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PECULIARITIES OF TECHNOLOGICAL DESIGN OF U-SHAPED SCREW TRANSPORT AND TECHNOLOGICAL WORKING BODIES

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Summary. *New methods of manufacturing U-shaped screw transport and technological working bodies (STTWBs) are considered in this paper, in particular, by stamping and winding a sheet with U-shaped indentations on a frame using a wedge; a solid forming shaft and a forming shaft with U-shaped indentations; execution of U-shaped indentations on the pipe blank; winding STTWBs U-shaped profile using rectangular blanks. The main factors that affect the technological design of U-shaped STTWBs and the requirements for them are found. The most suitable structural materials for manufacturing U-shaped STTWBs, the related materials (lubricants), and press equipment are proposed. The technological features of the design parameters of STTWBs made in different ways are also determined.*

Key words: *manufacturability, auger, spiral, method, manufacturing, screw transport and technological working bodies, U-shaped, screw workpiece.*

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Problem statement. The creation of new methods of manufacturing parts and mechanisms and, in particular, screw transport and technological working bodies (*STTWBs*) is indispensable condition of effective development of the domestic economy. In general, according to various estimates, the specific weight of *STTWBs* in loading and unloading operations in various industries is 40%, and in agriculture they also occupy a prominent place as a technological toolkit. Therefore, the development of new progressive methods of manufacturing *STTWBs* is an urgent issue, which many researchers pay attention to. Therefore, despite the significant number of conducted and publicized scientific studies devoted to the methods of manufacturing screw blanks, the level of technological support for the production of *STTWBs* does not fully meet modern requirements in terms of target orientation and material and energy intensity. The high requirements for the structural and technological parameters of *STTWBs*, compliance with their purpose, quality, reliability and durability require an in-depth analysis of the existing methods of their technological design and the search for new ones with a high degree of purpose and quality characteristics of both the manufacturing processes and the *STTWBs* structures themselves.

Analysis of recent research and publications. The issue of the peculiarities of technological design and research into the processes of manufacturing screw spirals is widely covered in the works of B. M. Hevko [3, 12], M. I. Pylypets [3, 9, 19, 24], R. M. Rohatynskyi [11, 22], V. V. Vasylkiv [1–3, 9, 24], O. L. Liashuk [7, 8, 12, 19, 23], A. E. Diachun [7, 8, 11, 16, 19, 23] and other domestic and foreign sources [4–6, 17, 18, 20, 21]. In general, attention was focused on the specifics of obtaining screw blanks by various methods, such as winding, rolling, stamping, etc. The manufacturability of *STTWB* constructions is ensured, as well as the process of their production, reducing energy and material costs, designing technological tools for the production of screw blanks, etc.

The objective of this paper is technological design of screw U-shaped transport and technological working bodies.

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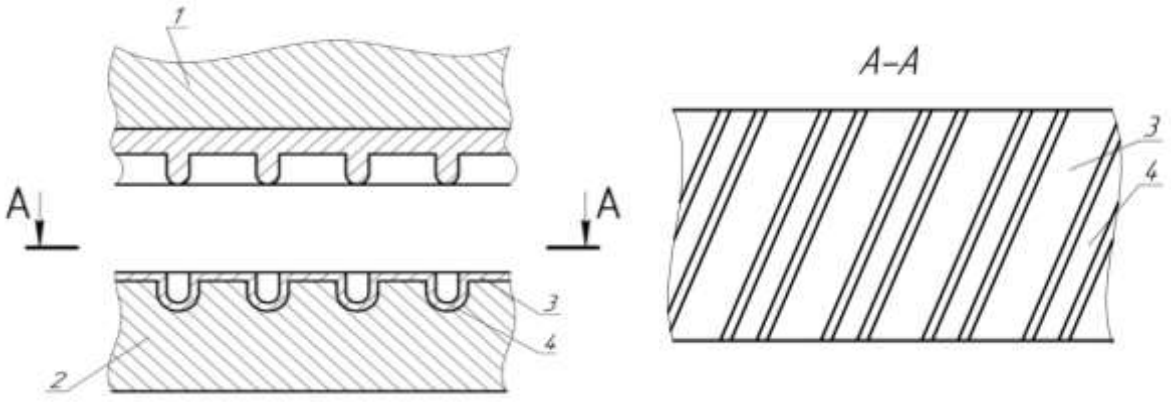
Implementation of work. Currently, screw working bodies are widely used not only for the main purpose of transporting goods, but also as technological working bodies in performing various operations, such as feeding, mixing, calibration, dosing, injection, grinding, etc. [20]. In particular, in agricultural production, they are widely used as transverse transport and cleaning means for moving and cleaning from the ground, piles and unnecessary remains of root crops. In particular, in order to increase the cleaning capabilities of root vegetables, vegetables and fruits, *STTWBs* are made with an eccentric displacement of the axes of rotation, an elliptical-conical or stepped shape, etc.

