UDC 514.18
DOI: 10.15587/1729-4061.2023.275508

CONSTRUCTION OF A FLAT WORKPIECE FOR MANUFACTURING A TURN OF THE RIGHT HELICOID

Serhii Pylypaka
Doctor of Technical Sciences, Professor, Head of Department*

Vyacheslav Hropost
Postgraduate Student*

Tetiana Kresan
PhD, Associate Professor, Head of Department***

Tatiana Volina
Corresponding author
PhD, Associate Professor*
E-mail: t.n.zaharova@ukr.net

Oleksandr Zabolotnii
PhD, Associate Professor***

*Department of Descriptive Geometry, Computer Graphics and Design**
**National University of Life and Environmental Sciences of Ukraine
Heroyiv Oborony str., 15, Kyiv, Ukraine, 03041
***Department of Natural, Mathematical and General Engineering Disciplines
Separate Subdivision of National University of Life and Environmental Sciences of Ukraine «Nizhyn Agrotechnical Institute»
Shevchenka str., 10, Nizhyn, Ukraine, 16600

In technology, a common helical surface is a right closed helicoid (auger). It is formed by a helical movement of a horizontal segment, provided that the axis of the auger crosses at one of its ends. The formation of the surface of an open helicoid is similar but the segment must intersect the axis and be located at a constant distance from it. It is known from differential geometry that the helical surface can be transformed by bending to the surface of rotation. This fact is taken as the basis for calculating the geometric shape of a flat workpiece. The surface of the open helicoid is non-disjointed, so the shape of the workpiece must be found in such a way as to minimize plastic deformations during surface formation.

Parametric equations of continuous flexion of the turn of an open helicoid into the section of a single-cavity hyperboloid of rotation have been derived. Continuous bending can be represented as a gradual deformation of the turn while reducing its step. The meridian of hyperboloid rotation is the corresponding area of hyperbola. The hyperboloid section is proposed to be approximated by the surface of the truncated cone. This approximation will be more accurate in the area of the hyperbole where it asymptotically approaches the segment of the right line. After selecting a cone, it becomes possible to determine its size and build its exact sweep since the cone is a unfolding surface. The sweep is constructed in the form of a flat ring with a cut sector and will be the desired flat workpiece to form a turn of the auger from it.

Most accurately, the surface of the turn of the open helicoid can be made by stamping the workpiece of the resulting form. For small-scale production of the helical surface of an open helicoid, it is advisable to weld flat rings together and, during installation, stretch along the shaft while twisting around its axis. The accuracy of the obtained surface will depend on the accuracy of the approximation of the hyperboloid section of rotation with a truncated cone, which is the topic of this work

Keywords: right closed helicoid, flat workpiece, continuous bending, parametric equations

Received date 27.01.2023
Accepted date 31.03.2023
Published date 28.04.2023

How to Cite: *Pylypaka, S., Hropost, V., Kresan, T., Volina, T., Zabolotnii, O. (2023). Construction of a flat workpiece for manufacturing a turn of the right helicoid. Eastern-European Journal of Enterprise Technologies, 2 (1 (122)), 6–11. doi: https://doi.org/10.15587/1729-4061.2023.275508*

1. Introduction

There are various technologies for the manufacture of turns of augers: stamping, rolling, bending. The problem is that, firstly, the surface is non-sweep, therefore, the exact dimensions of the flat workpiece do not exist, and secondly, there are no standards for the size of the turns (inner and outer diameters, pitch). The most accurate shape of the turn is achieved by stamping it from a flat workpiece, but it needs expensive equipment, which is why it is used in large-scale production. However, regardless of the technique for manufacturing the turns of the auger from flat blanks, the accuracy of the calculation of these blanks matters. Their shape can be determined on the basis of the theory of differential geometry with respect to the bending of helical surfaces. Given the possibility of obtaining new results, this approach is new, and the task itself is relevant.

2. Literature review and problem statement

Screw surfaces are very common in a variety of devices and mechanisms. They are widely used in screw conveyors for transporting various bulk materials, mixing them, grinding, dosing, and performing other technological operations. The use of screw surfaces in engineering is fully covered in [1]. The agricultural sector deserves special attention. Thus, in work [2], the use of a screw surface for the design of the working body for surface tillage is considered. A unit with such working bodies can be an alternative to disk tillage tools. Quite interesting is the use of screw surfaces in architecture. In article [3], screw non-unfolding surfaces are used for the design, manufacture, and installation of two pavilions: the butterfly gallery and the Molusco pavilion. Screw surfaces in terms of the presence of spectral gaps in them have been investigated in [4], which can be used in astronomy. All this confirms the geometric depth of helical structures.

