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SYNTHESIS AND EXPERIMENTAL STUDIES OF THE METHOD OF MANUFACTURING SCREW SPIRALS WITH A ROTATING PLUG WITH FEASIBILITY STUDY

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***Summary**. The structural synthesis of methods of winding screw spirals using the method of hierarchical grouping by means of morphological analysis is carried out and a number of alternatives that allowed to create the improved way of winding screw spirals with rotating plug is obtained. On the basis of the conducted multifactor experiment the study of torque of the process of screw workpiece calibration per step was performed and the regression dependence was obtained to determine the influence of winding width, wedge angle and winding thickness on the torque of the calibration process. It is established that calibration process of the turn of screw workpiece per step depends on the width, thickness of the spiral and the angle of the wedge of the device. With increasing inclination of the wedge of the device and the thickness of the winding, for the material steel 08kp, the torque increases and reaches 79 N m. It is established that the dominant factor influencing the value of torque is the angle of the wedge of the device, and the least influential is the winding width. The technical and economic estimation of the method of winding screw spirals with rotating plug is carried out and found that the annual economic effect, when replacing the basic version of winding screw spirals (winding on the frame) on the design (winding with rotating plug), when operating equipment in one shift is 16995.79 UAH.*

***Key words**: winding, rotating plug, technical and economic estimation.*

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Statement of the problem. Screw elements are widely used in various types of machines and mechanisms, and are the main parts of sectional screw conveyors as well. Therefore, close attention is payed to their development. But despite the significant amount of studies in the field of their technological production, the complexity and high energy consumption of their manufacturing processes, as well as increased requirements for quality, reliability, durability and design and technological parameters of these blanks, forces to search for new ways to obtain them.

Analysis of available research. Thus, formation of screw elements by pressing with subsequent formation of winding and welding in a spiral leads to significant material losses while cutting the rings, as well as low quality of spiral welded from the rings, compared to solid produced ones. Also, this method of manufacture is characterized by high complexity, waste production and cost of the process, and is implemented mainly in single and small-scale production. Rolling spirals is energy and capital consuming and becomes technologically justified only in mass production [5, 8]. Therefore, the most technological for mass production is the formation of screw elements from a tape strip by winding. For this reason, the development of advanced methods of winding screw spirals with a rotating plug is relevant and contributes to the production of energy-saving high-performance technologies.

Objectives of the research are to amend the technological effectiveness of machine screw working bodies, improve the technological process and developing high-performance technological equipment for their manufacture.

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Statement of the problem. The theory and practice of winding screw spirals (SS) suggests the main ways of their formation by winding the tape on different types of frames [5, 8, 9]. These methods also involve pressing the tape to these frames with different types of rollers. However, not so long ago new methods of winding SS with a rotating plug were proposed and investigated [1–4]. But the disadvantage of these methods was the lack of stability of SS winding process and, in particular, the problematic fracture of the spiral at the initial stage of winding [3]. Therefore, we have proposed an improved method of winding the SS with a rotating plug, which includes the use of additional forming rollers.

Results of the research. The main task of synthesis by morphological analysis [7] is to obtain SS structures with improved technical and economic characteristics. We used an improved version of this method of synthesis with a hierarchical grouping [1] of constructive features of the elements of SS winding process. This method allowed generation of alternatives at the appropriate hierarchical levels within the individual structural elements, and allowed to obtain a limited number of rational design solutions. In particular, during the implementation of this synthesis the main design features and elements used in winding SS are included in Table 1.

