Development and experimental studies of new types of sheet metal stamping equipment

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Abstract. In this paper, developed devices for gas sheet stamping are presented. The devices allow to significantly reduce the cost of products. They can be used both for food manufacturing, petrochemical industry and other branches of industry. Prototypes of products obtained experimentally are presented.

1. Introduction
A large proportion of the products of sheet rolling production is used in mechanical engineering for the production of thin-walled machine parts. The best quality of these parts is provided when making their sheet stamping. Traditional stamping equipment is only effective in mass production. However, many industries, in particular food, agricultural, chemical and energy engineering, aircraft engineering, rocket engineering, are characterized by low-volume production [1]. In the conditions of small-scale production, pulsed stamping methods are more effective, the varieties of which are electrohydraulic [2], Explosive Forming [3], hydrodynamic [4, 5], gas detonation forming [6] and other methods [7-10]. In the methods described above, the stamping process takes place in the cold state of the blank part. Many alloys of aluminum, titanium, molybdenum, tungsten have a low plasticity; therefore, when stamping parts of complicated shape, it is necessary to heat the blank part to the temperature range of warm or hot treatment.

2. Problem statement
The aim of this work is to develop new types of devices for sheet metal stamping with heating a workpiece as applied to conditions of small-scale production. To achieve this goal, we have developed new types of sheet metal stamping equipment, a device for gas stamping with two-sided heating of a workpiece, a gas molding device, a gas stamping device with a piston-type pressure multiplier [11].

3. Problem solving
The diagram of gas stamping device with two-way heating of a blank is shown in figure 1. The device comprises a matrix 1 and a combustion chamber 2, which are provided with inlet valves 4, 8, exhaust valves 6, 9 and spark plugs 5, 7. The stamped blank 11 is clamped between combustion chamber 2 and annular piston 13. Combustion chamber 2 and cavity of matrix 1 are filled with a combustible mixture through inlet valves 4 and 8, for instance, natural gas and compressed air. Combustible mixtures are ignited via spark plugs 5 and 7. In the process, as a result of the chemical interaction between combustible gas and the air, high-temperature and high-pressure gas is formed in both cavities, (pressure increases 7...8 times, temperature reaches 2000...2100 °C). Under two-way action of the gas, the blank 11 is heated intensively for a short period of time. After sample temperature has reached a specified value, valve 9 is opened and gas is released from the cavity 1. As a result, under the action of the gas pressure from the combustion chamber 2, blank part 11 deforms and fills the cavity of matrix 1.
Figure 1. Schematic representation of the experimental setup of the gas detonation forming process: 1 – matrix; 2 - combustion chamber, 3 – bolt; 4, 8 – inlet valves; 5, 7 – Igniter plug; 6, 9 – exhaust valves; 10 – nut; 11 - workpiece; 12 – cavity; 13 – annular piston; 14 – channel.

Theoretical and experimental studies [6] have shown that this method of stamping ensures intensive heating of thin-walled blanks to a specified temperature at a relatively low pressure of a combustible gas mixture. In particular, the pressure of the combustible gas mixture of 1.0 cp 1.2 MPa is sufficient for heating a steel blank of a thickness of 1 mm up to 900 °C, the heating time of the workpiece is 0.5 ... 0.6 s. The required value of the pressure of the fuel mixture for the implementation of the stamping process can be determined by the following relation:

\[ P_c = \frac{1}{\lambda_v} \frac{1}{1-\tau_u} R_{\text{min}} \sigma_s \left( 1 + \frac{V_m}{V_k} \right)^k \]  \hspace{1cm} (1)

where, \( V_m, V_k \) are the volume of the matrix and combustion chamber; \( k \) is the adiabatic exponent; \( \sigma_s \) is the yield point of the blank part of material; \( \lambda_v \) is the degree of pressure increase when the fuel mixture burns at a constant volume; \( \delta \) is the thickness of the blank part; \( \tau_u \) is the blank part heating time; \( R_{\text{min}} \) is the minimum radius of curvature of the blank part surface.

For practical testing of this stamping method, an experimental setup for gas stamping was created (figure 2).

The setup is very compact, its overall dimensions are 600x600x1250 mm. Installation does not require a special foundation. The device comprises a system for supplying and monitoring of energy carrier, for igniting said fuel and for igniting the flanged part of a stamped blank. The energy source is a mixture of compressed air and propane butane or other combustible gas, which is formed directly in the combustion chamber and cavity of the matrix.