Modeling of various kinds of objects and processes can be carried out in different ways. In [5], point calculus is used for this purpose. This approach makes it possible to create solid-state three-dimensional models for various branches of science and technology of mechanical engineering, construction, and medicine. The problems that arise during visualization using this method are described in [6]. The authors of works [5, 6] propose to use interpolation methods for modeling multivariate processes based on the experiment planning matrix [7]. Article [8] proposes a method of constructing a torus grid for creating images of a model according to specified parameters and finds characteristic key determinants that ensure the implementation of the fundamental component of architectural formation in automated design systems. But the cited article does not disclose aspects of the production of the formed surfaces. In [9], a mathematical notation of petal closed screw surfaces is given; however, without taking into account the sweep of the surface and the process of its manufacture. Simulation of cutting a screw surface with a milling tool in an AutoLISP environment in order to predict the result obtained is revealed in [10]. Such a process requires the presence of parametric equations of the helical surface and vector characteristics of the tool positioning.

Thus, work [11] developed a system and criteria for a controlled choice of technology to ensure the required quality of the surfaces of parts. In [12], the authors set out the indicators that characterize the quality of the surface layer. The accuracy of the elements of complex screw surfaces from a microgeometric point of view is discussed in article [13]. Among the numerous machining processes by which such surfaces can be obtained, the authors considered threading. The article discusses the kinematics of the process, the influence of many design parameters on the elements of accuracy, but the material presented does not give an idea of the sweep of the surface for its manufacture. It should be noted that increasing the wear resistance and durability of parts is often proposed to be carried out by progressive processing methods. For example, in [14], for this purpose it is proposed to use electric doping of metal surfaces with graphite. In [15], the protective surface layer is proposed to be created using nanostructures formed by ionic nitriding and electro-spark doping. It is clear that the process of developing the latest technologies to ensure the proper quality of surfaces, their testing and implementation is rather long and costly. In addition, often the test results require further adjustment of the technological process and repeated tests. However, the symbiosis of the process of developing appropriate technologies with geometric methods of surface design can speed up this process, minimize the need to adjust the technology while reducing its cost.

It should be noted that much attention is paid to various approaches to the manufacture of turns of screw surfaces. Theoretical bending of the surface of an open helicoid from the point of view of differential geometry is considered in [16]. Work [17] considered existing technologies for the manufacture of turns from a rectilinear strip by winding it, by deforming flat blanks in the form of a ring into a finished turn.

Consequently, the technique of manufacturing the turns of the auger from flat blanks does not matter as much as the accuracy of the calculation of these blanks. Improving accuracy can be provided by methods of differential geometry, namely: determining the shape of the turns of the auger based on the theory of bending of screw surfaces. This suggests that it is expedient to conduct a study on the analytical calculation of a flat workpiece for the manufacture of a turn of a right open helicoid.

3. The aim and objectives of the study

The aim of this study is to construct a turn of a right open helicoid by analytically calculating its flat workpiece. This will make it possible to improve the accuracy of the calculation, which, in turn, will help obtain the exact dimensions of the flat workpiece.

To accomplish the aim, the following tasks have been set:

– to find an analytical pattern of deformation of the turn of a right open helicoid into the surface of rotation;

– to build a conditional sweep of the turn of the right open helicoid by approximating the resulting surface of rotation by the cone.

4. The study materials and methods

The formation of the surface of a right closed helicoid occurs by a helical movement of a horizontal segment. In this case, the axis of the auger and the end of the segment intersect. The formation of the surface of an open helicoid is similar but the segment intersects the axis and is at a constant distance from it. From differential geometry it is known that the helical surface can be bent to the surface of rotation. This fact can be taken as the basis for the calculation of a flat workpiece.

The surface shape of a right open helicoid is very similar to that of a right closed helicoid, known in technology as auger. Projections of one turn of an open helicoid with a cylindrical shaft are shown in Fig. 1.

