases and to become less critical, the difference between P_1 up to start up and after start-up decreases also.

Up to this moment the influence of heating of gas is minimum and also limits only by some increase of temperature in volume V2 sometimes reaching $\Delta T = 100 \ldots 200$ K. The further reduction of **d** results that cavity V1 ceases to feel pressure variation P_2 in any case (as before start-up, and ambassador). Then on process of start-up renders significant influence to gas heating, which results in sizeable recompression in a cavity V_1 and, accordingly, increase of the consumption through the diaphragm of the cathode. It, certainly, does not reduce time of achieve stationary mode consumption through the diaphragm.

4. The significant influence to time of recovery of the consumption renders a ratio between volumes V_1 and V_2. The numerical analysis shows, that at $(V1/V2) > 2$ influences of heating of gas to a boost of the cathode process have no effect also time of stationary mode achieve is determined only by filling of volume V_1. And, the it is more volume V_1, the more time of stationary mode achieve So, for example, time of a boost t= 800 ms for $(V1/V2) = 20$, and for $(V1/V2) = 40$ we have t = 1,6 s. At commensurable volumes $V_1 \approx V_2$

And $V_1 < V_2$ the process of a boost in basic depends on heating gas in a cavity and the minimum time of a boost is reached at $V_1 \to 0$. This limiting case was used for code check of calculation. At $V_1 = 0$ dynamic systems of gas feed system will be recorded as (for simplification of the analysis the equation of a condition of ideal gas) is used:

$$\frac{dP}{dt} = \frac{RT}{V}\dot{m}_0 + \frac{P}{T}\frac{dT}{dt} - \frac{RT}{V}\dot{m}_g$$
$$\dot{m}_g = \mu S_g \frac{P}{\sqrt{RT}}\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} \qquad (11)$$

The solution of a system can be recorded in a general view:

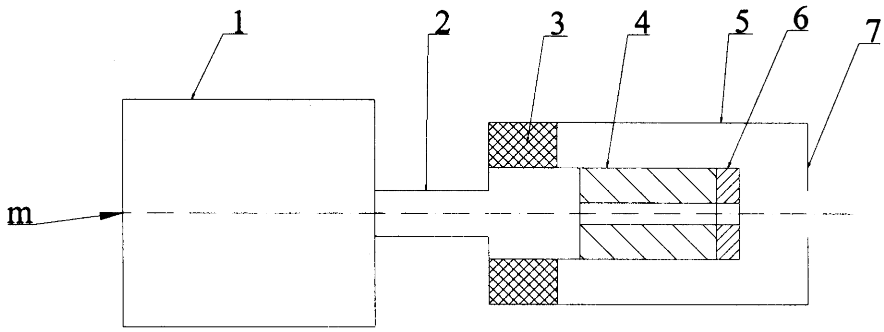
$$P(t) = \exp\left[-\int_0^t \varphi(\xi)d\xi\right] \times$$
$$\times\left\{P_0 - \int_0^t \psi(V)dV \cdot \exp\left[\int_0^V \varphi(\xi)d\xi\right]dV\right\} \qquad (12)$$
$$\varphi(\xi) = \frac{1}{T(t)}\frac{dT}{dt}(t) - \mu S_g\sqrt{k\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}\cdot\frac{\sqrt{RT(t)}}{V}$$
$$\psi(V) = \frac{R\dot{m}_0}{V}T(\tau)$$

The good admission of outcomes of calculation is observed at $V_1 = 0$ and calculation at $V_1 = 0{,}01V_2$. The difference at calculations was at a level of a numerical round-off error.

In an outcome of the numerical solution the possible reasons not authorized reset of discharge were analyzed. The correlation between the geometrical sizes of a flowing channel and dynamic characteristics SHHC and possible paths of improving of dynamics changes of start-up is shown. The logic of more optimum start-up of the cathode was found and the parameters of a system SHHC – gas feed system, ensuring the least time of recovery of the fixed consumption are determined.

