

The presence of the "locking effect" when the fluid flows through the cylindrical throttle channels

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Abstract. A study was made for the continuous flow of the working fluid through a cylindrical throttle channel (so-called "locking effect"). The flow of the fluid into the atmosphere and the change in absolute pressure at the inlet to the throttle channel ranging between 0.221 MPa and 0.24 MPa are studied. It was found that the pressure in the compressed section inside the throttle channel remains almost constant and equal to 4 kPa. A comparison is made of the experimental values of the flow rate determined for the same absolute pressure difference Δp in the separated and unseparated flow regimes. Knowing that the value of the flow coefficient μ in the zone of the existence of the "locking effect" can be determined from known data for the process of fluid outflow from holes with a sharp edge in a thin wall. Also, similar phenomena occur when fluid flows through small holes and slots in the guide, control and regulatory equipment of various hydraulic systems.

1. INTRODUCTION

Studies show that the hydrodynamic characteristics of fluid flows in hydraulic systems that contain throttle channel are very complex and have a significant impact on the performance of these systems [1–4].

The task that developers of hydraulic systems for various purposes often have to solve, is to provide control over the values of the working fluid pressure and its flow rate. One of the ways to control these parameters is the so-called throttle control method. It is customary to call a regulating device a throttle capable of establishing a certain relationship between the calculated differential pressure across the throttle and the flow rate [5–12]. In hydrodynamics, this relationship is expressed by the formula:

$$Q = \mu A \sqrt{2\Delta p / \rho} \quad (1)$$

Where Q — the volumetric flow rate through the throttle;

μ — flow rate coefficient;

A — area of throttle channel;

$\Delta p = (p_{in} - p_{out})$ — differential pressure in the throttle;

p_{in} — pressure at the inlet of the throttle;

p_{out} — pressure at the outlet of the throttle;

ρ — density of the working fluid.

It is known that when liquid flows through a throttle channel of a cylindrical shape, whereas the ratio of the length of the channel to its diameter in the range from two to four, two flow modes are possible — separated (Fig. 1a) and unseparated (Fig. 1b).



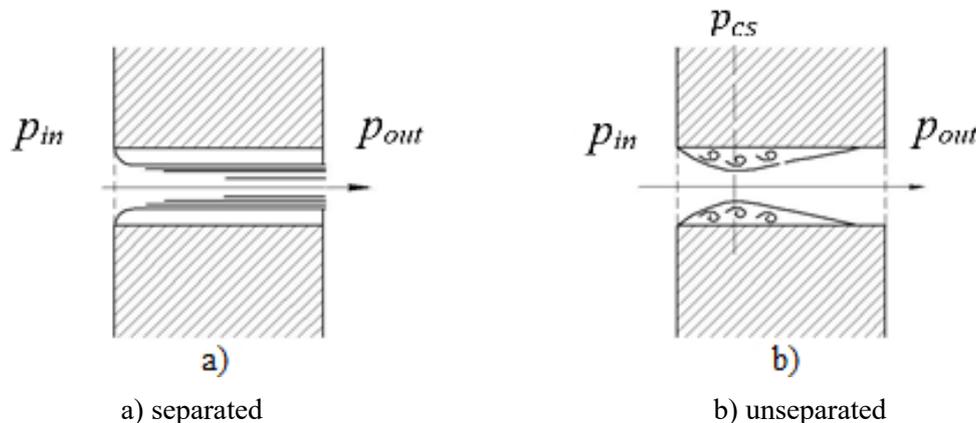


Figure 1. Expiration modes

In the separated flow mode, the hydrodynamic parameters are close to the parameters of the flow from a hole in a thin wall. In the unseparated flow mode, the flow rate of the working fluid through the throttle at a given inlet pressure may depend on the pressure value at the outlet, or it may not depend (so-called “locking effect”) [13–18]. The last mode represents a special particular interest to developers of hydraulic systems and control devices for their work. When the hydraulic actuator operates in the existing mode of the “locking effect”, the speed of movement brought by it in the movement of the load ceases (up to certain limits) depends on the magnitude of this load and will remain constant.

One of the research goals is to develop recommendations on the use of formula (1) for applied calculations of throttle devices based on the use of a throttle channel of cylindrical shape with a ratio of channel length to its diameter in the range from two to four. From the analysis of formula (1), creates the following questions:

1. What is meant by area “ A ” of a cylindrical throttle channel?
2. What is meant by the pressure drop in separated and unseparated modes of expiration?
3. How to determine the value of the coefficient of flow μ during unseparated flow mode?

Some clarifications of well-known answers to the first question are given in the articles [12].

