Research and Development of a Technological Process and Stamping Equipment for Radial Extrusion of the "Picabur Body" Part

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Abstract: The article talks about the production of the "Picabur Body" part using resource-saving extrusion stamping technology. The energy method and the finite element method were chosen as the research method. A kinematic version of the methods of radial extrusion with contour upsetting and a design diagram of the radial extrusion process are given. The deformation center and stress-strain state during extrusion stamping of the above part are determined. The mechanism and sequence of filling the working cavity of the die are revealed. The scheme of the die and its main working elements during extrusion stamping of the Pickabur Body are also given. The principle of operation of die tooling and technological equipment, which was used in radial extrusion stamping, is described.

1 INTRODUCTION

In developed countries, the development of heavy, mining, and light industries has a positive effect on the economy of their countries. In the manufacture of "Picabur body", widely used in various branches of mechanical engineering, with flanges or thickenings of various configurations, one of the promising technologies is cold radial extrusion. A feature of radial extrusion technology is the ability to actively regulate the deformation and force parameters of the process by changing the kinematics of movement of the forming tool. Quite a lot of work has been devoted to studying the process of radial extrusion. However, practically until now the influence of nonmonotonic deformation in the processes of cold radial extrusion has not been considered. New combined methods of radial extrusion, which themselves contribute to the healing of damage to metals during deformation, have practically not been developed or investigated. The resulting gap hinders the implementation of cold radial extrusion processes for the production of rod parts with a wide flange. One of these new combined methods of cold die forging is the method of radial extrusion with contour upsetting, which is being developed taking into account the effective use of non-monotonic deformation. When developing new combined extrusion methods, it is necessary to determine the force mode, evaluate the deformability of the workpiece and determine their advantage. At present, technological processes of radial extrusion with contour upsetting have not yet been studied.

In this regard, the study of the technological process of radial extrusion from the "Picabur body" is an urgent problem.

2 MATERIALS AND METHODS

In the world improvement of product quality and labor in the engineering industry speeding up production due to increased productivity the occurrence of the process is of particular importance. At the same time bending of the surface layer of metal in the production of tools One of the important tasks is to increase the endurance and operational time is

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considered. The material for the research was the picabur body, which is produced by extrusion stamping from St3 steel at Geoburtechnica.

3 RESULTS AND DISCUSSION

The method is based on the theory of plastic flow, since it allows one to determine the kinematic, stress and deformation states at any point in the zone of plastic deformation, and take into account anisotropy, non-stationarity and the history of deformation. The following basic assumptions are used: the material is considered rigid-plastic, and strain or rate hardening is taken into account by the average value of the yield stress over the deformation zone; Contact friction forces during ordinary extrusion obey Siebel's law, and when extruding with active friction forces, they obey Amonton's law.

Theoretical analysis is carried out in the following sequence:

1. The source of plastic deformation of the workpiece is divided into areas convenient for setting the field of suitable flow velocities in them. The specified expressions for flow rates can include both specific dependences, justified experimentally, and functions of a general form

$$v_x = v_x(x, y, z, t),$$
$$v_y = v_y(x, y, z, t),$$
$$v_z = v_z(x, y, z, t), \qquad (1)$$

At the boundaries between regions, the continuity condition can be observed in a relaxed form, satisfying the condition of constant flow in integral form.

2. Based on the flow rates (1), the components of the strain rate are found:

$$\xi y = \frac{1}{2}\left(\frac{\partial v_i}{\partial xj} + \frac{\partial v_j}{\partial x_i}\right). \qquad (2)$$

3. Each region contains the intensity of strain rates.

$$\xi_1 = \sqrt{\frac{2}{3}\,\xi_y\xi_y} \qquad (3)$$

If it is necessary to simplify the solution, the value of the strain rate intensity is averaged over one or several coordinates and in the process of further analysis is considered independent of these coordinates.

4. Expressions (2) and (3) are substituted into the equations for the relationship between stresses and strain rates

$$\sigma_y = \partial_y \sigma + \frac{2\sigma_i}{3\xi_i}\xi_i \qquad (4)$$

Where ∂y - Kronecker symbol.

