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DEVELOPMENT OF THE COMBINED TECHNOLOGICAL PROCESS OF BLANK STACKS FLANGES FORMATION BY THE METHOD OF STAMPING BY ROLLING AND ROTARY DRAWING

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The article presents the results of the development and research of the combined technological process of forming the outer and inner flanges of the lids of fractional and distillation columns on sheet blanks by the method of stamping by rolling and rotary drawing. For this purpose, equipment has been developed that allows to form both outer and inner flanges of the blank in one run of the conical roll.

Studies have shown that technological capabilities of the process are limited by the risk of destruction of the top layers of the outer flange bending center and its corrugation, as well as by the neck formation or destruction of the peripheral areas of the inner flange. To assess the deformability of the outer flange, the stress-strain state of its bending center was investigated. According to the set stress values, the stress state of the material is determined, the maximum value of which on the surface of the bending zone is $\eta \approx 1{,}73$. *Formula for determining the minimum radius of the mandrel, which when using the values of the critical ductility of the material allows to prevent destruction. As well, an expression for determining the maximum width of the flange, provided that the destruction of peripheral areas is prevented, is obtained.*

As corrugations formation is the main danger in forming the external flanges by the stamping by rolling method (SR), the expression for determining the maximum width of the flange under the condition of a stable process is obtained. If it is necessary to get more developed flanges, it is proposed to provide thinning of their walls by rotary extraction at the second stage.

When forming the inner flanges of the blank stacks radial compressive stresses and tangential tensile stresses in the material are brought about. The action of tangential stresses causes loss of stability of the flange by way of neck formation. The value of the critical strains increases with the approach to the state of plain-strain deformation. Therefore, it is recommended to develop process parameters based on construction of the critical strains diagrams.

Key words: *rolling stamping, rotary drawing, outer and inner flanges, blank stacks, strain, fructure, loss of stability.*

Introduction. In manufacturing machines, devices and apparatus a large number of different shell components are used. Therefore, in various branches of mechanical engineering, the processes of ductile deformation of blank stacks with a local deformation center have become widespread. They allow to increase productivity and to reduce energy consumption of production. One of such processes is rotary drawing, which provides form change of flat or shell blanks with the help of straining elements on a rotating mandrel [1].

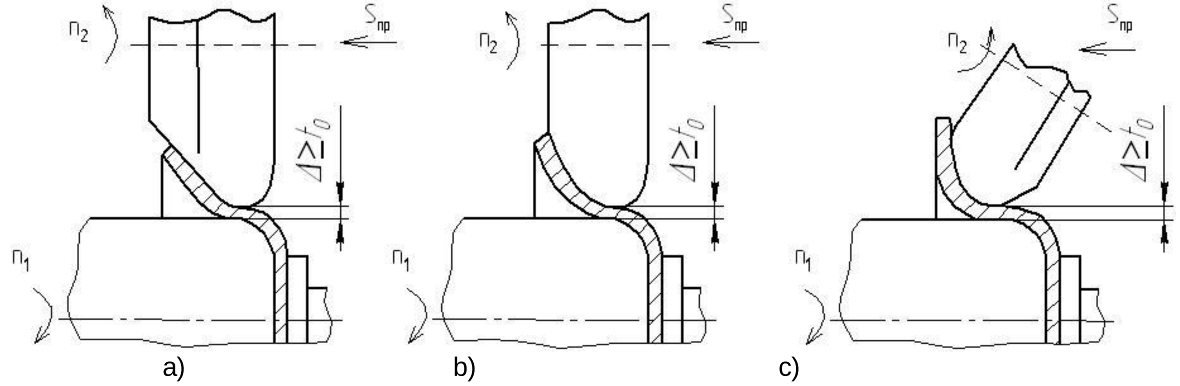
Rotary drawing processes, especially on CNC machines, are multivariate ones due to their ability to actively control the trajectory of the straining tool and its position relative to the blank. Besides, the advantages of the rotary drawing are that it allows making parts that are difficult or almost impossible to obtain by traditional methods of drawing on presses (parts with a curved, stepped or convex-curved surface). In addition, equipment required for the implementation of rotary drawing processes is much simpler and cheaper than in traditional cold sheet metal stamping processes.

Analysis of recent research. One of the types of rotary drawing is a one-run rotary drawing without wall thinning. It consists in converting a flat rotating blank into a hollow part or increasing the length of the hollow blank by moving it through a localized deformation center with a decrease in the transverse dimensions of the semi-finished product without intentional thinning of the wall. In this case, the deformation center in the forming process moves along a trajectory that is identical to the shape of the elongated shell, and sequentially forms the entire blank. This process is carried out under the condition that the gap (Δ) between the pressing tool and the mandrel is greater than the initial thickness of the blank t:

$$\Delta > k(t \pm \delta_1),$$

where k is the coefficient that takes into account the thickening of the blank edge after drawing; $k=1{,}1 \div 1{,}2$; δ_1 – the blank stack thickness tolerance, *mm.*

