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STRUCTURAL-PARAMETRIC SHAPING OF SOIL TILLAGE TOOLS

One of the important directions in the modern development of the scientific school of applied geometry at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" is the methodology of structural and parametric shaping of various technical objects. Significant theoretical and practical achievements have been made in this field in recent years. In particular, this applies to implementations in the aviation industry, general mechanical engineering, and other sectors of the national economy.

The current difficult period in Ukraine is related to the military actions on its territory. In such conditions, agriculture has become a significant component of our country's economy. Therefore, further improvement of this sector represents a pressing scientific and applied problem. One of the ways to successfully solve the outlined problems is, in particular, the improvement of the used tillage tools. In this regard, defining the optimal shape and dimensions of these technical objects is considered progressive. These factors not only significantly improve the quality of soil cultivation but also contribute to the preservation of its fertility, reduction of energy consumption in the corresponding technological processes, and so on.

The application of computer-based structural and parametric geometric modeling enables productive and flexible implementation of multi-faceted analysis of a large number of design options during the development of industrial products. This approach ensures comprehensive optimization, including various tillage implements. An important aspect of this process is the use of integrated generalized geometric models that encompass a wide range of technical objects. This concept significantly enhances the efficiency of existing computer information technologies.

This article reviews some fundamental results obtained regarding the structural and parametric shaping of certain agricultural machinery products. For example, this includes tillage disks, chisel plows, and moldboard plows. The publication also presents proposed new methods and techniques of geometric modeling, outlines their development directions, and identifies the prospects for conducting further related scientific research.

Keywords: *automated design; geometric modeling; tillage tools; structural- parametric shaping.*

Problem Statement. In the current difficult wartime, the improvement of agriculture, including the used tillage tools, is an urgent issue for Ukraine. This improvement allows to increase production efficiency, reduce available energy, material and financial costs, improve the preservation of soil fertility, etc. One of the progressive directions in this context is the rational shaping of these technical objects. This publication is dedicated to highlighting some of the developments of the scientific school of applied geometry at the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" in this field.

Analysis of Recent Research. The article [1] outlines the main directions of current scientific research in the field of applied geometry and engineering graphics conducted at Igor Sikorsky Kyiv Polytechnic Institute. This concerns the development of an integrated complex methodology for the automated forming of various technical objects, their manufacturing and operation processes, in particular, tillage tools. Publication [2] shows the ability to realize the specified goal by means of computer structural-parametric geometric modeling. The publication [3] presents some improvements of the relevant theoretical foundations in the form of a generalization of the appropriate models by applying to their components cyclic, namely repetitive, shaping operations. Research [4] introduces a methodology proposed by the authors for productive automated design of groups of technical objects, illustrated with the example of agricultural disks, which relies on the appropriate systematization of geometric means. The work [5] analyzes tillage tools, classifying them in terms of shaping aspects. The last two publications complement each other in terms of using integrated classifications to ensure productive automated geometric modeling of certain groups of technical objects. Articles [6, 7] discuss specific cases of structural and parametric shaping, using the examples of moldboard and arrowhead plowshare, respectively. Publication [8] examines the impact of the geometric parameters of arrowhead plowshare on the energy performance of a combined cultivator-seeder. Thus, the literature review demonstrates significant theoretical and practical contributions of the applied geometry scientific school at Igor Sikorsky Kyiv Polytechnic Institute in the structural-parametric shaping of tillage tools.

The goals and tasks of the article consist in the necessary systematization and generalization of the existing works of the scientific school of applied geometry of Igor Sikorsky KPI in relation to tillage tools, determination of further promising directions of their development

Main Part. The basic principles of structural-parametric geometric modeling are sufficiently illustrated in publication [1] using the example of aircraft construction. Publications [2, 3] propose enhancing this approach by properly integrating existing methods, techniques, practices, and algorithms of geometric modeling. Research [4] highlights a methodology for productive automated shaping of various agricultural disks. Its generalization is presented in article [5], which provides a mathematical framework for effectively combining appropriate systematization of geometric means and corresponding classifications of the technical object groups being developed, using the example of tillage tools.

