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Computational Approach to Geometric Modeling of Plow Bodies

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Abstract. In this article, a detailed analysis of modern research and publications on the selected subject was carried out related to the computer-variant geometric modeling of the working surfaces of the plow blades. Based on this, a new method of proper design was proposed. The performed scientific investigations aimed to create a flexible, productive, and universal approach for the automated shaping of tillage tools. The accentuated effectiveness of geometric modeling was achieved using a developed special mathematical apparatus adapted for use in the environment of current computer information systems of an engineering profile. The implementation was based on such parametric lines as heterogeneous rational B-splines, which are acceptable in automated design systems. The specified geometric models were characterized by the coverage of a sufficiently large range of plow heads. The indicated means of forming could conveniently adapt to the changing conditions of designing tillage tools suggested by theoretical calculations and practical experiments. The given facts contributed to the multifaceted clarification of the specified information. They also ensured the appropriate integration and the possibility of determining the most rational options among the studied varieties of plow dumps. Simultaneously, the most common group of dumps with cylindrical and other plow working surfaces was considered. The significant role of geometric models for qualitative coordination and the effective combination of many other models (e.g., strength, manufacturing technology, and operation conditions) was emphasized. This was aimed at comprehensive optimization throughout their life cycle, in this case of plows. The proper solution to the presented problems contributed to a successful solution to the actual scientific and applied problem of improving the quality of machinery.

Keywords: design modeling, rational geometry, working surfaces, process innovation.

1 Introduction

Currently, an essential problem for humanity is the issue of providing food for the global population, which has been growing recently [1]. Therefore, improving agricultural production is quite urgent [2]. One of the practical directions in the outlined plan is the further improvement of tillage tools, in particular, dump plows [3].

Many contradictory, technical, economic, environmental, and other requirements are put forward to these means. For example, this applies, on the one hand, to increasing the productivity of production and, on the other hand, to reducing all kinds of costs for it, preserving soil fertility in the absence of undesirable effects on the environment.

Modern computer information technologies contribute to the solution of the above problems [4]. First of all, this applies to systems of automated design of industrial products. One of their fundamental bases is geometric modeling. This is because, without geometric models, it is practically impossible to design and manufacture many modern technical objects [5]. The specified means are interconnected and coordinate with other models, such as strength, manufacturing technologies, and operation.

Therefore, to improve the quality of various products, improving existing and developing new effective methods and techniques of computer molding becomes essential [6]. In order to do this, it is necessary to consider both the existing multifaceted requirements for the designed technical objects and the corresponding capabilities of automated geometric modeling tools [7]. It is desirable to improve the latter to ensure their proper accuracy, flexibility, productivity, universality, predictability, and necessary controllability of forming processes. All this requires conducting fundamental and applied scientific research in modern geometric modeling of industrial products [8].

This publication is devoted to solving some of the above-outlined issues regarding the computer-based variant shaping of plow bodies with cylindroid and other working surfaces.

2 Literature Review

The foundations of modern computer geometric modeling were laid back in the 60s of the last century. This applies, in particular, to the works of Pierre Bézier and Paul de Casteljau, who worked for the Renault and Citroen automobile companies, respectively. The results of the research of these scientists went down in history as Bézier curves and surfaces and de Castellier's algorithm. Further development of engineering computer forming was carried out in 1972 by Maurice Cox and Carl de Boor, who proposed a recursive method for calculating B-splines, which include Bézier curves. An even more general mathematical apparatus is non-uniform rational B-splines (NURBS – non-uniform rational B-spline) and various surfaces built on their basis.

Garcıa [9] presented the general current state of geometric modeling using NURBS, emphasizing the importance of geometric parameters and characteristics for optimizing technical objects. The method of free deformation (free-form deformation) was defined as one of the promising directions. Notably, the latter effectively adapts the designed product to all the requirements. This applies to such structural, technological, operational, and other properties as strength, cost of production, productivity, and operation cost-effectiveness.

The authors of [10] investigate adaptive optimization shaping using NURBS and other splines in acoustics. Using parametric computer geometric forms for solving various optimization engineering problems is considered [11]. Implementing ultra-precision turning based on the curvature of processed NURBS surfaces was analyzed [12]. Researchers [13] present the proposed parametric adaptive method of predicting the ship's hull deformation to ensure its flexible and productive automated shaping using NURBS.

Some appropriate mathematical foundations for this are highlighted in the article [14]. The expediency of computer-free deformation for optimizing the geometry of ships is described in the work [15]. In addition to NURBS, it is also possible to use other splines, such as those discussed in [16].

This scientific research has an integrated character. That is, it concerns computer geometric modeling and automated design of specific products of agricultural engineering, in particular, plow bodies. Therefore, in addition to modern progressive means of forming, described in literary sources [9–16], relevant publications on the creation and practical application of working bodies of tillage tools were also analyzed.

Nassir [17] experimentally investigates the influence of different types of fallow plows, in particular, helical, semi-digger, and general-purpose, on the physical properties of the soil at three states of its moisture and four speeds of tractor movement. The obtained results confirmed the significant role of the types of fallow plows, soil moisture content, and tractor speed in the physical properties of the soil obtained after tillage, such as its porosity and grinding coefficient. Concerning the geometry of the plows, the importance of their dimensions, installation angles relative to the direction of movement, and the shape of the working surfaces are emphasized.