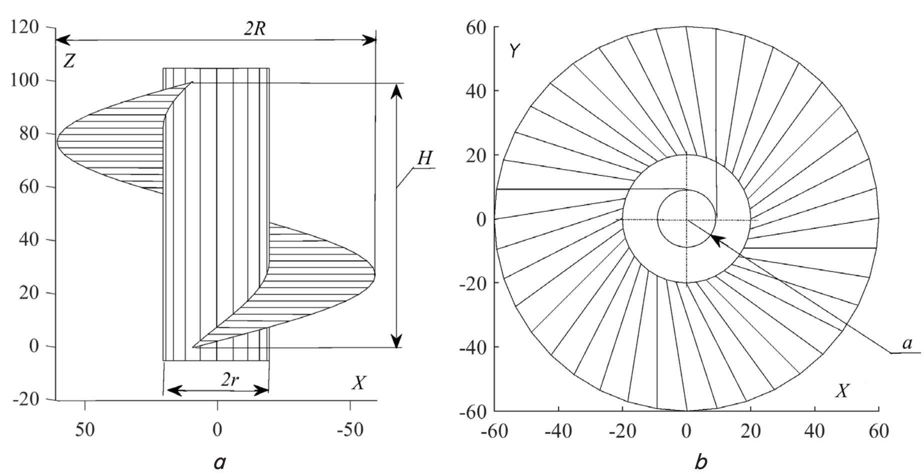


Fig. 1. Projections of the turn of a right open helicoid: *a* – frontal projection; *b* – horizontal projection

The difference is the fact that the rectilinear product surfaces of the open helicoid do not cross its axis, as in the surface of the auger, but pass near it at a certain distance *a*. On a horizontal projection, these generatrices are tangential to the circle of radius *a* (Fig. 1, *b*). All three circles (radii *a*, *r* – the inner edge of the surface, that is, the shaft, *R* – the outer edge of the surface) are projections of helical lines.

For an open helicoid, unlike a closed one, the shaft has a limit on the minimum value of the diameter – its radius cannot be less than *a* since there is no surface there (Fig. 1, *b*).

The surface of the turn of both closed and open helicoids is made of sheet material. Since the surfaces are non-sweep, the flat workpiece for deformation into the surface is approximate. For its construction for the closed helicoid as a very common surface in technology, reference literature is used. For a closed helicoid, such data are absent, so the construction of an approximate sweep can be carried out based on information from differential geometry, namely the fact that any helical surface can be bent into the surface of rotation. Therefore, the turn of an open helicoid must be bent into the appropriate section of the rotation surface, which can be approximated with a cone. For the cone, as for the unfolding surface, it is possible to build an exact sweep, which will be approximate for the turn of the open helicoid.

So, the calculation is carried out on the basis of the theory of differential geometry regarding the bending of screw surfaces into the surface of rotation. The calculations and visualization of the results are performed in the environment of the Mathematica and MatLab software.

5. Results of the calculation of a flat workpiece for the manufacture of a turn of a right helicoid

5. 1. Determining the analytical regularity of continuous flexion of the turn of the right open helicoid into a single-cavity hyperboloid of rotation

The bending of the surface in differential geometry is understood as its deformation, in which the lengths of the lines on the surface and the angles between them do not change. Work [16] presents parametric equations for the continuous bending of an oblique helicoid into a single-cavity hyperboloid of rotation. Continuous bending refers to such bending from the initial position to the final one when as many intermediate ones can be built between them. One of the intermediate positions is a right open helicoid. Below are the parametric equations of continuous bending of the surface from [16] for the case when the initial state is the surface of a right open helicoid, and the final one is the surface of a single-cavity hyperboloid of rotation:

$$X=\frac{a\cos p\gamma\cos(p\gamma-\gamma)}{\cos\gamma}\cos\left(\frac{\cos\gamma}{a\cos(p\gamma-\gamma)}s\right)-$$
$$-u\cos(p\gamma-\gamma)\sin\left(\frac{\cos\gamma}{a\cos(p\gamma-\gamma)}s\right);$$

$$Y=\frac{a\cos p\gamma\cos(p\gamma-\gamma)}{\cos\gamma}\sin\left(\frac{\cos\gamma}{a\cos(p\gamma-\gamma)}s\right)+$$
$$+u\cos(p\gamma-\gamma)\cos\left(\frac{\cos\gamma}{a\cos(p\gamma-\gamma)}s\right);$$