In the process of a one-run rotary drawing compression and tensile stresses are brought about in the metal, which at certain geometric ratios of the diameter, thickness and size of the blank flange lead to destruction of the material, as well as loss of stability of the molding process. Destruction of the blanks material occurs in the presence of tensile stresses, low ductility of the material and reaching significant deformations. The loss of stability of the process is characterized by the formation of corrugations and excessive local thinning of the walls in the form of a neck. In this regard, two types of a one-run rotary drawing are distinguished: without and with the pressure of the buckle holder. One-run rotary drawing without pressure, with the use of rollers of different shapes, as shown in Fig. 1, is used in manufacturing blanks with the elements of relatively small size. In this case, formation of corrugations can be avoided.



a) b) c)

Fig. 1. Schemes of application of deforming tension: a – by a roller with a rectilinear working surface; b – by a roller with a curved working surface; c – by a roller established at a preset angle

At the one-run rotary drawing the schemes shown in Fig. 1*a* and *b* are mainly applied, as they make it possible to achieve a higher degree of deformation, compared with the scheme in Fig. 1*c*.

To obtain flanges and collars the process of stamping by rolling (SR) is also used [2], the stages of implementation of which are shown in the process flow chart in Fig. 2.

The advantage of this method is its simplicity, which lies in elimination the need for active control of the deforming tool trajectory and its position relative to the blank, as well as high process productivity and quality of the formed surface. At the same time, the danger of destruction of the blank material and loss of the developed flanges formation stability remains: formation of corrugations of the external and the neck of the internal flanges may occur.

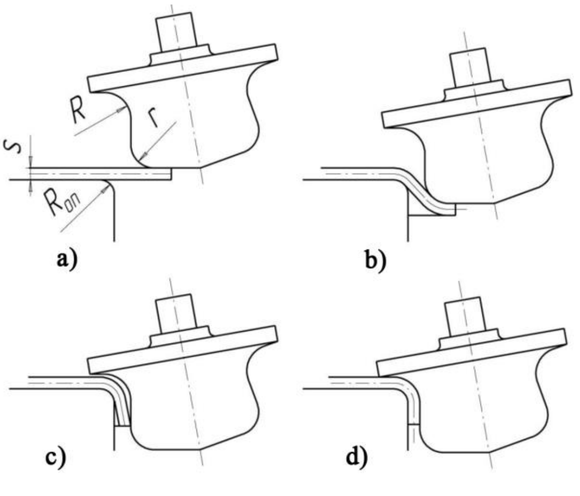


Fig. 2. Stages of flanges formation with the stamping by rolling method

The purpose of the research is to provide the necessary mechanical characteristics and geometric shape of axisymmetric parts of sheet material based on the blanks formation and deformability astimation depending on the parameters of the combined stamping by rolling-rotary drawing process.

The task of the research is to develop a combined process of forming inner and outer flanges on blanks stacks, to establish factors limiting the technological capabilities of the process and on the basis of the stress-strain state analysis and ductility of metals to ensure production of quality lids for fractional and distillation columns.

Presentation of the main material. In order to achieve the goal of the research, an installation was designed for the formation of outer and inner flanges with a conical roll by the SR method, the general view of which is presented in Fig. 3*a*. Fig. 4 shows the process of forming the outer flanges of the lid of the fermentation column.

Technological capabilities of this process are limited by the risk of destruction of the outer layers of the bending center of the outer flange and its corrugation, as well as formation of the neck or destruction of the peripheral parts of the inner flange.


a) b)

Fig. 3. Assembled representation of the SR installation: a) formation of inner flanges on the lid of the fermentation column; b) appearance of the lid of the fermentation column with the formed inner and outer flanges


a) b)

Fig. 4. The process of forming the outer flange of the lid of the fermentation column by the SR method: a) intermediate stage, b) the final stage

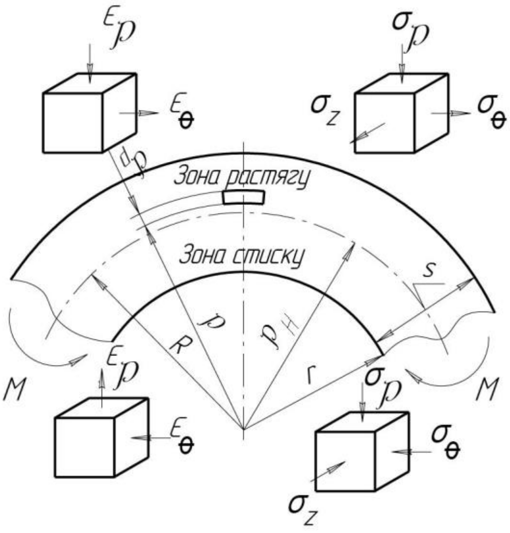
To assess the deformability of the outer flange, let us investigate the stress-strain state of its bending center by the transverse force *P*, taking into account the strengthening. In this case, we neglect the action of the cross-sectional force *Q*, due to the smallness of tangential stresses in the radial directions [3]. Let’s substitute the action of the transverse force with the bending moment *M*, as shown in Fig. 5.