A particular drawback of this work in the geometrical aspect is the lack of analysis and the necessary scientific generalizations regarding the effect of changing the specified parameters of the size and shape of the plows on their tillage characteristics. This is one of the unsolved issues of known scientific literary sources and is a prospect for further research.

Ali Alwan [18] describes a methodology similar to the previous work, studying three types of dump plows (helical, digger, and general-purpose) and the influence of three tillage depths and three movement speeds on the tractor's required traction force. The presented information complements the previous one and attests to many possible combinations of the available operating conditions of dump plows and their significant effect on the properties of cultivated soils. Also, unfortunately, this article does not investigate the effect of varying the shape and size of the dumps on the obtained results. These tasks are relevant to the performance of many theoretical and experimental works.

Sergii Tishchenko [19] considers a geometrical model of the unfolding surface defined by two guide curves. At the same time, the mathematical apparatus for the necessary constructions is laid out. It is noted that the given surface has been used successfully in the construction of a general-purpose plow. However, the issue of free deformation of the surface in order to adapt it to the requirements of proper theoretical calculations or the conditions of conducting computer or natural experiments was not investigated. The specified problem is an actual direction for implementing new scientific research in agricultural engineering.

Juraev [20] highlighted the geometric modeling of plow bodies in the AutoCAD system but without implementing flexible variant shaping and describing the corresponding mathematical apparatus. It is emphasized that the proposed method allows for shortening the design time and simplifies the process of determining rational geometric parameters and characteristics for the products being designed.

The article [21] studied the influence of the dimensions and corresponding angles of the interaction of the plow blades with the soil on the obtained properties of its cultivation. Simultaneously, the analysis of the shape of these agricultural tools was not carried out, although the latter also significantly determines the values studied in this article. The publication [22] uses information about the geometry of the surfaces of these working bodies to determine the damage to the fallow plow using automated strength calculations. The publication [23] shows that the shape and dimensions of the fallow plows form the basis for determining the loads acting on them and the resulting structural deformations.

The research [24] studied the influence of dump types (two types of moldboard slatted and general purpose), two tillage depths, and two tractor speeds on some obtained physical properties of the soil. A particular perspective on the use of rail dumps is shown.

The universal approach proposed in this article to the computer variant design of plow dump surfaces is also suitable for the construction of other tillage implements, in particular, the colters analyzed in [25], loosening plows [26], or the construction of the working bodies of tillage implements by the methods described in [27] bionics. In the analyzed literature, such a progressive direction of computer automated forming, widespread in shipbuilding, aviation, and other industries, as variant computer geometric modeling is not investigated.

Thus, the method for automated plow design proposed in this article implements flexible and productive variant shaping of dump surfaces using generalized computer geometric models.

3 Research Methodology

3.1 The applied mathematical model

The approach to computer variant modeling of plow dumps presented later in this publication is based on the materials of the two previous sections of the article.

This refers to the perspective of automated design justified in the introduction to improve the quality of agricultural machines and the leading role in the mentioned processes of geometric modeling. The stated facts determine the corresponding requirements for computer tools for form creation. For example, the proper provision of geometric models for the accuracy of constructions and their variant flexibility, productivity, universality, predictability, and controllability.

The analysis of modern research showed that NURBS and the surfaces and virtual solids created on their basis are the most promising in the considered plan. The specified mathematical apparatus effectively implements the desired properties of automated forming, specified in the previous paragraph, and satisfies the principles of design computer optimization of free deformation of processed objects. The outline significantly contributes to the productive coordination of specific conflicting requirements of various disciplines, such as strength, manufacturing technology, operation, economy, and ecology, and provides the possibility of multifaceted optimization of industrial products.

The performed literature analysis testified to the effectiveness of applying the free computer deformation methodology for shipbuilding products, acoustics processes, ultra-precision turning, etc. However, in the field of automated design of tillage tools, particularly plow bodies, this approach is not widespread enough. Available explorations are aimed, on the one hand, or only at carrying out full-scale soil cultivation experiments without a detailed study of the effect on the obtained results of varying the geometry of the fallow shelves. On the other hand, it is only for the construction of certain surfaces without highlighting the means for flexible predictive control of shaping to appropriately adapt to the existing needs of both practice and theory of soil-working mechanics. The same applies to the sources considered regarding automated design in the AutoCAD system and strength calculations in the SolidWorks package.

Thus, the scientific research method proposed in this publication consists of creating computer variants that are sufficiently universal geometric models of plow bodies with cylindroid and other working surfaces. This provides an effective combination of theoretical and practical research in the field of designing the specified tillage tools, which is a relevant component of the rather relevant scientific and applied problem of the modern adequate food supply of the population of our planet.

