Investigation of application of flanging process for obtaining convex parts

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Abstract. In this paper the new method of forming based on flanging is investigated. The obtained experimental results supported the theoretical conclusions and allowed us to define geometric dimensions of a blank for forming of the thin axisymmetric parts with minimal thickness fluctuations. This analysis serves as a foundation for further design of the technological process.

1. Introduction

Development of new designs in the sphere of aircraft engines [1, 2] is limited by the possibilities of the know sheet metal stamping methods to obtain needed parts, including methods of obtaining thin-walled axisymmetric shells, which are widespread and have a variety of shapes and sizes. Investigation of the mechanism of the forming process for parts [3-8] with minimal thickness fluctuations [9] by solving the theoretical equations and the posibility of the application of the improved methods could significately lower the labor intensity of the manufacturing.

2. Methods and theoretical foundations

Let us analyse one of the methods for manufacturing thin-walled convex parts. The experimental die is presented as a simplified design, in which moving sectors are presented as 4 segments of a conical shell split along the generatrix. During the forming, the moving sectors form a gap, which is constant along the length and is similar between the two neighboring sectors. Such conditions are fulfilled due to the action of the friction forces on the contact surface between the elastic elements and the moving sectors. The friction forces also restrain the movement of the sectors along the plane perpendicular to the axis of the stamp.

The distinctive feature of this stamp is the presence of the conical hollow elastic element, inner surface of which corresponds to the outer surface of the assembled segments. In this case the process could be split into two stages. In the first stage the conic angle of the workpiece and the conic angle of the elastic element must comply with the following condition:

$$tg\alpha_{blank} \le f_{el}\,, \tag{1}$$

where f_{el} - maximal friction coefficient between the blank and the elastic element;
α_{blank} - conical angle of the blank.

On the second stage, when the workpiece is pressed to the die (figure 1 right side), it becomes clamped due to the action of the friction forces from the elastic element and due to the friction forces from the die as well, and cannot move towards the smaller edge, even in the cases of large conic angles of the generatrix of the die, which not comply with the expression (1), but satisfy the following condition:

$$tg\alpha_{part} \le f_{el} + f_1, \quad (2)$$

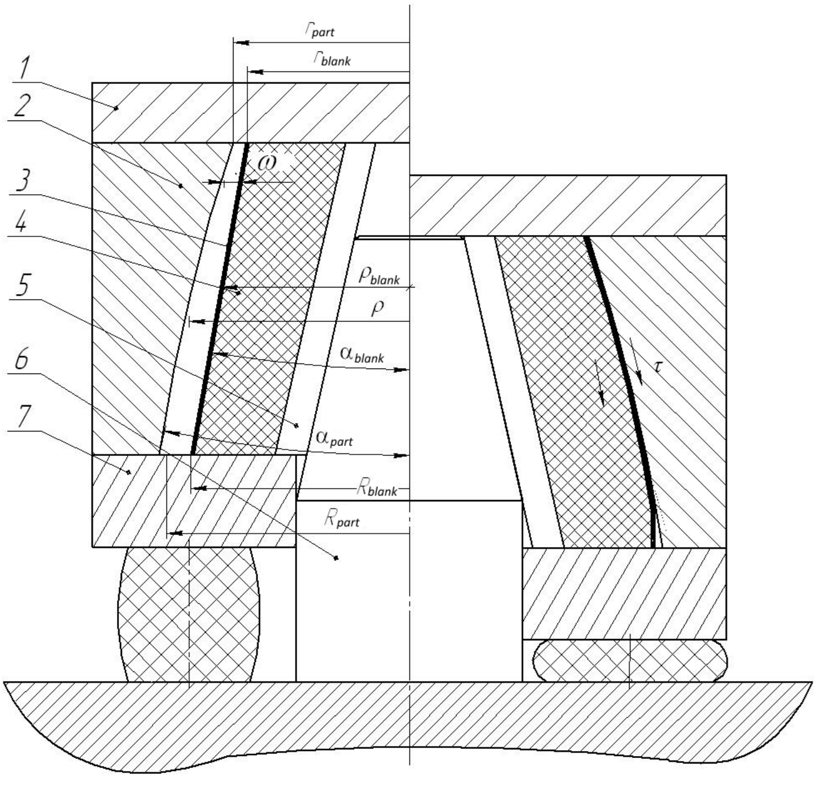
where f_1 - the friction coefficient between the workpiece and the die.

