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SOFTWARE DEVELOPMENT FOR MODELING OF UNIVERSAL ELASTIC ROTARY COMPENSATOR FOR THE “PRESS-AND-DIE” SYSTEM ERRORS OF CRANK PRESS FOR DRAWING-FORMING OPERATIONS

The technological operations performed on the C-frame crank presses are accompanied by distortions of the slider. It reduces tool life and aggravates the conditions of its exploitation [1], which declines in the quality of stamped products and precision of the cut surface on the separation operations. Currently, several of technical solutions to the extent necessary to reduce the distortions in the "press-and-die" system of a crank press. In all cases the most rational to choose the most cost-effective devices that require a minimum of costs and lead to a good stabilizing effect.

The compensators designed for specific technological effort have become widespread, for example a compensator for errors of the directions of press slider as polyurethane plate that mimics the shape of the upper plate of the stamp [2, 3]. This structure is characterized by a variable stiffness due to the presence of holes disposed with different pitch in each direction. The effective use of such polyurethane based compensators is defined by its properties, because the elastic plate with a draft of up to 25 % withstands up $7{\cdot}10^6$ loading cycles of compression. The operating results gave reason to modify the design, thus improving its durability.

The disadvantage of the above devices is fixed average stiffness, which limits the range of computational technological effort and the need for replacement of the compensator in case of a change of process parameters.

To solve these problems the construct of universal error compensator was designed (Fig.1) according to the source [4]. The compensators has a basis of composite pre-stressed elastic element configured in the form of two rigid (round for example) polyurethane plates with openings. One of the plates is displaceable by turning relative to the other, which enables to change the supporting surface area and leads to a change in compensator rigidity by varying of the overlap relation, that extending the range of technological operations.

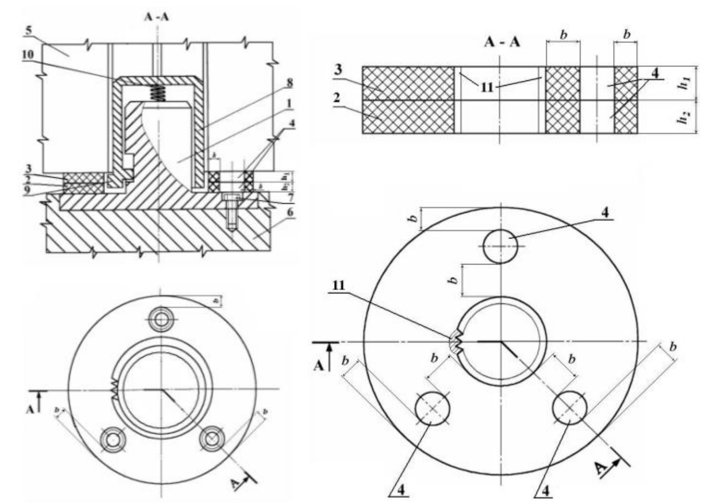

Fig. 1. The universal compensator of the errors of the slide direction:
1 – shank; 2 and 3 – the lower and the upper elastic circular plates; 4 – openings in the elastic plates; 5 – press slide; 6 – upper die-plate; 7 – screw connection the shank and the upper die-plate; 8 – cowl; 9 – the cog of the cowl for the fixing of the rotated elastic plate; 10 – spring; A-A - the designation of the cross-section; h_1 и h_2 – thickness of the upper and lower elastic circular plates; b – distances between openings, inner outer walls of compensator

The aim of this work is developing of mathematical model and computer-aided method of the calculation of universal elastic rotary error compensators of the "press-die" system of crank presses by example of drawing-forming operation.

he compression pre-tests were carried with different shape samples from polyurethane brand SKU-PFL-100 (СКУ-ПФЛ-100, 100 Shore hardness). During the processing of experimental data the value of compression pressure q was calculated as:

$$q = P_d / F_{op} , \tag{1}$$

where P_d – deformation force;

F_{op} – supporting area of the compensator.

Dependence between the pressures during compression of polyurethane (q) and the degree of upsetting (ε) for $\varepsilon \le 0.2 \div 0.3$ is:

$$q = 52 \cdot \varepsilon + 1.92 . \tag{2}$$

The shape factor (Φ) was determined by the formula [3, 5]:

$$\Phi = F_{bok} / F_{op} , \tag{3}$$

where F_{bok} – lateral surface area of the compensator.

