METHOD OF CALCULATING PNEUMATIC IMPACTORS WITH ONE CONTROLLED CHAMBER

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When developing pneumatic impactors, many design engineers use pV diagrams describing the dependence of pressure in the chamber on its volume. In particular, for pneumatic punches and pipe-driving machines having one controlled chamber, the calculations are based on an examination of processes of an idealized working diagram of the cycle of the controlled chamber [1]. Idealization consists in the assumption that filling of the chamber occurs in the admission section only on the forward stroke, and on the return stroke in this section p = const, expansion and compression of the air are adiabatic and are described by the Poisson equation, and emptying of the chamber is realized with a zero increment of volume, i.e., instantaneously. The work of the forces of compressed air in the admission section is assumed equal to the product of the integral increment of pressure and amount of the increment of the chamber volume in this section. Since in reality the work performed by compressed air in this section of the cycle is determined by a more complex dependence, the authors of method [1] introduced a correction factor C. Based on experimental data, they recommend taking its value within 0.25-0.35.

Furthermore, it is considered that the pressure in the rear chamber is constant and does not depend on its volume.

However, this method does not enable determining the duration of the cycle and, consequently, the compressed-air flow rate, or finding the time and velocity of the striker in any section of motion. The assumption about instantaneous exhaust introduces substantial distortions when determining these parameters. The design dependences represented in a dimensional form limit the possibilities of their analysis and broader use.

Figure 1 shows the idealized working diagram of the cycle of a pneumatic impactor with one controlled chamber.

The thermodynamic process under consideration is in accord with the following characteristic states depicted by points 0-5 in the pV diagram and described by the coordinates: V_0, the initial volume of the controlled chamber; V_1, the volume of the controlled chamber at the time of disconnecting it from the compressed-air line; V_2, at the time of the start of emptying (exhaust); V_3, at the time of equalization of its pressure with the atmospheric pressure; V_4, at the time of the start of compression of the air; V_5, at the time of the start of admission; p_0-p_5, the pressures at the corresponding points of the working diagram, where $p_3 = p_4$ and are equal to the atmospheric pressure p_a.

The increments of the volumes in the admission and expansion sections will be respectively

$$V_1 - V_0 = l_c S_1, \tag{1}$$

$$V_2 - V_1 = V_4 - V_5 = l_e S_1, \tag{2}$$

where l_c is the length of the striker stroke, when the controlled chamber is connected with the line (admission section); l_e is the length of the stroke of the striker during expansion or compression of the air (expansion section); S_1 is the working area of the controlled chamber.

Since admission and exhaust are realized through the same channel in pneumatic punches and pipe-driving machines, the increment of the volume in the exhaust section is taken equal to the increment of the volume in the admission section, consequently

$$V_3 - V_2 = V_3 - V_4 = l_c S_1. \tag{3}$$

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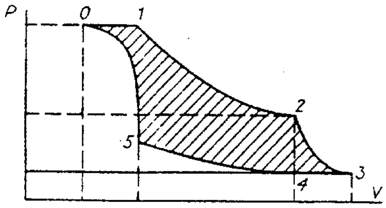

Fig. 1. pV diagram of the working cycle in a controlled chamber.

Considering that energy is a common quantitative measure of motion, we will determine the parameters of the pneumatic impact mechanism on the basis of notions about work being performed as one of the main forms of energy transmission.

On the basis of the aforesaid, let us examine the work of compressed air in the control chamber on the basis of the adopted idealized pV diagram (see Fig. 1).

Processes 1-2 and 4-5 are considered adiabatic. The relations between pressures and volumes are described by the Poisson equation. The work of compressed air during these processes is determined by the known dependences of thermodynamics [2].

We will estimate the work of compressed air in the admission and exhaust sections as in the known method [1] with the introduction of a correction factor. We will take the previous relation of work in the admission, exhaust, and expansion sections. The introduction of a new factor α, other than C, will be required in that case. In view of the fact that the work of compressed air in the expansion section, according to the proposed pV diagram and to the pV diagram used in the known method, will be the same under equal initial and final states, the value of the correction factor α will be determined from the condition of preservation of the relation of work in the admission, exhaust, and expansion sections experimentally selected in [1].