According to the formulas of Cox and de Boer, the B-spline of the k-th order with $(n+1)$-th characteristic points is determined by the dependence:

$$\mathbf{r}(u)=\sum_{i=0}^{n} N_{i,k}(u)\mathbf{r}_i, \qquad (1)$$

where r(u) – the radius-vector; $u \in [t_{k-1}, t_{n+1}]$ – parameter; $(t_0, t_1, \ldots, t_{n+k})$ – non-decreasing sequence of parameter nodes; r_i – radius vectors of the vertices of the characteristic broken line; $n \in \mathrm{N}$; $2 \le k \le n+1$.

Parametric expressions $N_{i,k}(u)$ are calculated by the recursive formula:

$$N_{i,1}(u)=\begin{cases}1, u \in [t_i, t_{i+1}]\\ 0, u \notin [t_i, t_{i+1}]\end{cases},$$

$$N_{i,k}(u)=\frac{(u-t_i)}{t_{i+k-1}-t_i}N_{i,k-1}(u)+\frac{(t_{i+k}-u)}{t_{i+k}-t_{i+1}}N_{i+1,k-1}(u). \qquad (2)$$

Next, modeling the guidelines for the cylindroid surfaces of the plow blades with NURBS of the second degree can be considered. This is due to the latter’s simplicity, the predictability of their shaping, ease of control, versatility, and predictable changes in curvature.

The 2nd expression (2) assumes that the limit {0/0} approaches 0. The dependence (1) is a polynomial of degree k-1 on each segment $t \in [t_j, t_{j+1}]$, where j – a non-negative integer, and $j < n + k$.

The maximum possible order of a B-spline is equal to the number of its characteristic points. For admissible values of u, the basic functions $N_{i,k}(u)$ satisfy the following conditions:

$$N_{i,k}(u) \ge 0, \ \sum_{i=0}^{n} N_{i,k}(u)=1. \qquad (3)$$

According to expressions (1) and (3), the given parametric curve is inside the convex hull for radius vectors r_i, where $i\in(0, 1, \ldots, n)$. The geometry of this line also depends on the vector of parameter nodes, which includes $n + k + 1$ elements that may or may not be at the same distance. In this regard, uniform and non-uniform B-splines are distinguished. The repetition of the same values at the ends of the nodal vector in a quantity equal to the order of the given curve ensures its passage through the first and last characteristic points. In the unified nodal vector, the values increase from zero with a unit step.

Thus, for the considered case study of modeling by the 2nd degree curves ($k = 3$, $n = 2$). The unified nodal vector:

$$(t_j)_0^{n+k} = (0, 0, 0, 1, 1, 1). \tag{4}$$

Based on (2) and (4), it can be obtained:

$$N_{0,1}(u) = \begin{cases} 1, u \in [t_0, t_1] \\ 0, u \notin [t_0, t_1] \end{cases}, \quad N_{1,1}(u) = \begin{cases} 1, u \in [t_1, t_2] \\ 0, u \notin [t_1, t_2] \end{cases},$$

$$N_{2,1}(u) = \begin{cases} 1, u \in [t_2, t_3] \\ 0, u \notin [t_2, t_3] \end{cases}, \quad N_{3,1}(u) = \begin{cases} 1, u \in [t_3, t_4] \\ 0, u \notin [t_3, t_4] \end{cases},$$

$$N_{4,1}(u) = \begin{cases} 1, u \in [t_4, t_5] \\ 0, u \notin [t_4, t_5] \end{cases}. \tag{5}$$

For the parameter $u\in[0, 1]$ and the quantities (5), taking into account the requirements (3), it can be chosen $N_{2,1}(u)$ as the basis function of the first order.

Next, by analogy, it can be calculated the basic functions of the 2nd order

$$N_{1,2}(u) = \frac{u - t_1}{t_2 - t_1} N_{1,1}(u) + \frac{t_3 - u}{t_3 - t_2} N_{2,1}(u) = (1-u) N_{2,1}(u) = 1 - u,$$

$$N_{2,2}(u) = \frac{u - t_2}{t_3 - t_2} N_{2,1}(u) + \frac{t_4 - u}{t_4 - t_3} N_{3,1}(u) = u N_{2,1}(u) = u,$$

and the 3rd order

$$N_{0,3}(u) = \frac{u - t_0}{t_2 - t_0} N_{0,2}(u) + \frac{t_3 - u}{t_3 - t_1} N_{1,2}(u) = (1-u) N_{1,2}(u) = (1-u)^2,$$

$$N_{1,3}(u) = \frac{u - t_1}{t_3 - t_1} N_{1,2}(u) + \frac{t_4 - u}{t_4 - t_2} N_{2,2}(u) =$$

$$= u N_{1,2}(u) + (1-u) N_{2,2}(u) = 2u(1-u);$$

$$N_{2,3}(u) = \frac{u - t_2}{t_4 - t_2} N_{2,2}(u) + \frac{t_5 - u}{t_5 - t_3} N_{3,2}(u) = u N_{2,2}(u) = u^2. \tag{6}$$

Based on expressions (1) and (6), the following B-spline equation of the 3rd order can be obtained:

$$\mathbf{r}(u) = (1-u)^2 \mathbf{r}_0 + 2u(1-u)\mathbf{r}_1 + u^2 \mathbf{r}_2, \tag{7}$$

where $u\in[0, 1]$.

