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Simulation of Two-Chamber Devices for Pulsed Sheet Stamping

Botashev A.Yu.
North Caucasus State Academy
Cherkessk, Russia
botashev11@mail.ru

Musaev A.A.
Kh. Ibragimov Complex Institute of the Russian Academy of Sciences
Grozny, Russia
brain_95@mail.ru
m.k.kh@mail.ru

Betrahmadov R.V.
Kh. Ibragimov Complex Institute of the Russian Academy of Sciences
Grozny, Russia
brv1964@yandexs.ru

Saidov M. A.
Grozny State Petroleum Technical University named after Academician M.D. Millionshchikov
Grozny, Russia
saidoff@bk.ru

Mazhiev K.Kh.
Grozny State Oil Technical University named after Academician M.D. Millionshchikov
Kh. Ibragimov Complex Institute of the Russian Academy of Sciences
Chechen State University
Grozny, Russia

Mazhieva A.Kh.
Grozny State Oil Technical University named after Academician M.D. Millionshchikov
Grozny, Russia
a.mazhieva@mail.ru

Mazhiev A.Kh.
Kh. Ibragimov Complex Institute of the Russian Academy of Sciences
Academy of Sciences of the Chechen Republic
Grozny, Russia
adammazhiev@mail.ru

Mazhiev A.Kh.
Kh. Ibragimov Complex Institute of the Russian Academy of Sciences
Academy of Sciences of the Chechen Republic
Chechen State University
Grozny, Russia
aslanmazhiev@mail.r

Abstract **– Two-chamber device refers to pulsed sheet punching methods. This device is intended for use in small-scale production. Due to its design and efficiency it can significantly reduce the cost of stamped products. The article describes the principle of operation of the device, defines the criteria for the similarity of the device and analyzes the similarity criteria in terms of modeling two-chamber devices.**

Keywords – Modeling; two-chamber device; pulse sheet stamping; working stroke; gas stamping; effective energy; fuel mixture.

I. Introduction

Technical and economic characteristics of machines and apparatus are largely determined by the quality of the parts of which they are composed. In turn, the quality of parts is largely determined by the technology of their production. In this regard, it can be argued without exaggeration that the most high-quality parts are those obtained by stamping, sheet stamping. However, traditional sheet punching methods are effective only in large-scale and mass production. In many industries, the share of small-scale production is large [1]. Under these conditions, pulsed punching methods are more effective [2, 3]. Currently there is a wide variety of impulse punching methods.

This electro-hydraulic stamping [4], gas detonation stamping [5], gas stamping with heating the workpiece [6-8,12,13]. The use of these methods of stamping in conditions of small-scale production can significantly reduce the cost of stamped products. However, they provide for stamping only thin-walled products. In this regard, the development of new methods of pulsed sheet stamping, expanding their technological capabilities, and devices for their implementation is an important task. One of the ways to expand the technological capabilities of impulse punching is punching with a solid body using an intermediate elastic medium. This is implemented in a two-chamber device for pulsed sheet stamping, which is a domestic invention [9] that allows stamping parts with a thickness of up to 4 ... 5 mm.

In the study and design of new machines and devices, modeling methods are widely used [10,14], which increases their efficiency. In this regard, it is necessary to develop a methodology for modeling two-chamber devices for pulsed sheet punching based on the similarity theory.

The aim of this work is to develop a scientific base for the optimal design of two-chamber devices for pulsed sheet stamping. To achieve this goal, the following tasks were set: determination of the criteria for the similarity of two-chamber impulse sheet punching devices; analysis of these similarity criteria and determination of conditions for modeling two-chamber devices.

II. PRINCIPLE OF OPERATION OF THE DEVICE FOR PULSE STEELING

The scheme of the two-chamber device for sheet stamping is shown in fig. 1. The device includes a housing 1, in which a combustion chamber 2 and a working cylinder 6 are placed, separated from each other by a piston 4. A die 11 is attached to the end of the housing 1 by means of a plate 9, bolts 8 and nuts 10 between the end face of the body 12 1 and the matrix 11. In the end part of the housing 1 there is an annular cavity 14 in which an annular piston 13 is installed, which serves to press the flange part of the workpiece 12. A disk 5 made of an elastic material, for example of rubber, is mounted on the end of the piston 4. The inlet valves 15, 16 and exhaust valves 3, 7 are installed on the housing. To the lower end of the housing 1 is attached a pre-chamber 18, fitted with spark plugs 19, which are connected to the combustion chamber 2 by a channel 17.

