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E. A. FROLOV, S. G. YASKO, S. I. KRAVCHENKO

Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine

DEFINITION OF THE INFLUENCE OF TECHNOLOGICAL AND CONSTRUCTIVE PARAMETERS OF TECHNICAL SYSTEMS ON ENERGY-POWER CHARACTERISTICS OF PNEUMATIC-SHOCK FORMING

On the basis of the developed mathematical model a refined method of energy-power parameters calculating of pneumatic-mechanical forming is created with taking into account constructive and technological parameters of the technical system equipment. The dependences for determining the maximum pressure in the system with its rigidity are obtained and the temporal characteristics of deformation and load with account of rigidity of the technical system base are determined. Defined dependences enable to manage effectively the pneumatic impact deformation process.

Keywords: *technological system, high-velocity forming, pneumatic-shock stamping, energy-power parameters, technological characteristics, constructive characteristics.*

Introduction

The most important task of the aerospace engineering industry is the production of competitive products while increasing productivity and reducing labour intensity of production. In the case of plate-stamping production, especially in the the specific conditions of the aerospace manufacturing at discrete-unstable programs of products release method of the high-speed forming based on technology and equipment of pneumatic-mechanical forming by liquid and elastic environments meets these requirements in full, compared to traditional stamping tool [1].

This technology allows to perform all types of forming of parts from sheet blanks, and spatial blank thickness of from 0,1 to 4,0 mm operations.

Statement of the problem

The effective solution of major technological problems associated with the deformation of the stamped material is impossible without the creation of reliable and convenient methods for determining the influence of design-technological parameters of the technical system equipment "hammer-liquid-workpiece" on the energy characteristics of the pneumatic impact loading parameters (maximum pressure and time of loading).

It is known that these parameters have significant influence on the stampability of the material, the manufacturing accuracy of parts and the stability of the high-speed forming process [2].

As the analysis of existing domestic research has shown, modern methods of pneumatic impact forming energy calculation have quite general nature [3–6] and do not represent the most essential features of this process [7–10].

Below is a brief analysis of recent foreign studies.

Work [11] covers the basics of hydroforming of tubes and sheet metal hydroforming, with guidelines for product design, material selection, and computer simulation of the process and tool design.

Work [12] is described in general terms the experience of applying pulsed electromagnetic sheet metal forming, cutting and trimming and cleaning of cylinder heads of internal combustion engines.

Work [13] is described in detail technology of high speed forming. However, in the considered work did not show the calculation methodology for a specific serial equipment pneumomechanical pulse forming.

Work [14] is described the experimental set-up of the liquid shock tube and presents the results of experiments performed with fully clamped circular copper disks subjected to the impulsive load of the liquid shock wave. The strain conditions of the deformed disks are determined and the deformation energy is calculated. Also the theoretical approach to predict the midpoint deflection of the specimen is given. Experimentally are determined the local and average strain rate.

Work [15] on the influence of significant process parameters, such as the working media density, on the pressure distribution when using the pneumomechanical and electrohydraulic high speed processes forming. These results showed that the change of the working media density, for example, can effectively increase the pressure effect during forming. A comparison of electrohydraulic and pneumomechanical forming showed that it is possible to achieve a clear geometry edges of the workpiece with the aid of the two above-mentioned processes which cannot be achieved with the conventional process. Thus, these processes have a high potential for the production of complex shapes due to the optimal use of the deformability of the material used.

Work [16] analyzes the impact of various process parameters on the forming result, and especially on the reproducibility and reliability of each process, with the aim of creating a pneumomechanical and electrohydraulic forming is suitable for industrial use. One of the important objectives of this research work is to analyze the impact and interactions of the kinetic energy and the venting of the acceleration tube on the forming result with pneumomechanical forming.

In the works discussed above have not considered the issues of influence on the process pneumomechanical forming the dependencies maximum pressure in the system with its rigidity and the temporal characteristics of deformation and load with account of rigidity of the technical system base.

The purpose of research

The research is aimed at developing of reliable energy-power parameters of pneumatic-shock forming of parts calculating methods taking into account constructive and technological parameters of the technical equipment system.