$$Z=s\sin p\gamma+u\sin(p\gamma-\gamma). \quad (1)$$

In (1), the independent variables are *s* – the arc length of the helical line located on the cylinder of diameter *a*, and *u* – the length of the rectilinear surface generatrix, the countdown of which starts from this helical line. Two other values are constant: γ – the angle of rise of the specified helical line; *p* – bending parameter, which can take values ranging from 1 (initial position of the surface) to 0 (final position of the surface). To select the desired bending section, you need to set the values of constants and the limits of change of independent variables *s* and *u*. At $u=0$, equation (1) will describe the helical line, which in its initial position is located on the cylinder of radius *a* and which is the guide for the formation of the surface. It is necessary to find the limits of changing the length of the arc *s*. To get one turn of the surface, the point on the helical line must make one full revolution, that is, 2π. The expression in parentheses of trigonometric functions $\frac{s\cos\gamma}{a\cos(p\gamma-\gamma)}=\alpha$ is the value of the angle of rotation. Equating it to 2π:

$$s=\frac{2\pi a}{\cos\gamma}. \quad (2)$$

Therefore, *s* must vary within $s=0...2\pi a/\cos\gamma$. The next step is to find the value of the constant *a*. When turning the point of the helical line by an angle of 2π, which corresponds to the value of the arc *s* (1), its coordinate *Z* must be equal to step *H*. From the last equation (1) at $u=0$ and $p=1$, corresponding to the helical line before the start of bending, one can obtain:

$$H=s\sin\gamma=\frac{2\pi a}{\cos\gamma}\sin\gamma,\ \text{hence}\ a=\frac{H\cos\gamma}{2\pi\sin\gamma}. \quad (3)$$

It is also necessary to determine the limits of the change in distance *u*. At $u=0$, equation (1) describes the guide screw line on the cylinder of radius *a*. At $u=\rho=\text{const}$, other helical lines will be described, including those that limit the section, at $\rho=r$ and $\rho=R$ (Fig. 1, *a*). The distance ρ (that is, the distance from the surface axis to a point on this surface) can be found from the following expression:

$$\rho^2=X^2+Y^2=\frac{\cos^2(p\gamma-\gamma)}{\cos^2\gamma}\left(a^2\cos^2 p\gamma+u^2\cos^2\gamma\right). \quad (4)$$

Having solved equation (4) with respect to *u*, we can find its value for a given value ρ. Radii *r* and *R*, which limit the section of the helicoid, are set in the initial position, that is, until the surface is bent. This position corresponds to the value $p=1$. This value of *p* must be substituted in (4) and solved with respect to *u*:

$$u=\sqrt{\rho^2-a^2}. \quad (5)$$

The angle γ is the only constant value that can be selected from a certain range of valid values. Let the source surface be a right open helicoid with increments $H=100$ and radii $r=20$ and $R=60$. In addition, let $\gamma=\pi/3$. From formula (3): $a=9.19$. The length of the helical guide line can be determined from expression (2): $s=115.5$. So, the arc *s* varies within $s=0...115.5$. Finally, from formula (5), we find the limits of the change of the parameter *u*, alternately inserting into it instead of ρ the radii *r* and *R*: $u=17.8...59.3$. According to these data, using equations (1), the initial ($p=1$), the final ($p=0$), and some intermediate positions of the surface were constructed when it was bent (Fig. 2).