In the view of the foregoing, the generatrix equation for the conical surface of the workpiece could be written as follows:

$$\rho_{blank} = a + b\rho,$$

where ρ - the coordinate on the work surface of the die.

This method of flanging allows calibration by 5-7% of the blank, obtained by bending of the flat sector welded along the generatrix.



1 – upper plate; 2 –die; 3 –blank; 4 –elastic element; 5 –e moving sectors; 6 –conical punch; 7 –lower plate; ω - minimal gap between the diameters of the blank and the die

Figure 1. The scheme of the flanging of the thin-walled conical part.

The coefficients a and b could be found from the following conditions:

at $\rho = R_{part}$; $\rho_{blank} = R_{blank}$;
at $\rho = r_{part}$; $\rho_{blank} = r_{blank}$.

Let us write the line equation:

$$\rho_{blank} = R_{blank} - \frac{R_{blank} - r_{blank}}{R_{part} - r_{part}}\left(R_{part} - \rho\right), \tag{3}$$

where the numerator equals:

$$R_{blank} - r_{blank} = \chi_{blank} \sin \alpha_{blank}, \tag{4}$$

where χ_{blank} - the length of the generatrix along the median surface of the blank;
R_{blank} - the radius of the larger edge of the blank;
r_{blank} - the radius of the smaller edge of the blank;
R_{part} - the radius of the larger edge of the part;
r_{part} - the radius of the smaller edge of the part.

The length of the generatrix could be found from the consistency of the volume condition [10]:

$$\varepsilon_\rho + \varepsilon_\theta + \varepsilon_S = 0, \tag{5}$$

where $\varepsilon_\rho, \varepsilon_\theta, \varepsilon_S$ - the deformations in the meridional and tangential directions and in the direction of the thickness of the part.

Taking into account the following geometrical ratios $R_\rho = \infty$, $\alpha_{part} = \alpha_{blank} = const$, the forces balance equation [10], in the absence of the friction forces on the outer surface, takes the following form:

$$\rho \frac{d\sigma_\rho}{d\rho} + \sigma_\rho - \sigma_\theta\left(1 + f_{el} \cdot ctg\alpha_{blank}\right) = 0, \tag{6}$$

where α_{blank} - the angle between the generatrix of the blank and the axis of the symmetry.

We use the transversely isotropic body plastisity condition:

$$\sigma_\theta = \beta\sigma_S = \sigma_S^*, \tag{7}$$

where σ_S - the yield stress;
β - the coefficient equals to $\beta = \sqrt{2}\sqrt{1-\mu}$ [10];
μ - the coefficient of the anisotropy of a transversely isotropic body.

The solutions (6) and (7), without the considiration of a hardening and alteration of thickness, takes the following form:

$$\sigma_\rho = \beta\sigma_S\left(1 + f_{el} \cdot ctg\alpha_{blank}\right)\left(1 - \frac{\overline{\rho}}{\overline{R}_{part}}\right) \geq 0, \tag{8}$$

where $\overline{\rho} = \frac{\rho}{r_{part}}$; $\overline{R}_{part} = \frac{R_{part}}{r_{part}}$.

