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FORMALIZED DESCRIPTION AND SYNTHESIS OF SCHEMES FOR SHAPING HELICAL FLIGHTS AND AUGER BILLETS BASED ON THE COMPONENTIC METHODS

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Summary. *Based on the use of the componentic methods the universal concept for the formalized description of the ways of shaping the helical flights and auger billets, obtained by different technological methods, is developed. The method takes into account the amount, composition and direction of shaping and auxiliary movements of the executive bodies in the coordinate system of technological equipment, the design features (shape) and direction of movements of the sections of the initial billets and the principle of its transformation to the spiral form, also the composition and direction of movements of the working surfaces of shaping tools.*

The results obtained can be used for the synthesis of new progressive schemes for the shaping of helical flights and auger billets.

Key words: *helical flight, auger billet, synthesis, shaping scheme.*

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Statement of the problem. In modern mechanical engineering, machine parts such as screws, obtained from helical flights (HF) and auger billets (AB) are widely used. At present, numerous ways of their formation are formed [1]. The state program "Resource-saving and energy-efficient technologies of mechanical engineering" aims to create fundamentally new technologies along with the development and improvement of existing ones, which should include the manufacture of these billets. The ability of constant product updating, which is based on the implementation of systematic methods of synthesis of new optimal technical solutions, taking into account the technological capabilities of a particular enterprise is of great importance in strengthening competitive positions. Science-intensive and energy-saving production of such billets based on the implementation of new methods of their obtaining stimulates the development of many industries that use such screw products.

However, the solution to the problem of synthesis of new methods of HF and AB manufacturing is associated with the need to process a large amount of material, the complexity of identifying and taking into account existing technologies such elements of their structure that have a significant impact on overall efficiency. The lack of an effective method of formalized description of such schemes complicates the task of synthesis of new technological methods and selection of appropriate technological equipment for their implementation based on the use of standard solutions.

Analysis of available research results. A large number of papers are devoted to the synthesis and substantiation of new methods of manufacturing HF and AB, among which we have pointed out the works [1–10]. In particular, the method of structural synthesis of methods of forming winding HF by hierarchical grouping using morphological analysis is considered in papers [1–5]. The scientific approach to the search for new technical solutions based on the kinematic parameters of HF and AB formation is given in papers [6, 7]. In [8] the expediency of using the method of synthesis of technological operations based on a formalized description of technological transitions, used equipment and tools is substantiated. These techniques are focused on the synthesis of winding methods. They do not cover other technological methods, such as sheet molding, acceleration, sludge, etc. The method of choosing the best option among several technical solutions is covered in the paper [9].

Despite significant advances in the development of theory and practice of exploratory design of technological processes of HF and AB, there are several unsolved problems due to the need of taking into account the design features of the initial billets, the type of interaction of the billet with the tool and process characteristics using componentic methods. In addition, under the conditions when information technologies are widely used all over the world, there is a need for formalized description of the process of forming these billets based on detailed hierarchical structuring of the technological method, taking into account the principles of composition and kinetics. This approach is conceptually described in the paper [10]. Therefore, the task of the given investigation is the development and practical implementation of such concept.

The objective of the paper is to develop the method of formalized description and synthesis of HF and SB forming methods using structural formulas that combine structural formulas of technological equipment with the type of billet and its shape, movements of its parts, and the type of tool force on such billet, which is the basis of parametric synthesis and to search the necessary equipment for the implementation of methods of their manufacturing.

Statement of the problem. It is known that for the analysis and further synthesis of the metal-cutting machines composing scientifically justified methods of combining - the so-called components method, the author of which is Vragov Yu.D. [11, 12] are widely used. The basis of this method is the system of notation of coordinate axes and movements of combining blocks. Thus, translational motions along the coordinate axes are denoted according to the designations of the axes (X, Y, Z are the primary motions, U, V, W, and P, Q, R are the duplicating motions of the second and third turns, respectively). Rotational movements around the axes parallel to X, Y, Z axes are denoted by letters A, B, C respectively, and additional - d and e. Therefore, the combining option of the machine tool is written in the form of structural formula (SF) of combining $F = \alpha_1 \ldots \alpha_m \; 0 \; \alpha_{m+1} \ldots \alpha_b$, that describes the order of the blocks and their possible movements (linear and angular) in the selected coordinate system. Here $\alpha_1 \ldots \alpha_m \, , \alpha_{m+1} \ldots \alpha_b$ - is the notion of the machine tool moving blocks by symbols of the coordinate movements that they perform; 0 is the indicator of the stationary block (fixed base block).

Investigation results. The application of such technique requires modification to describe the schemes of HF and AB formation not only by methods of metal processing by cutting, but also by pressure, casting of metals and alloys, forming from polymeric materials, ceramics and rubber, etc. In addition, the process of obtaining these billets is characterized not only by the amount, composition and direction of forming and auxiliary movements of the executive bodies of technological equipment, but also by the directions of movement and shape of the billet, the principle of its transformation to form a spiral, composition and direction of forming surfaces.

Formalized description of technological methods of HF and AB formation.

In the description of the HF and AB forming schemes for the positive direction of the coordinate axis Z we take the direction from the billet to the main tool perpendicular to the side forming turn or flat annular section of the billet along the main spindle. This direction corresponds to the direction of the tool removal from the original billet. The X axis is always horizontal and parallel to the generating plane of the initial billet and opposite to the direction of its supply to the deformation zone.

Important characteristics of the HF and AB forming process are the type of tools, the direction of their working surfaces movement and the principle of their influence on the initial billet for its transformation into helical spiral:

$$I = \left\{ I_{1.i}^{\varphi 1.k1}, I_{2.i}^{\varphi 2.k2}, \dots I_{n-1.i}^{\varphi(n-1)}, I_{n.i}^{\varphi n.kn}, S_i^{\varphi s} \right\}, \quad (1)$$

where $I_{1.i}^{\varphi 1.}, I_{2.i}^{\varphi 2}, \dots$ is the designation of tools and coordinate movements of their working surfaces; $S_i^{\varphi s}$ is the designation of supporting element (frame, shaft); n is the number of tools; i is tool version; $\varphi 1, \varphi 2, \dots \cdots \varphi n, \varphi(n+1)$ is the list of designations of coordinate movements of working surfaces of the corresponding tools in coordinate system of the technological equipment; $k_1, k_2, \dots$ is the code of the principle of tool influence on the initial billet for the helical spiral formation (subtype J_1 of technological operation according to the classification of technological operations, which is given in paper [10]; for example, 8 – asymmetric crimping, 10 – bending on the edge, 11 – twisting). This code is marked on one of at least two tools.