The main material

In this article we present the main results obtained during the development of the methodology for calculating the impact energy and certain linear dimensions of the working chambers for operations in which the deflection of the workpiece during a single loading is small compared with the size of details in plan, the resistance to plastic deformation can be considered proportional to the deflection. This assumption gave a possibility to express the inertial and elastic characteristics of the workpiece through the coefficients m_w and k_w, taking them for constant values.

Since the subject of the study was the final stage of the workpiece deformation, wherein the technical equipment system "hammer – liquid – workpiece" was considered as a single system, making free vibrations and deduced from the equilibrium state by the hammer blow against fluid. They also believed that such a model can be saved until the moment of hammer rebound from the liquid. The studied system is not conservative as the workpiece is plastically deformed. Since the definition of the dissipative function is a rather complicated task that requires individual approach to each workpiece, usually in the form of reliable experimental data, in this case a different approach is used: a solution of the problem for two cases is given. In the first case, the system is considered to be conservative, in the second one dissipative losses are taken into account, however, the damping properties of the system are estimated to the maximum. Since the solutions are close to each other in a quantitative sense, any real case can be estimated as intermediate between these two given. For the base model while developing a design scheme cylindrical working chamber with rigid walls was taken, in the bottom of which (x = 0) the blank is located, a liquid column with height L, the density ρ, the mass m, the cross-sectional area F is above the workpiece. The loading is carried out by solid body (hammer) with weight m_h and an initial velocity V_0.

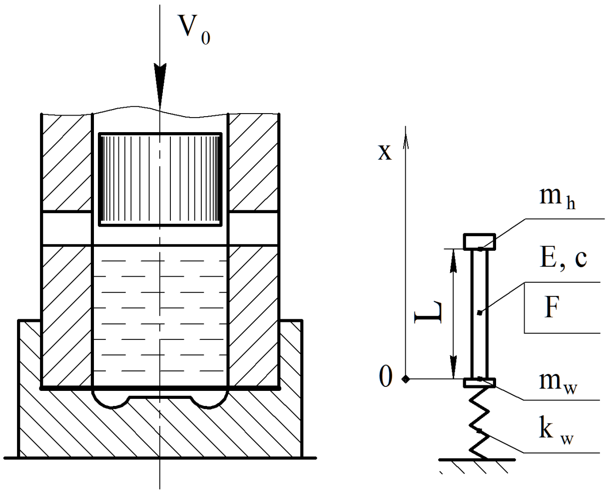


Figure 1. Design scheme

Figure 1 shows a diagram of the working chamber and a dynamic design scheme, from which follows that the problem reduces to solving of a one-dimensional relative to spatial coordinates linearizing equations

$$c^2 \cdot u_{xx} = u_{tt}, \qquad (1)$$

together with equations specifying boundary conditions:

$$u(t,0)\cdot(k_3 - m_3\omega^2) = E\cdot F\cdot u_x(t,0);$$

$$u(t,L)\cdot m_h\omega^2 = E\cdot F\cdot u_x(t,L);$$

$$u(0,x) = 0;$$

$$u_t(0,x) = u_0\cdot\exp N(x/L - 1);$$

$$p = E\cdot u_x;$$

where u – the displacement of section x at the instant t;

c – the speed of sound in the liquid;

N – some positive number, $N \gg 1$, $N \gg \beta$;

p – the pressure of fluid in cross section x at the instant t;

$\tau = t\cdot c / L$ – time in relative units;

ω – circular frequency associated with the period T in ratio ω=2π/T and equal ω=βc/L, where β – positive roots of the frequency equation:

$$\frac{\alpha}{\beta}-\mathrm{tg}\beta=\frac{\alpha\cdot\mathrm{tg}\beta+\beta}{n-\gamma\beta^2}.$$