Geometric figures used (abbreviated as *GF*) are defined by a set

$$GF = (GF_i)_0^{N_{GF}} = (GF_i)_0^5, \qquad (1)$$

where $GF_0 = PT$ – *points*, $GF_1 = LN$ – *lines*, $GF_2 = SR$ – *surfaces*, $GF_3 = SL$ – *solids*, $GF_4 = MF$ – *multidimensional figures*, $GF_5 = CF$ – *combined figures.*

Geometric modeling methods (*GM)* of figures (1) are described by a tuple

$$GM = (GM_i)_1^{N_{GM}} = (GM_i)_1^2, \qquad (2)$$

where $GM_1 = GMC$ – *geometric methods of creation*, $GM_2 = GMM$ – *geometric methods of modification*.

Elements (2) are presented as

$$GM_1 = (GM_{1_j})_1^{N_{GM_1}} = (GM_{1_j})_1^2, \qquad (3)$$

where GM_{1_1} = *kinematic*, GM_{1_2} = *analytical*;

$$GM_2 = (GM_{2_j})_1^{N_{GM_2}} = (GM_{2_j})_1^3, \qquad (4)$$

where GM_{2_1} = *motion*, GM_{2_2} = *deformation*, GM_{2_3} = *operations on sets of points.*

Further levels of classification of the applied geometric tools are presented in publication [5]. This work also proposes *a method of integrated classifications for automated shaping of groups of industrial products*. In this case, it represents a combination of ordered geometric methods (1) ... (4) and a performed systematization of the mentioned objects, in our case, tillage implements.

Based on the structural-parametric approach, a set of processed tillage tools *TT* has been formed

$$TT = (TT_i)_1^{N_{TT}} = (TT_i)_1^3, \qquad (5)$$

where $TT_1 = TTM$ – *main*, $TT_2 = TTS$ – *surface*, $TT_3 = TTP$ – *special processing*.

The main processing tools are presented as a tuple

$$TTM = (TTM_i)_1^{N_{TTM}} = (TTM_i)_1^3, \quad (6)$$

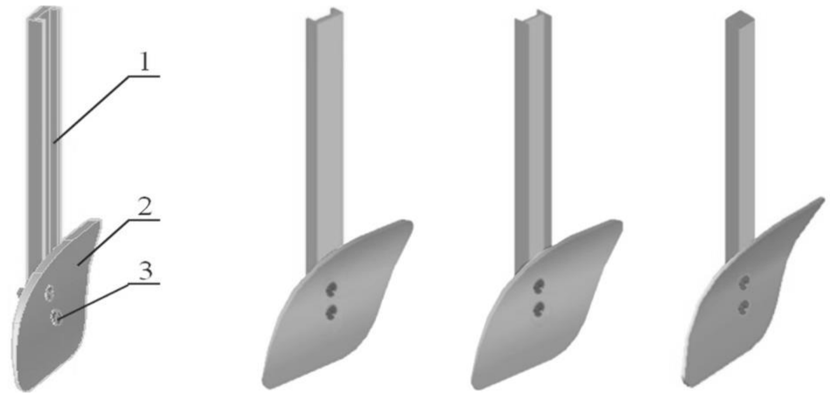
where $TTM_1 = MTT$ – *moldboard*, $TTM_2 = DTT$ – *disk*, $TTM_3 = CTT$ – *chisel*.

In more detail, the classification of elements (5) and (6) is considered in the publication [5]. The study [6] analyzed the structural-parametric shaping of moldboard, which are related to tillage tools of surface cultivation.