The stressed state of the element in the bending zone will be three-dimensional, and the deformed one will be flat ($\varepsilon_z = 0$) [3]. General equation of equilibrium of the blank constant thickness zone element with axisymmetric deformation of the blank taking into account the forces of friction on the contact surface [3] will be as follows:

$$\rho\frac{d\sigma_\rho}{d\rho} + \sigma_\rho - \sigma_\theta - \frac{\mu\rho}{\sin\alpha}\left(\frac{\sigma_\rho}{R_\rho} + \frac{\sigma_\theta}{R_\theta}\right) = 0, \tag{1}$$

where σ_ρ is meridional tension; σ_θ – latitude stress; μ – coefficient of friction; ρ – distance from the axis of symmetry; R_ρ, R_θ – radii of curvature in meridional and latitudinal sections.

Under conditions when friction can be neglected, equation (1) takes the form:



(1)

Fig. 5. Scheme of the stress-strain state of metal under bending

$$\rho\frac{d\sigma_\rho}{d\rho} + \sigma_\rho - \sigma_\theta = 0. \tag{2}$$

Since we have an equation with two unknowns, let's supplement it with the energetic yield criterion:

$$\sigma_i = \frac{1}{\sqrt{2}}\sqrt{(\sigma_\rho - \sigma_\theta)^2 + (\sigma_\theta - \sigma_z)^2 + (\sigma_z - \sigma_\rho)^2}. \tag{3}$$

Under plain strain:

$$\sigma_z = \frac{\sigma_\rho + \sigma_\theta}{2}. \tag{4}$$

Then, taking into account (4), the yield criterion (3) will be written in the following form:

$$\sigma_\rho - \sigma_\theta = \frac{2}{\sqrt{3}}\sigma_s. \tag{5}$$

To obtain solutions that give analytical expression of the stress field taking into account hardening, it is necessary to have, firstly, an analytical expression of the hardening curve (dependence of yield strength on strain). The use of the hardening curve in the $\sigma_s - \varepsilon_i$ coordinates in metal processing by pressure operations analysis leads to significant mathematical difficulties, even if the dependence of the yield strength on the intensity of deformation is given in a simple analytical function. These difficulties are due to the complex functional relationship of deformations. The hardening curve is presented in the form of power approximation [3]:

$$\sigma_s = \sigma_m + A\varepsilon_i^{\,n}, \tag{6}$$

where σ_m is the yield tensile strength.

For the case of a plain strained state:

$$\begin{aligned} \varepsilon_\theta &= -\varepsilon_\rho; \\ \varepsilon_z &= 0. \end{aligned} \tag{7}$$

Then:

$$\varepsilon_i = \frac{\sqrt{2}}{3}\sqrt{\left(\varepsilon_\theta - \varepsilon_\rho\right)^2 + \left(\varepsilon_\rho - \varepsilon_z\right)^2 + \left(\varepsilon_z - \varepsilon_\theta\right)^2} = \frac{2}{\sqrt{3}}\varepsilon_\theta. \tag{8}$$

As can be seen from Fig. 5:

$$\varepsilon_{\theta}=\frac{l-l_{\acute{\imath}}}{l_{\acute{\imath}}}=\frac{\rho}{\rho_{\acute{\imath}}}-1. \qquad (9)$$

Taking into account that:

$$\ln(x)=\ln(1+(x-1))\approx x-1,$$

we shall obtain:

$$\varepsilon_{\theta}\approx\ln\left(\frac{\rho}{\rho_{\acute{\imath}}}\right). \qquad (10)$$

For the tensile zone (outer fibers), the stress distribution will be determined from the following equations:

$$\left\{\begin{array}{l}
\rho\cdot\dfrac{\sigma_{\rho}}{d\rho}+\sigma_{\rho}-\sigma_{\theta}=0;\\
\sigma_{\rho}(R)=0;\\
\sigma_{\theta}-\sigma_{\rho}=\dfrac{2}{\sqrt{3}}\cdot\sigma_{s};\\
\sigma_{z}=\dfrac{\sigma_{\rho}+\sigma_{\theta}}{2};\\
\sigma_{s}=\sigma_{m}+A\varepsilon_{i}^{\,n};\\
\varepsilon_{i}=\dfrac{2}{\sqrt{3}}\ln\dfrac{\rho}{\rho_{н}}
\end{array}\right. . \qquad (11)$$

For the compression zone (internal fibers), respectively:

$$\left\{\begin{array}{l}
\rho\cdot\dfrac{\sigma_{\rho}}{d\rho}+\sigma_{\rho}-\sigma_{\theta}=0;\\
\sigma_{\rho}(r)=0;\\
\sigma_{\rho}-\sigma_{\theta}=\dfrac{2}{\sqrt{3}}\cdot\sigma_{s};\\
\sigma_{z}=\dfrac{\sigma_{\rho}+\sigma_{\theta}}{2};\\
\sigma_{s}=\sigma_{m}+A\varepsilon_{i}^{\,n};\\
\varepsilon_{i}=\dfrac{2}{\sqrt{3}}\ln\dfrac{\rho_{н}}{\rho}
\end{array}\right. . \qquad (12)$$

Having solved the system of equations (11) and (12), we shall find the stress distribution over the thickness of the blank, with consideration of the hardening.