Implementation of technological schemes of HF and SB formation depends on the shape and directions of movements of sites of the processed billet. In the general case, such billet in the process of obtaining a spiral can be considered as a logical union of the section «Initial billet» («B»), located before entering the deformation zone, a group of sections «$IB1$», «$IB2$»… «Intermediate billets», which are limited by contact tool (s) (bending roller; rolling rollers; fork mechanism; punches; punch and anvil; die and punch, etc.) with the billet, as well as the section «Formed helical spiral» («*HF*»). In zones of transition of section «*B*» to the section «*IB*», as well as section «*IB*» to section «*HF*» there are force factors that cause deformations and, consequently, change the type of the section.

Taking into account the coordinate displacements of the sections of the processed billet, its structural formula is as follows:

$$Z = I_{f_B}^{\varphi_n} \bigcup IB1_{f_{IB1}}^{\varphi_1} \bigcup IB2_{f_{IB2}}^{\varphi_2} \dots \bigcup IB\theta_{f_{IB\theta 1}}^{\varphi_\theta} \bigcup HF^{\varphi_{HF}} = B_S \bigcup \left[\bigcup_{j=1}^{\theta} IB\theta_{f_{IBj}}^{\varphi_j} \right] \bigcup HF^{\varphi_{HF}}, \quad (2)$$

where $\varphi_n, \varphi_1, \varphi_2, \dots \varphi_\theta, \varphi_{IB}$ is designation of the list of coordinate displacements of sections of «B», «IB» and «HF» types in the coordinate system of technological equipment layout; θ is designation of the serial number of the section «IB»; f_I, f_{IB1}, … is designation of the shape of the corresponding parts of the processed billet.

For example, the following shapes of the sections «Initial billet» are possible: Bs is strip; Br is flat ring; Bsp is spiral; Brs - ring sector, etc. Similarly, the shapes of the sections «Intermediate billet» are denoted in the following way: IBs – strip; IBr – ring; IBsp – spiral; IBrs – ring sector, IBcor.sc – screw corrugated, IBcor.r – ring corrugated, etc.

In the designation of the sections «Initial billet» we can use the billet codes from the generalized technological route [10].

Taking into account (1) and (2) the scheme of HF and AB formation can be described in the form of SF layout of technological equipment taking into account coordinate movements of working surfaces of tools and shapes of the sections of processed billet:

$$F = \underbrace{\alpha_1 \ldots \alpha_m \; 0 \; \alpha_{m+1} \ldots \alpha_b}_{\substack{\text{structural formula} \\ \text{of technological equipment}}} \underbrace{B_{f_B}^{\varphi_n} I_{1.i}^{\varphi 1.} I_{2.i}^{\varphi 2.k2} IB1_{f_{IB1}}^{\varphi_1} \ldots IB\theta_{f_{IB\theta 1}}^{\varphi_\theta} I_{n-1.i}^{\varphi(n-1)} I_{n.i}^{\varphi n.kn} S_i^{\varphi s} HF^{\varphi_{HF}}}_{\substack{\text{structural formula that describes the shape and movement} \\ \text{of the working surfaces of tools and parts of the processed billet}}}, \quad (3)$$

The list of coordinate displacements $\varphi_n, \varphi_1, \varphi_2, \ldots \varphi_\theta, \varphi_{HF}$ can contain elements from the list $\alpha_1 \ldots \alpha_m, \alpha_{m+1} \ldots \alpha_b$ in the case of the application of drive tools, in which the coordinate displacements of the working surfaces coincide with the directions of movement of the executive bodies of the technological equipment. Movements can also be formed due to the drive equipment or to the frictional interaction of the billet with the tool.

In the absence of "IB" section the notation $B_{f_B}^{\varphi_n} \rightarrow HF^{\varphi_{HF}}$ is used. That is, the SF of the process is as follows: $F = \alpha_1 \ldots \alpha_m \; 0 \; \alpha_{m+1} \ldots \alpha_b B_{f_B}^{\varphi_n} I_{1.i}^{\varphi 1.} I_{2.i}^{\varphi 2.k2} \rightarrow HF^{\varphi_{HF}}$.

Structural formulas of equipment layout are written in the form of symbols of controlled coordinates α_m from left to right in the order of nodes in the direction from the billet to the tool. The sign of the stationary block (fixed base block) divides the structural formula into two parts. To the left of «O» sign is the composition of the blocks which ensure the movement of the billet, and to the right – those that ensure the movement of tools (Fig. 1).

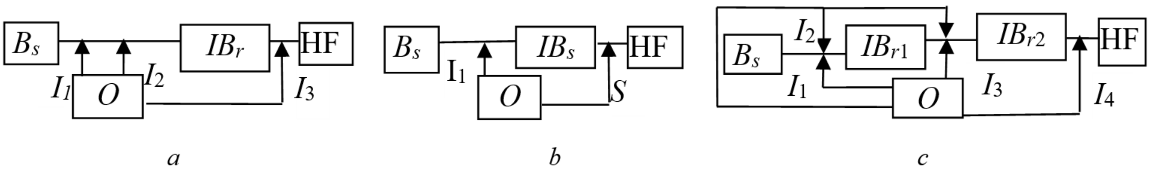


Figure 1. Block diagrams of HF production:
a – profiling of strip billet to the formation of corrugated HF;
b – obtaining of HF by winding on the frame;
c – obtaining of HF by the method of uncoated winding
on three-roller profile bending machine

For example, the SF of the scheme of winding HF forming with open winding by the method of discrete winding of the strip billet with the edge on the mandrel with parallel arrangement of the axis of the roller relative to the frame is as follows:

$$F = \hat{C}_h \, O(ZXbW / Ud + rW) B_s^{Z,X} I_{1.i}^{Z.10} IB1_s^{Z,X} S_i^{C_h} HF^{C_h}, \quad (4)$$

Examples of technological schemes of HF and AB formation with designation of movements of arrangement of technological equipment and tools, and coordinate movements of structural elements of preparation are shown in Fig. 2.