For this purpose, the composition definition is first performed, see Fig.1,a modeled rod-moldboard *RM*

$$RM = (rm_i)_1^{N_{RM}} = (rm_i)_1^3, \quad (7)$$

where $rm_1 = RD$ – *rod*, $rm_2 = MB$ – *moldboard*, $rm_3 = SJ$ – *screw joint*.



a *b*

Fig. 1. Rod-moldboard:
a – composition of elements (1 – rod; 2 – moldboard; 3 – screw joint);
b – design variants

Further, definitions for the elements rm_i have been established and their design options, which are described by sets

$$rm_i = (rm_{i_j})_1^{N_{rm_i}}, \quad (8)$$

where N_{rm_i} – number of variants rm_i,
and vectors of parameters

$$P_{i_j} = (p_{i_{jk}})_1^{Np_{i_j}}, \quad (9)$$

where Np_{ij} – number of parameters *j*-th variant of the *i*-th element.

The practical use of expressions (7) ... (9) is illustrated in Fig.1, b which shows that different types of rods are being researched

$$RD = (rd_i)_1^{N_{RD}} = (rd_i)_1^3, \quad (10)$$

where rd_1 – *channel*, rd_2 – *H beam*, rd_3 – *square*.

In the general case, other constituent sets (10) are also possible.

Also structural variants of moldboard are also analyzed

$$MB = (mb_i)_1^{N_{MB}} = (mb_i)_1^3 \tag{11}$$

and screw joint

$$SJ = (sj_i)_1^{N_{SJ}} = (sj_i)_1^4. \tag{12}$$

The above-mentioned means of geometric modeling are used directly for the construction of objects (10) ... (12). Relevant similar examples are considered below.

The structural relationship between the variants of the n-th and m-th elements of the rod-moldboard *LM* is represented by adjacency matrices.

$$C_{nm} = \left\| c_{n_r} c_{m_s} \right\|, \tag{13}$$

where r, s – natural numbers; $r \in (1 \ldots N_n)$, $s \in (1 \ldots N_m)$; N_n, N_m – the number of variants n-th and m-th element; $c_{n_r} c_{m_s} \neq 0$ in the interaction n_r and m_s; $c_{n_r} c_{m_s} = 0$ – in opposite case.

Expressions (7) ... (13) make it possible to build a graph structural-parametric model that ensures complex optimization of the designed object.

In the publication [7], the structural and parametric shaping of arrowhead plowshare *AP* is given, see Fig. 2. At the same time, the main attention is paid to the mathematical apparatus for constructing the surfaces of these tools.

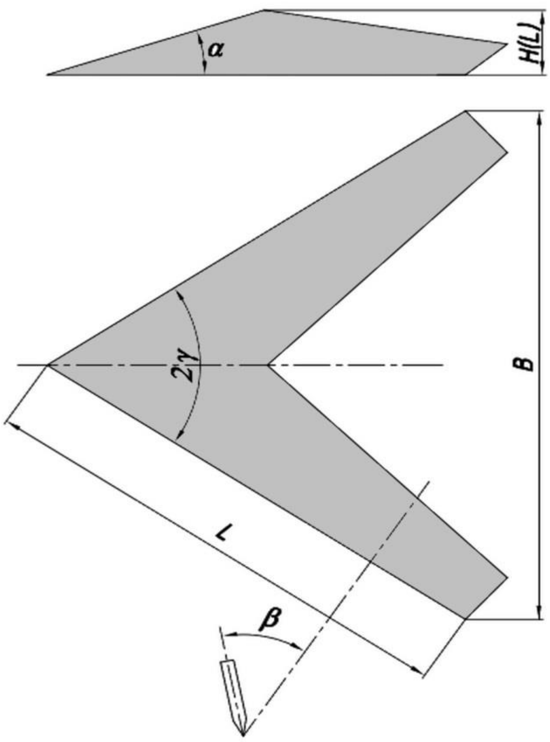


Fig. 2. Geometric parameters of the arrowhead plowshare

The parameters used are described by the set

$$P_{AP} = (P_{AP\,i})_1^{N_{P_{AP}}} = (P_{AP\,i})_1^6 = (\alpha, \beta, 2\gamma, B, L, H(L)), \qquad (14)$$

where α – angle of entry into the soil, β – the angle of soil collapse, 2γ – the angle of divergence of the plowshare, B – width of the plowshare, L – the length of the cutting blade, $H(L)$ – the height of the plowshare.