Here we introduce the dimensionless parameters: the relative mass of the liquid $\alpha = m_l/m_h$, where m_l – mass of the liquid; the relative mass of the workpiece $\gamma = m_w/m_l$, where m_w – mass of the workpiece; the relative rigidity of the workpiece $n = k_w/k_c$, where k_c the stiffness of the working chamber, for cylindrical chamber $k_c = E\cdot F/L$. Analytical solution of the given system has the form:

$$u=\frac{v_0\cdot L}{c}\cdot\sum_{i=1}^{\infty}\left(\frac{\beta_i\cdot\cos\frac{\beta_i\cdot x}{L}}{n-\gamma\cdot\beta_i^2}+\sin\frac{\beta_i}{L}\right)\cdot B_i\cdot\sin\omega_i t;$$

$$B_i=\frac{1}{\beta_i}\cdot\frac{f_i}{0{,}5\cdot a\cdot S_i+f_i^2+\frac{\alpha\cdot\gamma\cdot\beta_i^2}{(n-\gamma\cdot\beta_i^2)^2}};$$

$$f_i=\frac{\beta_i}{n-\gamma\cdot\beta_i^2}+\sin\beta_i;$$

$$S_i=\left(\frac{\beta_i}{n-\gamma\cdot\beta_i^2}\right)^2\cdot\left(1+\frac{\sin 2\beta_i}{2\beta_i}\right)+\frac{2\sin^2\beta_i}{n-\gamma\cdot\beta_i^2}+\left(1-\frac{\sin 2\beta_i}{2\beta_i}\right).$$

Assuming x=0, we have for workpiece

$$u=\frac{v_0\cdot L}{c}\sum_{i=1}^{\infty}a_i\cdot\sin\beta_i\cdot\tau=\sum_{i=1}^{\infty}A_i\cdot\sin\beta_i\cdot\tau, \qquad (2)$$

where

$$a_i=\frac{\beta_i\cdot B_i}{n-\gamma\cdot\beta_i^2};$$

$$p=\rho\cdot c\cdot v_0\sum_{i=1}^{\infty}\beta_i\cdot B_i\cdot\sin\beta_i\cdot\tau. \qquad (3)$$

Since a real system is not conservative, its total energy over time is reduced. The energy change was evaluated in the following way. If we restrict with two harmonic components, the system energy, for example, at the instant $\tau_1 = 3\pi/2\beta_2$ equals

$$\varepsilon=\varepsilon_0-k_w\frac{A_2^2}{2}-k_w\cdot A_1\cdot A_2\cdot\sin\left(\frac{3\pi\beta_1}{2\beta_2}\right). \qquad (4)$$

Through summation of all the harmonic components and time deformation of the workpiece τ_0, the expression (4) can be transformed to $\varepsilon=\varepsilon_0\cdot e^{-2r(\tau)}$, where

$$-2r(\tau)=\sum_{i=2}^{\infty}\sum_{k=1}^{k=k_1}\ln\left[1-\eta_i-2\eta_1\frac{a_i}{a_1}\cdot\sin\frac{\beta_1\pi}{\beta_i}(2k-\varphi)\right],$$

for even harmonics φ=0,5, for odd – φ=1,5; k_1 – integer and it is equal to

$$k_1\approx\frac{\tau_0\cdot\beta_i}{2\pi};\qquad \eta_i=\alpha\cdot n\cdot a_i^2.$$

Assuming the total energy of the system as variable and assuming that the oscillation frequency of the system remains equal to the frequency of free oscillations, we get the expression for determining the pressure on the workpiece taking into account dissipative losses at $\tau\le\tau_0$:

$$p=\rho\cdot c\cdot v_0\cdot e^{-r(\tau)}\sum_{i=1}^{\infty}\beta_i\cdot B_i\cdot\sin\beta_i\cdot\tau. \qquad (5)$$

Since in the system under study the pattern of waves propagation is complex, the analysis of formulas (2) to (5) was done using a PC.