5. From the joint solution of the system of equilibrium equations

$$\frac{\partial \sigma_y}{\partial x_i} = 0, \qquad (5)$$

taking into account expressions (4), the stresses are found. Arbitrary integration constants are found from the boundary conditions. If necessary, to simplify the solution of the system, the Huber-Mises energy plasticity condition is used in the form

$$\sigma_{ii\,(max)} - \sigma_{jj\,(min)} = \beta\sigma_3 \qquad (6)$$

where β is the Lode coefficient, which for an isotropic material is taken equal to its average value β = 1, 1.

The use of a simplified plasticity condition that does not take into account the tangential stresses instead of the flow law associated with the exact energy condition is not a disadvantage, since, on the one hand, it allows one to avoid a decrease in accuracy using approximate integration methods, and on the other hand, the analysis showed that all the main terms obtained from the proposed method, the stress formulas coincide with those obtained on the basis of the associated flow law, and the minor terms give a slight overestimation of the result, which, firstly, is consistent with the upper estimate method, and secondly, makes it possible to compensate for the mismatch of tangents that is always present in the boundary conditions for non-zero friction stresses, which cannot be taken into account in existing momentless theories of plasticity.

6. Based on the found stresses, based on the coupling equations (4) and kinematic boundary conditions, the specific form of the velocity functions specified at the beginning of the solution in general form is determined.

7. If it is necessary to take into account the anisotropy of the properties of the initial workpiece, the plasticity condition and the relationship between stresses and strain rates from the theory of plasticity of anisotropic Mises -Hill bodies are used. The analysis of this theory made it possible to introduce an indicator of the form $k = \sigma_{sp} / \sigma_{sz}$ (where σ_{sz} is the yield stress along the axis of the workpiece, σ_{sp} is the yield stress in the radial direction), and obtain the plasticity conditions of an anisotropic body in the form

$$\left|\sigma_p - \sigma_z\right| = \beta\sigma_{pz,}$$
$$\left|\sigma_0 - \sigma_p\right| = \beta\sigma_{sz.} \quad (7)$$

In these expressions, the coefficient values are in the interval

k≤ $\beta \leq 2 / \sqrt{4 - k^2}$ at k< 1, interval k≤ $\beta \leq 2 / \sqrt{4 - k^2}$ k > 1.

If k = 1, then the interval of change of the coefficient P completely coincides with the interval of change of the Lode coefficient used in the theory of plasticity of an isotropic body

8. A.A. Ilyushin's formula is integrated, relating the strain rate to the accumulated strain

$$\xi i\_ = \frac{de_i}{dt} = \frac{\partial e_i}{\partial t} + v_x \frac{\partial e_i}{\partial x} + v_y \frac{\partial e_i}{\partial y} + v_z \frac{\partial e_i}{\partial z}, \quad (8)$$

resulting in accumulated deformation

$$e_i = f(x, y, z) \quad (9)$$

where C - is an arbitrary constant.

9. Lagrange expressions are integrated

$$v_x = (x, y, z, t) = \frac{dx}{dy} \qquad v_x = (x, y, z, t) = \frac{dy}{dy} \qquad v_x = (x, y, z, t) = \frac{dz}{dy} \quad (10)$$

As a result, the dependences of the current coordinates of the particle (Eulerian coordinates) on the initial coordinates (Lagrange coordinates) and time are found:

$$x = \psi_1(x_0, y_0, z_0, t)$$
$$y = \psi_2(x_0, y_0, z_0, t)$$
$$z = \psi_3(x_0, y_0, z_0, t) \quad (11)$$

10. Using expressions (11), the initial coordinates of the particle are determined from the condition $e = e_0$, for $e = e_0$, $x = x_0$, $y = y_0$, t = 0, $z = z_0$. An arbitrary constant value $e_{0 \text{ is found}}$, taking into account the history of deformation;

e_{10} =0, if the original workpiece has no accumulated deformation. For convenience, you can replace the time with the punch stroke

$$s = v_0 t \quad (12)$$

where v_0 is the speed of movement of the punch.