The dependencies of the compression force from the shape factor and the degree of upsetting (compression) without lubrication (4) and lubricated (5) polyurethane plates were obtained on the basis of the developed mathematical model:

$$P = 0.001436 - 0.164223 \cdot \Phi - 0.289477 \cdot \varepsilon + 25.110390 \cdot \Phi \cdot \varepsilon ; \tag{4}$$

$$P = -0.000434 - 0.000613 \cdot \Phi - 0.086781 \cdot \varepsilon + 0.128789 \cdot \Phi \cdot \varepsilon . \tag{5}$$

The design of universal compensator of the errors of slide direction was considered. There two elastic circular plates with the radius (R) from polyurethane (СКУ-ПФЛ-100) with openings that have radiuses (r_1) and (r_2) where serves as the basis for composite prestressed elastic element (Fig. 1 and Fig. 2).

The scheme for calculation of the overlapping of two openings of rotary elastic plates of universal compensator of the errors of slide directions is shown on Fig. 2. This task is considered for the case when the radiuses of the openings (r_1) and (r_2) can not coincide.

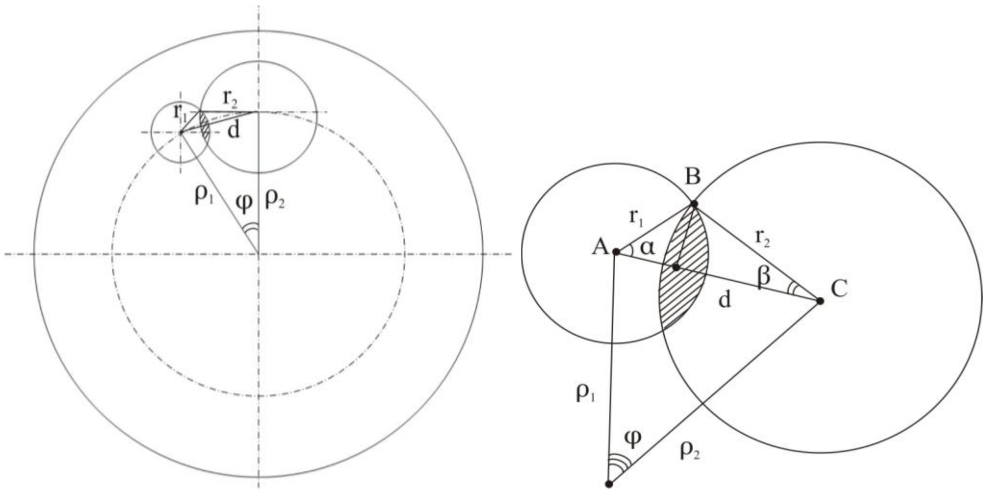

Fig. 2. Scheme for determination of overlapping of openings of universal compensator of slide direction errors:
d – distance between the centers of the openings of elastic compensator plates; ρ_1 – distance from the axis of rotation to the center of the smaller opening; ρ_2 – distance from the axis of rotation to the center of a larger opening; φ – angle between the lines that beginning from the common origin to the centers of the openings in the plates

The distances (a) and (b) between adjacent openings in elastic plates and between the opening and the wall of the compensator according to [4] are:

$$a \geq 0.63(h_1 + h_2); \qquad b \geq 0.63(h_1 + h_2), \tag{6}$$

where h_1 and h_2 – thicknesses of the upper and lower elastic plates, but the difference of thickness between the upper and lower elastic plate does not exceed 20 %.

Also the following limitations were introduced in the design of compensator: radiuses of the elastic plates of the compensator should be less than the length (A) and width (B) of the die-plate (correspondingly: $R < A$ and $R < B$), and the common height of the compensator should not exceed 1/3 of stamping space (H_{pr}):

$$(h_1 + h_2) \leq H_{pr}/3. \tag{7}$$

The supporting area of the compensator elastic plates is determined as: $F_{op.pl} = \pi \cdot R^2$.

The distortion of the slide axis on angle (φ_0) causes to irregularity of deformation of the elastic plates of universal rotary compensator in height. And the maximum of angle deviation should not exceed:

$$\varphi_0 \leq \operatorname{arctg}((h_1 + h_2)/2R). \tag{8}$$

Based on the imposed restrictions the radiuses of elastic plates of the compensator were determined as:

$$R = 0.9 \cdot C_{AB}/2, \tag{9}$$

where is $C_{AB} = \min(A, B)$.

One of the elastic plates of the compensator is movable by rotating about the other. This is enables to change the supporting surface area and leads to a change in the rigidity of the compensator, which is calculated by the formula:

$$C = P/\Delta, \tag{10}$$

where P – compression force;

Δ – value of upsetting of the compensator.