By their purpose arrowhead plowshare are divided into flat-cutting *(FP)* and universal (*UP*)

$$AP = (FP, UP). \qquad (15)$$

The following expressions determine the intervals for changing the parameters given in set (14), respectively, for flat-cutting plowshare and universal plowshare

$$\begin{gathered} P_{FP1} = \alpha = [6^0],\ P_{FP2} = \beta = [15^0 \ldots 18^0],\ P_{FP3} = 2\gamma = [60^0 \ldots 68^0], \\ P_{FP4} = B = [145 \ldots 260\,\text{мм}],\ P_{FP5} = L = [120 \ldots 210\,\text{мм}]; \end{gathered} \qquad (16)$$

$$\begin{gathered} P_{UP1} = \alpha = [13^0 \ldots 16^0], P_{UP2} = \beta = [28^0 \ldots 30^0], P_{UP3} = 2\gamma = [60^0 \ldots 70^0], \\ P_{UP4} = B = [220 \ldots 410\,\text{мм}],\ P_{UP5} = L = [240 \ldots 350\,\text{мм}]. \end{gathered} \qquad (17)$$

In order to increase the technological indicators of soil cultivation, in addition to arrowhead plowshares with straight outlines, it is appropriate to use curvilinear contours under certain conditions.

Project variants of theoretical surfaces (*TS*) of arrowhead plowshare are reproduced in sets

$$TS_{AP} = (TS_{AP_n})_{n=1}^{N_{TS_{AP}}}. \qquad (18)$$

Since the plowshare have a longitudinal vertical plane of symmetry, only one of their sides will be described mathematically in the future. The other is obtained by the operation of symmetry.

Note that, in the general case, half of the arrowhead plowshare can be supplied by several surfaces, for example, Coons,

$$TS_{AP_n} = (TS_{AP_{n_k}})_{k=1}^{N_{TS_{AP_n}}}, \qquad (19)$$

where each element in this case is defined by a dependency

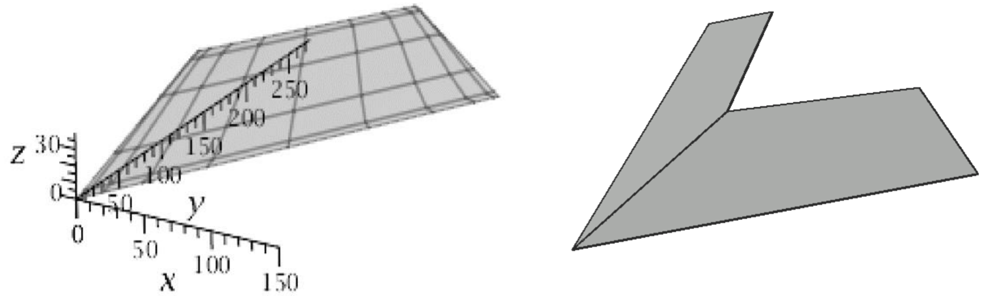
$$\begin{gathered} TS_{AP_{n_k}}(u,v) = (1-v)\mathbf{r}_{i,j}(u) + v\,\mathbf{r}_{i,j+1}(u) + (1-u)\mathbf{r}_{i,j}(v) + u\,\mathbf{r}_{i+1,j}(v) - \\ -(1-v)(1-u)\mathbf{r}_{i,j} - (1-v)u\mathbf{r}_{i+1,j} - v(1-u)\mathbf{r}_{i,j+1} - vu\mathbf{r}_{i+1,j+1}, \\ u = [0,1],\ v = [0,1],\ i = 0 \ldots\ N_i - 1,\ j = N_j - 1, \end{gathered} \qquad (20)$$