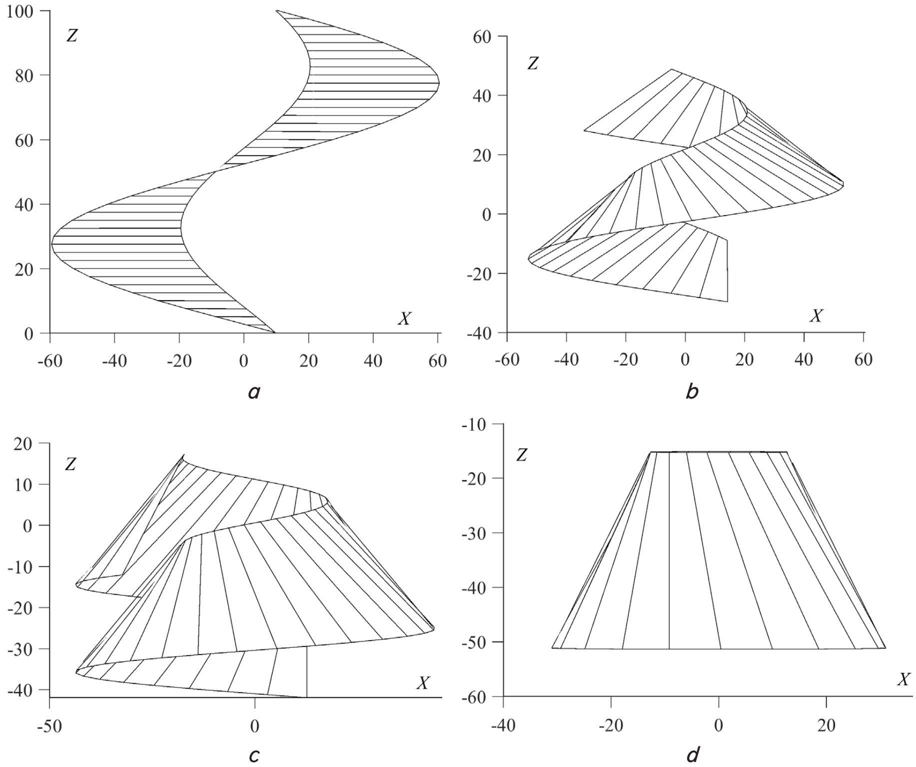


Fig. 2. Frontal projections of the positions of the turn of the right open helicoid when it is bent into the surface of a single-cavity hyperboloid of rotation: *a* – $p=1$; *b* – $p=0.5$; *c* – $p=0.25$; *d* – $p=0$

Fig. 2 shows that when bent, the rectilinear generatrices remains rectilinear, that is, the surface remains line-like all the time. It should be noted that the angle of rotation of the point along the guide of the helical line varies from 0 to 2π, which corresponds to one turn of the helicoid. This can be seen by substituting expression (2) into the α angle expression at $p=1$. If we take $p=0$, which corresponds to the bending of the surface in a single-cavity hyperboloid of rotation, then we get $\alpha=2\pi/\cos\gamma$, which corresponds to the angle $\alpha=4\pi$. This means that the resulting hyperboloid (Fig. 2, *d*) is double, that is, during its formation, two full revolutions are made.

5. 2. Construction of a conditional sweep of the turn of a right open helicoid

As noted above, the surface of the open helicoid is non-sweep, so we can talk about an approximate sweep. As can be seen from Fig. 2, *d*, the hyperboloid section is close to the surface of the truncated cone. Replacing the hyperboloid section with a truncated cone will make it possible to find a sweep of the cone that can be built accurately. It is necessary to write the parametric equations of the meridian hyperboloid, which is hyperbole. One equation is obtained from expression (4) at $p=0$, and the second is the last equation (1) also at $p=0$. So, the parametric equations of the meridian hyperboloid will be written:

$$\rho_h=\sqrt{a^2+u^2\cos^2\gamma};$$

$$z_h=-u\sin\gamma. \tag{6}$$

In Fig. 3, *a*, part of the meridian is built, and the *AB* section, which is built at the found limits of the change of the parameter u and corresponds to the section of the hyperboloid, highlighted by a thickened line. The radius of the upper base of the hyperboloid section, obtained at the minimum value of the variable u, is indicated by ρ_{hA}, and the lower, at the maximum value of u, by ρ_{hB}. The arc *AB* of the meridian of the surface practically coincides with the segment of the right line, which we take as a rectilinear generatrix of the cone. Fig. 3, *a* demonstrates that the accuracy of the approximation of the hyperboloid of rotation by the cone increases as the radius ρ_{hA} increases, which corresponds to the shaft radius r. If we take the minimum value of the shaft radius $r=a=\rho_{hA}$, then the approximation accuracy will be the worst.

To build a sweep of a truncated cone that approximates the resulting surface of the hyperboloid of rotation, it is necessary to have its dimensions. To do this, it is enough to have the coordinates of points A and B (Fig. 3, *a*). We take the segment *AB* as a rectilinear cone generatrix. The coordinates of points A and B are obtained from equations (6), in which, for convenience, we proceed from the variable u to the variable ρ. To this end, we take into account expressions (5) for u and (3) for a. After substituting them in (6), we get:

$$\rho_h=\frac{\cos\gamma}{2\pi}\sqrt{4\pi^2\rho^2+H^2};$$

$$z_h=-\frac{\cos\gamma}{2\pi}\sqrt{4\pi^2\rho^2\mathrm{tg}^2\gamma-H^2}. \tag{7}$$

Expressions (7) make it possible to get the coordinates of points A and B through the specified design parameters of the helicoid. When substituting $\rho=r$ in them, we get the coordinates of point A, and at $\rho=R$ – the coordinates of point B. For example, for given parameters $H=100$, $r=20$, $R=60$, $\gamma=\pi/3$, we get:

– point A coordinates: $\rho_{hA}=12.8$, $z_{hA}=15.4$;

– point B coordinates: $\rho_{hB}=31.0$, $z_{hB}=51.4$.