Table 1

Morphological table of structural features of the elements of winding screw spirals with rotating plug

<table>
<tr><th rowspan="2">1. Frame</th><th rowspan="2">2. Workpiece guides</th><th rowspan="2">3. Rotating plug</th><th colspan="2">Support plug</th><th rowspan="2">6. Fixation plug</th></tr>
<tr><th>4. Degree of freedom</th><th>5. Presence of forming rollers on the surface</th></tr>
<tr><td>1.1. Smooth shaft with fastening unit</td><td>2.1. Roller</td><td>3.1. Available</td><td>4.1. Movable in the radial direction</td><td>5.1.With rollers placed in a circle</td><td rowspan="4">6.1. Available and movable in radial and axial directions</td></tr>
<tr><td rowspan="3">1.2. Threaded shaft</td><td rowspan="3">2.2. Guide surface with groove</td><td rowspan="3"></td><td rowspan="3">4.2. Immovable</td><td>5.2. With rollers placed on the part of the circle</td></tr>
<tr><td>5.3. With one roller</td></tr>
<tr><td>5.4. Without rollers</td></tr>
</table>

The morphological model of the process of winding screw spirals with rotating plug (Table 1) can be represented in the form of a morphological matrix formed by numerical designation of the corresponding alternatives placed in the morphological table [7]:

$$N = K_1 \cdot K_2 \cdot K_3 \cdot ... \cdot K_j = \prod_{j=1}^{n} K_j \, , \tag{1}$$

where n is the number of alternatives to the design feature of the elements; K_i is an alternative to the constructive feature of the element of a certain subgroup of the corresponding hierarchical level.

$$N_{wss} = \begin{vmatrix} 1.1 \\ 1.2 \end{vmatrix} \cap \begin{vmatrix} 2.1 \\ 2.2 \end{vmatrix} \cap \begin{vmatrix} 3.1 \end{vmatrix} \cap \begin{vmatrix} 4.1 \\ 4.2 \end{vmatrix} \cap \begin{vmatrix} 5.1 \\ 5.2 \\ 5.3 \\ 5.4 \end{vmatrix} \cap \begin{vmatrix} 6.1 \end{vmatrix} = 32.$$

It is clear that when using the classical method, the number of synthesized variants is excessive for analysis. Therefore, we applied the method of synthesis of hierarchical groups with their division into subgroups using morphological analysis [1]:

$$N_1 = \sum_{z=1}^{l} \sum_{x=1}^{q} \prod_{i=1}^{m} K_i \tag{2}$$

where z is the hierarchical level; l is the number of hierarchical levels; x is a certain subgroup of the corresponding hierarchical level; q is the number of subgroups of the corresponding hierarchical level; K_i is an alternative to the constructive feature of an element of a certain subgroup of the corresponding hierarchical level; m is the number of alternatives of the constructive feature of the elements of a certain subgroup of the corresponding hierarchical level.

To use this method, a model of the mechanical system «Method of winding screw spirals with a rotating plug» was developed (Fig. 1) and the structural features of the elements were fixed for certain subgroups and the corresponding hierarchical levels. Therefore, the first hierarchical level includes the features of process of elements 3, 4 and 6; subgroup I of the second hierarchical level includes a feature of process of element 1; subgroup II of the second hierarchical level includes a feature of process of element 2; subgroup III of the second hierarchical level includes a feature of the process of element 5.