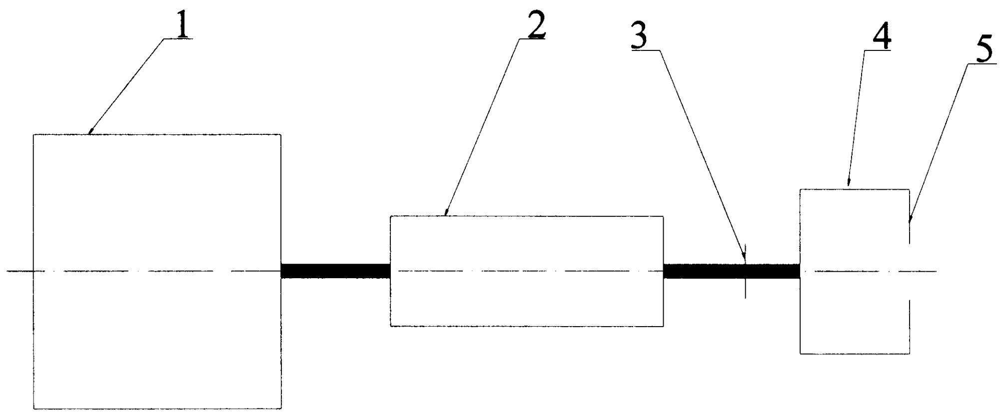
Conclusion

Results of SHHC startup gas-dynamic processes from "cold" state mathematics modeling (MM) are presented in the paper. MM allows to describe main processes and show of directions to SHHC dynamic characteristics improvement providing. But for assurance equivalent between the experiment and calculated data it is necessary to MM modernizing and taking into account of numbers factors (n_e, T_e, T_a) influence to SHHC start .



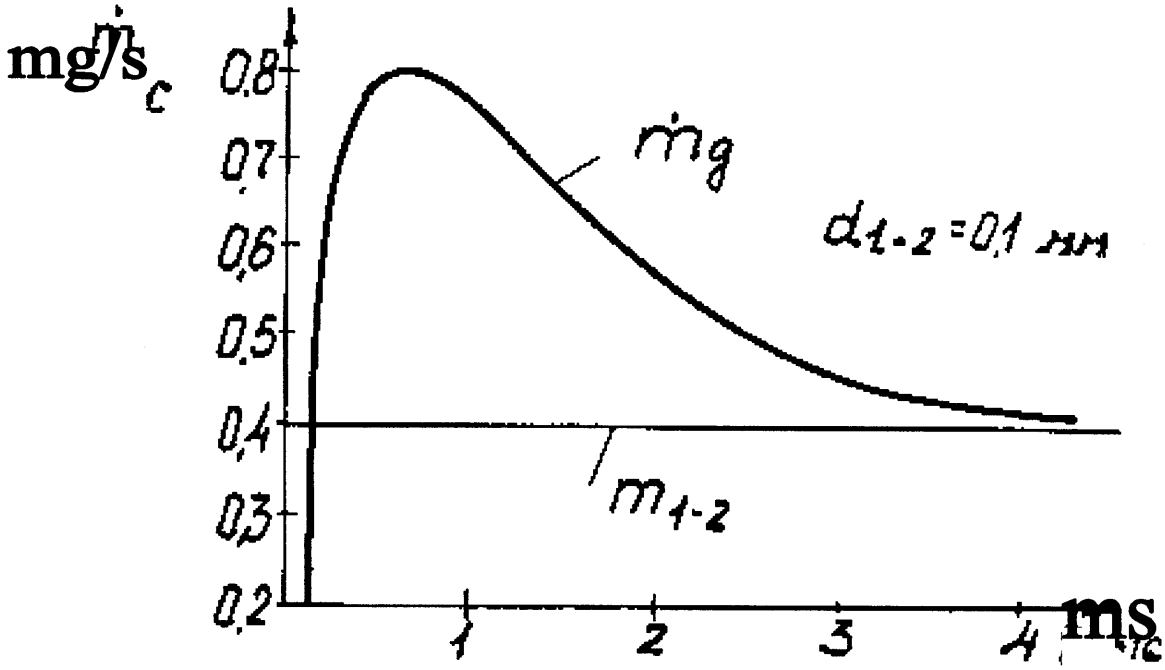
1-Volume; 2 – gas feed tube; 3 – insulator; 4- emission tablet; 5 – break-down electrode; 6 – diaphragm; 7-iaphragm of break-down electrode.