11. Using expressions (11), the sizes of zones in which material points in the process of deformation pass the same path are determined; the deformation field in such zones is stationary.

12. If necessary, the directions of the fibers of the macrostructure are found using expressions (11). By taking the initial coordinates of any material point of any fiber of interest to the researcher and substituting them into expressions (11), it is possible to determine where this point will move at a certain value of the working stroke s. By repeating this procedure for a sufficient number of points on a single fiber, the shape and position of that fiber macrostructure in the stamped product can be determined.

13. For a certain value of the working stroke, according to formula (9), the average value of the accumulated deformation in the zone of plastic deformation is calculated, from which the average value of the yield stress of the workpiece is determined.

14. To determine the size of the source of plastic deformation, the principle of minimum specific deforming force (minimum of the total deformation energy) is used. For a hardening material, minimization is carried out taking into account the dependence of the average yield stress on the accumulated deformation, which in turn depends on the size of the source. The shape of individual flanges of the site of plastic deformation is determined by found expressions for flow velocities.

16. As a result of such calculations, a diagram of the change in force during extrusion is constructed, showing the effect of hardening of the workpiece material on the force characteristics of the process.

15. To obtain intercomparable solutions suitable for determining the optimal geometry of the tool, it is necessary to satisfy the following requirements when fulfilling points 1 and 5: design schemes, kinematics and boundary conditions must transform into one another in the limiting cases of different tool shapes. The final criterion for checking intercomparability is the comparison of formulas specific deforming force in related cases of different tool shapes. In order to expand the applicability of formulas, for hollow products it is advisable to choose calculation schemes suitable for analysis not only at the quasi-stationary stage of extrusion, but also under bottom effect conditions.

The process of radial extrusion is divided into two stages (Fig. 1.);

- at the first stage, the metal is deformed by moving the punch at speed V_a in order to form a thickening in some part of the product;

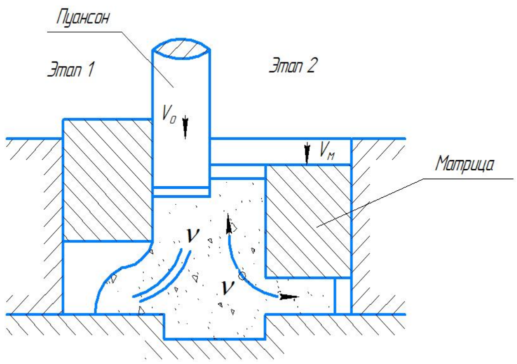

Figure 1: Kinematic version of radial extrusion methods with contour upsetting.

- at the second stage, only such a separate thickening is deformed with forced movement of the matrix at speed $V_м$, subject to the release (removal) of the punch. It is the removal of the punch at the second stage that creates the opportunity to control by deformation. Due to the fact that at the second stage only the contour part of the thickening is deposited, this process is called the “extrusion process with contour settlement”.

It was established that when studying the force regime and deformability for the process of radial extrusion (as the first stage of fishing with contour settlement), the influence of the angle of the straight transition edge was not sufficiently clarified.

The entire process of deformation by extrusion with contour upsetting is divided into two stages: and the first stage occurs as usual radial extrusion and is called “upsetting by extrusion.” For the first stage, the force mode was analyzed taking into account the influence of the angle of the straight transition edge.

The energy method makes it possible to take into account the main features of the process and simultaneously determine both the active deforming force developed by the punch and the reactive force perceived by stationary tools. An upper estimate of such forces can be obtained from the energy balance if it includes the powers developed by reactive forces at the virtual speeds of movement of the corresponding parts of the tool, and the linearization of all powers relative to the virtual and specified speeds of the tool is carried out.