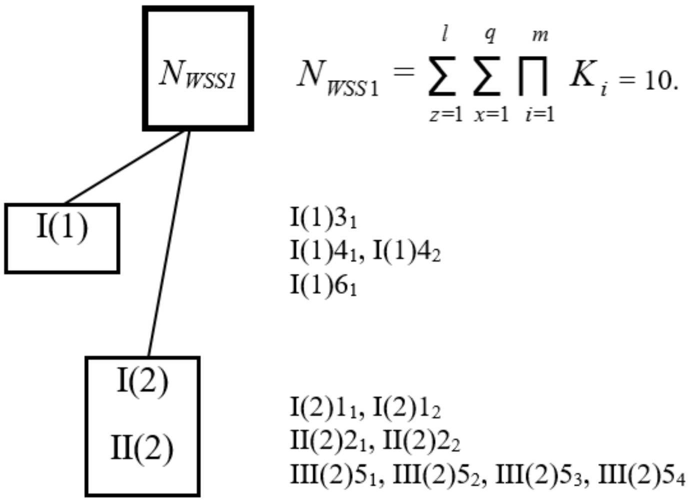
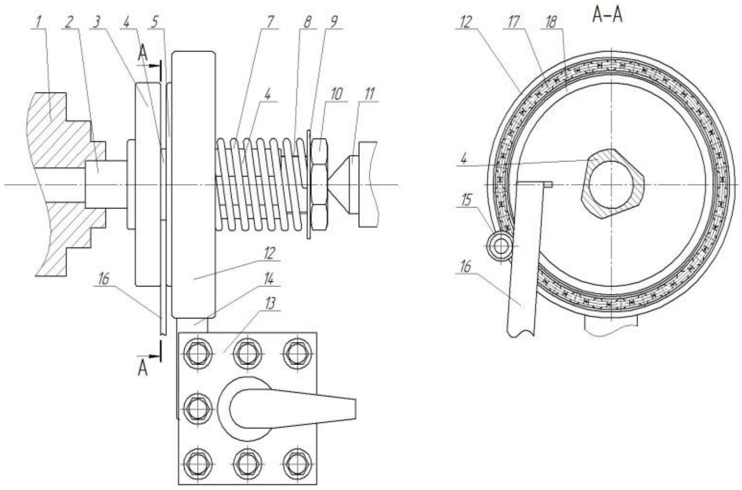


Figure 1. Model of mechanical system «Method of winding screw spirals with rotating plug»: (1), (2) – corresponding hierarchical levels; I – III – subgroups of hierarchical level

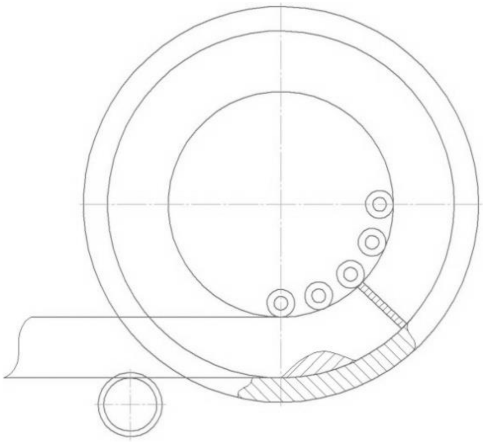
The number of generated alternatives when using this method will be 3.2 times less than the number of generated alternatives when using the traditional method:

$$N_{wss1} = \begin{vmatrix} 3.1 & \begin{matrix} 4.1 \\ 4.2 \end{matrix} & 6.1 \end{vmatrix} \cap \begin{vmatrix} 1.1 \\ 1.2 \end{vmatrix} \cap \begin{vmatrix} 2.1 \\ 2.2 \end{vmatrix} + \begin{vmatrix} 4.1 \\ 4.2 \\ 4.3 \\ 4.4 \end{vmatrix} = 10.$$

Using the results of morphological synthesis, improved, in comparison with the previously developed [1–4], variants of methods of winding screw spirals with a rotating plug with the use of additional forming rollers were generated (Fig. 2). They differ only in the presence and number of arranged forming rollers in a circle.



a)



b)

Figure 2. Schemes of winding screws spirals with rotating plug:
a) – constructive scheme of winding screw spirals; b) – view of the support roller plug

The analysis of researches of winding screws spirals with a rotating plug is presented in [3]. After winding the screws spirals with a rotating plug in a tight package, it is necessary to calibrate them to the step described in [1]. Experimental studies to determine the torque of the calibration process of the turn of a screw workpiece per step were performed for workpieces made of materials: steel 08 kp *(= 276 MPa, P = 483 MPa)* and St 3 *(= 368 MPa, P = 526 MPa).* Based on a multifactor experiment to study the torque of calibration process of the winding of the screw workpiece per step, obtained a regression dependence to determine the effect of the winding width B_0, the angle of the wedge α and the winding thickness H_0 on the torque of the calibration process:

$$M_{кр(B_0,\alpha,H_0)} = -18,21 + 1,27\alpha + 0,066B_0H_0 - 0,37\alpha^2 + 0,21\alpha H_0 + 0,81H_0^{\,2} \qquad (3)$$

After checking the adequacy of the approximating models and assessing the significance of the coefficients of the regression equation according to Fisher's and Student's criteria, the response surface (Fig. 3) is constructed within the variable input factors: winding width $20 \le B_0 \le 50$ (mm), wedge angle $10 \le \alpha \le 30$ (degrees) and winding thickness $2 \le H_0 \le 6$ (mm).