Consequently,

$$\alpha(p_1 - p_5)(V_1 - V_0) + \alpha(p_2 - p_A)(V_3 - V_4) = C(p_1 - p_4)(V_1 - V_4). \tag{4}$$

To impart to the relations a more general form and the possibility of their use for calculating dynamically similar machines, we will reduce the expression obtained to a dimensionless form.

As the unit parameters we will take l_c, S_1, and p_a. The quantity S_1 is known beforehand and is selected from design considerations; l_c is taken as a unit parameter artificially. This is explained mainly by the difficulty in calculating it. As the original variant, we can recommend taking l_c equal to the diameter of the main channel.

We set

$$p_i = p^* \varkappa_i;\ \ l_i = l^* \xi_i;\ \ V_i = V^* \Lambda_i;\ \ A_i = A^* A_i, \tag{5}$$

where $p^* = p_a$, $l^* = l_c$, $V^* = l_c S_1$, $A^* = p^* V^* = p_a l_c S_1$ are respectively the constants of pressure, movement, volume, and work.

With consideration of the comments expressed above and reduced relations (1)-(3) and (5), we obtain

$$\alpha = \frac{\varkappa_1}{\varkappa_1 \div \varkappa_2} C. \tag{6}$$

In this case, the work of the compressed-air forces in the controlled chamber in a dimensionless form will be

$$\Lambda = \alpha(\varkappa_2 - 1)\left(\frac{\varkappa_1}{\varkappa_2} + 1\right) + \frac{\Lambda_1}{\nu - 1}\left(1 - \left(\frac{\varkappa_1}{\varkappa_2}\right)^{(1-\nu)/\nu}\right)\left(\frac{\varkappa_1}{\varkappa_2} - 1\right). \tag{7}$$

where ν is the Poisson ratio (for air $\nu = 1.4$).

From here

$$\Lambda_1 = \frac{\nu - 1}{1 - \left(\frac{\varkappa_1}{\varkappa_2}\right)^{(1-\nu)/\nu}} \left(\frac{A}{\frac{\varkappa_1}{\varkappa_2}(\varkappa_2 - 1)} - \alpha\left(1 + \frac{\varkappa_2}{\varkappa_1}\right)\right). \tag{8}$$

Using the adopted relations (1)-(3) and the Poisson equation, we will express the initial volume of the controlled chamber Λ_0, volume of the chamber at the time of the start of exhaust Λ_2, at the time of the end of exhaust Λ_3, and also the expansion stroke ξ_e in terms of the volume of the controlled chamber at the time of cutoff Λ_1:

$$\Lambda_0 = \Lambda_1 - 1, \tag{9}$$

$$\Lambda_2 = \Lambda_1 (\varkappa_1/\varkappa_2)^{1/\nu}, \tag{10}$$

$$\Lambda_3 = \Lambda_1 \left(\frac{\varkappa_1}{\varkappa_2}\right)^{1/\nu} + 1. \tag{11}$$

$$\xi_e = \Lambda_2 - \Lambda_1 = \Lambda_1 \left(\left(\frac{\varkappa_1}{\varkappa_2}\right)^{1/\nu} - 1\right). \tag{12}$$

The return stroke of the striker can be determined from the condition of equality of the work of compressed air in the controlled chamber and work of braking the striker in the rear chamber in the return-stroke section.

The work spent by compressed air in the controlled chamber during the return stroke of the striker is equal to the area bounded above the line of the change in the state 0-1-2-3 and below by the p_a = const (see Fig. 1). The work of braking in the rear chamber is equal to the product of the force acting in this chamber and amount of the return stroke l_r.

It is obvious that the force acting in the rear chamber is equal to $S_2 p_6$, where S_2 is the working area of the rear chamber, p_6 is the compressed-air pressure in the chamber.

