Calculation method and simulation of work of the ring elastic compensator for sheet-forming

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Abstract. The design of the elastic ring compensator of «press-and-die» system errors, the method and software for calculating its geometric parameters are given in the article. The developed method is based on the account of unevenness of the radial and altitudinal deformation (barrel-type shape) of the elastic working element made of polyurethane. A specific example of computer implementation of the developed mathematical model for calculating the sizes of such a compensator for steel-forming operations on an open-crank press is made. Approbation of the compensator was carried out in industrial conditions.

1 Introduction

The accuracy of «press-and-die» systems are affected from misalignment of the slide axis to press table surface in the loaded state, from distortion in the gaps between press and slide guides, as well as cumulative errors of the punching unit. [1-4]. Mechanical and elastic compensators are widely used to reduce errors in the «press-and-die» system of open-crank presses and ring compensators of elastomeric materials has not been studied enough. This makes it difficult to calculate their design parameters.

2 Analysis of literature and the problem formulation

There are two basic approaches to eliminate the influence of deformation of the C-shaped type frame on the alignment of «press-and-die» system. The first approach is the closure of open C-shaped type frames with using the ties [5], which greatly reduces its deformation. A second approach for solving the skew problem is to eliminate the misalignment between the upper and lower basing plates with various additional devices or elements (fig. 1, a). These devices or parts are called «compensators». A further alternative approach to reducing of errors of the «press-and-die» system can be die-free [6] and impression-free [7-8] methods of metal-forming.

The main purpose of installing a skew compensator in forging equipment is to ensure the transfer of the operating force from basic die elements, which have lost alignment as a result of deformation of the frame, to coaxial (parallel) basic die surfaces (fig. 1, a).

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Fig. 1. The opening of the C-shaped press frame (a) and the design of the elastic ring compensator (b), and its upgrading design (c): 1 – shank; 2 – compensator; 3 – die line connector; 4 – circuit of a formed product; 5 – slider; 6 – fixing pin; 7 – fasteners; 8 – upper plate; 9 – lower plate; 10 – frame; φ – skew angle of the slider

A promising direction to reduce of distortions in the «press-and-die» system is the using of different constructions of compensators, which are made, for example, of different brands of polyurethane. The choice of polyurethane is complicated by wide range of functional properties of the polyurethanes from various manufacturers. Recommendations for optimization of this choice are given in [9]. The method of calculating the optimum design parameters is discussed in [10]. Also, an automated method of calculation for the reconfigurable polyurethane compensators, taking into account the errors of "press-and-die" system, is proposed [11].

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Polyurethane elements are widely used for compensation of power and geometric deviations in metal forming technologies [10-13].

The method of fastening the upper plate to the press slider through an elastic compensator (fig. 1, a) is considered in [10, 11]. The example of the design of the ring elastic compensator is shown on fig. 1, b. However, the work of the ring compensator can be accompanied by cracking of the elastic plate because during the influence of deformation force the material can flow into non-technological openings, forming regions of increased concentration of stresses and unregulated deformations.

To solve this problem, the variant of the upgrading design of the compensator (fig. 1, c) was developed, according to which the ring elastic compensator is placed between two ground metal plates with a central hole and connected to them using an adhesive bond.

The disadvantage of the above-described method is the lack of optimal bonding conditions (the glue is applied to the entire surface area of the contact surfaces of the protective plates and the elastic element), which should be determined on the basis of the structural and technological features of the ring compensator and the physical and mechanical characteristics of the glue.

3 Purpose of the work

The purpose of this article is to develop a mathematical model and study the deformations of the ring elastic compensator for modeling its shaping under the conditions of the "press-and-die" system work with slider skewing, as well as the calculation of tangential stresses in the adhesive bond with protective plates to determine the optimum gluing parameters, which will help to reduce adhesive consumption, tangential stresses, increase the reliability of fastening the compensator and improve the working conditions.