The variation of the overlap coefficient (K_{per}) is carried out by shifting of the upper plate and is defined as:

$$K_{per} = F_{per.otv}/F_{otv}, \tag{11}$$

where $F_{per.otv}$ – overlapping area of the two plates openings;

F_{otv} – area of the plate openings.

According to the data of the works [6] the overlap coefficient in relation to the smaller opening of elastic plate of universal compensator of slide directions errors is calculated by the formula:

$$K_{per} = \frac{1}{\pi}\left(\arcsin A - A\sqrt{1 - A^2} + \omega^2 \arcsin\frac{A}{\omega} - \frac{1}{2}\sqrt{\omega^2 - A^2}\right), \tag{12}$$

where are $A = \sin\alpha$, $\omega = r_2/r_1$ (according to the scheme on Fig. 2).

The shape factor is defined as:

$$\Phi = F_{bok}/F_{op}, \tag{13}$$

where $F_{bok} = 4 \cdot \pi \cdot R \cdot (h_1 + h_2)$ – lateral area of the compensator,

$F_{op} = (2 \cdot F_{op.pl} - F_{per.pl})$ – supporting surface of the compensator ($F_{per.pl}$ – overlapping area of the two elastic plates).

In this case, take into account the irregularity of deformation caused by distortion of the slide axis on an angle (φ) at the certain technological compression force (P). The angle of misalignment is defined as:

$$\varphi_0 = \operatorname{arctg}(\Delta_{komp}/2 \cdot R), \tag{14}$$

where $\Delta_{komp} = 2.5 \cdot \Delta_{press}$ – maximum misalignment of the compensator, here $\Delta_{press} = P / C$ – maximum misalignment of the press, C – rigidity of the open type press ($C = 300\ldots1200$ [7]).

The upsetting of compensator during compressing should not exceed 20...25 % of the common height of the elastic plates. Then the total height of the compensator plates can be determined as:

$$(h_1 + h_2) = \Delta_{komp} / 0.2 . \qquad (15)$$

The using of universal elastic rotary compensator during the manufacturing of work-parts by drawing and forming operations is considers in this manuscript. The generalized scheme of process of the first drawing operation [8] is illustrates on the Fig. 3.

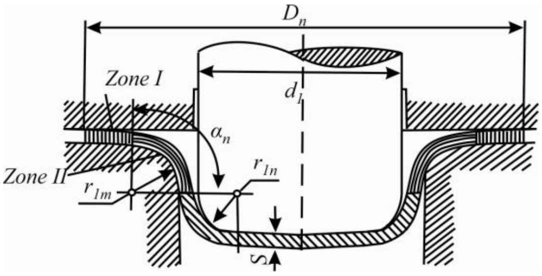

Fig. 3. The generalized process scheme of the first drawing operation:

I zone – a plane of a clamping; II zone – an area on the rounded part of the die-matrix; D_H – current diameter of sheet work-piece; d_1 – diameter of part after drawing; r_{1n} and r_{1m} – radiuses of curvature of the die-punch and die-matrix; α_H – angle of a curvature of die-matrix; S – thickness of the sheet work-piece

The force at the initial stage of drawing operation (P_{v0}) of the cylindrical type part without flange was calculated by the formula [7]:

$$P_{v0} = \pi \cdot d_1 \cdot S \cdot \sigma_b \cdot k_1 , \qquad (16)$$

where σ_b – strength tension of the material of the sheet work-piece;

k_1 – coefficient for the first drawing ($k_1 = 0.8$).

The current force of drawing operation (P_B) is defined as [8]:

$$P_B = \beta \cdot \sigma_{sr} \cdot (1 + f \cdot A) \cdot \left(\ln \frac{R}{r_1} - f \cdot A \right) + \frac{f \cdot Q}{\pi \cdot R \cdot S} + \frac{S}{2 \cdot r_{1m} + S} \cdot \sigma_b , \qquad (17)$$

where $\beta = 1.1$ and $\sigma_{sr} = 0.5 \cdot \sigma_b$;

f – friction coefficient, which has depends from the types of material and technological lubricant (took the $f = 0.128$);

$A = \frac{\pi}{2} - \frac{\pi \cdot a}{90\sqrt{a^2 - 1}} \cdot \mathrm{arctg}\left(\frac{a+1}{\sqrt{a^2 - 1}} \right)$, here are $a = 1 + \frac{x_1}{r_{1m} + 0.5 \cdot S}$ and $x_1 = \frac{d_1 - S}{2}$;

$R = D_H / 2$ – radius of the sheet billet (see Fig. 3);

$r_1 = d_1 / 2$ – radius of the part after drawing (see Fig. 3);

$Q = \pi \left[(D - 2 \cdot L_x)^2 + (d_1 + 2 \cdot r_{1m})^2 \right] q / 4$ – contact pressure, here D – current diameter of drawing work-piece, L_x – move of the slide.