For the tension zone:

$$\sigma_{\rho}=\frac{2}{\sqrt{3}}\cdot\left[\sigma_{m}\cdot\ln\left(\frac{\rho}{R}\right)+\frac{2^{n}}{\sqrt{3^{n}}}\cdot\frac{A}{n+1}\left[\left(\ln\frac{\rho}{\rho_{н}}\right)^{n+1}-\left(\ln\frac{R}{\rho_{н}}\right)^{n+1}\right]\right], \qquad (13)$$

$$\sigma_{\theta}=\frac{2}{\sqrt{3}}\cdot\left[\sigma_{m}+A\cdot\left(\frac{2}{\sqrt{3}}\cdot\ln\frac{\rho}{\rho_{н}}\right)^{n}+\sigma_{m}\cdot\ln\frac{\rho}{R}+\frac{2^{n}}{\sqrt{3^{n}}}\cdot\frac{A}{n+1}\cdot\left[\left(\ln\frac{\rho}{\rho_{н}}\right)^{n+1}-\left(\ln\frac{R}{\rho_{н}}\right)^{n+1}\right]\right], \qquad (14)$$

$$\sigma_{z}=\frac{2}{\sqrt{3}}\cdot\left[\frac{1}{2}\cdot\left[\sigma_{m}+A\cdot\left(\frac{2}{\sqrt{3}}\cdot\ln\frac{\rho}{\rho_{н}}\right)^{n}\right]+\sigma_{m}\cdot\ln\frac{\rho}{R}+\frac{2^{n}}{\sqrt{3^{n}}}\cdot\frac{A}{n+1}\cdot\left[\left(\ln\frac{\rho}{\rho_{н}}\right)^{n+1}-\left(\ln\frac{R}{\rho_{н}}\right)^{n+1}\right]\right], \qquad (15)$$

for the compression zone:

$$\sigma_{\rho}=\frac{2}{\sqrt{3}}\cdot\left[\sigma_{m}\cdot\ln\left(\frac{r}{\rho}\right)+\frac{2^{n}}{\sqrt{3^{n}}}\cdot\frac{A}{n+1}\left[\left(\ln\frac{\rho_{н}}{\rho}\right)^{n+1}-\left(\ln\frac{\rho_{н}}{r}\right)^{n+1}\right]\right], \qquad (16)$$

$$\sigma_\theta = \frac{2}{\sqrt{3}} \cdot \left[-\sigma_m - A \cdot \left(\frac{2}{\sqrt{3}} \cdot \ln \frac{\rho_н}{\rho} \right)^n + \sigma_m \cdot \ln \frac{r}{\rho} + \frac{2^n}{\sqrt{3^n}} \cdot \frac{A}{n+1} \cdot \left[\left(\ln \frac{\rho_н}{\rho} \right)^{n+1} - \left(\ln \frac{\rho_н}{r} \right)^{n+1} \right] \right], \quad (17)$$

$$\sigma_z = \frac{2}{\sqrt{3}} \cdot \left[-\frac{1}{2} \cdot \left[\sigma_m + A \left(\frac{2}{\sqrt{3}} \cdot \ln \frac{\rho_н}{\rho} \right)^n \right] + \sigma_m \cdot \ln \frac{r}{\rho} + \frac{2^n}{\sqrt{3^n}} \cdot \frac{A}{n+1} \cdot \left[\left(\ln \frac{\rho_н}{\rho} \right)^{n+1} - \left(\ln \frac{\rho_н}{r} \right)^{n+1} \right] \right]. \quad (18)$$

From formulas (13) and (16) it is seen that the stresses σ_ρ increase in absolute value as they move from the surface of the blank to its thickness.

On a neutral surface, when $\rho = \rho_{\acute{\imath}}$, the stresses σ_ρ, determined for the compression and tensile zones, are equal. If we equate these stresses with each other we shall get:

$$\sigma_m \cdot \ln \left(\frac{\rho_н^2}{R \cdot r} \right) + \frac{2^n}{\sqrt{3^n}} \cdot \frac{A}{n+1} \left[\left(\ln \frac{\rho_н}{r} \right)^{n+1} - \left(\ln \frac{R}{\rho_н} \right)^{n+1} \right] = 0. \quad (19)$$

Fig. 6 demonstrates a scheme of the stress-strain state of metal in the bending center at stamping by rolling.