N_i and $N_j = 1$ – the number of Coons segments along the length L and height H of the arrowhead plowshare,

$$\mathbf{r}_{n,m}(t) = \frac{(1-t)^2 \mathbf{r}_{0_{n,m}} + w_1 2u(1-t)\mathbf{r}_{1_{n,m}} + t^2 \mathbf{r}_{2_{n,m}}}{(1-t)^2 + w_1 2u(1-t) + t^2}, \qquad (21)$$

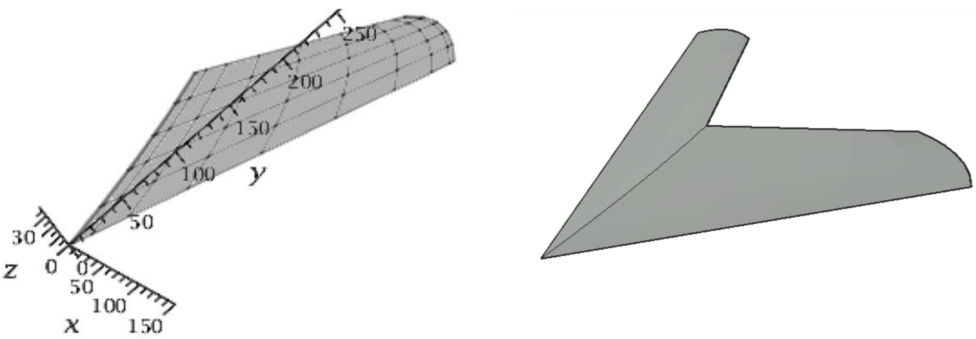
where for the parameters u and v formula (20) generalized notation t is applied; $\mathbf{r}_{n,m}(t)$ – the radius vector of the points of the curve of the second degree; $\mathbf{r}_{0n,m}$, $\mathbf{r}_{1n,m}$, $\mathbf{r}_{2n,m}$ – radius vectors of the vertices of the characteristic triangle; $w_1 \geq 0$ – weight coefficient; $n = 0 \ldots N_i$, $m = 0 \ldots N_j$.

In Fig. 3 shows some design varieties of arrowhead plowshare built on the basis of the proposed mathematical apparatus, see expressions (14) ... (21), automated variant formation.



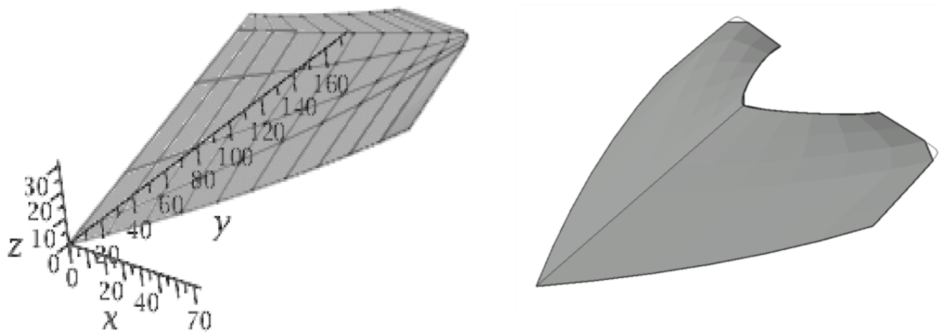
α=15°, β=27°, 2γ=60°, B=300 мм, L=300 мм, $H(L)$=39 мм

a



α=13°, β=18°, 2γ=60°, B=300 мм, L=300 мм, $H(L)$=39 мм

b



α=15°, β=18°, 2γ=70°, B=150 мм, L=150 мм, $H(L)$=32 мм

c

Fig. 3. Types of geometric models of arrowhead plowshare

At the same time, for each variant, the first image corresponds to the theoretical surface of the tillage tool, and the second to its computer solid model.

Fig. 3, *a* shows the use of a rectilinear limiting contour, and Fig. 3, *b* - lower and upper contours from straight line segments and their combination by curves of the second degree. Fig. 3, c illustrates the case of a limiting contour made entirely of curvilinear elements.