We will take $S_2/S_1 = \Psi$ and, taking into account that $p_6 = p^* \varkappa_6$ and $l_r = l^* \xi_r$, we obtain

$$\xi_r = \frac{1}{\Psi(\varkappa_6 - 1)} \left(\frac{A}{\left(\frac{\varkappa_1}{\varkappa_2}\right)(\varkappa_1 - 1)} - \alpha\left(1 + \frac{\varkappa_2}{\varkappa_1}\right)\right) \times$$
$$\times \left(\varkappa_1 + (\nu - 1)\frac{1 - (\varkappa_1/\varkappa_2)^{1/\nu}}{1 - (\varkappa_1/\varkappa_2)^{(1-\nu)/\nu}} + \alpha(\varkappa_2 - 1) + \varkappa_1 - 1\right). \tag{13}$$

To determine the time of motion of the striker and its velocity, we will examine the law of variation of momentum for a material particle

$$\frac{d\bar{j}}{dt} = \bar{F} \quad \text{or} \quad \frac{d}{dt}(m\bar{U}) = \bar{F}, \tag{14}$$

where $\bar{F}$ is the principal vector of external forces; $\bar{j}$, m, and $\bar{U}$ are respectively the momentum, mass, and velocity of the material particle, in the given case, the striker.

Projecting the vector equality (14) onto the path of motion of the striker from *a* to b, we obtain

$$\frac{d}{dt}(mU) = \sum_{i=1}^{n} F_{ab}^{\mathrm{I}} - \sum_{i=1}^{n} F_{ab}^{\mathrm{II}}, \tag{15}$$

where $\sum_{i=1}^{n} F_{ab}^{\mathrm{I}}$ and $\sum_{i=1}^{n} F_{ab}^{\mathrm{II}}$ are external forces acting on the striker respectively in the controlled and rear chambers in section *l* with length l_{ab}.

At points *a*, U is equal to U_a, and at point b, to U_b.

We will assume that the resultants of the external forces are equal to

$$F_{ab}^{\mathrm{I}} = \frac{\sum_{i=1}^{n} A_{ab}^{\mathrm{I}}}{l_{ab}}, \quad F_{ab}^{\mathrm{II}} = \frac{\sum_{i=1}^{n} A_{ab}^{\mathrm{II}}}{l_{ab}}.$$

where $\sum_{i=1}^{n} F_{ab}^{I}$ and $\sum_{i=1}^{n} F_{ab}^{II}$ are the total work of the compressed-air forces acting in section l_{ab} on the striker from the side of the controlled and rear chambers.

Having separated the variables and having taken from both sides of equality (15) the corresponding definite integrals, we obtain

$$m \int_{U_0}^{U_b} dU = \frac{1}{l_{ab}} \left(\sum_{i=1}^{n} A_{ab}^{I} - \sum_{i=1}^{n} A_{ab}^{II} \right) \int_{0}^{t_{ab}} dt$$

or

$$m(U_b - U_a) = \frac{1}{l_{ab}} \left(\sum_{i=1}^{n} A_{ab}^{I} - \sum_{i=1}^{n} A_{ab}^{II} \right) t_{ab}.$$

From here the time during which the striker will cover the path l_{ab} will be

$$t_{ab} = \frac{m l_{ab} (U_b - U_a)}{\sum_{i=1}^{n} A_{ab}^{I} - \sum_{i=1}^{n} A_{ab}^{II}}. \tag{16}$$

We will represent equality (15) in the form

$$m \frac{dU}{dl} \cdot \frac{dl}{dt} = F_{ab}^{I} - F_{ab}^{II}$$

or

$$mUdU = F_{ab}^{I} - F_{ab}^{II}.$$

Having integrated both sides of this expression, we obtain

$$\frac{m}{2} (U_b^2 - U_a^2) = \int_{ab} F_{ab}^{I} dl - \int_{ab} F_{ab}^{II} dl.$$

But

$$\int_{ab} F_{ab}^{I} dl = \sum_{i=1}^{n} A_{ab}^{I}; \int_{ab} F_{ab}^{II} dl = \sum_{i=1}^{n} A_{ab}^{II}.$$

From here

$$U_b = \pm \sqrt{U_a^2 \pm \frac{2}{m} \left(\sum_{i=1}^{n} A_{ab}^{I} - \sum_{i=1}^{n} A_{ab}^{II} \right)}, \tag{17}$$

here the "+" sign is for the return stroke of the striker and the "-" sign is for the forward stroke.