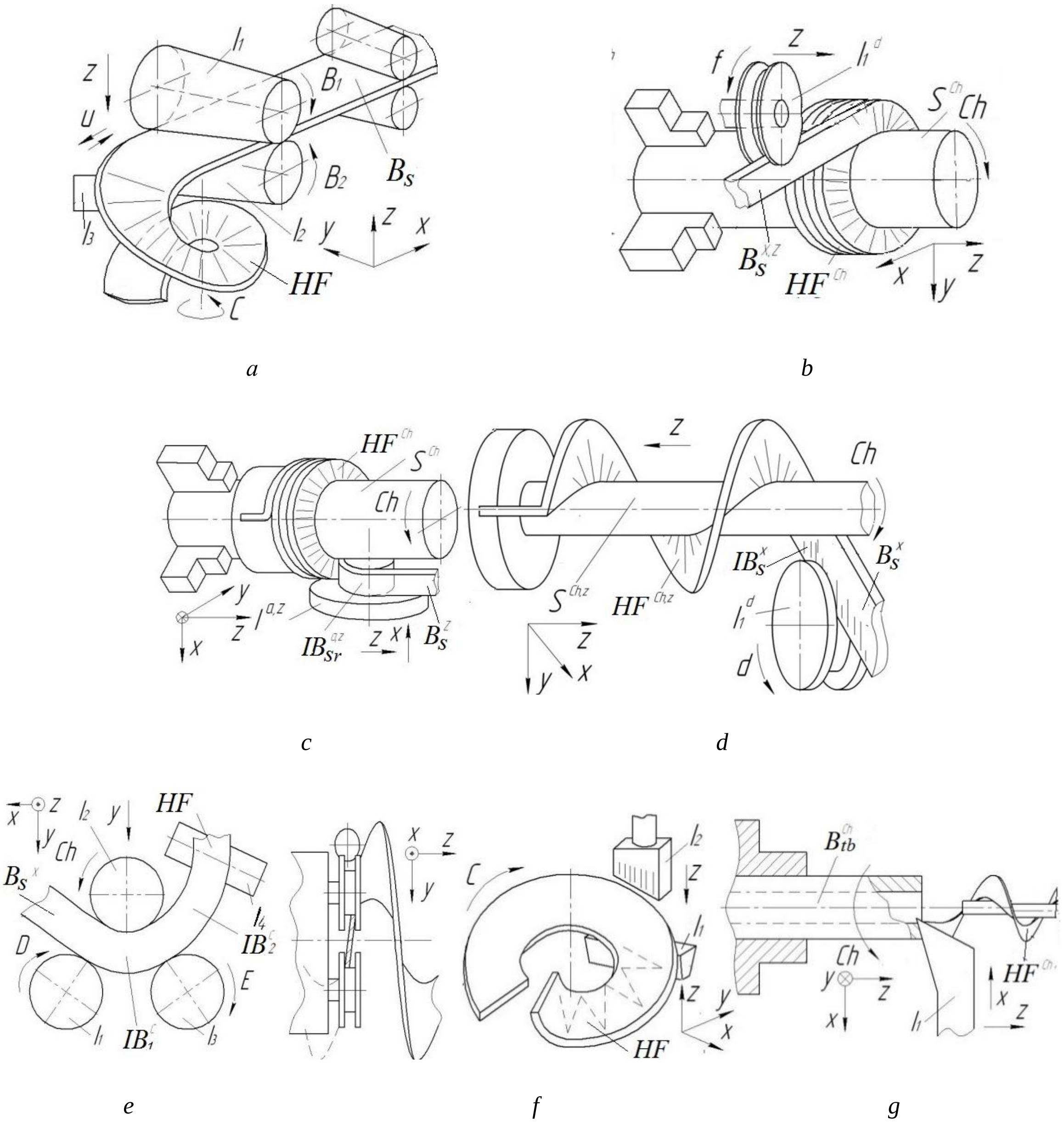


Figure 2. Typical technological schemes of formation sectional and long-dimensional HF, as well as AB with designation of movements of arrangement of technological equipment, tools and coordinate movements of structural elements of billet: a – obtaining multi-turn HF from initial strip billets b, c – obtaining HF with closed winding of turns by discrete winding of the strip billet with an edge on the mandrel in accordance with the parallel and perpendicular placement of forming tools relative to the mandrel; d – obtaining HF with open winding of turns by the method of discrete winding of the strip billet with an edge on the mandrel and with the parallel placement of the forming tool relative to the mandrel; e – obtaining HF by the method of strapless winding with the use of respectively three-roller profile-bending mechanism; f – obtaining sectional HF by incremental bending between the punch and the matrix, equipped with helical working surfaces; g – obtaining HF by turning cylindrical hollow billet

The peculiarity of this technique is due to the shape and directions of movement of the sections of the billet, which in many cases determine the possibility of implementing a certain technological method. In addition, based on the SF process it is possible to describe existing and synthesize new technological methods, as well as selection of technological equipment for their implementation by studying many SF configurations of technological equipment, many forms and directions of movement of billets. In this case, to solve the problem of data formalization and automation of the process of determining the total set of technological equipment configurations, it is advisable to use the method of Portman V.T. and Reshetova D.N. [12].

Synthesis of HF formation methods based on the use of SF.

Synthesis of HF formation methods is carried out based on SF formation by searching the number, composition and direction of forming and auxiliary movements of executive bodies in the coordinate system of technological equipment, forms and directions of sections «B», «IB», «HF» and principles of its transformation for the formation of spirals, composition and directions of movements of the working surfaces of forming tools. The selection of effective schemes is based on the analysis of the possibility of implementing the movements of the system elements by the type of equipment to be used, as well as the study of the energy efficiency of selected schemes.

Depending on the coordinate displacement of the section «Intermediate billet IB» several ways of winding HF formation can be identified (Fig. 3).

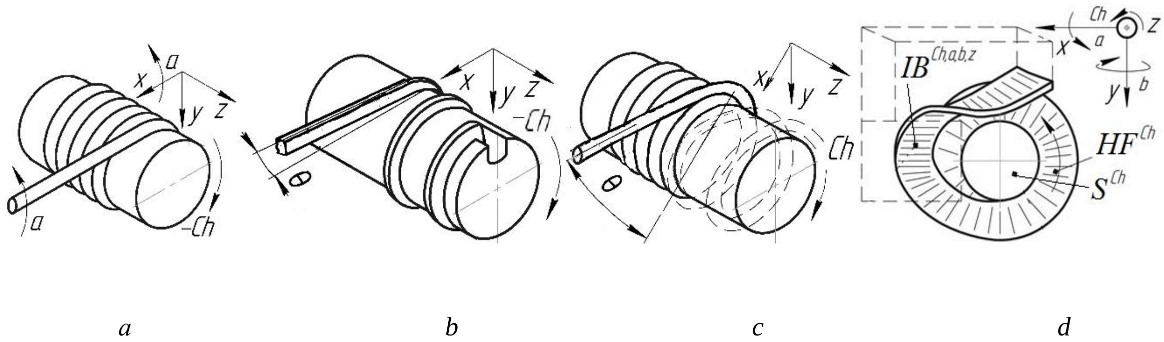


Figure 3. Scheme of HF formation: a-c – known; d – synthesized, in which IB section performs three circular motions (see also Fig. 8 and 9)