Now we compose the forces balance equation of a infinite-small element on the smaller edge side and by making similar transformation as we did for the other side of the blank (the larger diameter edge), we get:

$$\sigma_\rho = \beta\sigma_S \left(1 + f_{el} \cdot ctg\alpha_{blank}\right)\left(1 - \frac{1}{\bar{\rho}}\right) \geq 0\,, \tag{9}$$

If we equate (8) and (9), we get:

$$\left(1 + f_{el} \cdot ctg\alpha_{blank}\right)\left(1 - \frac{\bar{\rho}}{\bar{R}_{part}}\right) = \left(1 + f_{el} \cdot ctg\alpha_{blank}\right)\left(1 - \frac{1}{\bar{\rho}}\right). \tag{10}$$

Out of (10) we find the current radius, considering it as an average value:

$$\bar{\rho}_{aver} = \sqrt{\bar{R}_{part}}\ . \tag{11}$$

By the equation (11) we can find the radius of the elements in which the stresses σ_ρ are equal on the side of the larger and the smaller edges. By substituting $\bar{\rho}_{aver}$ in the equations (8, 9), the ratios could be found for $\bar{R}_{part} = 1.5$; $\alpha_{part} = 20°$; $f_{el} = 0.15$: $\frac{\sigma_u}{\beta\sigma_S} = 0.187$.

We take the assumption that the ratio of the stresses $\sigma_\rho / \sigma_\theta$ in the whole area of the deformation is close to zero, since the stresses on the edges of the blank are equal to zero and the increase of the steresses in the middle portion is insignificant. In such conditions, the blank can deform along the conical punch, reducing its length along the generatrix. Let us find the ratio of f_{el} and α_{blank} at which the blank would not slide out of the punch (see figure 2).

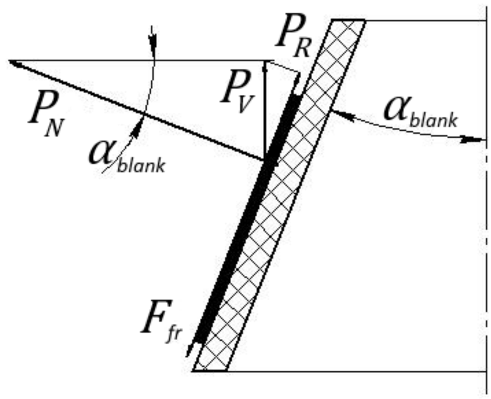


Figure 2. The scheme for identifying the condition which allows the deformation of the blank.

$$F_{fr} = P_N f_{el}\,; \tag{12}$$

$$P_V = P_N \sin\alpha_{blank} \cdot \cos\alpha_{blank}\,, \tag{13}$$

where P_N – the normal component of the force from the pressure.
From solving the equations (12) and (13) we get:

$$f_{el} \geq 0.5 \sin 2\alpha_{blank}\,. \tag{14}$$

Taking into account the accepted assumption, the linking equation takes the simplier form:

$$\varepsilon_S = -(1-\mu)\varepsilon_\theta . \tag{15}$$

For the deformation calculations we accept that:

$$\varepsilon_\rho = (\chi_{blank} - \chi_{part})/\chi_{blank} \;;\; \varepsilon_S = (S_{part} - S_{blank})/S_{blank} \;;\; \varepsilon_\theta = 1 - \frac{\bar{\rho}_{blank}}{\bar{\rho}} , \tag{16}$$

$$\chi_{blank} = \frac{\chi_{part}}{1 - \left(1 - \bar{S}_{part}\right)\frac{\mu}{1-\mu}} , \tag{17}$$

where χ_{part} - the length of the generatrix on the middle surface of the part;

S_{blank} - the thickness of the blank;

S_{part} - the thickness of the part.

The values of the lengths of the generatixes of the part could be found as:

$$\chi_{part} = R_\rho(\alpha_n - \alpha_0) = R_\rho \alpha_{blank} \text{ (see figure 3)}. \tag{18}$$

If we write the equation (3) in the dimentionless form, then taking into accout (4), we get:

$$\bar{\rho}_{blank} = \bar{R}_{blank} - \frac{\bar{\chi}_{blank} \sin \alpha_{blank}}{\bar{R}_{part} - 1}\left(\bar{R}_{part} - \bar{\rho}\right) , \tag{19}$$

$$\bar{\rho}_{blank} = \frac{\rho_{blank}}{r_{part}}; \quad \bar{R}_{blank} = \frac{R_{blank}}{r_{part}}; \quad \bar{R}_{part} = \frac{R_{part}}{r_{part}}; \quad \bar{\chi}_{blank} = \frac{\chi_{blank}}{r_{part}} ; \; 1 \le \bar{\rho} \le \bar{R}_{part} .$$