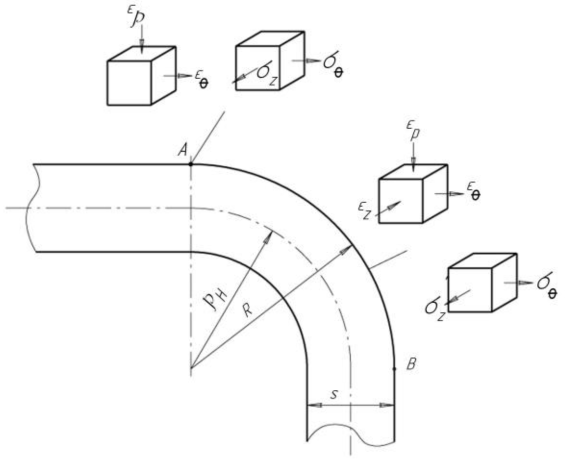


Fig. 6. The scheme of a stress-strain state of metal in the center of bending at stamping by rolling

According to (13), (14) and (15) in the dangerous zone *A* stresses have the values:

$$\sigma_\rho = 0; \quad (20)$$

$$\sigma_\theta = \frac{2}{\sqrt{3}} \cdot \left[\sigma_m + A \cdot \left(\frac{2}{\sqrt{3}} \ln \frac{\rho}{\rho_н} \right)^n \right], \quad (21)$$

$$\sigma_z = \frac{1}{\sqrt{3}} \cdot \left[\sigma_m + A \cdot \left(\frac{2}{\sqrt{3}} \cdot \ln \frac{\rho}{\rho_н} \right)^n \right]. \quad (22)$$

Then, indicator η characterizing the stress state of the blank material is equal to:

$$\eta = \frac{\sigma_\rho + \sigma_\theta + \sigma_z}{\sigma_i} = \sqrt{3} \approx 1{,}73. \quad (23)$$

That is, the stress indicator does not depend on the bending radius and is constant throughout the bending process.

Circular deformation on the outer fibers when bending the neutral surface to the radius $\rho_{\acute{\imath}}$ is:

$$\varepsilon_\theta = \frac{R - \rho_н}{\rho_н} = \frac{s}{2 \cdot \rho_н} = \frac{s}{2 \cdot r + s} = \frac{s}{2 \cdot R_{on} + s}. \quad (24)$$

According to (8), the intensity of the accumulated deformation on the outer fibers depending on the radius of the mandrel will be determined by the formula:

$$\varepsilon_i = \frac{\sqrt{3} \cdot s}{2 \cdot R_{on} + s} \le \varepsilon_{*c}\left(\eta = 1{,}73\right), \qquad (25)$$

where $\varepsilon_{*c}\left(\eta = 1{,}73\right)$ is the intensity of the accumulated deformation, which can be perceived by the material without destruction in the stress-strain state, which is characterized by the indicator $\eta = 1{,}73$. The value of intensity is taken from the diagram of ductility, which is constructed in the $\eta - \varepsilon_{*c}$ coordinates. The diagram of ductility, or the curve of the ultimate strain for the material of lids of the fermentation columns M01 is shown in Fig. 7, and the values of the ultimate strain for the characteristic indicators of the stress state – in Table 1.

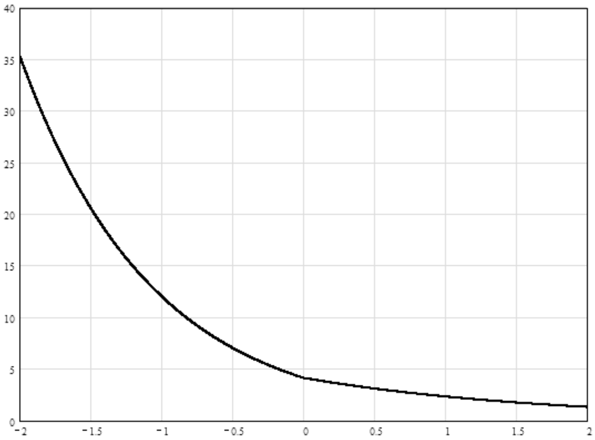


Fig. 7. Curve of the ultimate strain of copper M01

Table 1

Ductility characteristics of copper M01

Material	Ultimate ductility of materials under compression, torsion and tension			Coefficients of the material sensitivity to changes in the stress state indicator	
	$\varepsilon_{*c}(\eta = -1)$	$\varepsilon_{*c}(\eta = 0)$	$\varepsilon_{*c}(\eta = 1)$	$\lambda_1 = \ln\frac{\varepsilon_{*c}(\eta = 0)}{\varepsilon_{*c}(\eta = 1)}$	$\lambda_2 = \ln\frac{\varepsilon_{*c}(\eta = -1)}{\varepsilon_{*c}(\eta = 0)}$
Copper M01	12,0	4,1	2,3	1,78	2,93

Then the minimal radius of the mandrel is determined by the formula:

$$R_{on\,\min} = \frac{s}{2} \cdot \left(\frac{\sqrt{3}}{\varepsilon_{*c}(\eta = 1{,}732)} - 1 \right). \qquad (26)$$

Given the fact that at the $\eta \ge 1$ values of the stress state indicator the curve of the ultimate strain is almost parallel to the abscissa axis and, in addition, the ultimate state is practically limited by the formation of the neck, the minimal radius can be determined by the formula:

$$R_{\min} = \frac{s}{2}\left(\frac{\sqrt{3}}{\varepsilon_{*}(\eta = 1)} - 1 \right). \qquad (27)$$

In the work of Barkay V.F. [4] the stress-strain state on the periphery of the flange during the rotary drawing was investigated. According to this research, in the flange the linear stressed and volumetric deformed states are realized:

$$\begin{aligned} &\sigma_\theta = \sigma_\rho = 0, \\ &\sigma_z = -\sigma_s, \\ &\varepsilon_z = -\frac{2B}{D}, \\ &\varepsilon_\theta = \varepsilon_\rho = -\frac{\varepsilon_z}{2} = \frac{B}{D}, \end{aligned} \qquad (28)$$

Where $B \approx \dfrac{D-d}{2}$ is the width of the flange.