For such methods, the matrix of options for moving sections «*HF*» and «*S*» is:

$$\|F1\| = \begin{array}{c} \\ z \\ -z \\ 1 \end{array} \begin{array}{c} \begin{array}{cc} C_h & -C_h \end{array} \\ \begin{bmatrix} z, C_h & z, -C_h \\ -z, C_h & -z, -C_h \\ C_h & -C_h \end{bmatrix} \end{array}.$$

Based on the definition of a number of possible coordinate displacements of the sections of the billet, the matrix of variants of displacements of the sections is built. For example, the matrices of the main motions of «IB» section during its linear movement with simultaneous twisting (Fig. 3, a) are as follows:

$$F_1 = \begin{array}{c} \\ x \\ -x \\ y \\ -x, y \end{array} \begin{array}{c} \begin{array}{cccc} a & -a & b & -b \end{array} \\ \begin{bmatrix} (a,x)^* & (-a,x)^* & b(a,x)^* & (-b,x)^* \\ a,-x & -a,-x & (b,-x)^* & (-b,-x)^* \\ (a,x)^* & (-a,x)^* & b,y & -b,y \\ a,-x/y & -a,-x/y & (b,-x/y)^* & (b,-x/y)^* \end{bmatrix} \end{array};$$

$$
F_2 = \begin{array}{c} \\ z \\ -z \end{array}
\begin{array}{cccccc}
a,-x & -a,-x & b,y & -b,y & -x/y,a & -x/y,-a \\
a,-x,z & -a,-x,z & b,y,z & \left(-b,y,z\right)^{*} & \left(-x/y,a,z\right)^{*} & -x/y,a,z \\
a,-x,-z & -a,-x,-z & \left(b,y,-z\right)^{*} & \left(-b,y,-z\right)^{*} & -x/y,a,-z & \left(-x/y,a,-z\right)^{*}
\end{array}
$$

Examples of schemes for winding HF formation by the schemes shown in Fig. 3, a-c, are presented in Fig. 4 and 5. SF fragments of such sets are as follows:

Fig. 3, a – $IB^{a,-x,z}S^{-Ch}HF^{-Ch}$;

Fig. 3, b – $IB^{z/y,-z}S^{Ch}HF^{Ch}$;

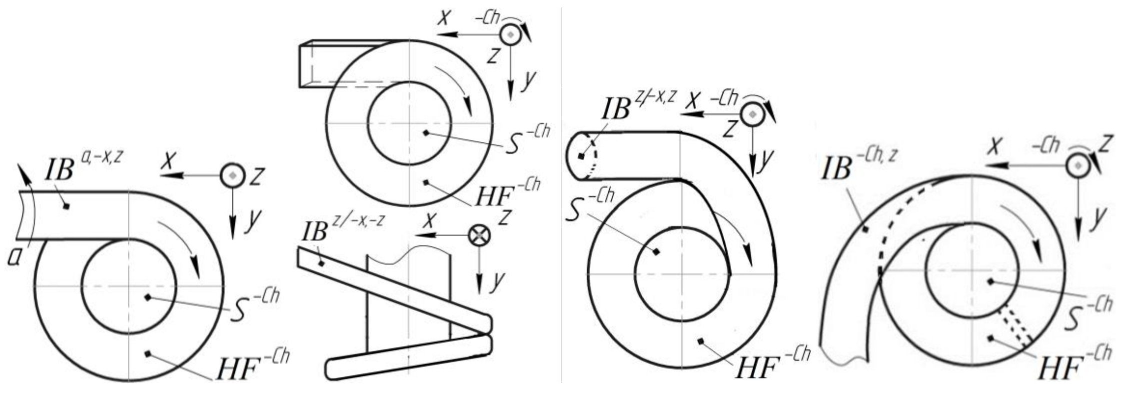
Fig. 3, c – $IB^{z/-x,z}S^{-Ch}HF^{-Ch}$;

Fig. 3, d – $IB^{b,-Ch,z}S^{-Ch}HF^{-Ch}$.

Based on the generalization, the main types of coordinate displacements of the «Intermediate billet» section are determined (Table 1).

The multivariate structure of other schemes of formation of HF is found based on search of variants of movements of sections of the processed preparation and a basic element of a spiral (mandrel). For example, the process of winding on the rod mandrel according to the scheme shown in Fig. 3, and can be implemented in different schemes, some of which can be described by the following SF:

$$
\begin{array}{cccc}
 & IB^{b,y,z}S^{Ch}HF^{Ch} & IB^{-a-x,z}S^{Ch}HF^{Ch} & IB^{-a,-x/y,z}S^{Ch}HF^{Ch} \\
IB^{a,-x}S^{-Ch,-z}HF^{-Ch,-z} & IB^{b,y}S^{Ch,-z}HF^{Ch,-z} & IB^{-a,-x}S^{Ch,-z}HF^{Ch,-z} & IB^{-a,-x/y}S^{Ch,-z}HF^{Ch,-z} \\
IB^{-a,-x,-z}S^{-Ch}HF^{-Ch} & IB^{-b,y,-z}S^{Ch}HF^{Ch} & IB^{a,-x,-z}S^{Ch}HF^{Ch} & IB^{a,-x/y,-z}S^{Ch}HF^{Ch} \\
IB^{-a,-x}S^{-Ch,z}HF^{-Ch,z} & IB^{-b,y}S^{Ch,z}HF^{Ch,z} & IB^{a,-x}S^{Ch,z}HF^{Ch,z} & IB^{-x/y}S^{Ch}HF^{Ch,z}
\end{array}
$$



a *b* *c* *d*

Figure 4. Schemes of forming winding HF with closed (*a, c, d*) and open (*b*) winding are realized by twisting (*a*) section «*IB*» of the billet, moving the section «*IB*» in the direction co-directed with the direction of the helical line HF (*b*) or at an angle relative to the mandrel in the direction opposite to the helical line HF (*c*) or with a circular motion around the Z axis of the section «*IB*» of the annular sector shape (*d*) in the presence of movement of the section «*IB*» along the axis of the mandrel simultaneous absence of axial movement of the mandrel and section «HF» along the Z axis