If we put $\bar{\rho}_{blank}$ in the expression (15) and taking into account the technologically possible thickness we replace $S_{part} = S_T$ in the equation (16), we get:

$$\bar{S}_T = 1 - (1-\mu)\left[1 - \frac{\bar{R}_{blank} - \bar{\chi}_{blank} \sin \alpha_{blank}\left(\bar{R}_{part} - \bar{\rho}\right)/\left(\bar{R}_{part} - 1\right)}{\bar{\rho}}\right], \tag{20}$$

where $\bar{S}_T = \dfrac{S_T}{S_{blank}}$.

The value of the independent relative radius $\bar{\rho}$ for the convex part (see figure 3) is:

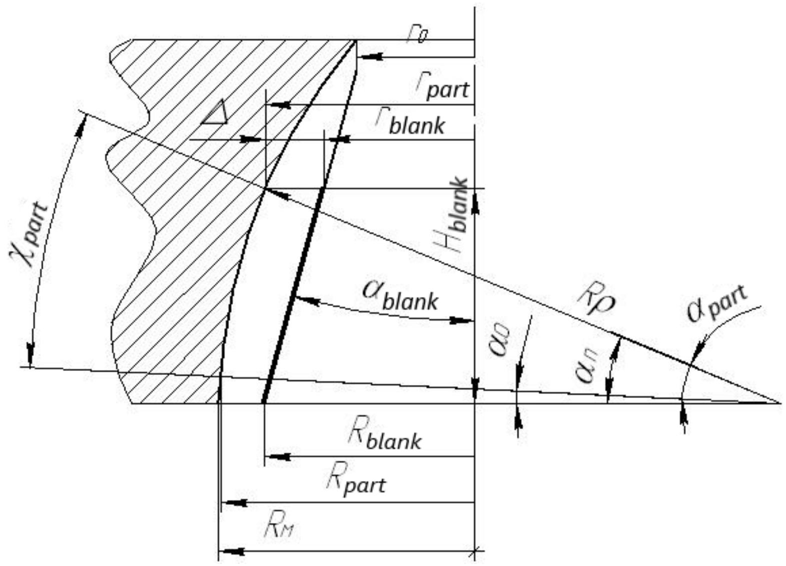
$$\bar{\rho} = \bar{R}_\rho \cos \alpha - \bar{a} , \tag{21}$$

where $\bar{a} = \dfrac{a}{r_{part}}$ - the distance between the center of the radius R_ρ and the axis of symmetry.

The equation of the generatrix of the conical surface of the blank is (see figure 3):

$$\bar{\rho}_{blank} = \bar{R}_{blank} - \frac{\bar{R}_{blank} - \bar{r}_{blank}}{\alpha_n - \alpha_0}(\alpha - \alpha_0) , \tag{22}$$

$$\bar{\rho}_{blank} = \bar{R}_{blank} - \frac{\bar{R}_{blank} - \bar{r}_{blank}}{\alpha_n - \alpha_0}(\alpha_n - \alpha) . \tag{23}$$



α_n - angle formed by the radius R_ρ drawn between the large edge of the blank and the smaller edge of the part; α_0 - angle formed by the radius R_ρ drawn between the large edge of the blank and the larger edge of the part; H_{blank} - height of the blank; R_M - Radius of the larger edge of the die; Δ - gap between the smaller edge of the blank and the working surface of the die

Figure 3. The scheme of the geometrical dimensions of the blank and the die with the convex working surface.