According to known coordinates, the length of the segment *AB* can be found, that is, the length of the rectilinear truncated cone generatrix, which is denoted through L: $AB=L=40.3$.

It is known that the sweep of a truncated cone is a ring with a cut sector. The length of the rectilinear generatrix of the cone L is the difference between the radii R_0 of the outer and r_0 of the inner circles (Fig. 3, *b*). When constructing a sweep, it should be assumed that the arc length of a circle is determined by the product of the radius by the value of the central angle. For example, the arc length of the inner circle of radius r_0 will be written as the product of $\varphi\cdot r_0$ (Fig. 3, *b*). On the other hand, on the cone, this arc is the double circumference of the radius ρ_{hA} since the cone, according to the hyperboloid, is double. Accordingly, the arc length on the double cone will be equal to $4\pi\cdot\rho_{hA}$. Similarly, we reason with respect to the arc of the outer circle, taking into account that its radius R_0 is equal to $R_0=r_0+L$. Based on this, a system of two equations can be obtained:

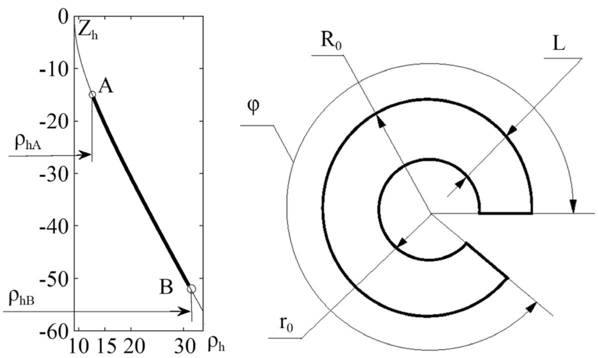
$$\begin{cases}\varphi r_0 = 4\pi\rho_{hA};\\ \varphi\left(r_0 + L\right) = 4\pi\rho_{hB}.\end{cases} \tag{8}$$

System (8) includes two unknown quantities: angle φ and radius r_0. System (8) must be solved with respect to the specified values:

$$r_0 = \frac{L\rho_{hA}}{\rho_{hB} - \rho_{hA}};$$

$$\varphi = \frac{4\pi}{L}\left(\rho_{hB} - \rho_{hA}\right). \tag{9}$$

In accordance with expressions (9), we find the dimensions of a flat workpiece for the manufacture of a helicoid turn (approximate sweep): r_0=28.3, φ=5.68 (325°), $R_0=r_0+L$=68.6.



a *b*

Fig. 3. Graphic illustrations for the construction of a sweep of a truncated cone that approximates a single-cavity hyperboloid of rotation: *a* – meridian *AB* of the section of the hyperboloid rotation; *b* – sweep of a truncated cone that approximates the hyperboloid

There is a limit to the choice of the angle γ. According to the second expression (3), it cannot be equal to zero, which is already clear from its physical essence since it is the angle of rise of the helical line. As noted above, $a \leq r$ (Fig. 1, *b*). At $a=r$, the angle γ will be minimal. To find it, in the second equation (3) a must be replaced by r and resolved with respect to γ: γ=Arctg($H/2\pi r$). For the case under consideration, γ=38.5°. In this case, point *A* (Fig. 3, *a*) will shift upwards along the curve and coincide with point zero, that is, the approximation of rotation by the hyperboloid cone deteriorates somewhat. As the γ angle increases, the radius *a* decreases, that is, the open helicoid approaches the closed one. At the same time, the dimensions of the workpiece change only at the beginning and, moreover, not significantly, and then practically do not change.

6. Discussion of results of investigating the methodology for constructing a flat workpiece for the manufacture of a turn of a right open helicoid

Since the exact dimensions of the flat ring – the blank of a right open helicoid do not exist, an approximate calculation is performed. Its essence is the fact that in the calculations we are guided by the equality of the lengths of the helical lines, which limit the turn of the auger in an external and internal way, and the corresponding lengths of the arcs of circles, which in the same way limit the flat ring. It is also assumed that the difference in radii between the external and internal cylinders limiting the turn of the helicoid must be equal to the difference between the outer and inner limiting circles of the flat ring. For this condition to be met, a flat ring should have a radial notch, as shown in Fig. 3, *b*.