Fig.1 The scheme of hollow cathode



1- Volume; 2 – 'spurious' volume; 3 – strip; 4 work cavity; 5 – diaphragm.

Fig. 2. The calculation scheme of cathode..



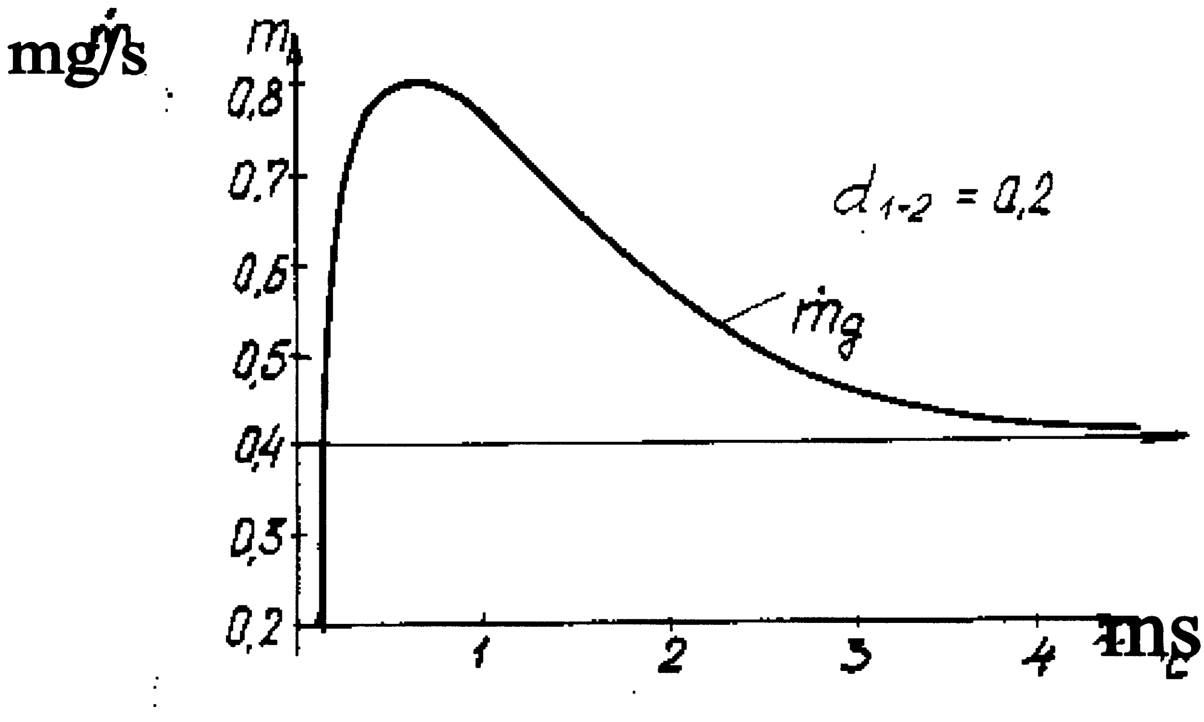
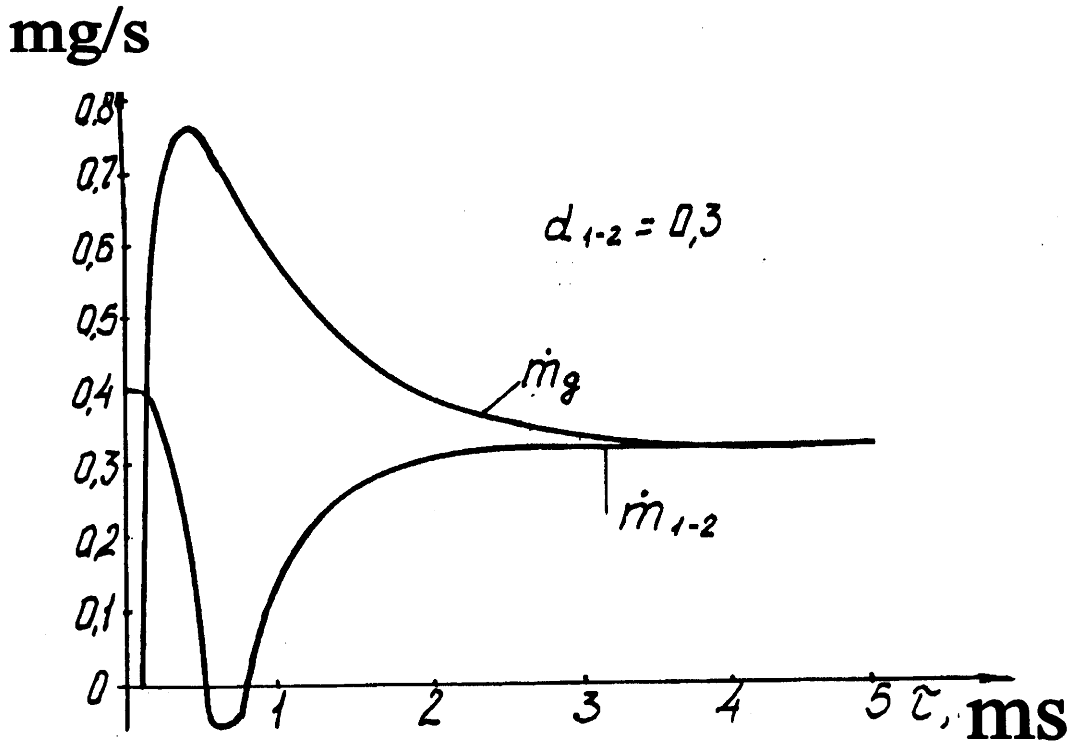