Below are the results of the research, which purpose was to find an answer to the second and third questions - what is meant by the pressure drop in formula (1) when it is used to calculate the parameters of the fluid flow through a cylindrical throttle channel.

2. METHODS

From the analysis of related literature, many authors of the studies assume fluid flows that are hydrodynamically similar in the area from the entrance to the sharp-edged hole to the most compressed section when flowing through the sharp-edged hole in the thin wall and in the area from the entrance to the most compressed flow section in unseparated flow through a cylindrical throttle channel.

Based on the foregoing, it can be assumed that the calculation of the parameters of the fluid flow through the cylindrical nozzles in the zone of the “locking” effect using formula (1) should be carried out with respect to the pressure drop Δp in the section between the nozzle inlet — $p_{in,abc}$ and the most compressed flow cross-section inside nozzle — $p_{cs,abc}$.

Experimental studies were carried out on a model of a cylindrical nozzle made of plexiglass. The drawing of the model is shown in Fig. 2.

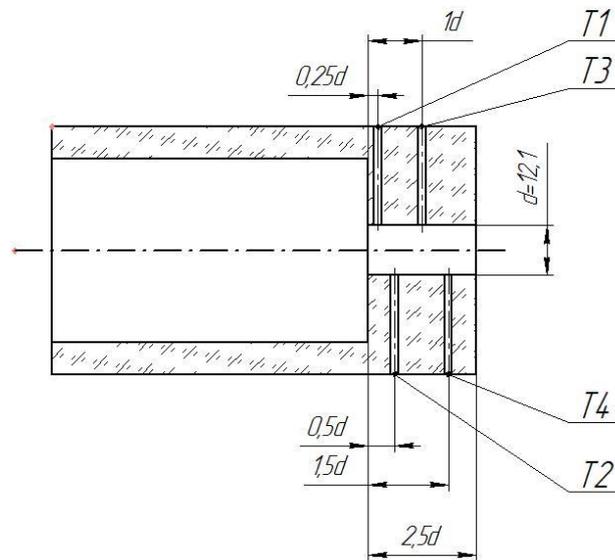


Figure 2. Experimental nozzle model

3. RESULTS

In fig. 3 shows an experimental graph of the absolute pressure variation p_{abc} in various sections of the flow inside the cylindrical nozzle as a function of the absolute pressure at the inlet of the nozzle $p_{in,abc}$. The experiment was conducted with the flow of liquid into the atmosphere. At the same time, atmospheric pressure p_{atm} equals 102124,652 Pa.

Overpressure was measured with an exemplary pressure gauge of accuracy class 0.15, and vacuum with an exemplary vacuum gauge of accuracy class 0.25. A model barometer was used to measure atmospheric pressure, and a mercury laboratory thermometer was used to measure the temperature.

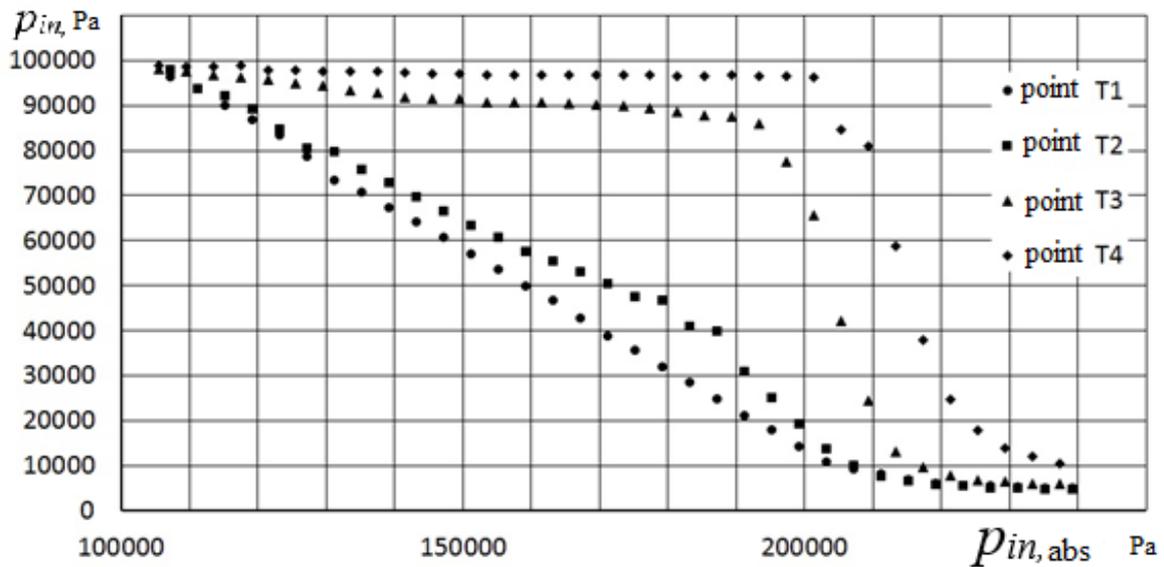


Figure 3. Graph of the absolute pressure values p_{abc} at points T1, T2, T3, T4 as a function of absolute pressure at the inlet of nozzles $p_{in,abc}$