We will use relation (16) for determining the time of the cycle T.

The path covered by the striker during the cycle is equal to the double value of the return stroke, i.e., $l_{ab} = 2l_r$.

The total work of the compressed-air forces in the controlled chamber during the cycle by agreement

$$\sum_{i=1}^{n} A_{ab}^{I} = A.$$

The total work of the compressed-air forces in the rear chamber $\sum_{i=1}^{n} A_{ab}^{II} = 0$.

In connection with the idealization of the working diagram of the cycle, presence of dissipative losses, differences of real processes from quasistatic, and a number of other unaccounted for factors, naturally, not all work of the compressed-air forces will be transformed into useful work by means of the impact.

Let us assume that the amount of the losses is proportional to the useful work $A_l = A_{im} \cdot \eta$, where A_l is unaccounted for losses; A_{im} is the impact energy; η is the coefficient of the losses of the work of the compressed-air forces not accounted for.

Expressed differently

$$A = A_{\text{im}} + A_{\ell}$$

or

$$A = A_{\text{im}}\,(1 + \eta). \tag{18}$$

Therefore,

$$T = 2\,(1 + K_{\text{rb}})\,\frac{mU_{\text{im}}\,l_{\text{r}}}{A}. \tag{19}$$

where $U_b = U_{im}$ is the impact velocity; $U_a = -K_{rb}U_{im}$ is the rebound velocity; K_{rb} is the rebound coefficient.

Since

$$U_{\text{im}} = \sqrt{\frac{2A_{\text{im}}}{m}} = \sqrt{\frac{2A}{m\,(1 + \eta)}}, \tag{20}$$

we finally obtain

$$T = \frac{2\sqrt{2}\,(1 + K_{\text{rb}})}{\sqrt{1 + \eta}}\,l_{\text{r}}\sqrt{\frac{m}{A}}. \tag{21}$$

In a dimensionless form, expressions (16), (17), (20), and (21) have respectively the following form:

$$\tau_{ab} = \frac{\xi_{ab}\,(U_{\text{b}} - U_{\text{a}})}{\sum\limits_{i=1}^{n} A_{ab}^{\text{I}} - \sum\limits_{i=1}^{n} A_{ab}^{\text{II}}}, \tag{22}$$

$$U_{\text{b}} = \pm\sqrt{U_{\text{a}} \pm 2\left(\sum_{i=1}^{n} A_{ab}^{\text{I}} - \sum_{i=1}^{n} A_{ab}^{\text{II}}\right)}. \tag{23}$$

$$U_{\text{im}} = \sqrt{\frac{2A}{1 + \eta}}. \tag{24}$$

$$\tau_{\text{cy}} = \frac{2\sqrt{2}\,(1 + K_0)}{\sqrt{1 + \eta}} \cdot \frac{\xi_{\text{r}}}{\sqrt{A}} \tag{25}$$

Here

$$U = U^{*}u, \qquad t_{ab} = t^{*}\tau.$$

where $U^{*} = l_c/t^{*}$ is the velocity constant, $t^{*} = (ml_c/S_ip_a)^{1/2}$ is the time constant.

Having substituted into (25) the dependence of the amount of the return stroke on the work of the compressed-air forces in the controlled chamber (13), we obtain

$$\tau_{\text{cy}} = \frac{2\sqrt{2}\,(1 + K_0)}{\sqrt{1 + \eta}\,\Psi\,(\varkappa_6 - 1)}\left(\left(\frac{\sqrt{A}}{\varkappa_1/\varkappa_2\,(\varkappa_2 - 1)} - \frac{\alpha}{\sqrt{A}}\left(1 + \frac{\varkappa_2}{\varkappa_1}\right)\times\right.\right.$$
$$\left.\left.\left(\varkappa_1 + (\nu - 1)\cdot\frac{1 - (\varkappa_1/\varkappa_2)^{1/\nu}}{1 - (\varkappa_1/\varkappa_2)^{(1-\nu)/\nu}}\right) + \frac{1}{\sqrt{A}}\,(\alpha\,(\varkappa_2 - 1) + \varkappa_1 - 1)\right). \tag{26}$$

To determine the velocity of the striker at characteristic points of the working diagram of the cycle in Fig. 1, we will use expression (23).