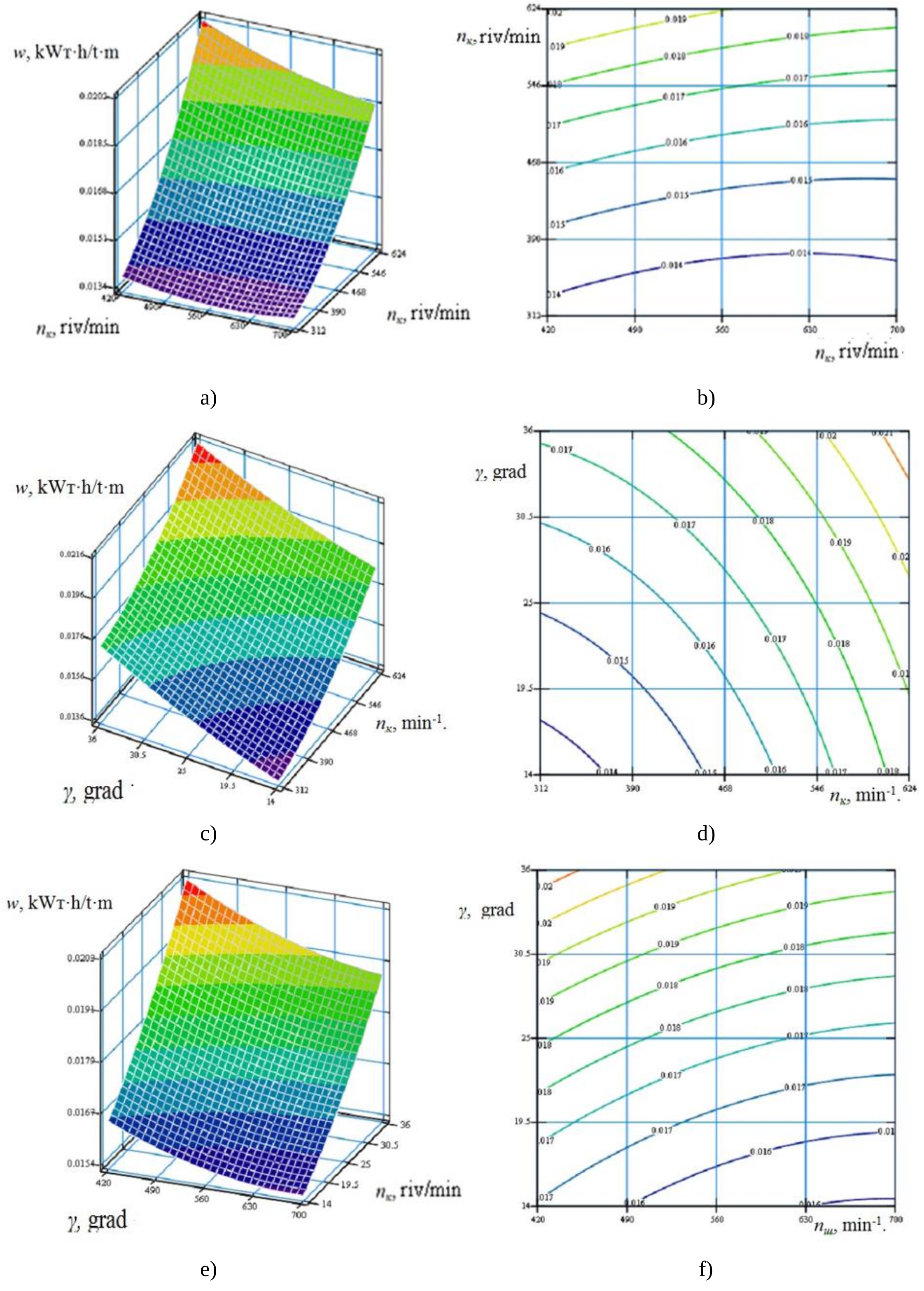
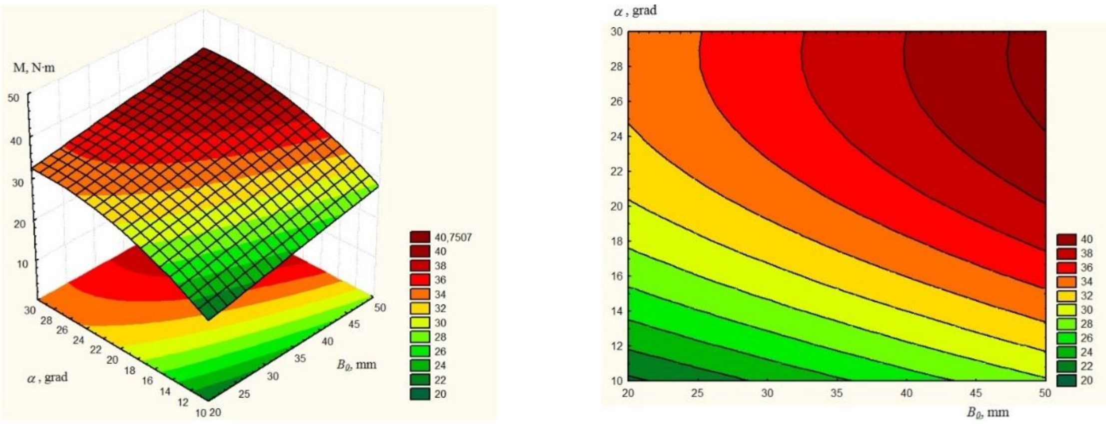