The operation of the device is as follows. Through the inlet valve 15 into the working cylinder is supplied compressed air. At the same time, combustible gas, for example propane-butane, and compressed air are successively fed through the inlet valve 16 into the combustion chamber 2. In this case, fuel mixtures are formed in the combustion chamber 2 and the prechamber 18. The pressure of the fuel mixture is set equal to the air pressure in the working cylinder 6, due to which the piston 4 remains stationary. The fuel mixture in the prechamber 18 is ignited using a candle 19. During the combustion of the fuel mixture from the pre-chamber 18 through the channel 17 a flame is pulled out. This causes intense combustion of the fuel mixture in the combustion chamber 2. In this case, during 0.005 ... 0.01 s, the pressure in the combustion chamber 2 increases 7 ... 8 times. At the same time, the exhaust valve 7 opens. Under the action of the pressure of the combustion products, the piston 4 with the elastic disk 5 moves rapidly, displacing the compressed air from the working cylinder 6 through the exhaust valve 7. At the end of the piston stroke 4, the elastic disk 5 deforms the workpiece 12 in the die cavity 11 In this case, the punching process is carried out by the accumulative kinetic energy of the piston 4 and the disk 5. At the same time, due to the shock interaction of the elastic disk 5 with the workpiece 12, the required force is deformed tions. This makes it possible to stamp parts with a thickness of up to 4 ... 5 mm.

After completion of the stamping process, the exhaust valve 3 opens and the combustion products are released from the combustion chamber 2. The piston 4 with the disk 5 under the action of gravity descends into its original position. Then, unscrewing the nuts 10, the matrix 11 is disconnected from the housing 1 and the stamped product is removed from it.

The effective energy of the device for stamping, which is formed in the process of acceleration of the piston, essentially depends on the design parameters of the device, as well as on the parameters of the gas in the combustion chamber and the air in the working cylinder. The optimal combination of these parameters provides the maximum effective energy of the device. Their definition includes both theoretical and experimental studies. In this case, the results of experimental studies should be presented in the form of criterion dependencies. For this, it is necessary to establish similarity criteria for this type of device.

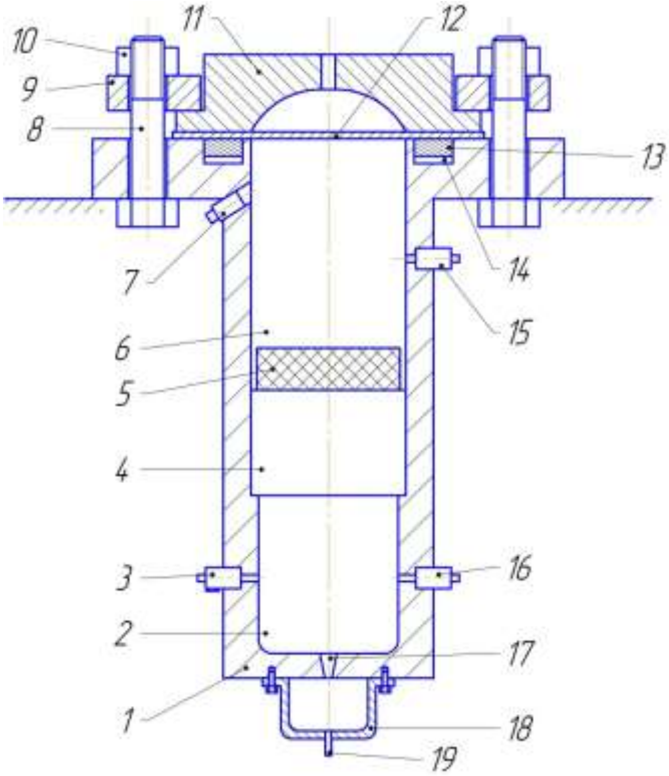

Fig. 1. Diagram of the two-chamber sheet punching device

III. DETERMINATION OF CRITERIA OF DEVICES RESEMBLENCE FOR PULSE STABLING

During the working stroke of the device, the acceleration of the piston together with the elastic disk is performed under the action of the pressure difference between the combustion chamber and the working cylinder. Therefore, the equation of motion of the piston can be written in the following form:

$$\frac{dw}{dt} = \frac{f_s}{m}\left(P_k - P_c\right), \tag{1}$$

where w - piston speed; m – piston mass with a disc; $f_ц$ – cross-sectional area of the working cylinder; $P_к$, $P_ц$ – pressure in the combustion chamber and the working cylinder, respectively; t – time.