The final height (L_B) of the work-piece at this stage is calculated as:

$$L_B = (D - d_1)/2 - h_{otv} , \qquad (18)$$

where h_{otv} – height of forming cavities.

The force of forming (P_F) of the cavities is determined by the formula [7, 8]:

$$P_F = n \cdot F_x \cdot k_{ff} \cdot S^2 \cdot \sigma_b(\varepsilon), \qquad (19)$$

where n – quantity of forming cavities;

F_x – current area of the formed relief;

k_{ff} – friction factor (took the $k = 0.8$ [7]);

$\sigma_b(\varepsilon)$ – functional dependence of the strength tension (σ_b) of the material of the sheet work-piece from the degree of work-piece deformation (ε).

The change of the area (F_x) from ($\pi \cdot d^2_{otv.in}/4$) to ($\pi \cdot d^2_{otv.k}/4$) and the change of the diameter (d_x) of the cavity from ($d_{otv.in}$) to ($d_{otv.k}$) have a linear nature.

The dependence $\sigma_b(\varepsilon)$ was worked out after the processing of the data [9]:

$$\sigma_b(\varepsilon) = -1115.4 \cdot \varepsilon^2 + 2129.2 \cdot \varepsilon + 394.35. \qquad (20)$$

The value (ε) was determined by the formula [7, 8]:

$$\varepsilon = 1 - 0.5 \cdot \left(\rho_1 + m_1' \Big/ \sqrt{1 - \rho_1^2 + m_1'^2} \right),$$

where are $m_1' = R_{BH}/d_{otv.in}$ and $\rho_1 = R_H/d_{otv.in}$, here $R_{BH} = (d_x - S')/2$ and $R_H = (d_x + S')/2$ – inner and outer radiuses of cavity, $S' = S\sqrt{d_{otv.in}/d_x}$ – lateral thickness of cavity.

The force of deformation at the stage of drawing-forming is determined by the formula:

$$P_{BF} = P_B + P_F. \qquad (21)$$

The special software is written in Borland Delphi 7 on the base of the developed mathematical model of drawing-forming processes and work of universal elastic rotary compensator. The interface of this software is shown in Fig. 4.

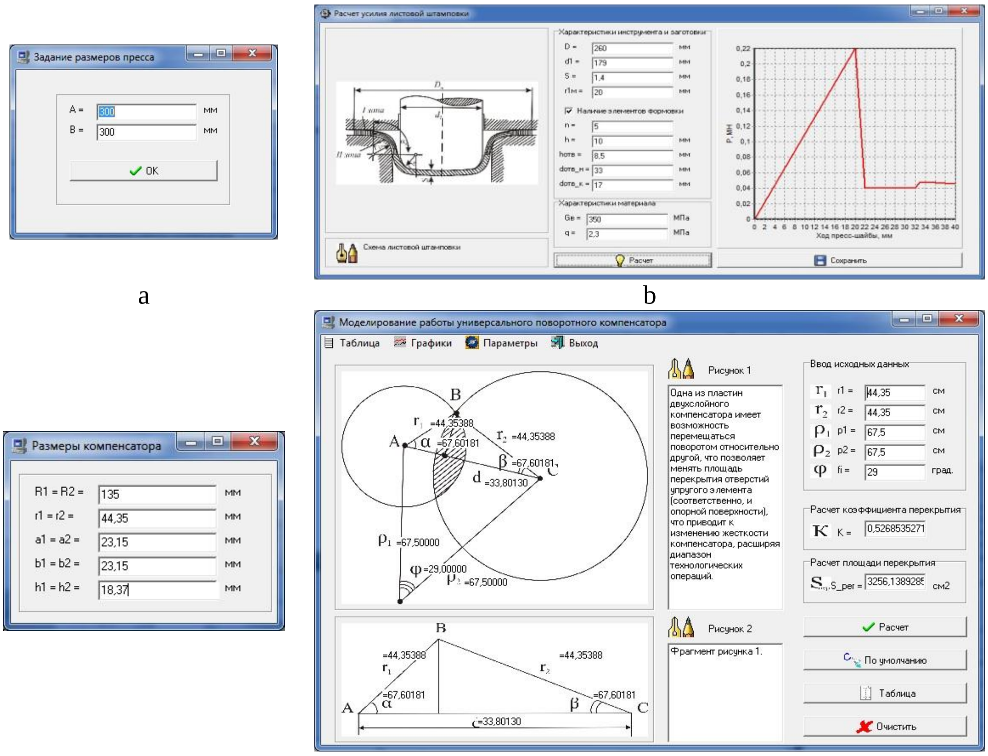

Fig. 4. The interface of developed software:
a – a sizing the press plate; b – the calculation of force modes of the drawing-forming operation; c – the calculation of compensator dimensions; d – the modeling results of compensator work