Comparison of the theoretical results with experimental data showed good convergence of the kinematic, power and all time parameters, which allowed to conclude about the possibility of using the above expressions as the basis for the development of practical methods for the calculation of energy-force and the design parameters of pneumatic-mechanical installations. Let k_w and u_w be default values. It is required to determine either impact energy or at a given energy the linear dimensions of the working chamber. Let's introduce the designation $p_{def}=k_w u_w/F$, where p_{def} – nominal pressure, which can be given the value of maximum pressure on the workpiece in the working chamber, assuming γ=0. On the other hand, if we introduce additional simplification and assume that k_w is approximately equal to the stiffness of the workpiece in terms of its static deformation, then p_{def} – the pressure required to obtain a given deflection in terms of the static. It is γ≠0 in real systems. However, workpiece is the most light-mass element of the deformable system. The analysis showed that in almost all cases of sheet-metal stamping with material thickness less 1,5 mm γ<0,1. In determining γ it should be meant that the inertial coefficient $m_з$ is less than the mass of the deformable parts of the workpiece M_w and $m_w=(0{,}15\div 0{,}30)M_w$ [2].

Fulfilled investigations of the workpiece mass effect on its final deflection showed that at the existing facilities in the operating range α, n, γ, this effect can be taken into account with sufficient for practice accuracy as correction factor λ=f(α, n, γ)=(0,93÷1,05), and in equation (2) for solving the given tasks the mass of the workpiece can be neglected, which greatly simplifies the practical calculation methodology of the impact energy. Using the expression (2, 3, 5) and dependence $\varepsilon_0=m_h\cdot v_0^2/2$, after elementary transformations we get:

$$\varepsilon_0 = \left(\frac{p_{def}}{\lambda \cdot D}\right)^2 \cdot \frac{V_l}{2E},$$

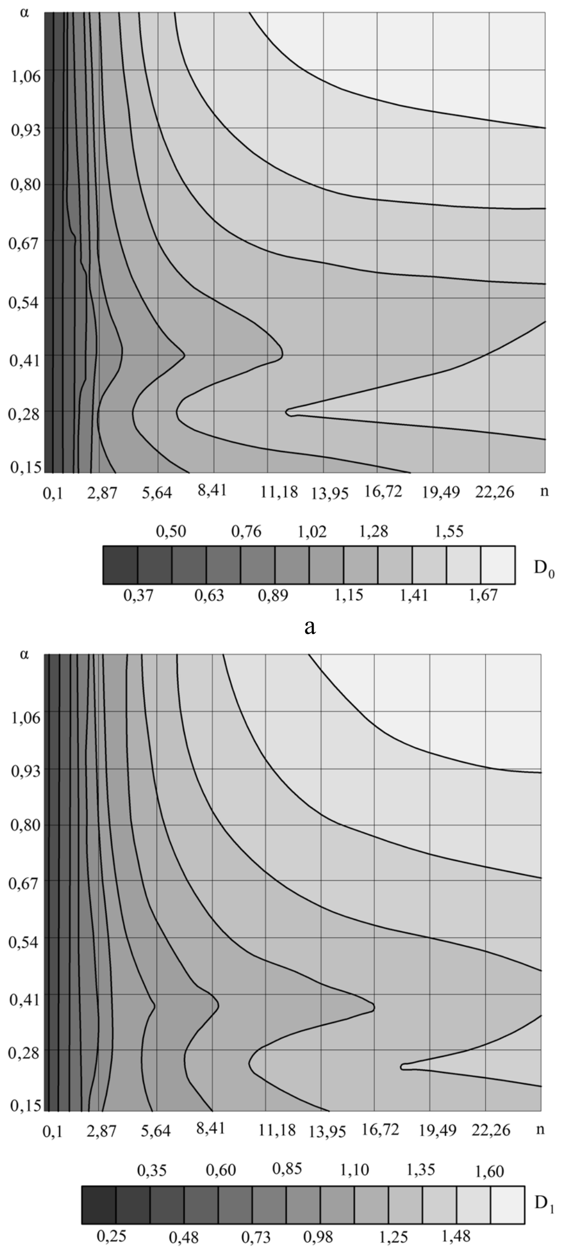
where $D = D_0 = \sqrt{\alpha}\sum_{i=1}^{\infty}\beta_i B_i \sin\beta_i \tau_p$ (without taking into account dissipative losses);

$$D = D_1 = e^{-r}\sqrt{\alpha}\sum_{i=1}^{\infty}\beta_i B_i \sin\beta_i \tau_{p1};$$

τ_p, τ_{p1} – the duration of maximum pressure;

V_l – the volume of liquid in the working chamber;

E – modulus of the bulk compression of the fluid.



a

b

Figure 2. Nomogram for determining the coefficients: a – D_0, b – D_1

Figure 2 presents a nomogram, where knowing α and n it is possible to determine D_0 and D_1, which were by the first eight members of the series. The determination of the cameras linear parameters turns into the determination of coefficient D from the known values of ε_0 and $p_{def.}$ It follows from the nomogram that a set of values α and n corresponds to single value of D.