Then the stress index η is equal to:

$$\eta = \frac{\sigma_\theta + \sigma_\rho + \sigma_z}{\sigma_i} = -1, \qquad (29)$$

and the intensity of deformations accumulated on the periphery of the flange is:

$$\varepsilon_i = \frac{3}{2} \cdot \left|\varepsilon_z\right| = \frac{3B}{D} \le \varepsilon_{*c}(\eta = -1). \qquad (30)$$

From formula (30) we shall obtain the expression for determining the maximal width of the flange, on conditions of the product peripheral sections destruction prevention:

$$B_{\max} = \frac{D \cdot \varepsilon_{*c}\left(\eta = -1\right)}{3}. \qquad (31)$$

The maximum width of the flange under the condition of a stable process without corrugations formation can be determined by the method [5]:

$$B_{\max} = \left(\frac{1}{\cos\sqrt{-c_1 + \sqrt{c_1^2 + c_2}}} - 1 \right) \cdot \frac{D}{2}, \qquad (32)$$

where $c_1 = \dfrac{19}{30} \cdot c_2$;

$$c_2 = \frac{1}{\dfrac{631}{3150} + \dfrac{4 \cdot \sigma_s \cdot D^2 \cdot \left(1 - \nu\right)^2}{20 \cdot E \cdot s^2}}.$$

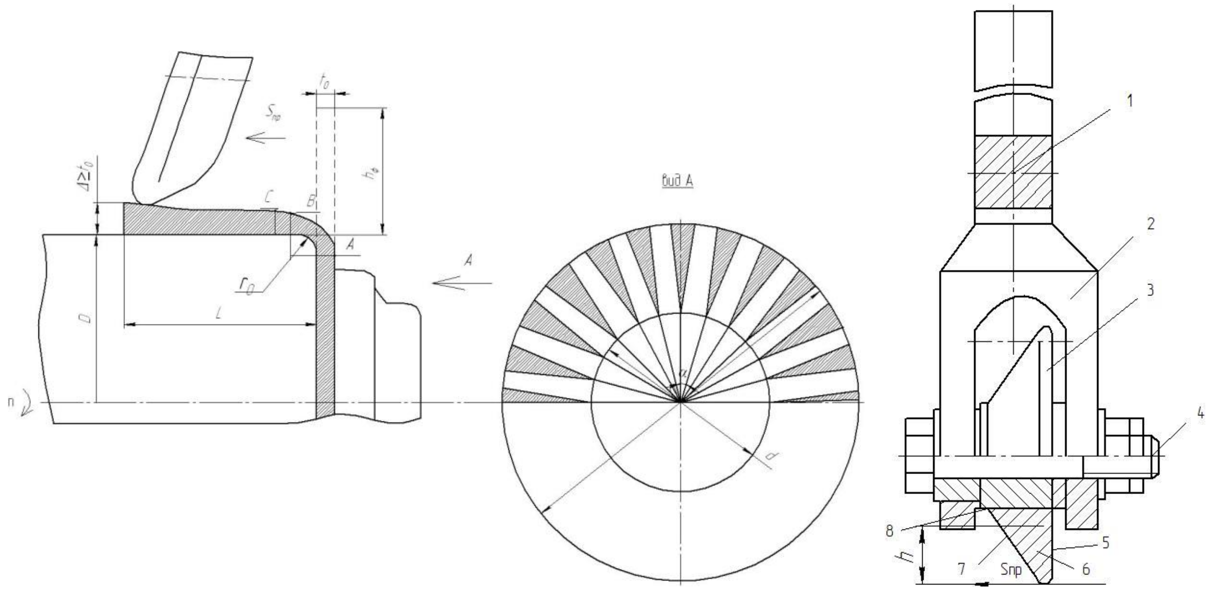
As the maximal value of the flange the least of the values calculated by formulas (31) and (32) is taken.

It should be noted that ductility of copper M01 under uniaxial compression is quite high (see Table 1), thus the maximal width of the flange is limited by the risk of corrugation (32).

In Fig. 8 a diagram of the process of forming a flange with thinning of the wall is shown. In this case, the blank with a diameter *D* can be converted into a cylinder with a diameter *d* and a length *L* in the presence of rotational *n* and reciprocating motion S_{rev}. And since the volume of the metal does not change, the length of the part *L* when drawing will be:

$$L = h_f(D-d)/2d = h_f(K+1)/2, \qquad (33)$$

where $h_f = (D - d)/2$ is the height of the flange, $K = D/d$ – degree of extraction. At $K=2$, $L=1.5\,h_f$.



a) b)

Fig. 8. The scheme of forming the flange with the wall thinning a) and structural elements of the pressure roller b)

The formation of the flange with the thinning of the wall is carried out by rotary drawing due to the extrusion of the metal. The extruded metal is conventionally shown in Fig. 8a by the shaded excess triangles. As can be seen from the diagram, the part of the triangle that is in the bottom of the part is changed only slightly, but the part that forms the wall undergoes the greatest changes. Folding of the flange occurs due to the fact that any element of the deformed area, passing through the center of deformation in the presence of a bend, is drawn-down as a result of the transverse compression deformation.