For the return stroke of the striker

$$U_1 = \sqrt{U_0^2 + (A_{0-1}^{\text{I}} - A_{0-1}^{\text{II}})}.$$

Since

$$|U_0| = |K_{rb}U_{im}| = \left|K_{rb}\sqrt{\frac{2A}{1+\eta}}\right|. \quad (27)$$

$$U_1 = \sqrt{\frac{2K_{rb}^2 A}{1+\eta} + 2((\varkappa_1 - 1) - \Psi(\varkappa_6 - 1))};$$

$$U_2 = \sqrt{U_1^2 + 2(A_{1-2}^{I} - A_{1-2}^{II})} = \quad (28)$$

$$= \sqrt{U_1^2 + 2\left(\frac{1}{\nu - 1}(\varkappa_1\Lambda_1 - \varkappa_2\Lambda_2) - \xi_e(\Psi(\varkappa_6 - 1) + 1)\right)};$$

$$U_3 = \sqrt{U_2^2 + 2(A_{2-3}^{I} - A_{2-3}^{II})} = \sqrt{U_2^2 + 2(\alpha(\varkappa_2 - 1) - \Psi(\varkappa_6 - 1))}. \quad (29)$$

At the point of maximum return $u_r = 0$. (This point is not shown on the working diagram.)

For the forward stroke of the striker

$$U_4 = -\sqrt{U_3^2 - 2(A_{3-4}^{I} - A_{3-4}^{II})}.$$

Since $A^1_{3-4} = 0$ and $U_3 = 0$, then

$$U_4 = -\sqrt{2(\xi_r - (1 + \xi_e))\Psi(\varkappa_6 - 1)}; \quad (30)$$

$$U_5 = -\sqrt{U_4^2 - 2(A_{4-5}^{I} - A_{4-5}^{II})} =$$

$$= -\sqrt{U_4^2 - 2\left(\frac{1}{\nu - 1}(\varkappa_5\Lambda_1 - \Lambda_2) - \xi_e(\Psi(\varkappa_6 - 1) + 1)\right)}; \quad (31)$$

$$U_0 = -\sqrt{U_5^2 - 2(A_{5-0}^{I} - A_{5-0}^{II})} =$$

$$= -\sqrt{U_5^2 - 2(\varkappa_1 - 1 - \alpha(\varkappa_1 - \varkappa_4) - \Psi(\varkappa_6 - 1))}. \quad (32)$$

Since by agreement $u_0 - u_{im}$, the latter expression has a verifying character.

Having substituted expression (23) into (22), we obtain

$$\tau_{ab} = \frac{2\xi_{ab}}{|U_b - U_a|}. \quad (33)$$

Thus, knowing the velocities at the boundaries of the section, we can determine the time of passage through this section by the striker.

In this case, the time of the cycle will be

$$\tau_{cy} = \sum_{i=1}^{n} \tau_{abi}. \quad (34)$$

We will estimate the flow rate of compressed air. This is done with an accuracy sufficient for practical purposes by reducing the compressed air expended during the cycle to atmospheric pressure [1].

The volume flow rate of compressed air during the cycle will be:

$$\Theta = 60\frac{V_1}{T}\left(\frac{p_1 - p_5}{p_a}\right), \text{ m}^3/\text{min}.$$

In a dimensionless form

$$q = \frac{\varkappa_1}{\varkappa_2}(\varkappa_2 - 1)\frac{\Lambda_1}{\tau_{cy}}, \quad (35)$$

where $\Theta = \Theta^* q$ (q is the dimensionless flow rate, Θ^* is the flow-rate constant). Within the scope of the adopted unit parameters

$$\Theta^* = 60S_1 l_c / t^*.$$

In view of the fact that there are two expressions for calculating τ_{cy}, we can estimate the flow rate of compressed air in two ways, using expression (26)

$$q = \frac{\sqrt{1+\eta}\,(\nu-1)\,\Psi(\varkappa_6-1)\,\varkappa_1/\varkappa_2\,(\varkappa_2-1)}{2\sqrt{2}\,(1+K_0)\left(1-(\varkappa_1/\varkappa_2)^{(1-\nu)/\nu}\right)}\times$$