From the experimental data shown in Figure 3, it is noticed that when the absolute pressure at the inlet p_{in} changes in the range from 0.221 MPa to 0.24 MPa, the pressure p_{abc} at points T1 and

T_2 remained the same and did not change much. Minimum Pressure Ratio at these points in the reduced range of its change to the pressure at the outlet of the nozzle (atmospheric pressure) was 0.46.

With a further increase in pressure at the inlet p_{in} , there was a sharp transition from an unseparated flow mode to a separated. The transition took place in the range of absolute values of this pressure from 0.245 to 0.25 MPa and with the ratio of the absolute pressure at the outlet to the absolute pressure at the inlet ranging from 0.417 to 0.408 MPa.

It was not possible to precisely establish the value of the pressure p_{in} , at which the transition from an unseparated to a separated mode occurred. The probable reason (as photography shows [5,6]) is the instability of the geometric parameters of the tail of the stream in the throttle channel of the nozzle and the total length of the vapor-gas cavity surrounding the stream inside the nozzle.

The above experimental data are in good agreement with the results of experimental studies presented in the book of B.N. Siova [13]. This result allows us to state that when the ratio of the absolute pressure at the outlet to the absolute pressure at the inlet varies from 0.46 to 0.408, a blocking effect occurs. In this zone, the pressure in the vapor-air cavity surrounding the fluid flow inside the throttle channel in the region of its most compressed section remains almost independent of the pressure at the outlet of it.

Based on the research results, it follows that it is expedient in formula (1) when calculating the flow parameters for Δp to take the difference in absolute pressures at the inlet to the throttle channel and in the vapor-air cavity surrounding the fluid flow inside the throttle channel in the region of its most compressed section ($\Delta p = p_{in,abs} - p_{1,abs}$). It should be noted that according to the results of published experimental studies of various authors, the magnitude of the absolute pressures in the analyzed flow region varied in the range from 2 kPa to 4.5 kPa.

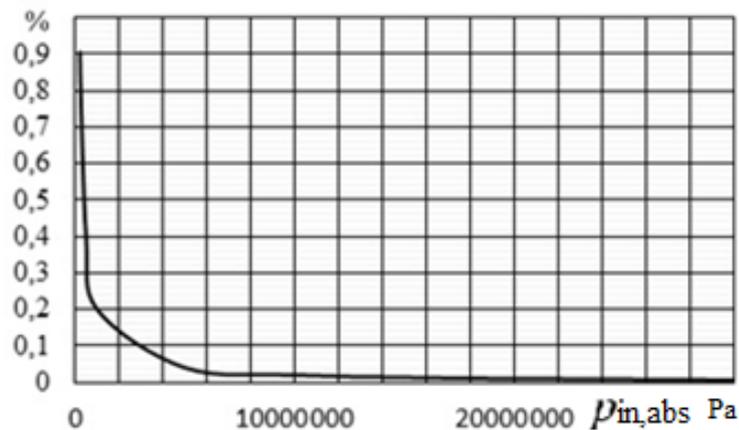


Figure 4. Evaluation of the degree of error in the percentage entered into the calculation $\sqrt{\Delta p}$ refusal of accounting $p_{cs,abs}$

Fig. 4 shows the results of assessing the degree of difference in the percent of root values from pressure drop $\Delta p = p_{in,abs} - p_{cs,abs}$, as a function of absolute pressure at the nozzle inlet $p_{in,abs}$. While taking in one case the value $p_{cs,abs}$ according to the data given in Fig. 3, and in another $p_{cs,abs}$ equal to zero. From the graph, it follows that in the range of pressure changes on a stream of the throttle channel starting from 0.5 MPa, the percentage of determination error Δ does not exceed 0.04%. Based on the foregoing, we can conclude that in applied calculations of hydraulic systems operating at high pressures at the inlet to the throttle, in formula (1), the pressure drop Δp with a fairly high degree of accuracy can be determined only by the magnitude of the absolute pressure at the inlet to the throttle channel.