In the light of the found relations (22) and (23), we can find the values of the relative thickness:

$$\bar{S}_T = 1-(1-\mu)\left[1-\frac{(\bar{R}_{blank}-\bar{r}_{blank})\dfrac{\alpha-\alpha_0}{\alpha_n-\alpha_0}}{\bar{R}_\rho\cos\alpha-\bar{a}}\right]. \qquad (24)$$

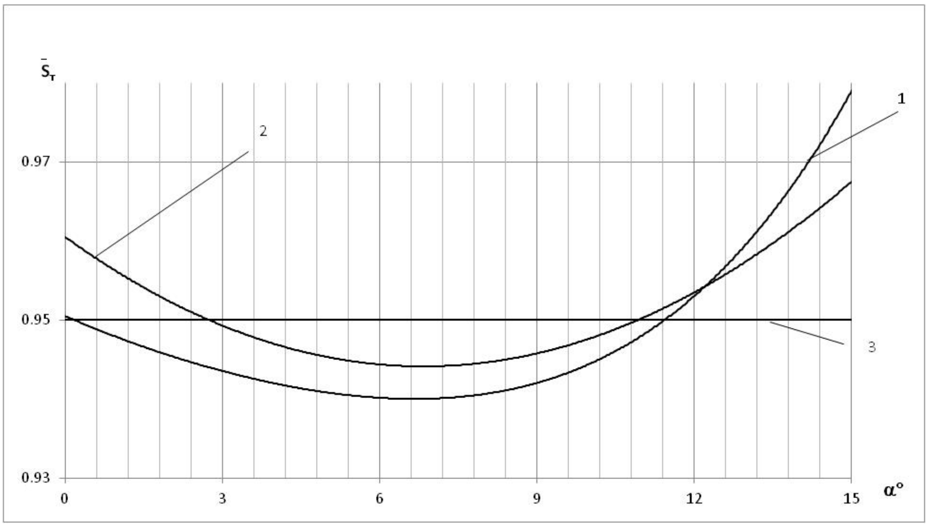
Now we can write the condition of the minimal tickness fluctuations relative to the constant set tickness, accepting that $\bar{R}_{blank}-\bar{r}_{blank}=\bar{\chi}_{blank}\sin\alpha_{blank}$:

$$\int_{\alpha_0}^{\alpha_n}\left\{\bar{S}_{part}-1+(1-\mu)\left[1-\bar{R}_{part}-\frac{\bar{\chi}_{blank}\sin\alpha_{blank}\dfrac{\alpha-\alpha_0}{\alpha_n-\alpha_0}}{\bar{R}_\rho\cos\alpha-\bar{a}}\right]\right\}^2\to\min\ . \qquad (25)$$

As the variable parameter we accept the angle of the generatrix $\sin\alpha_{blank}$ at the set larger radius of the blank. The solution is written in the form of the finite differences:

$$\sin\alpha_{blank}=\frac{(1-\mu)\overline{R}_{blank}\sum_{i=1}^{n}\frac{(\alpha_i-\alpha_0)}{(\overline{R}_\rho\cos\alpha_i-\overline{a})^2}-(\overline{S}_{part}-\mu)\sum_{i=1}^{n}\frac{\alpha_i-\alpha_0}{\overline{R}_\rho\cos\alpha_i-a}}{(1-\mu)\overline{\chi}_{blank}\sum_{i=1}^{n}\frac{(\alpha_i^2-\alpha_0)^2}{(\overline{R}_\rho\cos\alpha_i-a)^2(\alpha_n-\alpha_0)}}. \quad (26)$$

The changes of the thickness of the part with the curved generatrix are presented in figures (figure 4,5).



1- $\mu=0.5$ *;* $\alpha_{blank}=3.41°$ *; 2 -* $\mu=0.6$ *;* $\alpha_{blank}=5.18°$ *; 3 – set thickness value*

Figure 4. The distribution of the technologically possible thicknesses of the thin-walled convex part at the different values of the coefficient of the anisotropy of a transversely isotropic body during variation of the angle of the generatrix of the thin-walled blank. ($\overline{R}_{part}=1.144;\ \overline{R}_\rho=4.238;\ \overline{\chi}_{part}=1.109;$ $\overline{a}=3.094;\ \alpha_0=0;\ \overline{S}_{part}=0.95;\ \alpha_{part}=15°;\ \overline{R}_{blank}=1.027$)

The analysis of the graphs suggests, that along with the growth of the coefficient of the anisotropy of transversely isotropic body, the thickness fluctuations decrease.