However, finding the size of the ring can also be approached from the point of view of continuous bending of the helicoid surface into the surface of rotation. This approach corresponds to the physical essence of the process of making a turn by bending. On the basis of parametric equations (1), intermediate surfaces were obtained within one turn by reducing their step (Fig. 2). When the pitch is zero, the turn of the screw surface is converted into the corresponding section of the rotation surface. Such a section for bending the turn of a right open helicoid is the section of a single-cavity hyperboloid of rotation (Fig. 2, *d*). This makes it possible to obtain parametric equations of the meridian (6), which is the arc of hyperbole. Then, the coordinates of points *A* and *B* on the hyperbole are determined through the parameters of the helicoid surface turn (Fig. 3, *a*) using (7). After that, the *AB* arc is replaced by a rectilinear segment, which is the generatrix of the truncated cone. The cone is an unfolding surface, so its sweep, which is a flat workpiece for the manufacture of the helicoid turn, is built accurately. At the same time, it is possible to visually assess the accuracy of the approximation of the single-cavity section hyperboloid rotation with a truncated cone. It involves assessing the deviation of the *AB* arc from the rectilinear segment. Fig. 3, *a* demonstrates that this deviation is insignificant.

The peculiarity of the proposed method is the calculation of the flat workpiece of the turn in accordance with the physical essence of the bending process. In existing reference literature (for example, [18]), the parameters of the workpiece are calculated by comparing the corresponding lines on the turn and on the workpiece without taking into account the bending process. The obtained calculation of the turn of the right open helicoid by analytical calculation of its flat workpiece with the proposed method differs slightly from the known methods of calculation but the method of obtaining it on the basis of the physical essence of bending gives reason to consider it more accurate. It should be noted that there are restrictions on the use of the developed approach to the calculation of a flat workpiece of the turn. They relate to the technology of its manufacture. The proposed method is designed for the manufacture of a turn by stamping sheet blanks. This is a limitation of the use of the method. The disadvantage is that the calculation does not take into account the thickness of both the surface of the turn itself and the thickness of the sheet material of the workpiece. In further studies, this factor may be taken into account to obtain more accurate results.

7. Conclusions

1. The application of theoretical bending of the surface of a right open helicoid by reducing its pitch makes it possible to obtain intermediate positions, ending with the final – single-cavity hyperboloid of rotation. The design dimensions of the helicoid are converted to the design dimensions of the hyperboloid. This makes it possible to replace with a certain accuracy the section of the hyperboloid with a truncated cone, which is described by the resulting analytical dependence.

2. The sweep of the cone will be an approximate sweep of the hyperboloid because it is non-sweep. However, the

presence of this section makes it possible to replace it with a truncated cone with maximum accuracy. Since in the theoretical bending of the length of the lines, the angles between the lines and the area of the section of the truncated cone do not change, the resulting sweep will be a flat workpiece for the manufacture of a turn of a right open helicoid.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

Funding

The study was conducted without financial support.

Data availability

All data are available in the main text of the manuscript.