In order to improve the functional capabilities of such *STTWBs*, the authors have developed a number of methods of manufacturing U-shaped screw blanks, for which Ukrainian patents have been obtained for a useful model [13–15]. Let's consider them in more details. In Fig. 1, the scheme of manufacturing knickknacks on a screw workpiece is shown; in Fig. 2 – Fig. 4, the schemes of winding the screw blanks when using various forming tools are shown. In particular, Fig. 2 shows the method of winding a sheet with U-shaped folds onto a frame, which is performed by bending a sheet with U-shaped folds using a wedge. The methods of winding a sheet with U-shaped bends on the frame using a continuous forming shaft (Fig. 3) and a forming shaft with U-shaped depressions (Fig.4) are shown.

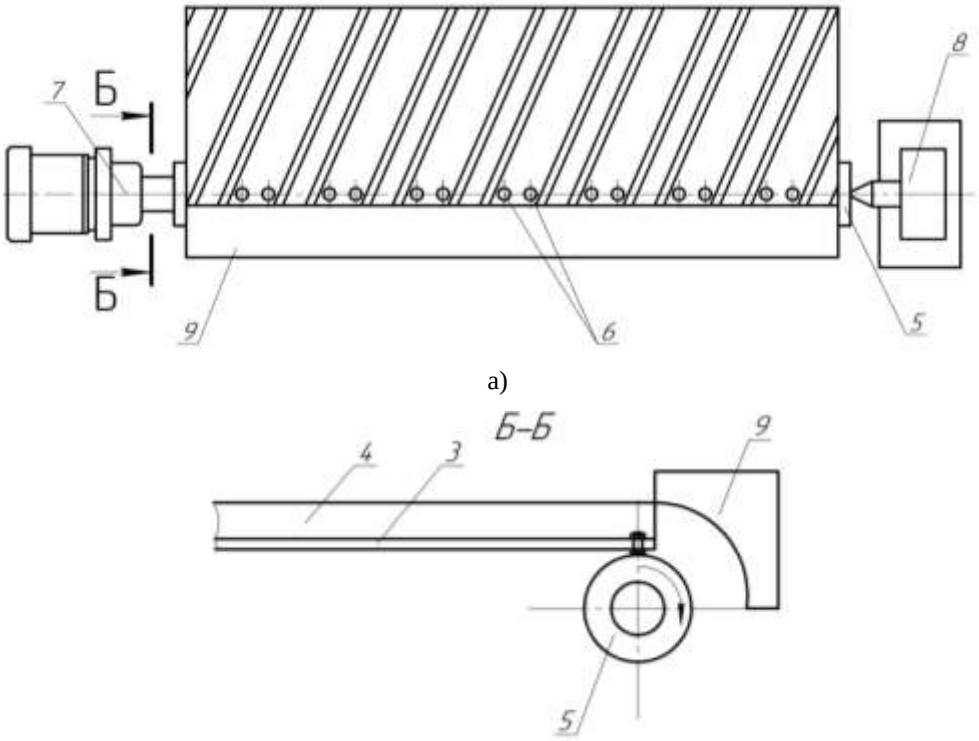
The presented methods of manufacturing *STTWBs* are implemented as follows. In the first operation (Fig. 1), on the sheet 3 at an appropriate angle to its length, U-shaped indentations 4 are applied with a punch 1 in the matrix 2 with the required pitch.