Let us write the condition of the minimal thickness fluctuations for the thin-walled part for two variable parameters of the equation of the generatrix of the conical surface of the blank, taking into account the expression (22):

$$\int_{\alpha_0}^{\alpha_{II}}\left\{\overline{S}_{part}-1+(1-\mu)\left[1-\frac{a_b+b_b(\alpha_n-\alpha)}{\overline{R}_\rho\cos\alpha-\overline{a}}\right]\right\}^2 d\alpha\to\min , \quad (27)$$

where $a_b+b_b(\alpha_n-\alpha)$ - the equation of the generatrix of the conical surface of the blank for the thin-walled convex part.

After simplifying the equation (27), we variate the expression (26) by two parameters a_b and b_b:

$$\int_{\alpha_0}^{\alpha_{II}} \left\{ \left[\bar{S}_{part} - \mu - (1-\mu) \frac{a_b + b_b(\alpha_n - \alpha)}{\bar{R}_\rho \cos\alpha - \bar{a}} \right] \frac{d\alpha}{\bar{R}_\rho \cos\alpha - \bar{a}} = 0 \right., \tag{28}$$

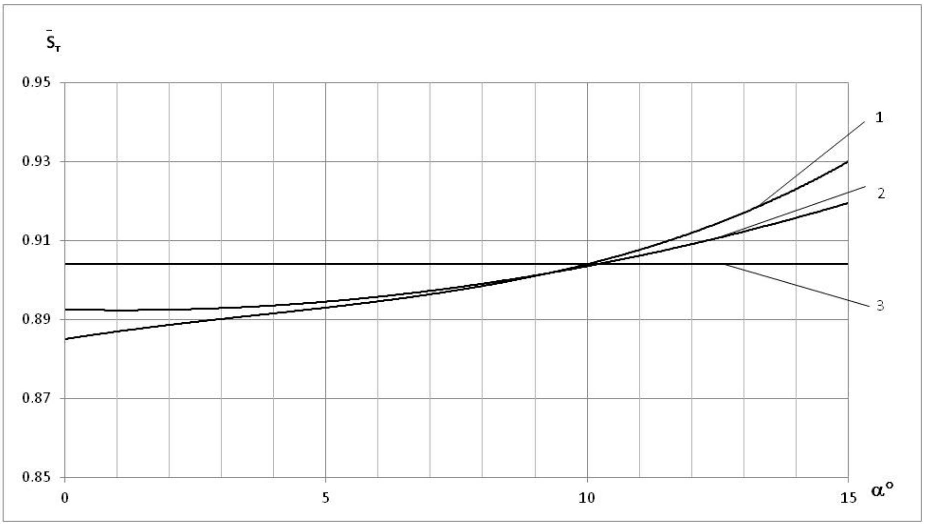
$$\int_{\alpha_0}^{\alpha_{II}} \left\{ \left[\bar{S}_{part} - \mu - (1-\mu) \frac{a_b + b_b(\alpha_n - \alpha)}{\bar{R}_\rho \cos\alpha - \bar{a}} \right] \frac{(\alpha_n - \alpha) d\alpha}{\bar{R}_\rho \cos\alpha - \bar{a}} = 0 \right..$$