The dependence (7) corresponds to a Bézier curve of the second degree. This confirms the generalizing nature of B-splines related to the indicated curves. An even wider class is NURBS, which on the basis of (1) are presented in the form:

$$\mathbf{r}(u) = \frac{\sum_{i=0}^{n} N_{i,k}(u) w_i \mathbf{r}_i}{\sum_{i=0}^{n} N_{i,k}(u) w_i}, \tag{8}$$

where w_i – non-negative weights are used to improve shaping control, and an increase in w_i draws the processed curve to the corresponding characteristic point.

Dependence (8) is a ratio of polynomials, hence the name “rational B-spline”. In the case study of the 2nd degree, it can be obtained:

$$\mathbf{r}(u) = \frac{w_0(1-u)^2 \mathbf{r}_0 + 2w_1 u(1-u)\mathbf{r}_1 + w_2 u^2 \mathbf{r}_2}{w_0(1-u)^2 + 2w_1 u(1-u) + w_2 u^2}, \tag{9}$$

where $w_0 = w_2 = 1$, $w_1 \geq 0$.

Using expression (9), line segments, arcs of ellipses, circles, parabolas, and hyperbolas can be constructed. Figure 1 presents components of the topological quadrangle of the Coons surface, with the help of which the piles of plows will be built.

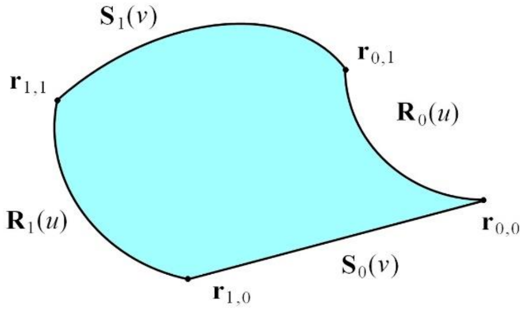


Figure 1 – Coons surface

The equation of this surface passing through arbitrary boundary four parametric curves $R_0(u)$, $R_1(u)$, $S_0(v)$, $S_1(v)$, which meet at the points $\mathbf{r}_{0,0}$, $\mathbf{r}_{0,1}$, $\mathbf{r}_{1,0}$, and $\mathbf{r}_{1,1}$ the following form:

$$\begin{aligned} \mathbf{R}(u,v) &= (1-v)\mathbf{R}_0(u) + v\mathbf{R}_1(u) + (1-u)\mathbf{S}_0(v) + u\mathbf{S}_1(v) - \\ &- (1-v)(1-u)\mathbf{r}_{0,0} - (1-v)u\mathbf{r}_{0,1} - v(1-u)\mathbf{r}_{1,0} - vu\mathbf{r}_{1,1}, \end{aligned} \tag{10}$$

where $u\in[0, 1]$, $v\in[0, 1]$ – parameters; $r_{0,0} = R_0(0) = S_0(0)$, $r_{0,1} = R_0(1) = S_1(0)$, $r_{1,0} = R_1(0) = S_0(1)$, and $r_{1,1} = R_1(1) = S_1(1)$.

Curves (9) are proposed to be parametric lines of relation (10). For the central characteristic points and their weighting coefficients of the lines $R_0(u)$, $R_1(u)$, $S_0(v)$, $S_1(v)$, the designations (P_1, w_1), (P_2, w_2), (P_3, w_3), and (P_4, w_4) will be used.

3.2 Modeling of working surfaces of plow blades

It is known that cylindroid surfaces are most often used for general-purpose plows, which are formed by the movement of a rectilinear generator along two curved guides. At the same time, the generator is always parallel to a particular chosen plane. Apart from the cylindrical, the rest of the cylindroid surfaces are non-expandable. If one of the guides is straight, a conoid surface can be obtained.

Let us determine the conditions that ensure the construction of cylindroid surfaces for the mathematical apparatus presented in the previous subsection of this article. Let’s create an appropriate surface (Figure 2).

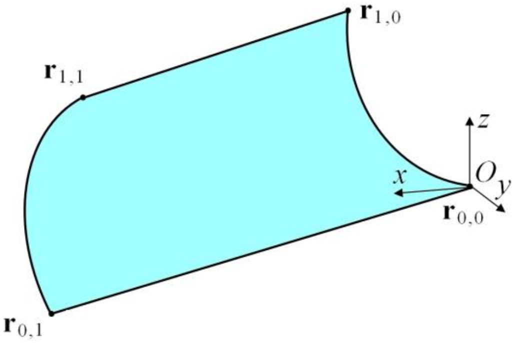


Figure 2 – Scheme of construction of a cylindroid surface

In the rectangular Cartesian coordinate system *Oxyz*, where *Oxy* is considered the plane of parallelism. Note that the following considerations are applied by analogy in cases of another plane.