In the second operation, winding is carried out on the frame 5 by pre-fixing the sheet 3 with U-shaped indentations 4 on the frame 5 with screws 6, and fixing the frame 5 in the drive support 7 and the center 8. Winding the sheet 3 with U-shaped notches 4 on the frame 5 is performed by bending the sheet 3 with U-shaped indentations 4 using either a wedge 9 (Fig. 3), or a forming shaft 9 (Fig. 4), or a forming shaft with U-shaped indentations 9 (Fig. 4), on which U-shaped indentations geometrically correspond to the U-shaped indentations 4 applied to the sheet 3. The width of the sheet 3 is determined by the required diameter of the screw workpiece, and bending involves superimposing the adjacent U-shaped indentations 4 on each other, followed by fixing the edges of the sheet 3 to each other by a known method (for example, welding or riveting).



a) b)

Figure 1. Scheme of manufacturing indentations on a screw workpiece:
a) manufacturing of indentations; b) view along A-A in figure 1 a



a)

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Figure 2. General view of winding a sheet with U-shaped indentations on the frame by bending it with a wedge: a) scheme of winding; b) view along Б-Б in figure 2 a

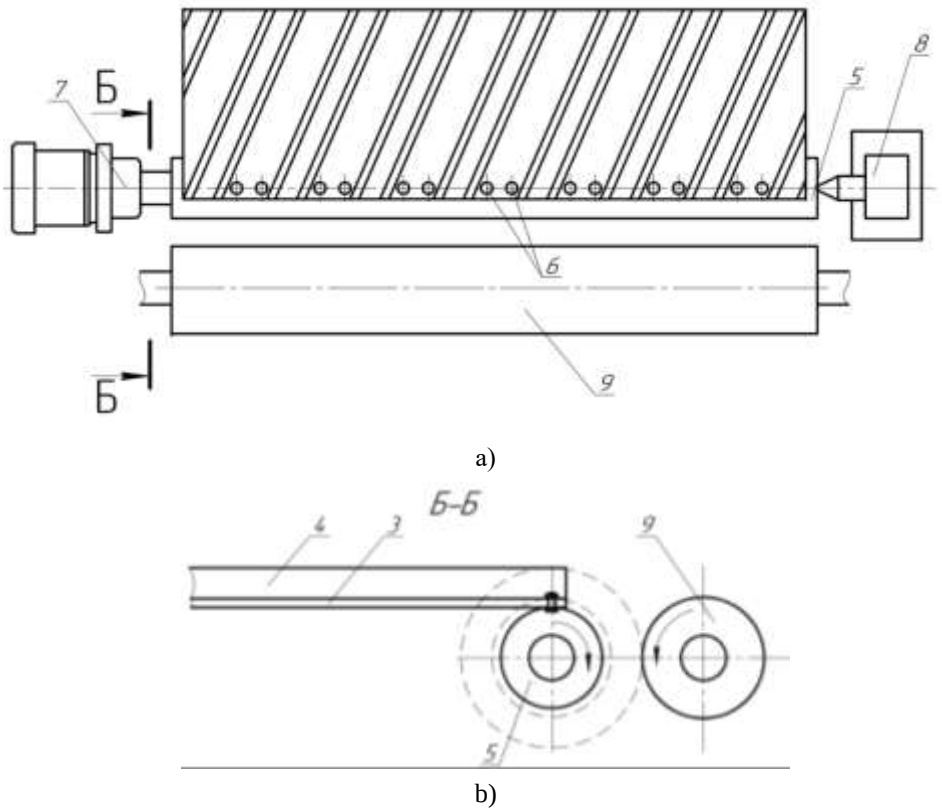

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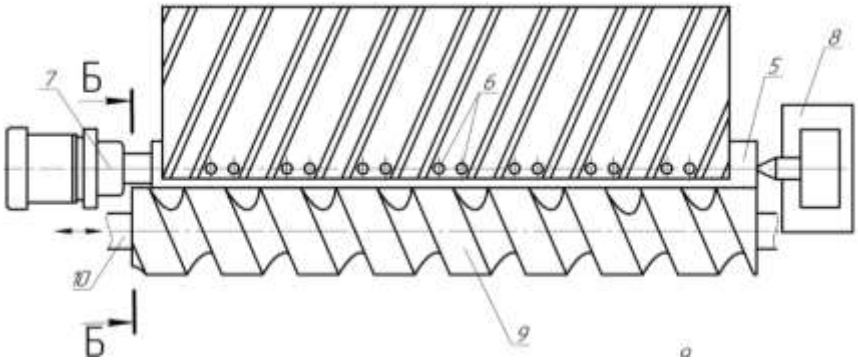
Figure 3. General view of winding a sheet with U-shaped indentations on the frame by bending it with the help of a solid forming shaft: a) scheme of winding; b) view along Б-Б in figure 3 a