By substituting the integrals with the finite sums, we can find the parameters a_b and b_b:

$$b_b = \frac{\mu - \bar{S}_{\partial em}}{1-\mu} \frac{\sum_{i=1}^{n} \frac{\alpha_n - \alpha_0}{\bar{R}_\rho \cos\alpha_i - \bar{a}} \sum_{i=1}^{n} \frac{1}{(\bar{R}_\rho \cos\alpha_i - \bar{a})^2} - \sum_{i=1}^{n} \frac{\alpha_n - \alpha}{(\bar{R}_\rho \cos\alpha_i - \bar{a})^2} \sum_{i=1}^{n} \frac{1}{\bar{R}_\rho \cos\alpha_i - \bar{a}}}{(\sum_{i=1}^{n} \frac{\alpha_n - \alpha}{(\bar{R}_\rho \cos\alpha_i - \bar{a})^2})^2 - \sum_{i=1}^{n} (\frac{\alpha_n - \alpha}{\bar{R}_\rho \cos\alpha_i - \bar{a}})^2 \sum_{i=1}^{n} \frac{1}{(\bar{R}_\rho \cos\alpha_i - \bar{a})^2}}; \tag{29}$$

$$a_b = \frac{(\bar{S}_{part} - \mu) \sum_{i=1}^{n} \frac{1}{\bar{R}_\rho \cos\alpha_i - \bar{a}} - (1-\mu) b_b \sum_{i=1}^{n} \frac{\alpha_n - \alpha_i}{(\bar{R}_\rho \cos\alpha_i - \bar{a})^2}}{(1-\mu) \sum_{i=1}^{n} \frac{1}{(\bar{R}_\rho \cos\alpha_i - \bar{a})^2}}. \tag{30}$$

Now we demonstrate (see figure 5) the technologically possible values of the thincknesses of the parts for the case of variation by two parameters. In compatrisson with the variation by the $\sin\alpha_{blank}$ parameter. The acheved values of the technologically possible thicknesses is signifficantly closer to the set value for the convex part with the same geometrical dimensions.



1- $\mu = 0.5$*; 2 -* $\mu = 0.6$*; 3 – set thickness value*

Figure 5. The distribution of the technologically possible thicknesses of the thin-walled convex part made out of the conical blank.
($\bar{S}_{part} = 0.9; \bar{R}_{part} = 1.068; \bar{\chi}_{part} = 1.1; \bar{R}_\rho = 4.23; \bar{a} = 3.094$)

3. Experimental technique and results

After analysing the theoretical basis of the flanging process of the conical blank, it should be noted that at the same conditions the thinckness fluctuations are lower in case of variation by two parameters and higher in the case of vatiation by only one parameter.

In the result of the experiment we should obtain the convex part made from the brass L62 blank with $S_{blank} = 0.213\times10^{-3}m$, $\mu = 0.5$, and the following geometrical dimensions: $R_\rho = 91\times10^{-3}m$; $r_{part} = 47.2\times10^{-3}m$; $R_{part} = 54.4\times10^{-3}m$; $a = 36.6\times10^{-3}m$ and $S_{part} = 0.95\times10^{-3}m$ at $\alpha_{part} = 22.4°$ and $\chi_{part} = 36.2\times10^{-2}m$. Using the equations (8) and (10) at $\varepsilon_S = 5\%$ we can find the dimensions of the conical blank.

In order to conduct the process in the laboratorical conditions the usiversal hydraulical mashine CDMPU-30 was used, with force gauge up to 300 kN (the scale division is 0.1 kN). The speed of the crosshead is 0-10 mm/sec. The blank was set in the stamp and subjected to deformation until it completely touches the work surface of the die. In order to find the moment then the process has ended, the force diagrams of the stamp with and without the blank were recorded (see figure 6). The intersection point a on the diagram registers the moment then the blank completely touches the work surface of the die and the force is conducted to the walls of the die.