As the initial data the size of the die-plate was set: $A = 300$ mm and $B = 300$ mm. The drawing-forming operation was modeled for condition of manufacturing of the part “the Lower Bottom” for the OP-6 type fire-extinguishers (Fig. 5). The radiuses of curvature of the die-punch and die-matrix are $r_{1n} = 20$ mm and $r_{1m} = 20$ mm correspondingly. The forming operation is intended to get 5 cavities which are disposed at a distance of 60 mm from the part axis. The material of used sheet billet is a steel St.3 brand (≤ 0.22 C), thickness of a sheet is $S = 1.4$ mm, the initial diameter $D = 260$ mm. The views and dimensions of the part are shown on the Fig. 5.

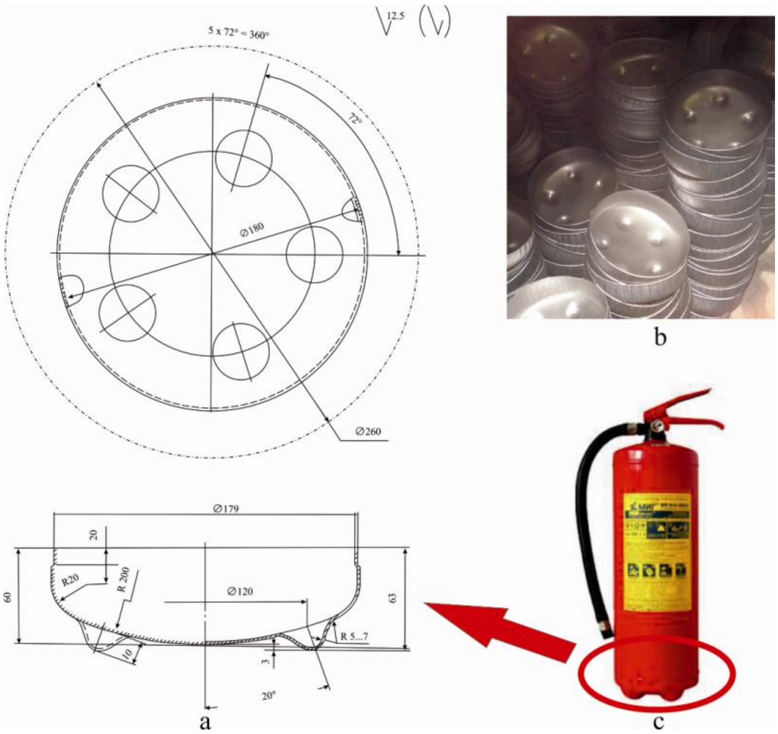

Fig. 5. The views and dimensions of the "The Lower Bottom" for fire-extinguisher OP-6 type

Based on received results the initial dimensions of the universal elastic rotary compensator (Fig. 4) are calculated: radiuses of elastic plates $R_1 = R_2 = 135$ mm, the radiuses of the plate openings $r_1 = r_2 = 44.35$ mm, the distance between adjacent openings in the elastic plates and between the openings and the compensator walls $a_1 = a_2 = b_1 = b_2 = 23.15$ mm, the height of the elastic plates $h_1 = h_2 = 18.37$ mm. There found for optimum rigidity of compensator is upper elastic plate must turn relatively to lower elastic plate at the angle $\varphi = 29$ degrees.

CONCLUSIONS

The using of the elastic compensators is a perspective and low-cost way to reduce of the distortions of slide direction at the “press-die” system of press equipment. There was developed a mathematical model and software for calculation of the parameters of the universal elastic rotary error compensators of the “press-die” system.

Software allows to calculate: 1) the compressive force of the compensator depending on the executing technological operation; 2) the shape factors of the elastic compensator and determinate of optimal geometric dimensions for its design; 3) the overlap coefficient and determinate the optimum angle of rotation of the upper plate of the compensator for achieving of the necessary rigidity.

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