Fig. 5 shows experimental plots of the flow rate of fluid Q flowing through the model of a cylindrical nozzle (Fig. 2) under separated and unseparated modes of flow as a function of $\sqrt{\Delta p}$. In

this case, Δp was determined in the separated mode of expiration as $(p_{in. abs.} - p_{atm})$, and in the unseparated mode as $(p_{in. abs.} - p_{cs. abs.})$.

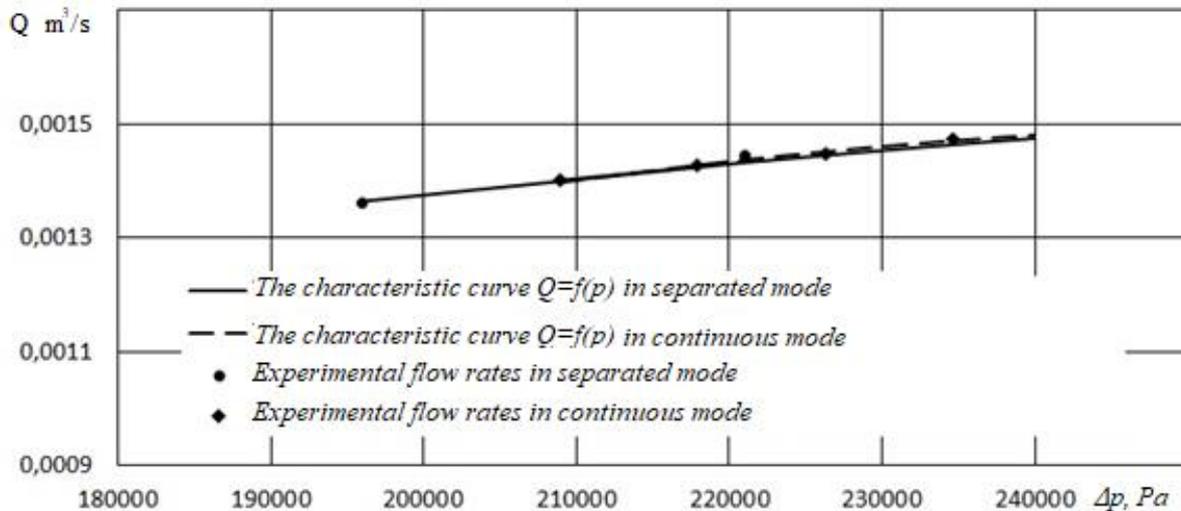


Figure 5. Flow characteristics of separated and unseparated modes of fluid flow

Analysis of the data shown in Fig. 5, shows that the difference in flow rates determined for the same pressure drop Δp in the range of its change from 0.22 to 0.24 MPa in the separated and unseparated flow regimes varies from 0.12 to 0.49%.

The obtained experimental results confirm the assumptions made in the literature [2, 7, 8, 9, 10] about the hydrodynamic similarity of the process of fluid outflow in the section from the inlet to the compressed section of the flow both when it flows through a hole with a sharp edge in a thin wall and when through cylindrical nozzles. analysis of the results of calculating the hydrodynamic parameters of the process of the flow of an ideal fluid through a flat model of a cylindrical nozzle, performed by the method of professor s. s. rudneva [6] showed that in the zone of the flow regimes corresponding to the existence of a “locking effect”, the values of the flow coefficients practically become equal to their values when they flow out of round holes with a sharp edge in a thin wall. from the foregoing it follows that the value of the flow coefficient μ in formula (1) when it is used to calculate the parameters of fluid flow through cylindrical nozzles in the zone of existence of the “locking effect” can be determined from known data for the process of fluid flow from holes with a sharp edge in a thin wall [1].

4. CONCLUSION

1. Based on the above research results, it follows that it is expedient in formula (1) when calculating the flow parameters for Δp to take the difference in absolute pressures at the inlet to the throttle channel and in the vapor-air cavity surrounding the fluid flow inside the throttle channel in the region of its most compressed section ($\Delta p = p_{in. abs.} - p_{1 abs.}$).

2. Evaluation of the degree of error in the percentage entered into the calculation of refusal of accounting $p_{cs. abs.}$ allows us to conclude that in applied calculations of hydraulic systems operating at high pressures at the inlet to the throttle in formula (1), the pressure drop Δp with a sufficiently high degree of accuracy can be determined only by the magnitude of the absolute pressure at the inlet to the throttle channel.

3. The value of the flow coefficient μ to the formula (1) when it is used to calculate the parameters of the fluid flow through the cylindrical nozzles in the zone of existence of the “locking effect” can be determined from known data for the process of fluid flow from holes with a sharp edge in a thin wall [1].

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