In the process of piston movement, the gas in the combustion chamber expands, due to its transience, this process can be considered adiabatic. In this case, the air from the working cylinder is forced out into the atmosphere, and the mass of air in the working cylinder is continuously changing. Therefore, the parameters of air in the working cylinder obey the laws of thermodynamics of a body of variable mass. Based on these prerequisites and equation (1), the following dimensionless equations were obtained for describing the motion of the piston and changing the gas parameters in the combustion chamber and air in the working cylinder:

$$\frac{dX}{d\tau} = \overline{W}, \tag{2}$$

$$\frac{d\overline{W}}{d\tau} = a\left(\overline{P}_k - \overline{P}_c\right), \tag{3}$$

$$\frac{d\overline{P}_c}{d\tau} = \frac{\kappa_v}{1\text{-}X}\left(\overline{P}_2\overline{W} - b\overline{P}_c\sqrt{\overline{T}_{цс}}\right), \tag{4}$$

$$\frac{d\overline{T}_2}{d\tau} = \frac{\kappa_v - 1}{\kappa_v}\frac{\overline{T}_c}{\overline{P}_c}\left(\overline{P}_2\overline{W} - b\overline{P}_c\sqrt{\overline{T}_c}\right), \tag{5}$$

$$P_1 = \lambda\left(1 + \upsilon_c X\right)^{-\kappa_g} \tag{6}$$

$$a = \frac{f_c t_z{}^2 P_s}{mh}, \tag{7}$$

$$b = \frac{t_z}{f_c h}\mu f_k g\sqrt{\kappa_v R_v T_c}, \tag{8}$$

where $x = \frac{X}{h}$ - relative piston stroke;

$\tau = \frac{t}{t_z}$ – dimensionless time;

$\overline{W} = \frac{w}{w_s} = \frac{hw}{t_z}$ - dimensionless piston speed;

$\overline{P}_k = \frac{P_k}{P_s}$ - dimensionless gas pressure in the combustion chamber;

$\overline{P}_c = \frac{P_c}{P_s}$ - dimensionless air pressure in the cylinder;

$\upsilon_c = \frac{f_c h}{V_k}$ – relative cylinder volume;

$W_s = \frac{h}{t_z}$ – average piston speed;

X – piston movement; t_z – the combustion time of the fuel mixture in the combustion chamber;

V_k – volume of the combustion chamber; $\upsilon_ц$ – working cylinder volume;

P_c, T_c – pressure and absolute gas temperature in the cylinder;

h - initial height of the working cylinder;

R_v – air gas constant;

κ_v – air adiabat index; κ_g – adiabat index of combustion products;

f_k, μ – flow area and flow ratio of the exhaust valve of the working cylinder.

Equation (2) - (8) are dimensionless equations. If the phenomena are similar, then they are described by the same equations written in dimensionless form [11].

Then for such phenomena in the system of equations (2) - (8), the quantities $a, b, \upsilon_ц, \lambda, \kappa_в, \kappa_г$ will have numerically the same values. Based on this, we obtain the following similarity criteria.

$$\kappa_g = idem, \tag{9}$$

$$\kappa_v = idem, \tag{10}$$

$$\lambda = idem, \tag{11}$$

$$\upsilon_c = f_c h / V_k = idem \tag{12}$$

$$\frac{f_c t_z^2 P_s}{mh} = idem \tag{13}$$

$$\frac{t_z}{f_c h}\mu f_k g\sqrt{\kappa_v R_v T_s} = idem \tag{14}$$

Transform criterion (13)

$$\frac{f_c t_z^2 P_s}{mh} = \frac{f_c h t_z^2 P_s}{mh^2} = \frac{\upsilon_c V_k t_z^2 P_s}{mh^2} = \frac{\upsilon_c V_k P_s}{mw_s^2}$$