4 Research material

The compression pre-tests were carried with different shape samples from polyurethane brand SKU-PFL-100 (CKY-ПФЛ-100, 100 Shore hardness). The approximating dependence between the pressures during compression of polyurethane q and the degree of upsetting $\varepsilon = (H_0 - h) / H_0$ (where H_0 is the initial height of the compensator, h is the height of the deformed compensator) for $\varepsilon \leq 0.3$ is received as the result of studying the influence of the shape of the compensator on its elastic properties [10, 11]:

$$q = 52\varepsilon + 1.92. \quad (1)$$

A ring polyurethane element (fig. 2) with an outer radius R , an inner radius R_n and a height H_0 was considered. The support area of the compensator was determined as $F = \pi(R^2 - R_n^2)/4$. Misalignment of the slide at an angle φ causes the uneven deformation along the height of the compensator (fig. 2). Moreover, the maximum of angle deviation should not exceed $\varphi \leq \arctg(H_0/2R)$.

Fig. 2. Uneven deformation of the ring elastic compensator

The upsetting of the ring elastic compensator is accompanied by a simultaneous increase in the outer radius R and a decrease in the inner radius R_n . The changes in the radii ΔR and ΔR_n by analogy with the flow of a deformed ring metal preform at four characteristic points were considered. Without considering the shear strain, we had: $\Delta R_3 = \Delta R_4$ и $\Delta R_{n3} = \Delta R_{n4}$. Based on the accepted assumptions, only three characteristic points were considered.

The deformation of the ring elastic compensator is characterized by the presence of a neutral flow line of the material. The boundary of the material flow is the surface defined by the radius R_k . The contact tangential stress τ at points with radius R_k is equal to zero. At the same time, its average value was determined as:

$$\tau = \psi \tau_s; \quad \tau_s = q/\sqrt{3}; \quad \psi = \mu + \frac{1}{8} \cdot \frac{R - R_n}{H_0} \cdot (1 - \mu) \cdot \sqrt{\mu}, \quad (2)$$

where μ is the coefficient of friction.

The radius of the critical surface R_k , as well as the change in the outer radius ΔR and the inner radius ΔR_n at the i-point not taking into account the barrel shape and taking into account the unevenness of the radial deformation along the height were determined by the methods [I.Ya. Tarnovsky, 1963; L.A. Shofman, 1961]. However, preliminary calculations showed a significant difference in the values of R_k which showed the need to refine the dependence to determine the dimensions of the ring element with respect to barrel shape:

$$R_{k_i} = 63.25 \sqrt{\frac{R^2 \cdot R_n^2}{8000R^2 \cdot R_n^2 \cdot \ln \frac{R}{R_n} + 1599h_i^2(R^2 - R_n^2)}}. \quad (3)$$

The change in the outer radius ΔR and the outer radius ΔR_n at the i point was calculated as:

$$\Delta R_i = 0.375 \cdot R \cdot (H_0 - h_i) / H_0 \cdot (1 - R_{ki}^2 / R^2);$$

$$\Delta R_n = -0.375 \cdot R_n \cdot (H_0 - h_i) / H_0 \cdot (1 - R_{ki}^2 / R_n^2). \quad (4)$$

The compression pressure p_i at the upsetting of the ring polyurethane compensator is distributed unevenly along its diameter, so the calculation was applied for each deformable part on the four sides of the ring compensator taking into account the unevenness of deformation of the elastic element.

In order to achieve optimum bonding characteristics, the application of glue (diagram FL, diagram P, diaflex) [14] should be carried out only on areas limited by the shear stress zone τ with values not exceeding the critical shear stresses τ_k (fig. 2). According to the proposed method, a number of diagrams of tangential stresses are constructed depending on the geometric parameters of the compensator and zones are defined for which $\tau < \tau_k$ (fig. 2). The tangential stress τ in the adhesive layer of the polyurethane ring compound with metal protective plates is calculated by the method of Lamé, described, for example, in [15].