$$\times\frac{\sqrt{A}\left(\frac{A}{\varkappa_1/\varkappa_2\,(\varkappa_2-1)}-\alpha\left(1+\frac{\varkappa_2}{\varkappa_1}\right)\right)}{\left(\frac{A}{\varkappa_1/\varkappa_2\,(\varkappa_2-1)}-\alpha\left(1+\frac{\varkappa_2}{\varkappa_1}\right)\right)\left(\varkappa_1+(\nu-1)\frac{1-(\varkappa_1/\varkappa_2)^{1/\nu}}{1-(\varkappa_1/\varkappa_2)^{(1-\nu)/\nu}}\right)+\alpha(\varkappa_1-1)+(\varkappa-1)} \tag{36}$$

or expression (34)

$$q = \frac{\varkappa_1}{\varkappa_2}(\varkappa_2-1)\frac{\Lambda_1}{\sum\limits_{i=1}^{n}\tau_{abi}}. \tag{37}$$

The proposed design relations are substantially simplified if the values of the pressures at characteristics points of the pV diagram or the relations between them are known beforehand. In particular, p_1 = 0.58 MPa and $p_2 = 0.5p_1$ are usually taken on the basis of experimental data for pneumatic punches and pipe-driving machines.

The pressure in the rear chamber is considered equal to the pressure in the main line, i.e., p_6 = 0.7 MPa.

The values of the dimensionless coefficients are $\eta = 0.1$, $K_{rb} = 0$, $C = 0.25$.

In this case, expressions (8)-(13), (26), and (36) acquire the following form

$$\Lambda_1 = 0.586A - 0.557, \tag{38}$$

$$\Lambda_0 = 0.586A - 1.557, \tag{39}$$

$$\Lambda_2 = 0.961A - 0.914; \tag{40}$$

$$\Lambda_r = 0.961A + 0.086, \tag{41}$$

$$\xi_r = 0.375A - 0.357, \tag{42}$$

$$\xi_e = 1/\Psi\,(0.192A + 0.670), \tag{43}$$

$$\tau_{cy} = \frac{1}{\Psi}\left(0.518\sqrt{A} + \frac{1.807}{\sqrt{A}}\right), \tag{44}$$

$$q = \frac{1}{\Psi}\sqrt{A}\,\frac{4.299A - 4.087}{A + 3.490}. \tag{45}$$

Figures 2 and 3 show the dependences of the dimensionless parameters of pneumatic punches and pipe-driving machines on the work of the compressed-air forces in the controlled chamber calculated by expressions (38)-(45).

The following sequence of calculation is proposed for determining the parameters and design dimensions of pneumatic impactors with one controlled chamber.

1. The mass of the striker is determined by formula (20) on the basis of the required impact energy and collision velocity prescribed from strength conditions (about 4 m/sec for pneumatic punches and pipe-driving machines).
2. The value of the admission length l_c is selected from the recommendation given earlier, and the area of the controlled chamber S_1 is taken from design considerations.
3. The area of the rear chamber S_2 is determined from the relation $\Psi = S_2/S_1$. It is recommended to take Ψ = 0.4-0.55 [1].
4. The factor α should be selected with the use of relation (6). The values of C = 0.25-0.35 [1].
5. It is recommended to take the loss coefficient η equal to 0.1 [1]. Calculation experience shows that the rebound coefficient can be taken in the range 0-0.1.
6. Then the dimensionless values of the impact energy and pressure at characteristic points of the pV diagram in the controlled and uncontrolled chambers are determined.
7. The work of the compressed-air forces is found by expression (18) for obtaining the required impact energy.
8. The dimensionless parameters of the machine are determined by formulas (8)-(13).
9. Then the time of the cycle τ_{cy} and the compressed-air flow rate are found without consideration of leaks of compressed air through gaps in the movable joints q.
10. If it is required to determine the velocities and time of motion of the striker in characteristic sections of the stroke, it is necessary to use expressions (23) and (33).
11. The last stage of calculation is to change from the dimensionless values obtained to dimensional, using dimensional constants.
12. To determine the total flow rate, it is recommended to increase the flow rate obtained by a factor of 1.4-1.5 [1].