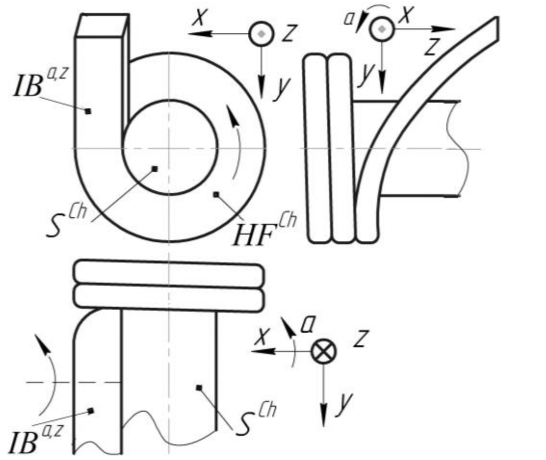


Figure 5. Sheme $IB^{a,z}S^{Ch}HF^{Ch}$ of discrete formation of winding HF using machine tool with the perpendicular placement of the forming roller relative to the axis of the mandrel and therefore the circular motion of the section "IB" around X axis in the presence of movement of such section along the axis of the frame and the absence HF area

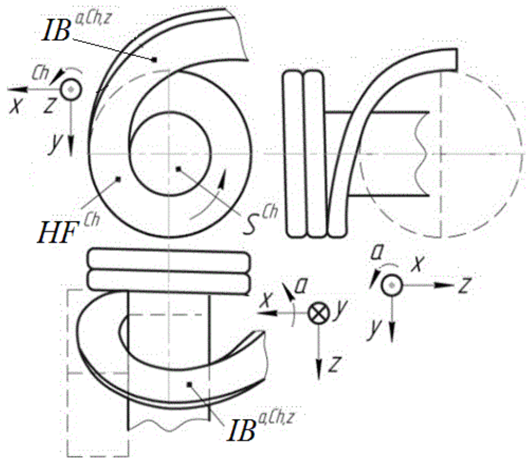


Figure 6. Synthesized sheme $IB^{a,Ch,z}S^{Ch}HF^{Ch}$ of discrete formation of winding HF using a machine tool with perpendicular placement of the forming roller relative to the axis of the mandrel and therefore two circular motions of the intermediate billet around X axis when it moves simultaneously along the axis of the mandrel

Table 1

The main methods of HF forming depending on the coordinated movements of "Intermediate billet" section in the schemes with its simultaneous movement along the axis of the mandrel and the main movement C_h

No	General feature of the movement of «Intermediate billet» section	The main types of coordinate movements of «Intermediate billet» section in the schemes with the main movement of C_h formation and simultaneous movement along the axis of the frame		Type of HF winding
		available	not available	
1	2	3	4	5
1	Perpendicular to the axis of the mandrel and parallel, or at an angle to X or Y axis	$\{-x,z\},\{y,z\},\{y,-z\},$ $\{-x,-z\},\{-x/y,\pm z\}$	$\{-x/y\},$ $\{-x\},\{y\}$	with closed or open winding
2	Perpendicular to the axis of the mandrel and parallel or at an angle to X or Y axis with simultaneous twisting (Fig. 3, *a*)	$\{-x/y,a,-z\},\{-x/y,-a,z\},$ $\{-x/y,a,z\},\{-x/y,-a,-z\}.$	$\{-x,\pm a\},$ $\{-y,\pm b\},\{\pm b,y\}$ $\{-x/y,\ \pm a\}$	with closed winding and initial inter-turn tension and round profile of cross-section of the turn
3	At an angle to the mandrel and in the direction opposite to the course of t helical line of HF (Fig. 3, c)	$\{-z/-x/y,-z\},\{z/-x/y,z\},$ $\{-z/y,\pm z\},\{-z/-x,z\},$ $\{z/y,\mp z\},\{z/-x,-z\},$	$\{\pm z/-x\},$ $\{\pm z/y\},$ $\{\pm z/-x/y\}$	with closed winding and initial inter-turn tension
4	At angle θ co-directed with the direction of the helical line of HF (Fig. 3, *b*)			with open winding
5	With circular motion around Z axis	$\{C_h,\pm z\},\{-C_h,\pm z\}$	$\{\pm C_h\}$	with closed or open winding

End of the table 1

1	2	3	4	5
6	With circular motion around he Y or X axes or axis inclined to the mentioned axes	$\{b,\pm z\},\{-b,\pm z\},\{\pm a,z\},$ $\{\pm a,-z\},\{b_{-x/y},z\},$ $\{\mp b_{-x/y},-z\},\{-b_{-x/y},z\},$ $\{a_{-x/y},\pm z\},\{-a_{-x/y},\pm z\}$	$\{\pm b\},\{\pm a\}$	with closed winding
7	Parallel to Z axis		$\{\pm z\}$	with open winding and profiled outer edge

In the process of analysis of movements the system of restrictions, which contains the main types of movements and the conditions of their relationship are determined. For example, for the scheme with circular feed of the "IB" section in the same direction or opposite to the main motion of the formation, it is important that the direction of the circular motion of "IB" section, "S" mandrel, and "HF" section coincide. Therefore, the schemes in which the axial movements of the sections "IB", "S" and "HF" differ in the direction ($IB^{-Ch,z}S^{-Ch,-z}HF^{-Ch,-z}$, $IB^{Ch,z}S^{Ch,-z}HF^{Ch,-z}$, $IB^{-Ch,-z}S^{-Ch,z}HF^{-Ch,z}$, $IB^{Ch,-z}S^{Ch,z}HF^{Ch,z}$), are inoperable, there are no axial displacements of at least one element of the system $IB^{-Ch}S^{-Ch}HF^{-Ch}$; ($IB^{Ch}S^{Ch}HF^{Ch}$). Kinematically complex but possible schemes include schemes with redundant movements (with duplicating unidirectional movements $IB^{-Ch,z}S^{-Ch,z}HF^{-Ch,z}$).

Evaluating the effectiveness of technological schemes.

To evaluate the effectiveness of technological schemes the method of describing the technical system in the energy space is used [10]. It makes it possible to describe items of production, billets, parts, etc. (material flow) by relevant energy categories – the energy content of material flow elements.