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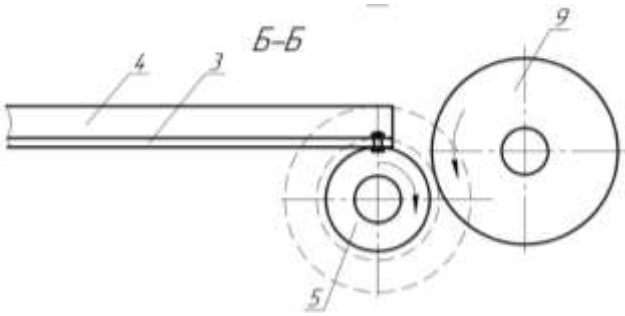

b)

Figure 4. General view of winding a sheet with U-shaped indentations on the frame by bending it with the help of a forming shaft with U-shaped depressions: a) winding scheme; b) view along Б-Б in figure 4 a

An example of the methods of manufacturing U-shaped *STTWBs* by: stamping and winding a sheet with U-shaped indentations on the frame with the help of a wedge, a solid forming shaft and a forming shaft with U-shaped depressions is shown in Table 1.

Table 1

Example of the methods of manufacturing U-shaped *STTWBs*

№	Sheet width, mm	Pitch of the screw workpiece, mm	Internal diameter of the screw workpiece, mm	Thickness of the workpiece sheet, mm	Height of U-shaped indentations, mm
1	315	70…120	100	0.8…1.5	5…50
2	472	120…180	150	1.0…2.0	5…70
3	630	170…240	200	1.5…2.5	5…90

We have also developed other methods of manufacturing U-shaped screw workpieces, for which applications for Ukrainian patents have been submitted. In particular, Fig. 5 shows the scheme of manufacturing screw workpieces by making U-shaped indentations on the pipe blank. Fig. 6 shows a scheme of winding *STTWBs* U-shaped profile made of rectangular rolled steel.

The method of manufacturing such *STTWBs* is implemented as follows. In the first operation, on the frame 1 with a U-shaped spiral protrusion 2, a pipe blank 3 (Fig. 5) or a strip of rectangular section 3 (Fig. 6) is fixed with screws 4, and then the frame 1 with a U-shaped spiral protrusion 2 and a pipe blank 3 (Fig. 5) or rectangular section tape 3 (Fig. 6) is fixed in the drive support 5 and the center 6. In the second operation, the forming roller 7 with a U-shaped indentation 8 is pressed against the pipe blank 3 (Fig. 5) or rectangular tape cross-section 3 (Fig. 6) and winding on a pipe blank 3 (Fig. 5) or a strip of rectangular cross-section 3 (Fig. 6) of a U-shaped spiral

protrusion 9 along its entire length by bending with the help of a forming roller 7 with a U-shaped depression 8, which geometrically corresponds to the U-shaped spiral protrusion 2 of the frame 1. In order to effectively perform the process, the forming roller 7 with a U-shaped indentation 8 is set at an appropriate angle, which corresponds to the step of the U-shaped spiral protrusion 2 of the frame 1. In the third operation, a pipe blank 3 (Fig. 5) or a strip of rectangular section 3 (Fig. 6) with the frame 1 is removed from the drive support 5 and the center 6. Then, the screws 4 are removed with twisting the pipe blank 3 (Fig. 5) or the strip of rectangular section 3 (Fig. 6) with U-shaped spiral protrusions 9 from the U-shaped spiral protrusion 2 of the frame 1.