The following lines are chosen as curvilinear guides:

$$\mathbf{S}_0(v) = \frac{(1-v)^2\mathbf{r}_{0,0} + 2w_3 v(1-v)\mathbf{P}_3 + v^2\mathbf{r}_{1,0}}{(1-v)^2 + 2w_3 v(1-v) + v^2},$$

$$\mathbf{S}_1(v) = \frac{(1-v)^2\mathbf{r}_{0,1} + 2w_4 v(1-v)\mathbf{P}_4 + v^2\mathbf{r}_{1,1}}{(1-v)^2 + 2w_4 v(1-v) + v^2}, \quad (11)$$

where $\mathrm{r}_{0,0} = (x_{0,0}; y_{0,0}; z_{0,0})$, $\mathrm{r}_{0,1} = (x_{0,1}; y_{0,1}; z_{0,1})$, $\mathrm{r}_{1,0} = (x_{1,0}; y_{1,0}; z_{1,0})$, and $\mathrm{r}_{1,1} = (x_{1,1}; y_{1,1}; z_{1,1})$.

At the same time, in (11) it is necessary to reach:

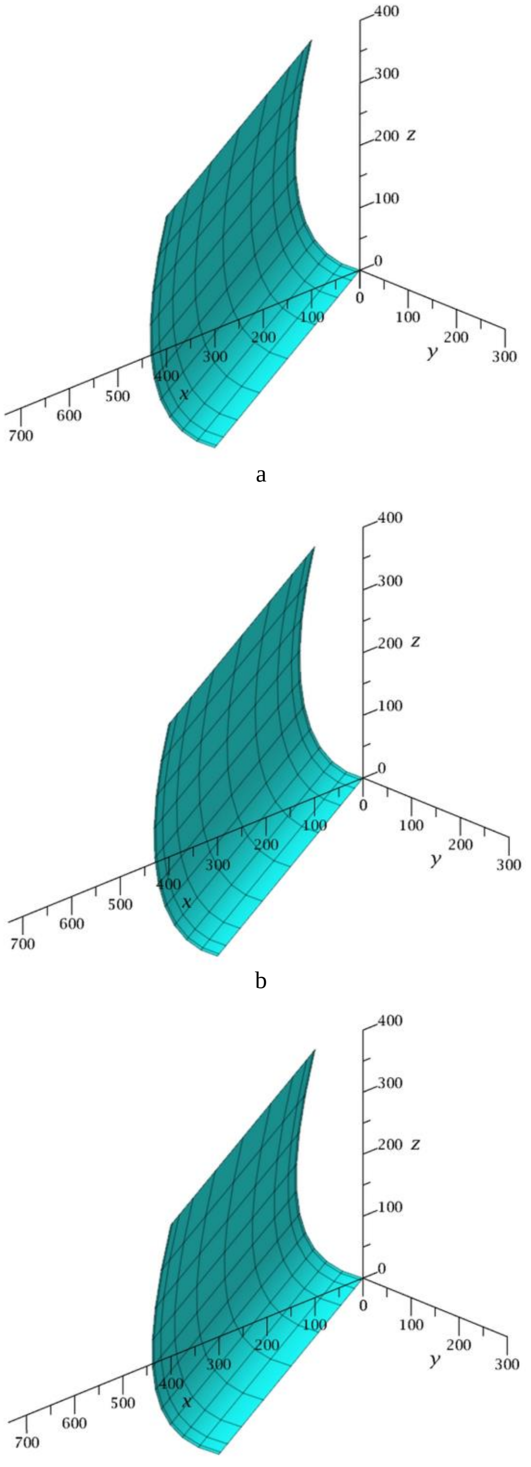
$$z_{0,1} = z_{0,0};\ z_{1,1} = z_{1,0}, \quad (12)$$

which follows from the initial and final conditions of construction of the cylindroid surface.

Variants of parabolic, elliptical, and hyperbolic surfaces are presented in Figure 3.

The equation of this surface is as follows:

$$\mathbf{R}(u,v) = (1-u)\mathbf{S}_0(v) + u\mathbf{S}_1(v). \quad (13)$$



a

b

c

Figure 3 – Variants of cylindrical surfaces: a – parabolic; b – elliptical; c – hyperbolic

It follows from (11) and (13) that in order to implement the parallelism of the generators of the *Oxy* plane, it is necessary to ensure

$$\frac{(1-v)^2 z_{0,0} + 2w_3 v(1-v) z_{\mathbf{P}3} + v^2 z_{1,0}}{(1-v)^2 + 2w_3 v(1-v) + v^2} =$$

$$= \frac{(1-v)^2 z_{0,1} + 2w_4 v(1-v) z_{\mathbf{P}4} + v^2 z_{1,1}}{(1-v)^2 + 2w_4 v(1-v) + v^2}, \qquad (14)$$

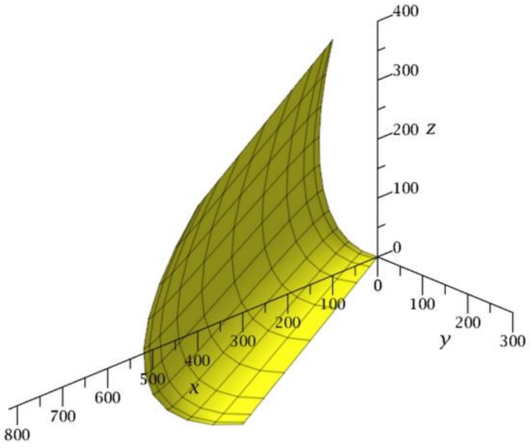
where $z_{\mathbf{P}3}$, $z_{\mathbf{P}4}$ – appliqués of points P_3 and P_4, respectively.