Based on the use of this approach, the structuring of the billet into sections can be considered as a result of the introduction of additional energy (E_{t1}, E_{t2}) through the action of machine tools (Fig. 7). Each formed section is characterized by useful energy (E_{IB}, E_{HF}) and energy of losses (E_{los1}, E_{los2}). Useful energy is the indicator of energy consumption for the formation and change of a certain shape (surface formation) and properties, as well as spatial location, for example, due to deformation and heating of the billet. It is the function of equipment parameters and shaping scheme.

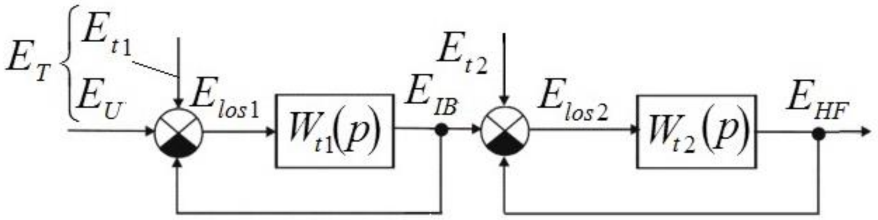


Figure 7. Block diagram of the main circuit of the energy model of workpiece transformation characterizing the process of HW formation

The energy of losses is determined by the losses in the drivers of technological system and in the areas of contact of machine tool with the billet.

The energy model is described as a system, the input of which is the total energy E_T, that is introduced, and the output – energy E_{HF} of *HF* section. There are the following equalities in the direct chain:

$$E_T = E_{t1} + E_U = E_{los1} + E_{IB};\ E_{IB} + E_{t2} = E_{los2} + E_{HF},$$
$$W_{t1}(p) = E_{IB}/E_{los1};\, W_{t2}(p) = E_{HF}/E_{los2};\, F(p) = E_{HF}/E_T, \quad (5)$$

where E_U is useful energy expended on the formation of "*IB*" section of the processed billet in the previous operation; $F(p)$ is transfer function of the closed system of «*IB*» section transformation into «*HF»* section, which determines the necessary energy resources for obtaining «*HF»* section with E_{HF} energy from the section «*B»* with E_U energy; and $W_{t1}(p)$ and $W_{t2}(p)$ are transfer functions of energy resources conversion into energy, respectively, «*IB»* and «*HF»* sections; E_{t1} and E_{t2} are energy supplied to the billet by the tools.

From formula (5) we see that:

$$F(p) = (1 + E_{t2}/E_{IB})\left(\left[W_{t1}(p)\right]^{-1} + 1\right)^{-1}\left(\left[W_{it2}(p)\right]^{-1} + 1\right)^{-1}$$

as

$$E_T = E_{IB}\left(\left[W_{t1}(p)\right]^{-1} + 1\right);\ E_{HF} = (E_{IB} + E_{t2})\left(\left[W_{t2}(p)\right]^{-1} + 1\right).$$

Thus, the search for rational way of HF forming from a variety of options should be carried out taking into account the limit values of transfer functions from conditions:

$$F^*_{\min}(p) < F(p) < F^*_{\max},\ F(p) \le 1,$$
$$W^*_{t1\min}(p) < W_{t1}(p) < W^*_{t1\max}(p),\ W^*_{t2\min}(p) < W_{t2}(p) < W^*_{t2\max}(p).$$

The quality factor of the energy circuit can be considered as the ratio of dissipated energy in the process of converting «*IB*» section into *«HF»* section to the energy entering the system. It characterizes the quality of the tools used, processing modes. In this approach, the concept of useful energy is important. All energy is useful except the energy, which is released in the form of heat.

The result of the described technique implementation.

Based on the use of the proposed technique application, a new method of HF manufacturing (see Fig. 6, 8 and 9) was synthesized, in which the initial billet in the form of continuous or cut-out multi-turn spiral with variable radius of curvature was used. This design reduces the degree of its deformation, compared with rectilinear flat tape, under the same conditions creating reserve for reducing the minimum bending radius of the tape, which is limited not by loss of stability, but the resource of metal plasticity.

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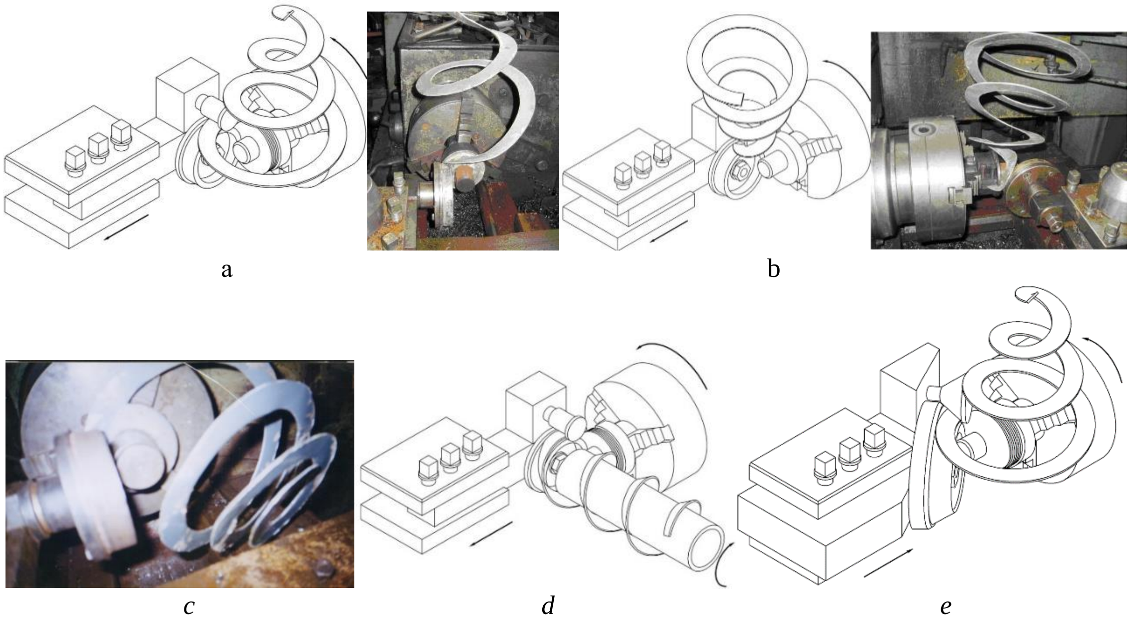
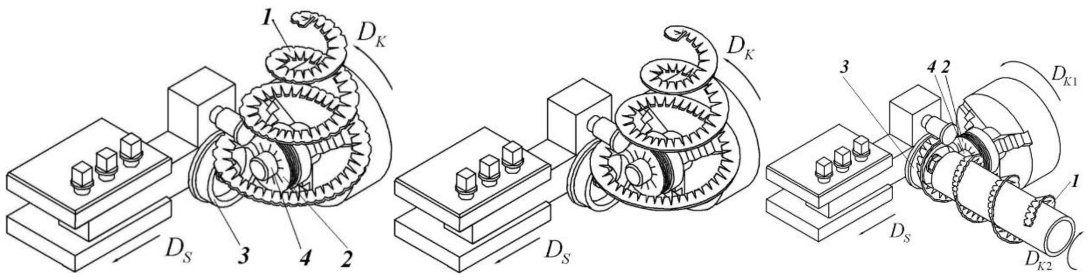