The dependence of the distances from the flow separation line R_k to the outer edge (a) and the inner edge (b) of the compensator from three factors (S/D , S/H_0 , ε) was established using the method of experiment planning (2^3):

$$a = 10.283 + 0.034 \frac{S}{D} + 0.46 \frac{S}{H_0} - 1.109 \varepsilon + 0.135 \frac{S}{D} \cdot \frac{S}{H_0} -$$

$$- 0.073 \frac{S}{H_0} \cdot \varepsilon - 0.034 \frac{S}{D} \cdot \varepsilon - 0.015 \frac{S}{D} \cdot \frac{S}{H_0} \cdot \varepsilon; \quad b = 0.929 a. \quad (6)$$

where S is the wall thickness of the compensator; D is outer diameter of the compensator.

The special software is written on the base of the developed calculation method. This software allows to calculate the dimensions of the ring elastic compensator after the upsetting with and without taking into account the barrel shape and also determine the bonding areas of the ring compensator with protective plates. The research of the work of the elastic ring compensator with parameters $R = 130$ mm, $R_n = 32.5$ mm, $H_0 = 13$ mm (fig. 3, a) was carried out. The angle $\varphi = 0.1$ rad. and the force $P = 0.2$ MN (fig. 3, a). According to the results of simulation (fig. 3, b), it is advisable to apply the adhesive to the areas of the compensator surface limited by distances $a_1 = 14.01$ mm and $a_2 = 13.94$ mm to the outer edge, $b_1 = 13.01$ mm and $b_2 = 12.946$ mm to the inner edge of the neutral line, $R_{k1} = 74.95$ mm and $R_{k2} = 74.99$ mm; the width of the adhesive layer from the maximum deformation side is 27.02 mm and from the minimal deformation side is 26.9 mm. As a result, the consumption of the adhesive compound was reduced by 72 %.

The upgraded design of the ring elastic compensator was tested during solving of the problem of increasing the accuracy of the dimensions of the stamped part "Bottom" of the washing machine "Donbass" (fig. 4) in the conditions of the enterprise JSC "Elektrobytpribor" (Mariupol).

Fig. 3. Software interface for modeling of the work of the ring elastic compensator taking into account the barrel shape (a) and plotting the shear stresses in the adhesive layer (b): 1 – The ring elastic compensator; 2 – Table, Graphics, Parametrs, Exit; 3 – Initial data; 4 – Input, Upsetting, Gluing; 5 – Before upsetting; 6 – Without taking into account the barrel shape (by I.Ya. Tarnovsky); 7 – Without taking into account the barrel shape (by L.A. Shofman); 8 – With taking into account the barrel shape; 9 – Diagram of the compression pressure; 10 – Save; 11 – Parametrs; 12 – Gluing; 13 – Simulation, Table of values; 14 – Diagram of the tangential stresses in the adhesive layer; 15 – Compensator sizes; 16 – Calculation

Fig. 4. The bottom of the washing machine "Donbass" (a) and a fragment of its drawing (b)

The compensator in the form of a flat ring made of polyurethane of SKU-PFL-100 grade had an outer diameter of 260 mm, an inner diameter of 65 mm and a height of 13 mm (fig. 1, b); The calculated thickness of two ground metal plates (fig. 1, c) was 0.8 mm (steel X18N9T). The operation was carried out on a single-crank press of a single action with a C-shaped frame with a nominal force of 1 MN (model KE 2130A).

The depth of molded ribs of activator jack (steel X18H9T) was measured from the front and rear of the press with depth gauge at six points on the extreme edges of the axis. Measurements were carried out using the compensator and without it. The upgraded design of the compensator made it possible to reduce the difference in depth of the ribs of the opening under the activator by 64-73 %.

5 Conclusions

Based on the performed analysis of the ring elastic compensator work under conditions of the "press-and-die" system work with slider skewing, its design, methodology and software for calculating its sizes after the upsetting were developed. This made it possible to evaluate the slider skew on the shaping of the elastic element, to determine the dimensions of the areas for bonding the elastic compensator to the protective plates, and to minimize shearing stresses in the adhesive layer by 72% and to improve the quality of the finished metal products from the sheet by 64-73%.

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