Clamping of the workpiece is carried out under the pressure of liquid. The apparatus allows for stamping parts of a sheet workpiece with a diameter of up to 400 mm. The shape of the part is determined by the shape of the matrix. The apparatus was used to carry out experimental studies of stamping of several types of part.

Figure 3 shows a honeycomb construction panel. Stamping of honeycomb construction panels out of aluminum sheet 2 mm thick was performed using a grid matrix with square cells measuring 90x90 mm.

The fuel mixture pressure of 0.4 ... 0.5 MPa ensured obtaining good quality parts.

In general, the results of the conducted experimental studies have shown that the method of gas stamping with double-sided heating of the blank part is applicable for stamping parts of both simple and complicated configuration with small curvature radii i.e. it has a wide range of technological capabilities. Therefore, this method can be effectively used in small-scale and pilot production, especially for stamping hard-to-deform alloys parts.

However, this device is not effective for stamping parts of small height, for instance, cap-type parts. In this case, due to the small height of the cavity of the matrix, the combustion process of the fuel mixture in it is unstable. Taking this fact into account, a method of gas molding with backpressure was developed to stamp thin-walled parts having a small height, schematic representation of the experimental setup shown in Fig. 4. A distinctive feature of this device is that cylinder 11 with piston 10 is fixed to body 2. Cavity 9 of cylinder 11 is communicated with combustion chamber 5 and cavity 12 is connected by pipeline 13 to cavity 18 of matrix 17.
To carry out the molding process, combustible gas and compressed air are supplied to the combustion chamber 5, and a combustible mixture is formed in it, and to the cavity 18 of the matrix 17, only compressed air is supplied, which also, through the pipe 13, enters the cavity of the cylinder 11. When spark plugs 7 ignite a combustible mixture, the pressure in the combustion chamber 5 begins to increase. Under this pressure, the piston 10 moves, displacing the air from the cavity 12 into the cavity 18 of the matrix 17 while doing so. Due to this, an increase in pressure in the combustion chamber 5 is accompanied by an increase in pressure in the cavity 18. This prevents the deformation of the workpiece 16 and prevents it from contacting the surface of the matrix 17. This allows for intense heating of the workpiece. When its temperature reaches a predetermined value, the valve 22 opens, and compressed air is discharged from the cavity of the matrix 17. Meanwhile, affected by combustion products, the workpiece 16 is deformed in the direction of the matrix 17, as a result of which the manufactured part is molded.

According to the scheme shown in figure 4, a setup for backpressure gas molding was created (figure 5).
Using this setup, backpressure gas molding studies were conducted. During the studies, aluminum sheet workpieces 0.5 mm, 1 mm and 2 mm in thickness and steel sheet workpieces 3 0.5 mm and 1 mm in thickness were molded. As a result of the studies conducted, the technology of molding several types of parts ensuring the production of parts of good quality has been developed. Photographs of the two types of parts are shown in figure 6. Based on the results of the studies, it can be concluded that the device for backpressure gas molding can be used in small-scale production for the manufacture of thin-walled parts of various configurations.

The considered devices allow for stamping thin-walled parts made of steel up to 1.5 mm thick, and of non-ferrous alloys — up to 2.5 ... 3 mm thick. For stamping parts of greater thickness, it is necessary to provide a significantly greater gas pressure on the surface of the in-process workpiece. In this regard, we have developed a gas stamping device with a piston pressure multiplier [7]. The scheme of this device is shown in figure 7.

For significant increase in the gas pressure on the surface of the workpiece, the device is equipped with an operating cylinder 6 comprising a piston 7, which is located between the combustion chamber 8 and the matrix 2. Moreover, the combustion chamber 8 comprises the prechamber 19, equipped with spark plugs 20.