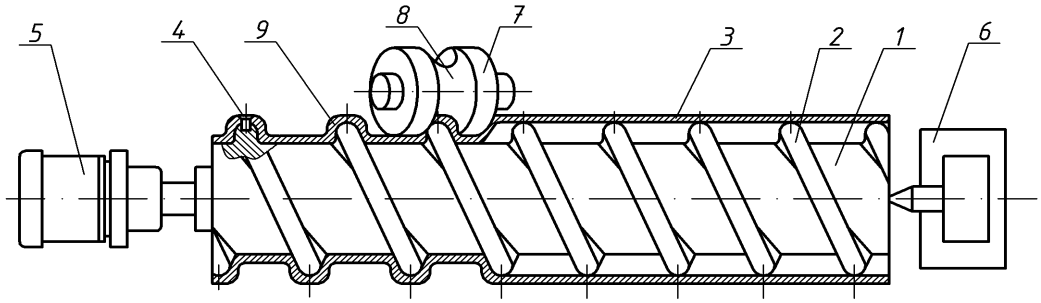

Figure 5. Scheme of manufacturing screw workpieces by manufacturing U-shaped indentations on a pipe blank

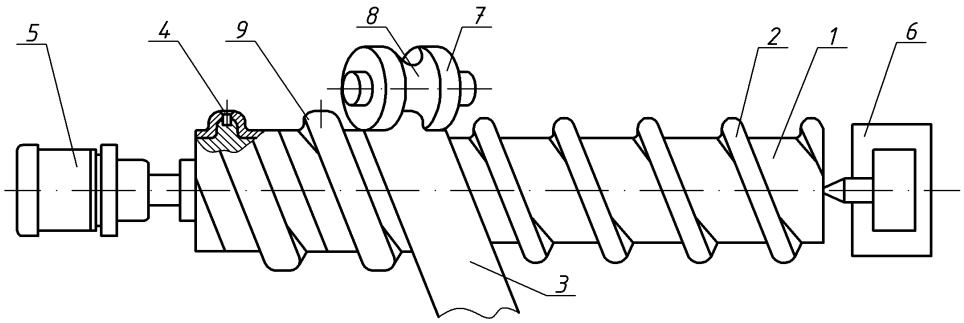

Figure 6. Scheme of manufacturing screw workpieces by winding a U-shaped profile made of a rectangular roll

An example of the method of manufacturing a screw workpiece by making U-shaped indentations on a pipe blank or winding a spiral of a U-shaped profile made of a rectangular roll, where the longitudinal feed of the roller clearly corresponds to the pitch of the U-shaped spiral projection of the frame, is shown in Table 2.

Table 2

Example of the method of manufacturing screw workpieces

№	Rotational frequency of a frame, rpm.	Longitudinal feed of the forming roller, mm/rev.	Pitch of the U-shaped spiral protrusion, mm	Frame diameter, mm	Thickness of a workpiece, mm	Height of U-shaped indentations, mm
1	0.083…0.15	70…120	70…120	100	0.8…1.5	5…50
2	0.125…0.225	120…180	120…180	150	1.0…2.0	5…70
3	0.166…0.3	170…240	170…240	200	1.5…2.5	5…90

The main factors that affect the technological design of U-shaped STTWBs:

- features of the functional purpose, which take into account the properties of the processed products, and compliance with the performed transport and technological operations for the transformation and transportation of products (roots, vegetables and fruits);
- specifics of technological processes, application of typification, and constructive imitation;
- the use of unified and standardized equipment and equipment in the design of technological processes for the production of U-shaped *STTWBs*;
- compliance of the materials (their cost and costs) used for the manufacture of U-shaped *STTWBs*;
- minimization of production costs and requirements for simplicity and safety of process execution;
- compliance with aesthetic requirements and ergonomic characteristics.

The important requirements for U-shaped *STTWBs*:

- compliance with the functional purpose, taking into account the properties of processed products (roots, vegetables and fruits);
- simplicity and cheapness of construction;
- the durability of the *STTWBs* structure, its resistance to corrosion and wear.

When designing U-shaped *STTWBs*, the system of development and delivery of products for production (DSTU 3278-95, DSTU 3973-2000, DSTU 3974-2000) should be applied, as well as a single system of design documentation (DSTU GOST 2.601:2006, DSTU GOST 2.001:2006), which determine the general rules for the development of products and design documents. In [14], the basic indicators of manufacturability and structural complexity of manufacturing screw spirals are presented.

The most common structural materials for manufacturing screw profile workpieces are steel 08 kp DSTU 2834-94, St. 3 DSTU 4651:2005, analogues of this material are steels: 040A10, 1449-1HR, 1HR, 2HR, DC01, DD13 (England); 1008,1010, A619, A622, G10080, G10120 (USA); 1.0322,1.0335, DC01, DC04, DC04G1, DD11, DDB, St12, St 14, St22, StW24, USt3, USt4 (Germany), 3C, DC01, DC04, DD13, FB8, Fd4, FR8, XC6 (France). Steel 20, 30, 45, 09Г2С, 08Х17Т, 12Х17, AISI 304, AISI 316 and other analogues can also be used for the production of screw blanks.