References

1. Sokolova, L. N. S., Infante, D. L. R., Vladimir, J. P., Ermakova, E. (2020). Helical surfaces and their application in engineering design. International journal of science and technology, 29 (2), 1839–1846. Available at: https://www.researchgate.net/publication/339600632_Helical_surfaces_and_their_application_in_engineering_design
2. Drahan, A. P., Klendii, M. B. (2021). Substantiation of the design of the working body of the screw section of the combined tillage tool. Perspective technologies and devices, 18, 66–73. doi: https://doi.org/10.36910/6775-2313-5352-2021-18-10
3. Albu, S. C. (2019). Simulation of Processing of a Helical Surface with the Aid of a Frontal-Cylindrical Milling Tool. Procedia Manufacturing, 32, 36–41. doi: https://doi.org/10.1016/j.promfg.2019.02.180
4. Kubota, Y., Ludewig, M., Thiang, G. C. (2022). Delocalized Spectra of Landau Operators on Helical Surfaces. Communications in Mathematical Physics, 395 (3), 1211–1242. doi: https://doi.org/10.1007/s00220-022-04452-4
5. Konopatskiy, E., Bezditnyi, A. (2021). Solid modeling of geometric objects in point calculus. CEUR Workshop Proceedingsthis link is disabled, 3027, 666–672. doi: https://doi.org/10.20948/graphicon-2021-3027-666-672
6. Konopatskiy, E. V., Bezditnyi, A. A. (2022). The Problem of Visualizing Solid Models as a Three-Parameter Point Set. Scientific Visualization, 14 (2), 49–61. doi: https://doi.org/10.26583/sv.14.2.05
7. Konopatskiy, E. V., Seleznev, I. V., Bezditnyi, A. A. (2022). The use of interpolation methods for modelling multifactor processes based on an experiment planning matrix. Journal of Physics: Conference Series, 2182 (1), 012005. doi: https://doi.org/10.1088/1742-6596/2182/1/012005
8. Madumarov, K. H. (2022). Graphical methods for depicting prismatic closed helical surfaces (PZVP). International journal of social science & interdisciplinary research, 11 (11). Available at: https://www.gejournal.net/index.php/IJSSIR/article/view/1128
9. Madumarov, K. H. (2021). Graphic methods of image and mathematical description of lobe closed helical surfaces. Nat. Volatiles & Essent. Oils, 8 (4), 2686–2694.
10. Andrés, M.-P., Alicia, L.-M.; Viana, V., Murtinho, V., Xavier, J. (Eds.) (2020). Developable helicoids from cylindrical helix and its application as architectural surface. Thinking, Drawing, Modelling. Cham: Springer, 107–120. doi: https://doi.org/10.1007/978-3-030-46804-0_8
11. Melnyk, V., Vlasovets, V., Konoplianchenko, I., Tarelnyk, V., Dumanchuk, M., Martsynkovskyy, V. et al. (2021). Developing a system and criteria for directed choice of technology to provide required quality of surfaces of flexible coupling parts for rotor machines. Journal of Physics: Conference Series, 1741 (1), 012030. doi: https://doi.org/10.1088/1742-6596/1741/1/012030
12. Gaponova, O. P., Tarelnyk, V. B., Martsynkovskyy, V. S., Konoplianchenko, Ie. V., Melnyk, V. I., Vlasovets, V. M. et al. (2021). Combined Electrospark Running-in Coatings of Bronze Parts. Part 2. Distribution of Elements in a Surface Layer. Metallofizika i noveishie tekhnologii, 43 (9), 1155–1166. doi: https://doi.org/10.15407/mfint.43.09.1155
13. Merticaru, V., Nagîț, G., Dodun, O., Merticaru, E., Rîpanu, M. I., Mihalache, A. M., Slătineanu, L. (2022). Influence of Machining Conditions on Micro-Geometric Accuracy Elements of Complex Helical Surfaces Generated by Thread Whirling. Micromachines, 13 (9), 1520. doi: https://doi.org/10.3390/mi13091520
14. Tarelnyk, V. B., Gaponova, O. P., Konoplianchenko, Y. V. (2022). Electric-spark alloying of metal surfaces with graphite. Progress in Physics of Metalsthis, 23 (1), 27–58. doi: https://doi.org/10.15407/ufm.23.01.027
15. Tarelnyk, V., Konoplianchenko, I., Gaponova, O., Radionov, O., Antoszewski, B., Kundera, C. et al. (2022). Application of wear-resistant nanostructures formed by ion nitridizing & electrospark alloying for protection of rolling bearing seat surfaces. IEEE 12th International Conference Nanomaterials: Applications & Properties (NAP). doi: https://doi.org/10.1109/nap55339.2022.9934739
16. Kresan, T., Pylypaka, S., Ruzhylo, Z., Rogovskii, I., Trokhaniak, O. (2021). Rolling of a single-cavity hyperboloid of rotation on a helicoid on which it bends. Engineering Review, 41 (3), 106–114. doi: https://doi.org/10.30765/er.1563
17. Hevko, I. B., Leshchuk, R. Ya., Hud, V. Z., Dmytriv, O. R., Dubyniak, T. S., Navrotska, T. D., Kruhlyk, O. A. (2019). Hnuchki hvyntovi konveiery: proiektuvannia, tekhnolohiia vyhotovlennia, eksperymentalni doslidzhennia. Ternopil: FOP Palianytsia V. A., 208. Available at: http://elartu.tntu.edu.ua/handle/lib/28927
18. Anuriev, V. I. (1978). Dovidnyk konstruktora-mashynobudivnyka. Moscow: Mashynobuduvannia, 1846.