Then, given the criterion (12), we can write

$$\frac{V_k P_s}{mw_s^2} = idem$$

Replacing the average piston speed with the true speed, we get

$$A = \frac{V_к P_c}{mw^2} = idem \tag{15}$$

Excluding time from the similarity criteria (13), (14), we obtain a new similarity criterion

$$B = \frac{mR_v T_c}{V_k P_s}\left[\frac{\mu f_k}{f_c}\right] \tag{16}$$

The effective energy of the device through which the stamping process is carried out is equal to the kinetic energy of the piston

$$E = \frac{1}{2}mw^2 \tag{17}$$

Comparing dependencies (15) and (17), it can be concluded that criterion A is the energy characteristic of the working stroke of the device for stamping.

$$E = \frac{V_k P_s}{2A} \tag{18}$$

IV. ANALYSIS OF CRITERIA OF SIMILARITY AND DETERMINATION OF THE CONDITIONS OF MODELING TWO-CHAMBER DEVICES

Let us determine the conditions under which the working strokes of two pulse punching devices, for example, a model and a sample, will be similar. According to the Kirpichev-Guhman theorem, those systems whose uniqueness conditions are similar are similar, and the criteria composed of the uniqueness conditions are numerically identical [11]. Such criteria are called defining criteria. In this case, the uniqueness conditions include the geometrical and physical parameters of the device included in the system of equations (2) - (8).

Therefore, the defining criteria are $\kappa_g, \kappa_v, \lambda, \upsilon_c$, B

The value of criterion A depends on the listed determining similarity criteria, that is, A is a definable criterion.

The similarity of the uniqueness conditions in this case comes down to the geometric similarity of the model and the sample, that is, they must be like the shape of the combustion chamber, working cylinder, piston and exhaust valve.

When used on a model and sample of fuel mixtures of the same composition, criteria (9) - (11) are automatically fulfilled. In this case, only υ_c and A are decisive criteria. Criterion υ_c is determined by the ratio of the volumes of the working cylinder and the combustion chamber. With an increase of $\upsilon_ц$ the effective energy of the device increases, but at the same time, the overall dimensions and mass of the device increase. Therefore, the rational values of υ_c are in a narrow range, that is, $\upsilon_c = 1.5...3.5$.

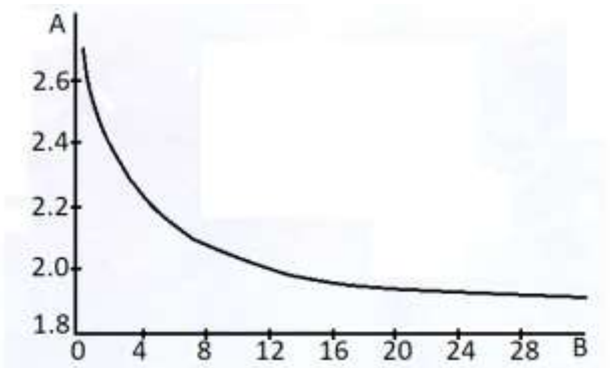

Fig. 2. Dependence of criterion A on criterion B at $\upsilon_c = 1.5$

Criterion B can vary over a very wide range. This criterion has a very significant effect on criterion A, and consequently, on the effective energy of the device for stamping. In fig. 2 shows a graph of criterion A versus criterion B at $\upsilon_ц = 1.5$. As can be seen from the graph, with increasing criterion B from 0.5 to 7 ... 8, the magnitude of criterion A decreases many times. With a further increase in B, the intensity of decrease in A significantly decreases, and at B> 20, the value of A practically does not change. In accordance with dependence (18), the reduction of criterion A leads to an increase in the effective energy of the device for stamping. Given this, we can conclude that when designing a device for pulse stamping, it is necessary to assign the values of criterion B not lower than 6 ... 8.

Acknowledgment

The working stroke of the device for pulse sheet punching is characterized by the following similarity criteria: $\lambda, \kappa_g, \upsilon_c$, A, B.

They, except for A, are the defining similarity criteria. Criterion A is the energy characteristic of the working stroke, its value depends on the values of the listed determining criteria. When using fuel mixtures of the same composition, the value of A depends only on υ_k and B.

When conducting experimental studies of the working course of the device, it is advisable to present their results in the form of criterial dependence $A = f(\upsilon_c, B)$, which gives them a generalized character. When designing a device for pulse sheet punching, the values of criteria υ_c and B of the designed device and its prototype should have the same numerical values.

In order to increase the effective energy of the device for pulse stamping, the value of criterion B should be assigned not less than 6.

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