The displaced volume of the metal can be defined by the expression:

$$V_{зм}=(t_o\pi/4(D^2-d^2)-(D-d)\pi d t_0/2, \qquad (34)$$

where t_0 is the thickness of the original blank.

$$V_{зм}=(t_o\pi/4)(D^2-d^2)-(D-d-2d)(t_o\pi/4)(D-d)^2. \qquad (35)$$

The degree of deformation is determined by the formula

$$\varepsilon = V_{зм}/V, \qquad (36)$$

where V is the volume of the blank.

The specified degree of deformation varies from 0 to 1.

To improve the flow conditions of the metal and increase the mechanical hardening, not straight line S_{ln} operation of the pressure roller is used, but a curvilinear one with the radius $R=r_0+t_0$.

The folds formed on the outer flanges are due to the action of circular compressive stresses, as less energy is used to form folds on the flange than when crimping. On the other hand, if the part has a very large thinning, then tilting the flange back and forth requires less energy than increasing the diameter in the radial plane.

Stability and productivity of rotary drawing of parts depends on the following factors: degree of strain, advance and frequency of the blank rotation, geometrical characteristics of the tool working surface, radius of the mandrel end part, the tilt angle of the roller axis to the axis of the mandrel, diameter of the roller, greasing, cooling.

To reduce the waviness of the blank surface, rollers of large diameters (100-350 mm) are used, as they have a more rigid fixing.

When drawing the inner flanges of the blanks stacks, radial compressive stresses and tangential tensile stresses work in the material. The action of tangential stresses causes a loss of stability of the flange by way of neck formation. Recently, in the technology of metal forming, in order to assess the quality of stamping of sheet materials, diagrams that establish the relationship between the main logarithmic strains e_1 and e_2 at the moment of stability loss are widely used [6]. With the help of such diagrams the level of ultimate strain in the plane of the sheet is distinguished. To construct such diagrams, samples of sheet metal are put to tests, during which the ratio of the main deformations $\alpha=e_2/e_1$ should remain constant. Based on the tests, the dependence of the ultimate strain e_1 on e_2 is obtained. If in the technological operation the values of strains e_1 and e_2 will correspond to the point below the boundary curve, then there will be no loss of stability when stamping such a product. Fig. 9 shows diagrams of ultimate strains for two materials.

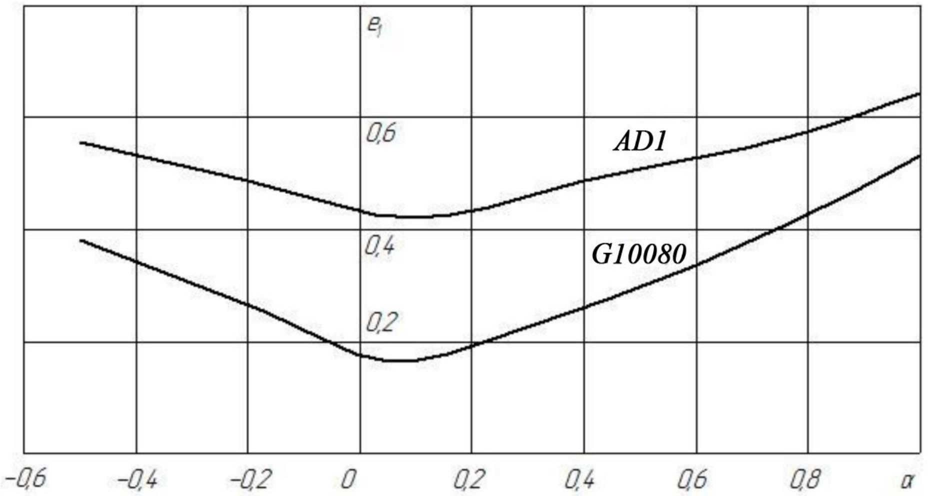


Fig. 9. Diagrams of ultimate strains for steel G10080 and aluminum AD1

Conclusions. Production of the outer and inner flanges of the lids of distillation and fractional columns using blank stacks by the stamping by rolling method has been investigated. Analysis of metal forming and stress-strain state of the blanks was carried out in order to assess and expand the technological capabilities of the process. The main factors limiting technological capabilities are the loss of stability and destruction of blanks. Formulas are obtained for determining the minimal radius of the

mandrel to prevent fracture of blanks under bending and maximal width of the flange, provided control of the peripheral areas destruction.

When forming the outer flanges, the main danger is material corrugating, thus an expression for determining the maximal width of the flange under the condition of a stable process is obtained in the research. If it is necessary to have more developed flanges, it is proposed to eliminate corrugation by thinning the wall with a rotary drawing method. In producing internal flanges, it is recommended to prevent the loss of stability of the flange through the neck formation by the way of realizing the state of plain-strain deformation on the basis of the ultimate strain diagrams construction.