Specific values of α and n are fixed by additional data: area of the plot on which the required pressure is created at the minimum possible liquid volume V_l etc.

Practical techniques training showed that the coefficient D by its numerical value is closer to D_0 only for calibration operations, and in other cases, $D_0 \approx D_1$. When the working chamber is cone, then

$$k_c = \frac{\pi \cdot d_1 \cdot d_2 \cdot E}{4l},$$

d_1, d_2, l – accordingly the diameter and height of the cone.

The given nomogram can be used to determine the maximum pressure on the bottom of the rigid chamber (without workpiece):

$$p_{max} = D_0\sqrt{\frac{2E\varepsilon_0}{V_l}}.$$

In this case $n = k_t / k_c$, where k_t – the rigidity coefficient of the table setup clamping mechanism.

Thus, a mathematical model used in this work enabled in contrast to the known in the literature [2-4] to enter in the design formulas the rigidity of the working chamber base.

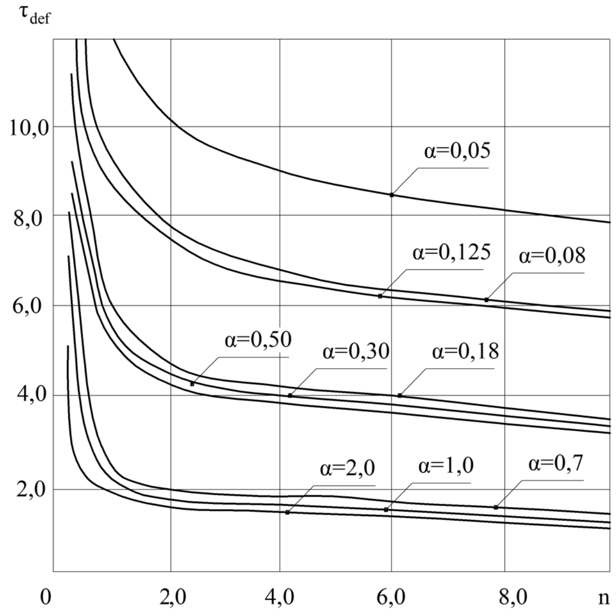


Figure 3. The dependence of the deformation time τ_{def} from the relative hardness of the workpiece n

Figure 3 and 4 shows graphs of the dependences the workpiece deformation time $\tau_{def.}$ and load action time τ_{load} from the relative rigidity of the workpiece n, that are obtained from the condition equality of the expressions (2) and (3) respectively $u=u_{max}$, $p=0$ at $\gamma=0$, $e^{-r(\tau)}=1$.

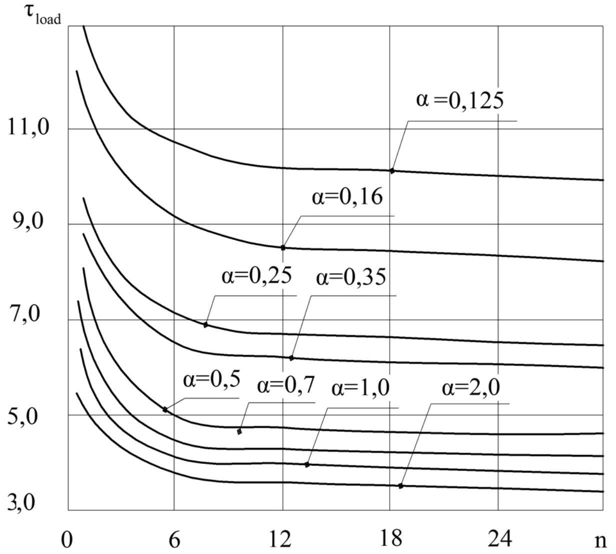


Figure 4. The dependence of the load action time τ_{load} from the relative hardness of the workpiece n

The time settings have an impact on, for example, stampability of the material, the manufacturing accuracy of parts, and the stability of the process. Thus, the decrease τ_{def} reduces parts springy, and increase τ_{load} increases the degree of stretch.