Figure 8. Options for the manufacture of winding HW with closed winding turns: *a* – stable process with complex discrete feed of the workpiece in the deformation zone; *b, c* – the winding process is not carried out; *d, e* – schemes with simplified method of feeding the workpiece into the deformation zone

However, while forming HF in this case, it is necessary to consider the option of the initial billet supply: the scheme of the spiral billet supply from larger diameter to smaller is characterized by the complexity of the initial billet supply into the deformation zone (Fig. 8, a) to the mandrel (Fig. 8, c), or in the direction from smaller diameter to the outer (Fig. 8, b) – are not carried out, so preference should be given to schemes (Fig. 8, d, e). In the latter case, the multi-turn flat or continuous-section tape spiral must be stretched up to the formation of intermediate spiral or continuous-section screw billet with constant inner diameter and variable pitch, or use a special roller.

The effective implementation of schemes (Fig. 8, d, e) in comparison with scheme (Fig. 8 a, b) is due to the reduction of the arm of the transverse bending force, which increases the stability of the process, increases the ductility of the metal due to increasing tangential stresses. However, for winding parts manufacture from spiral billets, it is advisable to use the device by oblique placement of the roller axis relatively to the mandrel.



a *b* *c*

Figure 9. Schemes of formation of winding HW with cutouts with closed winding of turns: *a* – the process of discrete supply of spiral continuous-section workpiece to the deformation zone; *b* – the process of discrete feeding of the spiral workpiece (with triangular cutouts on the inner edge) to the deformation zone; *c* – the scheme with the simplified way of workpiece feeding to the deformation zone: 1 – spiral workpiece; 2 – winding HW, 3 – roller, 4 – frame

Conclusions. Based on the use of components methods the universal technique of the formalized description of the ways of HF and AB formation, which receive various technological methods are developed. It takes into account the number, composition and direction of forming an auxiliary movements of executive bodies in the coordinate system of technological equipment, peculiarities of design (shape) and directions of movements of sections of the initial billet and the principle of its transformation to form spiral, composition and direction of working surfaces. Based on the technique of the formalized description of methods of HF and AB formation the method of structural synthesis of effective methods of manufacturing of such billets is developed. The developed method of synthesis allowed to identify previously not described in the technical literature methods of HF formation. Some of the considered schemes have the same classification features and kinematics, but are realized by the complex structure of movements of the processed billet sections. By current trends in the introduction of computer-integrated technologies in the educational process [13], the developed methodology can be implemented using modern software and recommended for implementation in the educational process in training specialists in «Applied Mechanics».

References

1. Hevko B. M., Pylypets′ M. I., Vasyl′kiv V. V., Radyk D. L. Tekhnolohichni osnovy formotvorennya riznoprofil′nykh hvyntovykh zahotovok, Ternopil′, Vyd-vo TDTU im. I. Pulyuya, 2009. 457 p. ISBN 966-305-014-4. [In Ukrainian].
2. Pylypets′ M. I., Vasyl′kiv V. V., Radyk D. L., Pylypets′ O. M. (2021) Peredumovy rozroblennya kombinovanykh operatsiy vyhotovlennya hvyntovykh i shnekovykh zahotovok metodom obrobky metaliv tyskom. Perspektyvni tekhnolohiyi ta prylady, Luts′k, Vyp. 18. P. 112–123. [In Ukrainian].
3. Gevko Iv. B., Gud` V. Z., Krugly`k O. A. Sy`ntez sposobiv navy`vannya spiralej shnekiv. Zbirny`k naukovy`x pracz` "Perspekty`vni texnologiyi ta pry`lady`". Lucz`k, 2018. Vy`pusk 12. P. 39–47. [In Ukrainian].
4. Gevko I., Katrych O. (2015) Syntez sposobiv navyvannia hvyntovykh zahotovok [Synthesis of the spiral pieces coiling methods]. Bulletin of TNTU (Tern.), Volume 80. No. 4. P. 156–163 [in Ukrainian].
5. Leshchuk R., Palivoda Yu., Navrotska T., Hevko B., Khoroshun R., Hevko A. Synthesis and experimental studies of the method of manufacturing screw spirals with a rotating plug with feasibility study. Scientific Journal of TNTU. Tern.: TNTU, 2021. Vol. 103. No. 3. P. 43–52. DOI: https://doi.org/10.33108/visnyk_tntu2021.03.043
6. Diachun A., Vasylkiv V., Korol O., Myhailiuk V., Golovatyi I., Kuras A. (2021) Investigation of geometrical parameters in screw surfaces whirling process. Scientific Journal of TNTU (Tern.). Vol. 101. No. 1. P. 68–78. DOI: https://doi.org/10.33108/visnyk_tntu2021.01.068
7. Vasyl′kiv V. (2010) Syntez skhem formoutvorennya hvyntovykh zahotovok. Obrobka materialiv tyskom, No. 1 (22). P. 167–173. [In Ukrainian].
8. Pylypets′ M. I., Vasyl′kiv V. V. (2012) Metod syntezu tekhnolohiy vyhotovlennya shyrokosmuhovykh hvyntovykh zahotovok, Visnyk SevNTU. Vyp. 128. P. 169–177. [In Ukrainian].
9. Rogatinskiy R., Hevko I., Gypka A., Garmatyk O., Martsenko S. (2017) Feasibility study of the method choice of manufacturing screw cleaning elements with the development and use of software. Acta Technologica Agriculturae, Nitra, Slovaca Universitas Agriculturae Nitriae. No. 2. P. 36–41. DOI https://doi.org/10.1515/ata-2017-0007
10. Vasyl′kiv V. V. Rozvytok naukovo-prykladnykh osnov rozroblennya tekhnolohiy vyrobnytstva hvyntovykh i shnekovykh zahotovok z vykorystannyam unifikatsiyi: avtoreferat dysertatsiyi na zdobuttya naukovoho stupenya doktora tekhnichnykh nauk: 05.02.08 – tekhnolohiya mashynobuduvannya / Vasyl′ Vasyl′ovych Vasyl′kiv; Ministerstvo osvity i nauky Ukrayiny, Natsional′nyy universytet "L′vivs′ka politekhnika". L′viv, 2015. 48 p. [In Ukrainian].
11. Vragov YU. D. Analiz komponovok metallorezhushchikh stankov. (Osnovy komponetiki). M.: Mashinostroyeniye, 1978. 208 pp. [in Russian].
12. Reshetov D. N., Portman V. T. Tochnost' metallorezhushchikh stankov. M.: Mashinostroyeniye, 1986. 336 p. [In Russian].
13. Vasylkiv V., Pylypets M., Danylchenko L., Radyk D. (2021) Use of computer-integrated technologies in training of engineering specialists. In: Ternopil National Ivan Puluj Technical University. Proceedings of the International Conference Advanced Applied Energy and Information Technologies, Ternopil, December 15–17, 2021. P. 74–80.