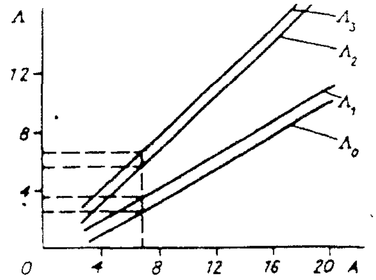

Fig. 2. Dependence of volumes on the work of compressed air in the controlled chamber.

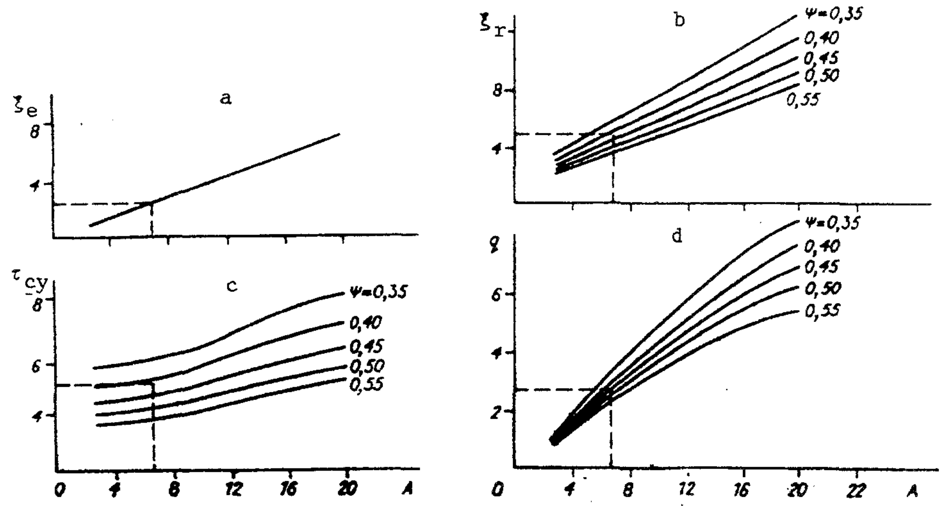

Fig. 3. Dependence of the expansion stroke (a), amount of the return stroke (b), cycle time (c), flow rate of compressed air (d) on the work of compressed air in the controlled chamber.

13. Simplified expressions (38)-(45) or the graphic dependences given in Figs. 2 and 3 can be used in calculations of pneumatic punches and pipe-driving machines.

Example of calculating the M400 pipe-driving machine.

Impact energy A_{im} = 4000 J; impact velocity U_{im} = 3.9 m/sec; area of controlled chamber S_1 = 0.0908 m^2 (the diameter is equal to 0.34 m); area of rear chamber S_2 = 0.038 m^2 (the diameter is equal to 0.22 m). Length of admission l_c = 0.07 m.

1. We determine the mass of the striker

$$m = \frac{2A_{im}}{U_{im}^2} = \frac{8000}{3{,}9^2} = 526 \text{ kg}.$$

2. We calculate

$$\Psi = \frac{S_2}{S_1} = \frac{0{,}038}{0{,}0908} = 0{,}419.$$

3. In view of the fact that the simplified dependences correspond to pressures and values of the dimensionless coefficients for pneumatic punches and pipe-driving machines, we will use them in determining the parameters of the machine.

For this purpose, at first we determine the dimensionless work of the compressed-air forces in the controlled chamber

$$A = (1 + \eta)\frac{A_{im}}{A^*} = 6{,}922.$$

4. The parameters and design dimensions of the machine will be: Λ_1 = 3.499; Λ_0 = 2.499; Λ_2 = 5.739; Λ_3 = 6.739; ξ_e = 2.239; ξ_r = 4.77; τ_{cy} = 4.9; q = 2.71.

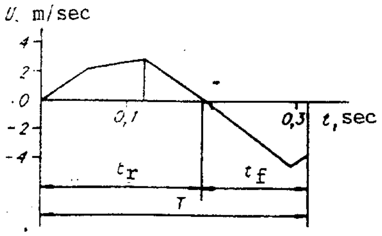

Fig. 4. Diagram of the velocity of the striker (t_r, t_f are respectively the time of the return and forward stroke).