Solutions were carried out using the following assumptions:

- normal component of the discontinuity velocity vector, discontinuities have only components directed along the block boundaries;
- specific contact forces friction on the contact surface constant and proportional to the flow resistance of the material;
- the workpiece material is homogeneous and non-strengthening;
- the speed of the tool is constant.

We accept the following kinematic possible velocity fields, a state of separate rigid blocks and satisfying the kinematic boundary conditions and the unexpectedness condition (Fig. 2). The accepted kinematically possible velocity fields are based on those established as a result of experimental studies of the shape and source of plastic deformation.

The forces of deformation and opening were determined from the power balance equation of external and internal forces at kinematically possible speeds of movement:

$$\rho\, \vartheta_n \pi R_0^2 + q v_M \pi (R_2^2 - R_2^0) = W_q + W_c + W_r \quad (13)$$

where: - power of plastic deformation in zones 2,3,4:

$$W_g = \sum W_{gi} = \sum 6_s \iiint 6_u dv; \quad (14)$$

- power of shear forces on the velocity discontinuity surfaces between zones *1-2, 2-3, 2-6,* 3-4:

$$W_c = \sum W_{cj} = \sum \frac{6_s}{\sqrt{3}} \iint [u]_{ij} ds; \quad (15)$$

- power of contact friction forces on the surfaces of contact with the tool: 1 and 5, 3 and 5, 4 and 5:

$$W_T = \sum W_{TK} = \sum \mu 6_3 \iint [u]_x dC. \quad (16)$$

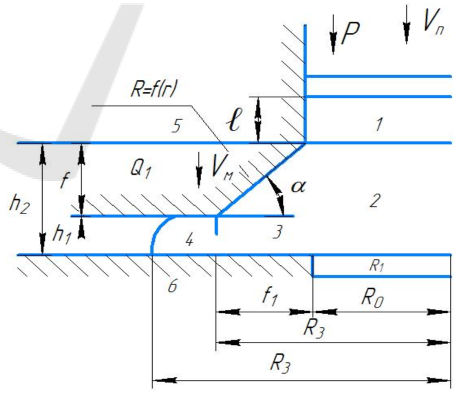

Figure 2: Calculation diagram of the radial extrusion process

Having calculated the powers of the forces of plastic deformation, shear and contact friction, substituting the found power values and the power balance equation 1, separating the terms containing v_n and $v_м$ we get:

$$\frac{P}{6_s} = 1 + \frac{1}{\sqrt{3}}\left[\frac{1+2\mu}{3}\frac{R_0}{h_2} + 2\mu\frac{1+\sqrt{1+2tg^2\sigma}}{tg\sigma}ln\frac{h_2}{h_1} + 2ln\frac{R_3}{R_2} + \frac{3}{2}tg\sigma + 2\mu\left(\frac{R_3}{R_1} - \frac{R_2}{R_1}\right) - \frac{h_2}{h_0} + 1{,}14\left(2ln\frac{R_2}{R_0} + 0{,}5y - 1n\frac{h_2}{h_1}\right) + 0{,}2tg\sigma\left(2ln\frac{h_2}{h_1} - ln\frac{R_2}{R_0}\right); \frac{Q}{6_3} = \frac{1}{\sqrt{3}}\left\{\frac{1}{y}\frac{h_2}{h_0} + 2\mu\frac{1+\sqrt{1+tg^2\sigma}}{tg\sigma}\left[(s^2 - tg\sigma)ln\frac{h_2}{h_1} - \frac{1}{2}y\,tg^2\sigma - s\left(\frac{R_2}{R_0} - 1\right)tg\sigma\right] + 2\mu\left(\frac{R_3}{h_1} - \frac{R_2}{h_2}\right) + 2ln\frac{R_3}{R_2} + 1{,}14\left[\frac{2}{y}ln\frac{R_2}{R_0} - \frac{s}{xtg\sigma} + \frac{1}{y}\left(\frac{s^2}{tg^2\sigma} - 1\right)\ln\frac{h_2}{h_1}\right] + \frac{1}{2y}\left(ytg\sigma + 2\frac{R_2h_1}{R_0R_0}\right) + 0{,}2\left[0{,}5tg\sigma - \frac{2s}{x} - \frac{tg\sigma}{y}ln\frac{R_2}{R_0} + \frac{2}{y}\left(\frac{s^2}{tg^2\sigma} - tg\sigma\right)ln\frac{h_2}{h_1}\right]\right\}\right] \quad (17)$$

Where $y = \frac{R_2^2}{R_0^2} - 1;\quad x = 1 + \frac{R_2}{R_0};\quad s = tg\sigma + \frac{h_2}{R_0}$.