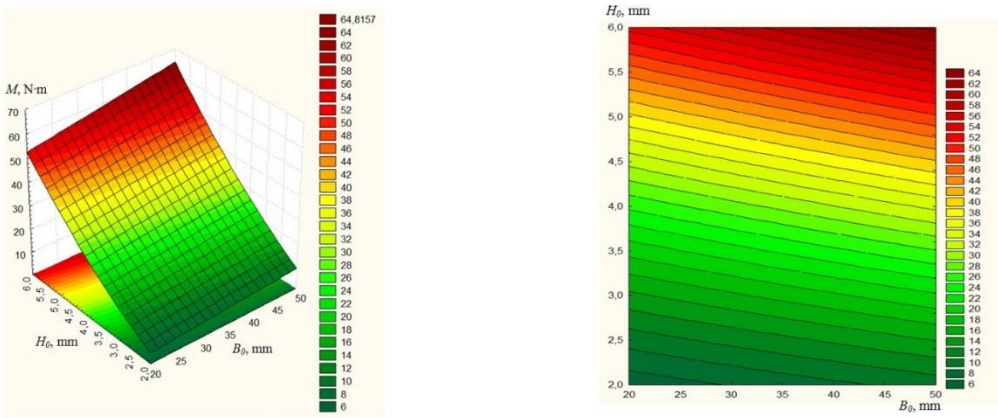