Based on (12) and (14), the final conditions for realizing a cylindroid surface in the form of formula (10) are as follows:

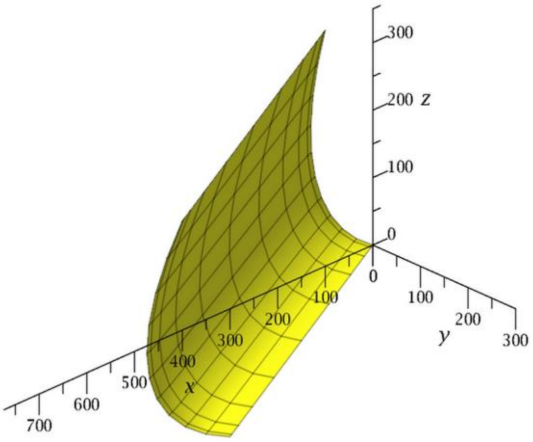
$$z_{0,1} = z_{0,0};\ z_{1,1} = z_{1,0};\ z_{\mathbf{P}_4} = z_{\mathbf{P}_3};\ w_4 = w_3. \qquad (15)$$

As can be seen, relations (15) only limit the significantly greater possibilities of variant geometric modeling using the mathematical tools presented above.

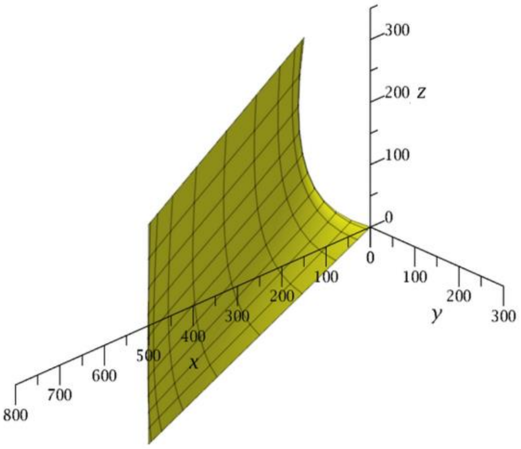
The corresponding cylindrical surfaces based on Figure 3 are presented in Figure 4.



a



b



c

Figure 4 – Cylindrical surfaces: a – based on Figure 3a; b – based on Figure 3b; c – based on Figure 3c

Before giving specific examples of computer-aided modeling, let’s focus on some general advantages of the proposed approach in terms of its universality, flexibility, predictability, and controllability.

From Figures 1–2 and the above mathematical dependencies, it can be seen that with the help of vertices $\mathrm{r}_{0,0}$, $\mathrm{r}_{0,1}$, $\mathrm{r}_{1,0}$, and $\mathrm{r}_{1,1}$, control points P_1, P_2, P_3, and P_4, and the weighting factors w_1, w_2, w_3, and w_4, the required dimensions of the plow blades, their contours, the required angles of inclination of the working surfaces, and the dynamics of their change, are determined quite simply and predictably. Appropriate adjustments are also made quite simply.

4 Results

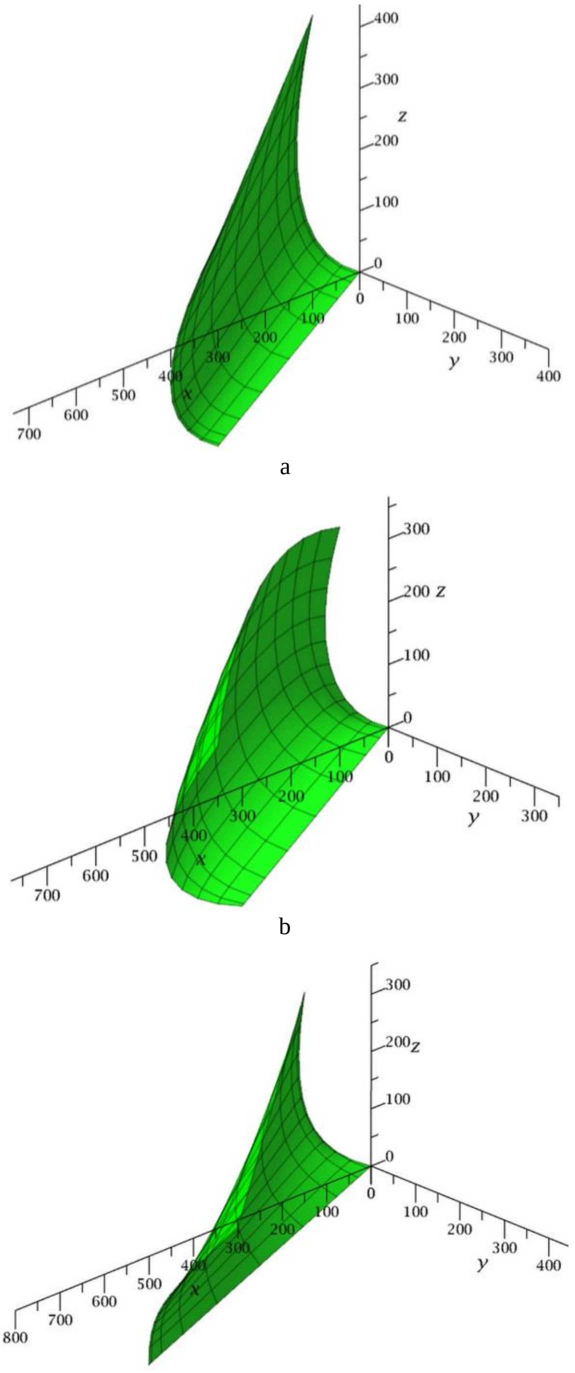
4.1 Variants of the cylindrical surfaces of the plow shafts