Список використаної літератури

1. Гевко Б. М., Пилипець М. І., Васильків В. В., Радик Д. Л. Технологічні основи формотворення різнопрофільних гвинтових заготовок. Тернопіль: вид-во ТДТУ ім. І. Пулюя, 2009. 457 с. ISBN 966-305-014-4.
2. Пилипець М. І., Васильків В. В., Радик Д. Л., Пилипець О. М. Передумови розроблення комбінованих операцій виготовлення гвинтових і шнекових заготовок методом обробки металів тиском. Перспективні технології та прилади. 2021. Вип. 18. С. 112–123.
3. Гевко Ів. Б., Гудь В. З., Круглик О. А. Синтез способів навивання спіралей шнеків. Збірник наукових праць «Перспективні технології та прилади». Випуск 12. ЛНТУ. Луцьк, 2018, С. 39–47.
4. Гевко І. Б., Катрич О. В. Синтез способів навивання гвинтових заготовок. Вісник ТНТУ. 2015. Том 80. № 4. С. 156–163.
5. Leshchuk R., Palivoda Yu., Navrotska T., Hevko B., Khoroshun R., Hevko A. (2021) Synthesis and experimental studies of the method of manufacturing screw spirals with a rotating plug with feasibility study. Scientific Journal of TNTU (Tern.). Vol. 103. No. 3. P. 43–52. DOI: https://doi.org/10.33108/visnyk_tntu2021.03.043
6. Diachun A., Vasylkiv V., Korol O., Myhailiuk V., Golovatyi I., Kuras A. Investigation of geometrical parameters in screw surfaces whirling process. Scientific Journal of TNTU. 2021. Vol. 101. No. 1. P. 68–78. DOI: https://doi.org/10.33108/visnyk_tntu2021.01.068
7. Васильків В. Синтез схем формоутворення гвинтових заготовок. Обробка матеріалів тиском. № 1 (22). 2010. С. 167–173.
8. Пилипець М. І., Васильків В. В. Метод синтезу технологій виготовлення широкосмугових гвинтових заготовок. Вісник СевНТУ. 2012. Вип. 128. С. 169–177.
9. Rogatinskiy R., Hevko I., Gypka A., Garmatyk O., Martsenko S. Feasibility study of the method choice of manufacturing screw cleaning elements with the development and use of software. Acta Technologica Agriculturae. Nitra. Slovaca Universitas Agriculturae Nitriae. 2017. № 2. P. 36–41. DOI https://doi.org/10.1515/ata-2017-0007
10. Васильків В. В. Розвиток науково-прикладних основ розроблення технологій виробництва гвинтових і шнекових заготовок з використанням уніфікації: автореф. дис. … д-ра техніч. наук: 05.02.08 / Міністерство освіти і науки України, Національний університет «Львівська політехніка». Львів, 2015. 48 с.
11. Врагов Ю. Д. Анализ компоновок металлорежущих станков. (Основы компонетики). М.: Машиностроение, 1978. 208 с.
12. Решетов Д. Н., Портман В. Т. Точность металлорежущих станков. М.: Машиностроение, 1986. 336 с.
13. Vasylkiv V., Pylypets M., Danylchenko L., Radyk D. (2021) Use of computer-integrated technologies in training of engineering specialists. In: Ternopil National Ivan Puluj Technical University, Proceedings of the International Conference Advanced Applied Energy and Information Technologies, Ternopil, December 15–17, 2021. P. 74–80.

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ФОРМАЛІЗОВАНИЙ ОПИС ТА СИНТЕЗ СХЕМ ФОРМОУТВОРЕННЯ ГВИНТОВИХ І ШНЕКОВИХ ЗАГОТОВОК НА ОСНОВІ МЕТОДІВ КОМПОНЕТИКИ

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Резюме. *На основі використання методів компонетики вперше розроблено універсальну методику формалізованого опису і синтезу способів формоутворення гвинтових і шнекових заготовок, які отримують різними технологічними методами. Вона враховує кількість, склад і напрямок формоутворюючих та допоміжних рухів виконавчих органів у координатній системі технологічного* *устаткування, особливості конструктивного виконання (форму) і напрямки рухів ділянок початкової заготовки та принцип її перетворення для утворення спіралі, склад і напрямок рухів робочих поверхонь формоутворюючих інструментів. Розроблена методика синтезу дозволила виявити раніше не описані в технічній літературі способи формоутворення гвинтових заготовок. Частина із розглянутих схем мають однакові класифікаційні ознаки й кінематику, але реалізуються складною структурою переміщень ділянок заготовки, яку обробляють.*

Відповідно до сучасних тенденцій упровадження комп'ютерно-інтегрованих технологій у навчальний процес, розроблена методика може бути реалізована з використанням сучасних програмних засобів і рекомендована для впровадження в навчальний процес у підготовці фахівців зі спеціальності «Прикладна механіка».

На основі використання запропонованої методики синтезовано новий спосіб виготовлення навивних гвинтових заготовок, у якому використовують початкову заготовку у формі суцільної чи з вирізами багатовиткової спіралі зі змінним радіусом кривизни її витків. Таке конструктивне виконання зменшує ступінь її деформації, в порівнянні з прямолінійною плоскою стрічкою, за інших однакових умов, створюючи резерв для зменшення мінімального радіуса згинання стрічки, який обмежується практично не втратою стійкості, а ресурсом пластичності металу.

Ключові слова: *гвинтова заготовка, шнекова заготовка, синтез, схема формоутворення.*

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