Conclusion

1. The method of the maximum pressure in the chamber of the installation calculating taking into account the structural parameters and rigidity of the equipment base has been updated.

2. The given graphic dependences can be effectively used to control the timing of deformation and at the pneumatic-shock forming process modeling.

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ОПРЕДЕЛЕНИЕ ВЛИЯНИЯ ТЕХНОЛОГИЧЕСКИХ И КОНСТРУКТИВНЫХ ПАРАМЕТРОВ ТЕХНИЧЕСКОЙ СИСТЕМЫ НА ЭНЕРГОСИЛОВЫЕ ХАРАКТЕРИСТИКИ ПНЕВМОУДАРНОЙ ШТАМПОВКИ

Е. А. Фролов, С. Г. Ясько, С. И. Кравченко

На основании разработанной математической модели создана уточненная методика расчета энергосиловых параметров пневмоударного формообразования с учетом конструктивно-технологических параметров технической системы оборудования. Получены зависимости для определения максимального давления в системе с учетом ее жесткости и определены временные характеристики деформирования и нагружения с учетом жесткости основания технической системы. Определенные зависимости позволяют эффективно управлять процессом пневмоударного деформирования.

Ключевые слова: технологическая система, высокоскоростное формообразование, пневмоударная штамповка, энергосиловые параметры, технологические характеристики, конструктивные характеристики.

ВИЗНАЧЕННЯ ВПЛИВУ ТЕХНОЛОГІЧНИХ І КОНСТРУКТИВНИХ ПАРАМЕТРІВ ТЕХНІЧНОЇ СИСТЕМИ НА ЕНЕРГОСИЛОВІ ХАРАКТЕРИСТИКИ ПНЕВМОУДАРНОЇ ШТАМПОВКИ

Є. А. Фролов, С. Г. Ясько, С. І. Кравченко

На підґрунті розробленої математичної моделі створено уточнену методику розрахунку енергосилових параметрів пневмоударного формоутворення з урахуванням конструктивно-технологічних параметрів технічної системи обладнання. Отримано залежності для визначення максимального тиску в системі з урахуванням її жорсткості і визначено часові характеристики деформування і навантаження з урахуванням жорсткості основи технічної системи. Залежності, що визначено, дозволяють ефективно керувати процесом пневмоударного деформування.

Ключові слова: технологічна система, високошвидкісне формоутворення, пневмоударна штамповка, енергосилові параметри, технологічні характеристики, конструктивні характеристики.

Фролов Егений Андреевич – д-р техн. наук, проф., зав. каф. технологии машиностроения, Полтавский национальный технический университет им. Юрия Кондратюка, Полтава, Украина, e-mail: frolov.poltntu@gmail.com, ORCID:0000-0002-2691-5386.

Ясько Станислав Георгиевич – аспирант каф. технологии машиностроения, Полтавский национальный технический университет им. Юрия Кондратюка, Полтава, Украина, e-mail: s.g.yasko@gmail.com, ORCID:0000-0001-6228-705X.

Кравченко Сергей Иванович – канд. техн. наук, доцент каф. технологии машиностроения, Полтавский национальный технический университет им. Юрия Кондратюка, Полтава, Украина, e-mail: 050Ser09@i.ua

Frolov Evgeniy Andreevych – Doctor of Technical Sciences., Professor, Head of the Department of mechanical engineering technology, Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine, e-mail: frolov.poltntu@gmail.com, ORCID:0000-0002-2691-5386.

Yasko Stanislav Georhyevych – postgraduate Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine, e-mail: s.g.yasko@gmail.com, ORCID:0000-0001-6228-705X.

Sergei Kravchenko Ivanovych – Candidate of Technical Sciences, docent of the Department of mechanical engineering technology, Poltava National Technical Yuri Kondratyuk University, Poltava, Ukraine, e-mail: 050Ser09@i.ua.