Figure 5 shows some variants of the cylindrical surfaces of the plow shafts. The units of measurement are millimeters.

The models have the following parameters:

$\mathrm{r}_{0,0} = (0; 0; 0)$,
$\mathrm{r}_{0,1} = (600; 300; 0)$,
$\mathrm{r}_{1,0} = (100; 0; 400)$,
$\mathrm{r}_{1,1} = (700; 300; 400)$;
$\mathrm{P}_1 = (300; 400; 0)$,
$\mathrm{P}_2 = (300; 200; 400)$,
$\mathrm{P}_3 = (200; 0; 100)$,
$\mathrm{P}_4 = (800; 300; 100)$;
$w_1 = w_2 = 0$.

For parabolic, elliptical, and hyperbolic cylindrical surfaces, $w_3 = w_4 = 1.0$, $w_3 = w_4 = 0.9$, and $w_3 = w_4 = 1.2$ were used, respectively.



a

b

c

Figure 5 – Types of other dump surfaces: a – based on Figure 4a; b – based on Figure 4b; c – based on Figure 4c

Variant computer forming is carried out according to the method described for cylindrical surfaces. It is only worth noting that in order to ensure the parallelism of the generators to the *Oxy* plane, restrictions (15) should be observed.

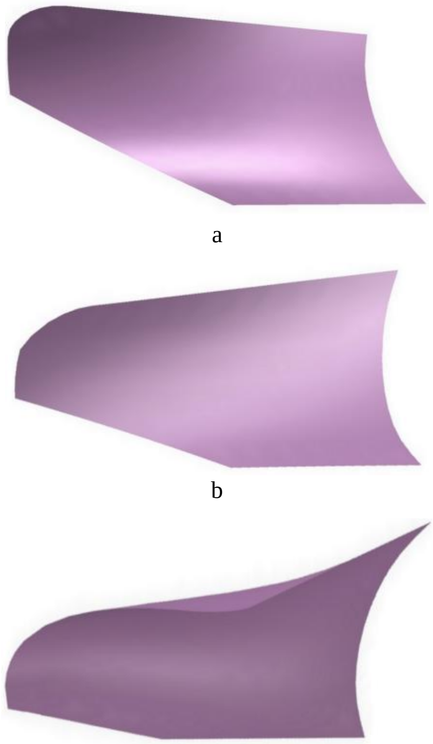
Let's continue with the illustrations of the automated geometric modeling of dumps based on further changes (Figure 5) of cylindroid surfaces.

For the 1st image, $r_{1,0}$ = (100; 0; 450) was changed, for the 2nd – $r_{1,1}$ = (700; 350; 300), P_2 = (300; 0; 400), $w_2 = 1$, and P_4 = (900; 300; 100), and for the 3rd – P_4 = (800; 500; 300) and $w_4 = 2$.

As can be seen from the above information, the creation of variants of surfaces is practically unlimited, primarily if, for this purpose, the specialized software tools for the automated generation of the necessary varieties can be used. Productive analysis of a more significant number of them contributes to confidence in determining the best of them. As a result, the quality of designed industrial products increases. The facts testify to the proposed approach's rather general and universal nature and its theoretical and practical significance.

4.2 The use of plow dump surfaces

The options for dump surfaces developed above serve as the preliminary definition of their most promising options. Specific calculations and computer or natural experiments will further refine the latter. From a geometric point of view, this concerns the construction contours of dumps (Figure 6) and the construction of proper virtual solid objects by giving the surfaces the required thickness (Figure 7).



a

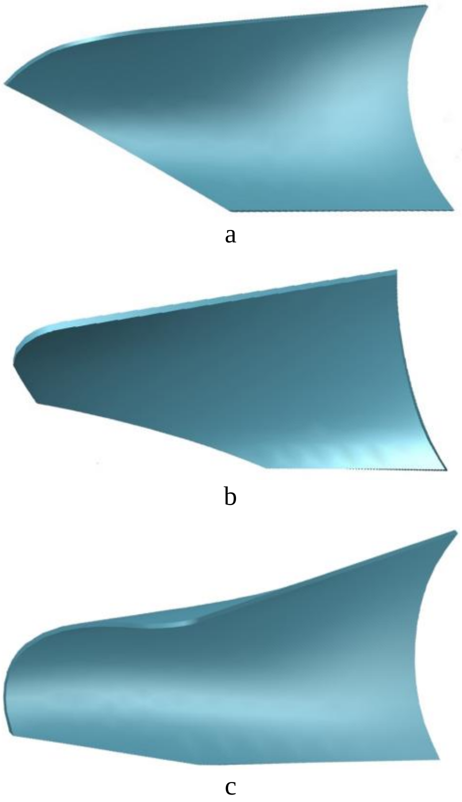
b

c

Figure 6 – Formation of structural contours of dump surfaces: a – the 1st option; b – the 2nd option; c – the 3rd option