Figure 3. Response surface (a, c, e) and two-dimensional cross-section of the response surface (b, d, e) torque $M_{(B_0,H_0)}$ dependence for the process of calibration of the turn of the screw workpiece in steps of:
a), b) α and B_0 at H_0 = 4 mm; c), d) H_0 and B_0 at α = 20 degrees; e), e) H_0 and α at B_0 = 35 mm



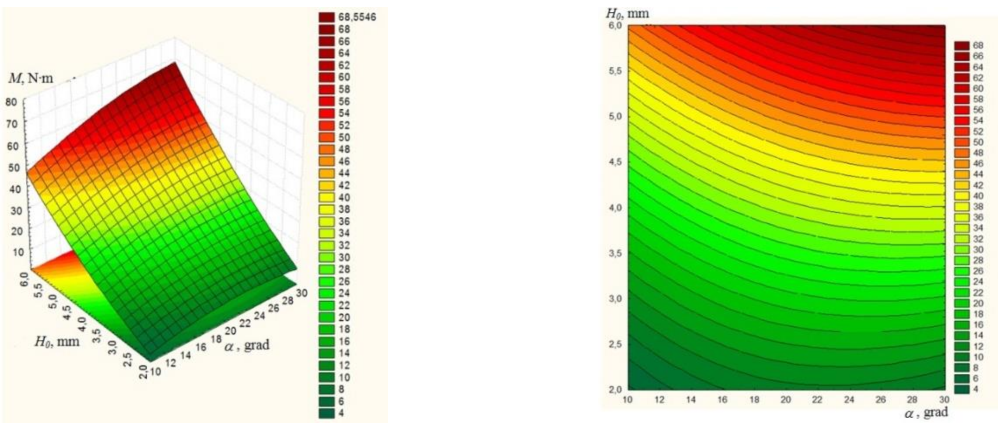
a) b)

Fugure 4. Response surface (a) and two-dimensional cross-section of the response surface (b) of the torque $M_{кр(B_0,\alpha)}$ dependence for the process of calibration of the turn of the screw workpiece per step (H_0 = 4 mm)



a) b)

Figure 5. Response surface (a) and two-dimensional cross-section of the response surface (b) of the torque $M_{(B_0,H_0)}$ dependence for the process of calibration of the turn of the screw workpiece per step (α = 20 degrees)



a) b)

Figure 6. Response surface (a) and two-dimensional cross-section of the response surface (b) of the torque $M_{кр(\alpha,H_0)}$ dependence for the calibration process of the turn of the screw workpiece per step (B_0 = 35 mm)

Due to graphical dependences of Fig. 3, the calibration process of the screw piece winding by one step depends on width, thickness of the spiral and the inclination angle of the wedge of the device. When the angle of the wedge α of the device and the winding thickness winding H_0 increase, for the steel 08 kp the torque grows and reaches 79 Nm. From the analysis of graphical dependences it is stated that the dominating factor that influences on the value of $M_{кр}$ is the angle of the wedge α of the device and the least influential is the spiral width B_0.

To determine the economic efficiency of the proposed method of winding screw spirals, technical and economic comparison of the processes of winding screw spirals with rotating plug (design version) and on the frame (basic version). Thus as the basic model of the machine on which calculation of winding cost will be carried out, the machine of model 16E16KP is selected. To ensure the winding process, special equipment was used. In the basic version it was a classic version of the frame with guide and clamping rollers, and in the design version synthesized model was applied: frame, mounting, supporting with forming rollers and rotating plugs (Fig. 2). The relative cost of special equipment in the project version is slightly higher than in the basic one.

Calculation of cost for winding screw spirals on the basic and design options was carried out in the manufacture of spirals 2 mm thick, 30 mm high, 100 mm outer diameter, made of steel 08kp, 3 m long tapes. In Table 2 (they are comparative and may be adjusted depending on changes in the cost of equipment, devices, duration of operations, etc.). In addition, we performed a comparative calculation only on some different operations of the technological process (similar operations on the duration and use of tools are not considered, such as calibration of the spiral).

Table 2

Data for comparison of methods of winding screw spirals

Data for calculation	Basic variant (winding on a frame)	Design variant (winding with rotating plug)
Electricity consumption, kW/h	3,61	3,26
Type and brand of equipment	16E16KP lathe and screw-cutting machine	16E16KP lathe and screw-cutting machine
Technological equipment	frame, guide and clamping rollers	frame, mounting, support with forming rollers and rotating plug
Cost of technological equipment, UAH	2150	3730
Duration of operation (including fastening of a strip, winding and removal of a dense package), s	131	114
Category of the worker	4	4

Calculation of certain different operations of the technological process of winding screw spirals using the known method was carried out [6]. 3. Calculation of the elements of the costs of individual operations on the basic and design options for technological processes of winding screw spirals was conducted and the results are shown in Table 3.