The use of cold-rolling in the form of strips according to DSTU EN 10139:2019, which regulates standard thicknesses from 0.1 to 10 mm is the most expedient. The sizes we use are 1.5; 2.5; 3.5; 4 mm. Standard strip width is according to DSTU EN 10139:2019: 40, 125, 250, 400, 500, 600 mm. In some cases, 650 mm is allowed. For the production of screw blanks with U-shaped indentations, it is practical to use strips with a width of 80 and 125 mm. This assortment is delivered in rolls or measured lengths.

If there is a need to use strips of non-standard sizes, a rolled sheet, which can be cut to the required width on dies, disk machines or disk rolling mills should be considered. The recommended thickness of rolled sheet from the standard series: 1.20; 1.30; 1.40; 1.5; 1.6; 1.8; 2.0; 2.2; 2.5; 2.8; 3.0; 3.2; 3.5; 3.8; 3.9; 4.0 mm.

Other dimensions and classification of hot-rolled sheet, limit deviations of dimensions and weight of hot-rolled sheet according to DSTU 8540:2015, hot-rolled thin sheet (up to 4 mm).

To reduce the effort during winding and as a separate technological medium, when applying U-shaped indentations to a sheet with a punch, it is advisable to use appropriate lubricants: industrial or silicone, the use of which is regulated by DSTU 4310:2004 or ISO 6743-7:86. The use of lubricants eliminates seizing, burrs, and sticking of parts during technological operations. Industrial lubricants of brands I-20, I-20A, I-40, I-50 are a relatively inexpensive solution, but synthetic silicone lubricants with low viscosity have better permeability. They are fluid and adhere well to the surface. This material can withstand high

loads and does not react to very low and high temperatures. Recommended brands are PMS-20 and PMS-50. It is most expedient to use aerosol silicone lubricants, since no additional equipment is required to apply this material. Silicone lubricants have high water resistance and are difficult to wash off with water and other variations of solvents. In the case of subsequent application of paint and varnish materials to the screw workpiece, alcohol solutions, acetone and vinegar must be used to remove silicone.

During preparatory operations for the production of screw blanks, when U-shaped indentations are applied to the sheet, it is advisable to use appropriate press equipment. Depending on the thickness of the initial workpiece, you can use crank presses of the K2116B, KD2124, KD2128, KD2130 type; eccentric and crank electromechanical PE-16, K2118B; automatic presses ESSA PLA-15, AB 6224; hydraulic P6328B, HDT 100, YL41-100, AR 1520/100.

The production technology of *STTWBs* significantly affects their design parameters and technical and economic indicators. It provides for the production of spirals by various methods, which include stamping with simultaneous or subsequent expansion of the coil and welding into a spiral, rolling of strip blanks on special rolling mills, or winding them on an edge, making U-shaped indentations on a sheet by stamping with subsequent winding on a frame, making U-shaped indentations on a pipe blank, winding a U-shaped profile on a flat billet, etc. There are also other methods of manufacturing *STTWBs* with elastic surfaces, which are not under the study of this work. In general, the technological features of the design parameters of *STTWBs* made of sheet or tape in various ways are presented in Table 3.

Table 3

Technological features of structural parameters of *STTWBs* produced by various methods

№	Forming method	Coefficient of material usage, K	Specific height of a wind, ($b'=B/H$, if B and H – width (height of a wind) and thickness of a workpiece)
1	2	3	4
1	Stamping of STTWBs	0.4–0.5	Unlimited
2	Rolling of STTWBs on rectangular workpieces	0.55–0.98	≤ 3
3	Rolling of STTWBs on trapezoidal workpieces	0.55–0.98	≤ 3.5
4	Rolling of STTWBs on rolls	0.55–0.98	≤ 1.5
5	Winding of STTWBs along the internal end profile on rectangular workpieces	0.9–1.0	2–16
6	Winding of STTWBs on the internal end profile on trapezoidal workpieces	0.9–1.0	2 – 21
7	Winding of STTWBs on the internal end profile on a round roll	0.9–1.0	0.8–3
8	Winding of STTWBs of workpieces with a cutout along the inner diameter	0.85–0.95	15–30
9	Winding STTWBs along the outer end profile on rectangular workpieces	0.9–1.0	2–19
10	Winding of STTWBs on the outer end profile on a round roll	0.9–1.0	0.8–3.4
11	Winding of STTWBs made of workpieces with a cutout along the outer diameter	0.5–0.9	15–30