In the first case, rational cuts of the bottom and rounding of the top of the dump are formed. The options presented in Figure 6 serve as relevant examples. In the second case, there is also a particular set of project varieties related to the thickness and the appropriate choice of the plow material, its construction, production, operation, and other properties. The outlined tasks go beyond the scope of this publication. Note that the mentioned questions relate to strength calculations using the finite element method, the definition of technological stresses in manufacturing dumpers by pressure, and the determination of the forces acting on them during operation. At all the listed stages of the life cycle of plows, their geometry is inextricably linked with them, significantly affecting various factors.

Therefore, searching for rational parameters of shape and size is one of the essential components of the complex optimization of tillage tools. An important component in the outlined process is flexible, productive, properly managed computer variant geometric models, which are the subject of this scientific study.


a

b

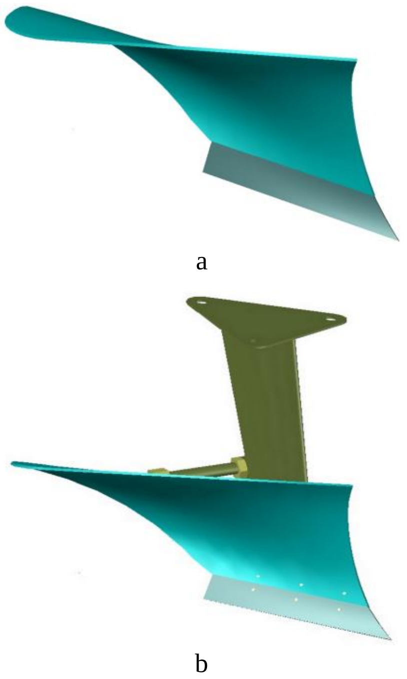
c

Figure 7 – Computer solid models of dumps:
a – the 1st variety 1; b – the 2nd variety; c – the 3rd variety

The next stage of automated molding is the construction of realistic solid parts and folding units (Figure 8), a more detailed study of manufacturing technologies and agricultural machinery operation.

Here, the task of a mutually optimal combinatorial combination of individual components and various processes associated with them becomes relevant. This applies not only to technical factors but also to ergonomic, economic, environmental, and other factors.

Therefore, tillage tools are created by a significant variety of object forms. It requires proper and effective integration with the multidimensional virtual space of project parameters of related particular disciplines, such as tillage mechanics, agrophysics, agrochemistry, agronomy, and agroecology.


a

b

Figure 8 – Examples of computer parts and assembly units using a plow blade: a – dump and plowshare; b – plow body

5 Discussion

The NURBS mathematical apparatus is the basis of modern computer geometric modeling used in current automated design systems [28–32]. These means are characterized by sufficient flexibility, predictability, and controllability in shaping. Their popularity is evidenced by their wide use in many industries, particularly automotive, shipbuilding, and general mechanical engineering.

Research works [33–37] on the development of tillage tools testify to the particular importance of the geometry of the working bodies for achieving the proper quality of tillage. At the same time, the issues of adapting computer geometric models to the various requirements of such related disciplines as strength, manufacturing technology, and operation were not considered.

The above circumstances determine the relevance of the chosen topic for this article. It offers a universal mathematical apparatus for flexible, productive, and predictable automated variant shaping of plow bodies based on Coons and NURBS surfaces. These tools are suitable for effectively playing a leading role in coordinating and integrating conflicting requirements of other disciplines during the design of tillage tools to ensure the possibility of their comprehensive optimization.

Appropriate test examples confirm the functionality of the proposed mathematical apparatus. Ways of prospective application of the created variant computer geometric models of plow bodies for further automated design of tillage implements are outlined.

Thus, these scientific investigations have achieved the primary goal of improving mathematical tools to improve agricultural machinery quality.

6 Conclusions

A new approach to computer variant geometric modeling of plow bodies is proposed, and a corresponding mathematical apparatus is developed based on the use of Coons and NURBS surfaces. A practical check of the obtained theoretical results was performed on specific test examples.

The universality, flexibility, proper controllability, and performance of the constructed geometric models are shown. Their basic leading role during the coordination and integration of project models of other disciplines in order to implement complex optimization of tillage tools is emphasized.

Prospective directions for applying the analyzed automated molding for effective processing of the entire life cycle of agricultural machinery are outlined. The scientific and applied topics presented in the article need further development by conducting relevant professional research.

Overall, the obtained results testify to a reduction of up to 10–15 % in the processing time of specific samples of tillage tools, with the provision of their proper quality.

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