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РОЗРОБКА КОМБІНОВАНОГО ТЕХНОЛОГІЧНОГО ПРОЦЕСУ ФОРМУВАННЯ ФЛАНЦІВ НА ЛИСТОВИХ ЗАГОТОВКАХ МЕТОДОМ ШТАМПУВАННЯ ОБКОЧУВАННЯМ І РОТАЦІЙНОЮ ВИТЯЖКОЮ

В статті наведено результати розробки і дослідження комбінованого технологічного процесу формування зовнішніх і внутрішніх фланців кришок бражних і ректифікаційних колон на листових заготовках методом штампування обкочуванням і ротаційною витяжкою. З цією метою була розроблено обладнання, що дозволяє за одну установку заготовки формувати конічним валком як зовнішні, так і внутрішні фланці.

Дослідження показали, що технологічні можливості процесу обмежуються небезпекою руйнування зовнішніх шарів осередку згинання зовнішнього фланця та його гофроутворенням, а також утворенням шийки чи руйнуванням периферійних ділянок внутрішнього фланця. Для оцінки деформовності зовнішнього фланця досліджено напружено-деформований стан осередку його згинання. За встановленими значеннями напружень визначено показник напруженого стану матеріалу, максимальне значення якого на поверхні зони згину становить $\eta \approx 1{,}73$. *Отримана формула для визначення мінімального радіуса оправки, яка з використанням значень граничної пластичності матеріалу при розтягу дозволяє запобігти руйнуванню заготовки. Отримано також вираз для визначення максимальної ширини фланця за умови запобігання руйнуванню периферійних ділянок.*

При формуванні зовнішніх фланців методом ШО основною небезпекою є утворення гофрів, тому в роботі отримано вираз для визначення максимальної ширини фланця за умови протікання стійкого процесу. При необхідності отримувати більш розвинуті фланці запропоновано на другому етапі забезпечувати потоншення їх стінки шляхом ротаційної витяжки.

При формувані внутрішніх фланців листових заготовок в матеріалі виникають радіальні напруження стиску та тангенціальні напруження розтягу. Дія тангенціальних напружень обумовлює втрату стійкості фланця у вигляді утворення шийки. Величина граничних деформацій при цьому зростає із наближенням до стану плоскої деформації. Тому рекомендовано розробляти параметри процесу на основі побудови діаграм граничних деформацій.

Ключові слова: *штампування обкочуванням, ротаційна витяжка, зовнішні і внутрішні фланці, листова заготовка, деформовність, руйнування, втрата стійкості.*

РАЗРАБОТКА КОМБИНИРОВАННОГО ТЕХНОЛОГИЧЕСКОГО ПРОЦЕССА ФОРМИРОВАНИЯ ФЛАНЦЕВ НА ЛИСТОВЫХ ЗАГОТОВКАХ МЕТОДОМ ШТАМПОВКИ ОБКАТЫВАНИЕМ И РОТАЦИОННОЙ ВЫТЯЖКОЙ

В работе приведены результаты разработки и исследования комбинированного *технологического процесса формирования внешних и внутренних фланцев крышек бражных и ректификационных колонн из листовых заготовок методом штамповки обкаткой и ротационной вытяжкой. С этой целью было разработано оборудование, которое позволяет за одну установку заготовки формировать коническим валком как внешние, так и внутренние фланцы.*

Исследования показали, что технологические возможности процесса ограничиваются опасностью разрушения внешних слоев заготовки в очаге изгиба внешнего фланца и его гофрообразованием, а также образованием шейки или разрушением периферийных участков внутреннего фланца. Для оценки деформируемости внешнего фланца исследовано напряженно-деформированное состояние места его изгиба. За полученными значениями напряжений определен показатель напряженного состояния материала, максимальное значение которого на поверхности участка изгиба составляет $\eta \approx 1{,}73$. *Получена формула для определения минимального радиуса оправки, которая с использованием значений предельной пластичности материала позволяет избежать разрушения заготовки. Получено также выражение для определения максимальной ширины фланца из условия предотвращения разрушения периферийных участков.*

При формировании внешних фланцев методом ШО основной опасностью есть образование гофров, поэтому в работе получено выражение для определения максимальной ширины фланца при условии протекания устойчивого процесса. При необходимости изготавливать более развитые фланцы предложено на втором этапе обеспечивать утонение его стенки путем ротационной вытяжки.

При формировании внутренних фланцев на листовых заготовках в материале возникают радиальные напряжения сжатия и тангенциальные напряжения растяжения. Действие тангенциальных напряжений обуславливает потерю устойчивости фланца путем образования шейки. Величина предельных деформаций при этом увеличивается по мере приближения до состояния плоской деформации. Поэтому рекомендовано разрабатывать параметры технологического процесса на основе построения диаграмм предельных деформаций.

Ключевые слова: *штамповка обкаткой, ротационная вытяжка, внешние и внутренние фланцы, листовая заготовка, деформируемость, разрушение, потеря устойчивости.*

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