To complete the stamping process, through the inlet valves 9, 12, 14, combustible gas and compressed air are supplied to the operating cylinder 6, the combustion chamber 8 and the cavity 3 of the matrix, as a result of which combustible gas mixtures are formed in them. At the same time, the mixtures in the combustion chamber 8 and the working cylinder 6 have the same pressure, and in the cavity 3, its pressure is 2 .. 3 times less. Combustible mixtures in the working cylinder 6 and in the cavity 3 are ignited simultaneously. As a result, when the mixtures are burned, the pressure in the two cavities increases sharply, but the pressure difference between the two still remains, that is, the pressure in the cavity of 3 is 2 by 3 times lower.
Under the action of the difference of pressures and the blank is drawn into a cavity 3. Since the gas in the cavity 3 is compressed, the deformation ceases when a certain bending of the blank is applied. This position of the blank is shown in figure 7 in the bar line. Then, with a candle of 20, a combustible mixture is lit in the forechamber 19. The resulting combustion products in the form of a torch are transmitted to the combustion chamber 8, which causes the combustible mixture therein to burn intensively. The pressure in the combustion chamber increases sharply, which causes intense displacement and acceleration of the piston. At the same time, under the action of the piston 7, the pressure and temperature of the gas in the operating cylinder increase rapidly, which ensures further heating of the workpiece until the temperature range of hot processing is reached. The exhaust valve 16 is then opened and the gas from the cavity 3 is released. Meanwhile, under the pressure of the gas in the cylinder 6, the workpiece is deformed and fills the entire cavity 3—a forming process of the manufactured part is completed.

A study of the work process of this device showed [6] that the presence of a piston multiplier in the design of the device allows to significantly increase the gas pressure on the surface of the stamped workpiece. When the device is operated without a prechamber, the pressure increases by 2 ... 2.5 times, and when operated with a prechamber, the pressure increases by 4 ... 5 times. This significantly expands the technological capabilities of this device.

A device for sheet stamping was created and mounted according to the scheme shown in Fig.7.

At this installation, experimental studies were conducted. During the experiments, the stamping was done on sheet blanks 1 mm thick of steel 3 using a cylindrical matrix 160 mm in diameter. As a result of the process, sphere-shaped bottoms were obtained. Figure8 shows one of the bottoms stamped at a pressure of the fuel mixture of 0.7 MPa. The obtained bottoms had a smooth surface with not scuffs or corrugations.
4. Conclusions

1. New types of devices for sheet stamping which provide stamping process with heating of a workpiece have been developed and created.

2. Practical testing of these newly developed devices was carried out, during which rational technological modes of stamping process were developed as well.

3. During testing, parts of good quality were obtained, which allows us to recommend developed devices for use in small-scale manufacture of stamping thin-walled steel and non-ferrous alloys parts.

5. References

[1] Ilin L N, Semenov E I 2009 *Technology of sheet stamping*. (Moscow: Drofa)
[2] Taranenko M E 2014 Possibilities of stamping of automobile sheets from modern high-strength materials at electro-hydraulic presses Forge and Forming Production. Die Forging [in Russian – Kuznechno-ShtampovochnoeProizvodstvo.Shtampovka] 9 34-40
[3] Bychkov S A 2007 *On the concept of using technological criteria for choosing pulse sheet metal stamping technologies*. Aerospace Engineering and Technology (in Russian – Aviatsionno-kosmicheskayatekhnika i tekhnologiya) 11 222-31
[4] Pavlenko V N 2002 *Perfection of design parameters and technical features of power units of press guns for hydrodynamic stamping: PhD thesis* (Kharkov)
[5] Musaev A A 2012 Development of initial data for the design of pilot-industrial sample of a two chamber device for gas sheet stamping. *News of HEIs. MechanicalEngineering* 3 43-8
[6] Sukhov V V 2007 *Creation of gas-explosive systems with multipoint initiation by the influence of methane-oxygen mixture*. Aerospace Engineering and Technology (in Russian – Aviatsyonno-KosmicheskayaTehnika i Teknologiya) 11 182-5
[7] Chudin V N, Yakovlev SS, Sobolev Ya A 2004 *Isothermal deformation of high-strength anisotropic metals* (Mashinostroenie-1, Publishing House of TulGU, Moscow) p. 427
[8] Larin S N 2010 Pneumoforming of cellular panels from anisotropic material. *Izvestiya TulGU. Tech Sci* 3: 51-61
[9] Zausaev A F 2010 *Difference methods for solving ordinary differential equations* (In: Proc. Help. Samara State University.Tech.un., Samara) p 100
[10] Erofeev V L, Semenov P D, Pryakhin A S 2008 *Heat engineering: textbook for high schools*. (ICC "Academic Book", Moscow) p 488
[11] Botashev A Yu and Bayramukov R A 2018 Development and study of gas sheet stamping machine with piston hydraulic amplifier Messenger of Samara University. Space Equipment, Technologies and Mechanical Engineering (in Russian – Vestnik Samarskogo Universiteta. Aerocosmicheskaya Tehnika, Tehnologii i Mashinostroenie) 17(2) 132-44