The second stage of the extrusion process with contour upsetting represents the stages of contour upsetting of the thickening formed at the first stage, provided there is a movable punch. Design diagrams are shown (in Fig. 3).

From the analysis of experimental studies, it was established that the change in the dimensions of the workpiece occurs in two stages:

1 - upsetting of the workpiece without changing the length of the workpiece rod (size *l*), as long as the dimensions of the workpiece or the friction conditions are such that $R_i < R_0$ (R_i is the radius of the separation boundary of the metal flow). This is the initial stage in the case of a large cavity height.

2-combination of the settlement of the annular part of the workpiece with the formation of a rod, the total height of which continuously increases if the dimensions of the workpiece lead to the value $R_i > R_0$. This corresponds to the last stages with a decrease in the height of the cavity (or as the matrices approach each other).

An analysis of the power mode for the second stage, which has more important implications for the analysis of the technological characteristics of this process, was carried out. The assumptions discussed above are used. We accept the following kinematic possible velocity fields, consisting of individual rigid blocks and satisfying the boundary conditions and the incompressibility condition. The accepted kinematically possible velocity fields are based on the shape and source of plastic deformation established as a result of experimental studies.

The energy balance equation will be written as:

$$p\,v_M\pi(R_1^2 - R_0^2) = W_g + W_c + W_t \quad (18)$$

where W_g is the power of plastic deformation in zones 1 and 2

$$W_g = \sum W_{gi} = \sum 6_s \iiint 6_u dv$$

- the power of shear forces on the velocity discontinuity surfaces between zones 1-2; 2-3 and 2-4;

$$W_c = \sum W_{cj} = \sum \frac{6_s}{\sqrt{3}} \iint [u]_{ij} ds; \quad (19)$$

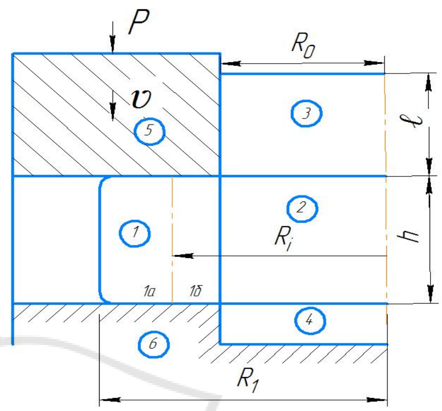

Figure 3: Design diagram for the second stage.

- power of contact friction forces on contact surfaces 1 and 3 with tool 5

$$W_t = \sum W_{tk} = \sum \mu 6_s \iint [u]_k dc; \quad (20)$$

Substituting all the found values of powers and transformations into the energy balance equation (4), we obtained a formula for determining the relative specific deformation force:

$$\frac{P}{6_s} = \frac{1}{\sqrt{3}(R_1^2 - R_0^2)}\left\{\frac{R_i^2 - R_0^2}{R_0}\left(\sqrt{3}R_0 + H + \frac{2}{3}\frac{R_0^2}{h}\right) + hR_0 + \sqrt{R_i^4 + 3R_1^4} - \sqrt{R_i^4 + 3R_0^4} - R_i ln\frac{R_0^2\left(\sqrt{R_i^4 + 3R_1^4} + R_i^2\right)}{R_1^2\left(\sqrt{R_i^4 + 3R_0^4} + R_i^2\right)} + 4\mu_1 l\frac{R_i^2}{R_0} + 4\frac{\mu_2}{h}\left[R_i^2(2R_i - R_1 - R_0) + \frac{1}{3}(R_1^3 + R_0^3 - -2R^3)\right]\right\} \quad (21)$$

The varying radius of metal separation determination R $_1$ is determined by solving the equation $\frac{\partial P}{\partial P_i} = 0$.