fig.3,4 The results of consumption change calculations in time of cathode start up .



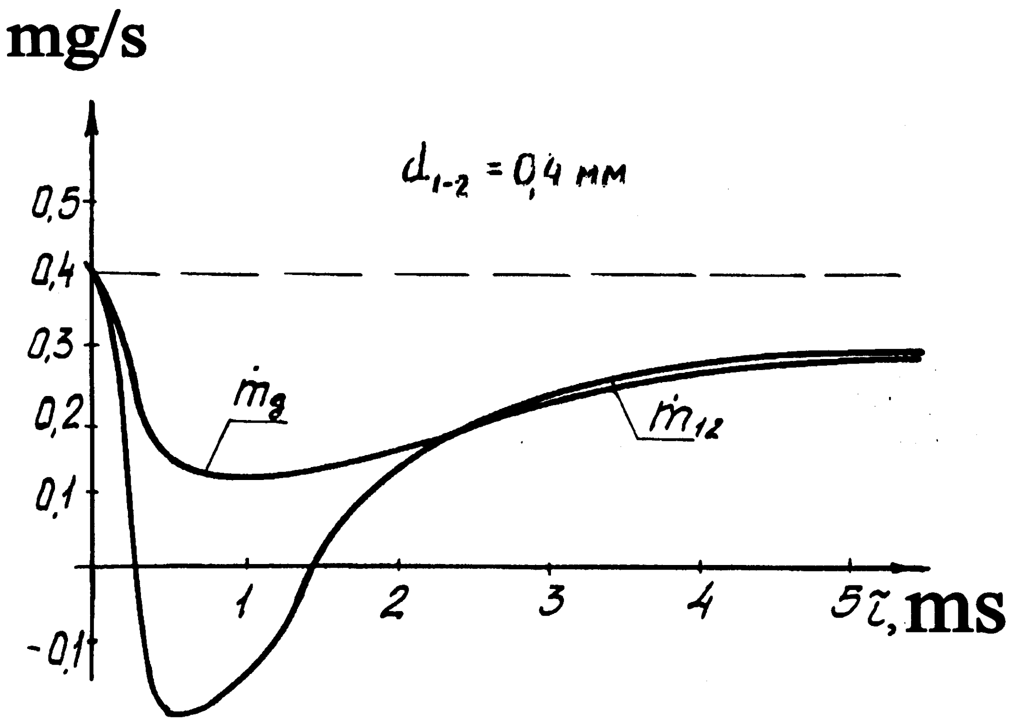


fig. 5,6 The results of consumption change calculations in time of cathode start up