The values of the parameters of the machine obtained can be determined from the graphs in Figs. 2 and 3. The values of the variant under consideration are marked on them by dashed lines.

5. Using the values of the dimensional constants, we determine the true values of the parameters under consideration:

$$V_1 = V^*\Lambda_1 = 0{,}0222 \text{ m}^3;\quad V_0 = V^*\Lambda_0 = 0{,}0159 \text{ m}^3;\quad V_2 = V^*\Lambda_2 = 0{,}0364 \text{ m}^3;$$
$$V_3 = V^*\Lambda_3 = 0{,}0428 \text{ m}^3;\quad l_e = l^*\xi_e = 0{,}157 \text{ m};\quad l_r = l^*\xi_r = 0{,}334 \text{ m};$$
$$T = t^*\tau_{cy} = \sqrt{\frac{ml_c}{p_a S_1}}\,\tau_{cy} = 0{,}313 \text{ sec};\quad \Theta = \Theta^* q = 60\frac{S_1 l_c}{t^*} q = 16{,}1 \text{ m}^3/\text{min}.$$

6. Using dependences (27)-(32), we determine the velocity of the striker at characteristics points of the cycle

$$u_1 = 2{,}24;\quad u_2 = 2{,}654;\quad u_3 = 1{,}627;\quad u_r = 0;$$
$$u_4 = -2{,}77;\quad u_5 = -4{,}14;\quad u_0 = -3{,}68.$$

But by agreement $u_0 = u_4$; $u_4 = 3.55$.

The error of the calculation is about 4%.

7. By expression (33) we determine the time spent on movement of the striker in the sections under consideration:

$$\tau_{0-1} = \frac{2\xi_c}{u_1} = 0{,}934;\quad \tau_{1-2} = \frac{2\xi_e}{u_1 + u_2} = 0{,}935;$$
$$\tau_{2-r} = \frac{2(\xi_e + \xi_c)}{u_2 + u_3} = 0{,}467;\quad \tau_{3-r} = \frac{2(\xi_3 - (\xi_r + 2\xi_c))}{u_3} = 0{,}650;$$
$$\tau_{3-4} = \frac{2(\xi_r - (\xi_e + \xi_c))}{|u_4|} = 1{,}103;\quad \tau_{4-5} = \frac{2\xi_c}{|u_4 + u_5|} = 0{,}648.$$
$$\tau_{5-0} = \frac{2\xi_c}{|u_0 + u_5|} = 0{,}250.$$

8. We determine the time of the cycle in the form

$$\tau_{cy} = \sum_{i=1}^{6} \tau_{ab_i} = 4{,}987.$$

Comparing τ_{cy} obtained with the value of τ_{cy} calculated by formula (44), we determine the error, which amounts to about 2%.

9. Using the time and velocity constants, we determine the real values of the velocities and time of the striker in the sections of the cycle under consideration:

$$U_1 = 2{,}35 \text{ m/sec};\ U_0 = 2{,}92 \text{ m/sec};\ U_3 = 1{,}79 \text{ m/sec};\ U_r = 0;$$
$$U_4 = -3{,}04 \text{ m/sec};\ U_5 = -4{,}55 \text{ m/sec};\ U_0 = -4{,}04 \text{ m/sec};$$
$$t_{1-0} = 0{,}0595 \text{ sec};\ t_{1-2} = 0{,}0596 \text{ sec};\ t_{2-3} = 0{,}0297 \text{ sec};\ t_{3-r} = 0{,}0414 \text{ sec};$$
$$t_{r-4} = 0{,}0703 \text{ sec};\ t_{4-5} = 0{,}0413 \text{ sec};\ t_{5-0} = 0{,}0159 \text{ sec}.$$

A graph of the change in the velocity of the striker during the cycle is given in Fig. 4.

Thus, the given method of calculating pneumatic impactors with one controlled chamber makes it possible to rather simply determine the parameters of the machine and it can be recommended to engineers designing pneumatic impact equipment for use in their practical activities.

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