The stamp for this part has its own characteristics. The matrix is made of two parts with a horizontal connector plane. The receiving cavity is made in one of the semi-matrices. The basic scheme of the die for radial extrusion is shown in Fig. 2. The stamp is made of steel 5XHM. Molybdenum disulfide with mineral oil was used as a lubricant.

The die contains a punch 4 mounted on the upper movable plate 7 with a pressure sleeve 5 covering it, as well as an upper half-matrix 3 connected to the plate 7 by means of rods 6. On the lower plate 12 is mounted matrix holder 2, in which is installed the lower half-matrix 10. In the vertical cavity of the half matrix 10 is placed counter punch 1, covered by a support sleeve 11. When clamped together, the half-matrixes form a working annular cavity. The mechanism of locking of the half-matrixes after their clamping is made in the form of at least two hinged (as a rule attached to the matrix holder) 2 rotary (in the vertical or horizontal plane) spring-loaded levers 9. The levers interact their working front edge with the upper end of the upper half-matrix 3. The rear side of each of the locking levers interacts with the drive mechanism, made in the form of, for example, a pneumatic cylinder or a spring-loaded pusher 8, hinged to the movable plate 7.

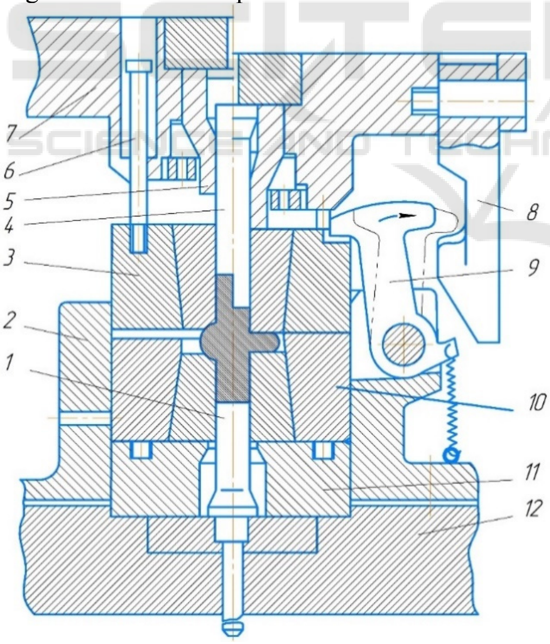

Figure 4: Schematic diagram of a die for radial extrusion

After clamping the half-matrixes, they are locked by levers rotated by the pushers. Half-matrixes under the action of metal extruded into the transverse cavity and sawing forces are extended to contact with the working edge of the levers 9. At the final stage of deformation, the sleeve 5 comes into contact with the half-matrix 3 and moves it downwards synchronously with the punch, which leads to a decrease in the cavity height and metal deposition in the flange area. This frees the levers 9, which due to springing are accelerated back to the initial position and do not prevent the lifting of the upper half-matrix with the movable plate 7 during the idle stroke of the press slide.

Taking into account all the above calculations, it was decided to test the theoretical research data in practice. As a result of the experimental work, the following results were obtained (Fig. 5; 6):

Figure 5: General view of the “Pikabur body” obtained by cutting

Figure 6: Forging produced by precision stamping by radial extrusion with contour upsetting

4 CONCLUSIONS

1. A new method of extrusion with contour upsetting has been developed, which uses the positive effect of the influence of non-monotonic deformation on the ultimate shape change of workpieces. The main technological parameters of the processes are established on the basis of studies of the force regime, stress-strain state and workpiece deformability.
2. Experiments on force modes were carried out to verify the reliability of the theoretical calculation. The discrepancy between calculated and experimental data in most cases did not exceed 20-25%.

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