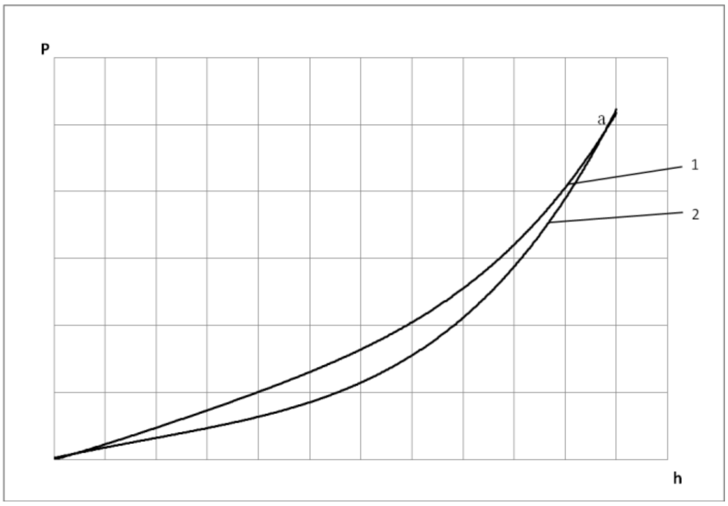
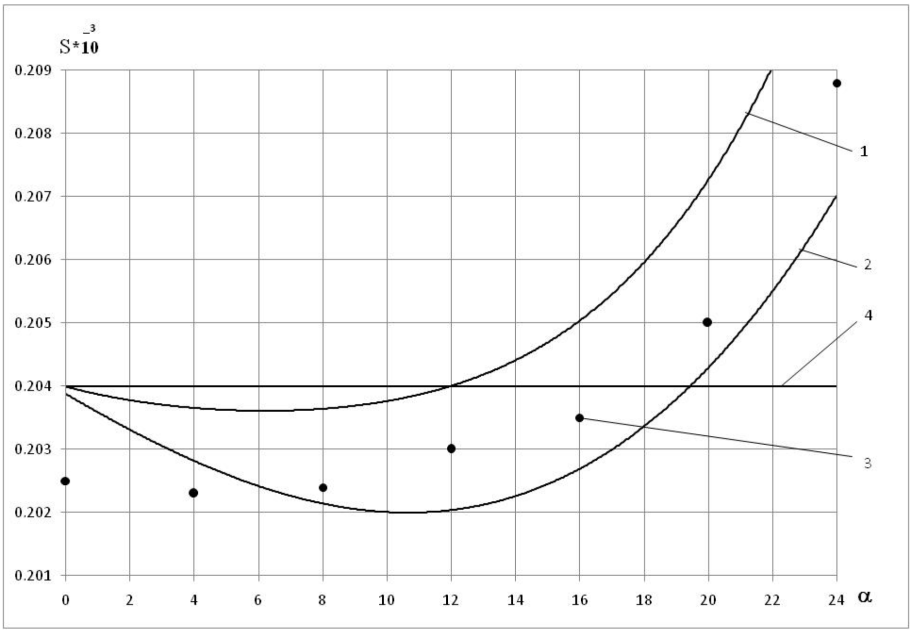


Figure 6. The diagrams of the deformation force of the stamp with (1) and without (2) the blank

The thickness was measured in four sections on eight ring elements, onto which the workpiece was marked, using the electronic indicator with a scale division of $10^{-6}m$. The error margin was less than two percent. For that purpose the obtained part was cut into four pieces. Before conduction of the experiment the flat samples were obtained by rolling on Quarto K220/75-300 DUO (DUO D240/300) rolling mill and their properties were estimated by the tests according to GOST 7855-55 and GOST 1497-61 on Tinius Olsen H5KT machine. The results of the thickness measurements for the part are presented in figure (see figure 7).



1 - $\alpha_{blank} = 5°$*; 2 -* $\alpha_{blank} = 8°$*; 3 – experimental points; 4 – set thickness*

Figure 7. The theoretical and experimental values of the thicknesses of the thin-walled convex part during flanging of the conical blank.

4. Conclusions

The minimal thickness fluctuation at the set parameters of the flangin process was acheved at the angle of the blank $\alpha_{blank} = 8°$ calculated by the expression (26). Other values, such as $\alpha_{blank} = 5°$, result in the thickness fluctuations of about 1.4 times higher. The suggested method of forming the thin-walled convex parts, based on the sheet metall stamping theory, agrees with the experimental data.

The implementation of the suggested method, based on the flanging process, allows achieving minimal thickness fluctuations in the produced part.

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