Table 3

Calculation of the cost elements for individual operations of technological processes of winding screw spirals

Cost elements	Basic variant (winding on a frame)	Design variant (winding with rotating plug)
Wage costs	1,68	1,47
Electricity costs	0,27	0,22
Equipment depreciation costs (equipment)	0,01 (0,008)	0,01 (0,011)
Total costs	1,96	1,7

The annual economic effect, when replacing the basic version of the winding the screw spirals (winding on the frame) on the design (winding with a rotating plug), when the equipment works in one shift, is:

$$E_{p} = (2070 / (114 / 3600)) \cdot (1{,}96 - 1{,}7) = 16995{,}79 \text{ UAH}$$

Conclusions. The structural synthesis of screw winding with rotating plug by hierarchical grouping by morphological analysis is carried out and a number of generated constructions with improved technical and economic characteristics are obtained, which made it possible to expand screw winding parameters with different types of spirals.

On the basis of the conducted multifactor experiment the study of the torque of calibration process of the screw workpiece per step was performed and the regression dependence was obtained to determine the influence of the winding width, wedge angle and winding thickness on the torque of the calibration process. It is established that the process of calibration of the turn of the screw workpiece per step depends on the width, thickness of the spiral and the angle of the wedge of the device. With increasing inclination of the wedge of the device and the thickness of winding, for the material steel 08kp, the torque increases and reaches 79 N m.

Technical and economic estimation of the method of winding screw spirals with rotating plug is performed. The annual economic effect, when replacing the basic version of winding screw spirals (winding on the frame) by the design one (winding with a rotating plug), with equipment working in one shift, is 16995.79 UAH.

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УДК 621.9.04

СИНТЕЗ ТА ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ СПОСОБУ ВИГОТОВЛЕННЯ СПІРАЛЕЙ ШНЕКІВ ОБЕРТОВОЮ ВТУЛКОЮ З ТЕХНІКО-ЕКОНОМІЧНИМ ОБҐРУНТУВАННЯМ

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Резюме. *Проведено структурний синтез способів навивання спіралей шнеків методом ієрархічного групування за допомогою морфологічного аналізу й отримано ряд альтернатив, що дозволило отримати вдосконалений спосіб навивання спіралей шнеків обертовою втулкою. На основі проведеного багатофакторного експерименту виконано дослідження крутного моменту процесу калібрування витка гвинтової заготовки на крок й отримано регресійну залежність для визначення впливу величини ширини витка, кута нахилу клина і товщини витка на величину крутного моменту процесу калібрування. Встановлено, що процес калібрування витка гвинтової заготовки на крок залежить від ширини, товщини спіралі й від кута нахилу клина пристрою. При збільшенні кута нахилу клина пристрою і товщини витка, для матеріалу сталь 08кп, крутний момент зростає й досягає 79 Н м. Адекватність апроксимуючих моделей та оцінювання значущості коефіцієнтів рівняння регресії перевірялась за критеріями Фішера та Ст'юдента в межах змінних вхідних факторів: ширини витка* $20 \le B_0 \le 50$ *(мм), кута нахилу клина* $10 \le \alpha \le 30$ *(град) та товщини витка* $2 \le H_0 \le 6$ *(мм). Встановлено, що домінуючим фактором, який впливає на значення крутного моменту, є кут нахилу клина пристрою, а найменш впливовим є ширина витка. Виконано техніко-економічне оцінювання способу навивання гвинтових спіралей навиванням обертовою втулкою й встановлено, що річний економічний ефект при заміні базового варіанта навивання гвинтових спіралей (навивання на оправу) на проектний (навивання обертовою втулкою) при роботі обладнання в одну зміну становить 16995,79 грн.*

Ключові слова: *навивання, обертова втулка, техніко-економічне оцінювання.*

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