The end of the table

1	2	3	4
12	Fabrication of STTWBs by stamping and winding a U-shaped indentations on a sheet frame	1.0	6.25–36
13	Fabrication of STTWBs by making U-shaped bends on the pipe billet	1.0	6.25–36
14	Winding STTWBs U-shaped profile on rectangular blanks	1.0	6.25–36

It is recommended to work out the construction of *STTWBs* for manufacturability in the following order. At the beginning, source materials are selected and analyzed. Then specify the volume of output, type and nature of production. Then, the indicators of the manufacturability of the designed *STTWBs* and the cost of its manufacture are analyzed, and measures to improve them are developed. It can be predicted that the U-shaped *STTWBs* manufactured by the proposed methods will have higher quality, operational reliability and durability compared to the previously known ones.

Conclusions. Based on the conducted research, the conclusions can be drawn:

1. New methods of manufacturing U-shaped STTWBs are proposed, in particular, stamping and winding on the frame of a sheet with U-shaped indentations with the help of a wedge, a solid forming shaft and a forming shaft with U-shaped indentations; execution of U-shaped indentations on the pipe blank; winding STTWBs U-shaped profile on rectangular blanks.

2. The main factors that affect the technological design of U-shaped STTWBs and the requirements related to them are found.

3. Structural materials for the manufacture of U-shaped STTWBs, related materials (lubricants) and press equipment are defined and characterized.

4. The technological features of the design parameters of STTWBs made in different ways are determined.

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ОСОБЛИВОСТІ ТЕХНОЛОГІЧНОГО ПРОЕКТУВАННЯ U-ПОДІБНИХ ГВИНТОВИХ ТРАНСПОРТНО-ТЕХНОЛОГІЧНИХ РОБОЧИХ ОРГАНІВ

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Резюме. *Гвинтові транспортно-технологічні робочі органи (ГТТРО) у сільськогосподарському виробництві використовуються в якості поперечних транспортно-очисних засобів для переміщення й очищення від землі, вороху та непотрібних решток коренебульбоплодів, овочів та фруктів. З метою покращення технології виготовлення цих ГТТРО запропоновано нові способи виготовлення U-подібних ГТТРО шляхом: штампуванням і навиванням на оправу листа з U-подібними вминаннями з допомогою клина, суцільного формувального вала та формувального вала з U-подібними впадинами; виконання на трубній заготовці U-подібних вминань; навивання ГТТРО U-подібного профілю з прямокутних заготовок. Встановлено, що основними факторами, які впливають на технологічне проектування U-подібних ГТТРО, є такі: особливості функціонального призначення, що враховують властивості перетворюваних продуктів, і відповідність виконуваним транспортно-технологічних операціям з перетворення й транспортування продуктів (коренебульбоплодів, овочів та фруктів); використання стандартизованого оснащення та обладнання при проектуванні технологічних процесів виготовлення U-подібних ГТТРО; відповідність матеріалів (їх вартість і витрати), які застосовуються для виготовлення U-подібних ГТТРО; мінімізація собівартості виготовлення та вимоги до простоти та безпечності виконання процесу; відповідність естетичним вимогам і ергономічним характеристикам. А головними вимогами, що ставляться до U-подібних ГТТРО, є відповідність функціональному призначенню з урахуванням властивостей перетворюваних продуктів (коренебульбоплодів, овочів та фруктів); простота й дешевизна конструкції; довговічність конструкції ГТТРО. В роботі визначено технологічні особливості конструктивних параметрів ГТТРО, виготовлених різними способами, які суттєво впливають на їх конструктивні параметри й техніко-економічні показники.*

Ключові слова: *технологічність, шнек, спіраль, спосіб, виготовлення, гвинтові транспортно-технологічні робочі органи, U-подібний, гвинтова заготовка.*

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