Due to its universality, the described approach also applies to the moldboards shown in Fig. 1. Obviously, by analogy, moldboards tillage tools are built, see set (6). The automated geometric modeling of agricultural discs discussed in the publication [5] is fully consistent with the given method of structural-parametric shaping. To some extent, this also applies to chisel plows. An example of supplementing the analyzed geometric models with descriptions of other disciplines, in particular soil mechanics, is the publication [8]. This specified integration is quite promising for further both scientific research theoretical and practical.

Thus, we have outlined the main contemporary directions of scientific research by the School of applied geometry of Igor Sikorsky KPI in relation to the structural-parametric shaping of tillage tools. It is worth noting that the obtained theoretical advancements undergo necessary validation through computer testing and conducting field experiments, facilitating their implementation into agricultural production. Currently, one doctoral dissertation and two works towards obtaining a Doctor of Philosophy degree are being conducted directly on this topic. The aforementioned results also relate to the research of the Department of Descriptive Geometry, Engineering and Computer Graphics regarding its scientific and technical work "Automated variant geometric modeling of technical objects" with the state registration number 0114U002701.

Conclusions. The article presents the current state of scientific investigations of the School of Applied Geometry of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" regarding the structural-parametric shaping of tillage tools. At the same time, the relevance of the mentioned topic in the modern difficult conditions of life in Ukraine is emphasized. A general relevant proposed methodology is provided. It is illustrated by its construction of specific appropriate mathematical and computer models. Their perspective in theoretical and practical terms is shown. Some directions for conducting further scientific research in the considered area are outlined. This will contribute to increasing the efficiency of geometric modeling of tillage tools in the environment of modern automated design systems.

References

1. *Vanin V. V., Virchenko G. A., Gumen O. M., Yurchuk V. P., Yablonskyi P. M.* Current state and perspectives for further development of scientific school of applied geometry of National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute». *Applied questions of mathematical modelling*, 2018. Vol. 2. P. 17–23. DOI 10.32782/2618-0340-2018-2-17-23 {in Ukrainian}

2. *Vanin V. V., Virchenko G. A., Hetman O. G., Yablonskyi P. M.* Structural-parametric forming as a means of integration of automated design for technical objects**.** *Applied geometry and engineering graphics*, 2019. Vol. 95. P. 46–50. {in Ukrainian}

3. *Vanin V. V., Virchenko G. A., Yablonskyi P. M.* To the question of generalization of structuralparametric shaping of technical objects. *Applied geometry and engineering graphics*, 2020. Vol. 99. P. 56–64. {in Ukrainian}

4. *Vanin V. V., Virchenko G. A., Yablonskyi P. M.* Automated geometric modeling of disk working bodies of technical objects. *Information systems, mechanics and control*, 2019. Vol. 21. P. 5–13. {in Ukrainian}

5. *Yablonskyi P. M , Virchenko G. A., Volokha M. P., Vorobiov O. M., Lazarchuk-Vorobiova Yu. V.* To the question of the analysis of geometric models of modern soil tillage tools. *Modern modeling problems*, 2022. Vol. 24. P. 182–189. {in Ukrainian}

6. *Vanin V. V., Virchenko G. A., Volokha M. P., Yablonskyi P. M., Vorobiov O. M.* To the question of computer geometric modeling of soil tillage tools by means of structuralparametric forming. *Applied geometry and engineering graphics*, 2022. Vol. 103. P. 16–22. DOI: 10.32347/0131-579x.2022.103.16-22

7. *Virchenko G. A., Volokha M. P., Yablonskyi P. M., Vorobiov O. M., Golova O. O., Lazarchuk-Vorobiova Yu. V.* Geometric modeling of arrowhead plowshare by means of structural-parametric shaping. *Abstracts of reports of XVIII international scientific and practical conference «Obukhov readings»*. Kyiv: NULES of Ukraine, 2024. P. 43–46. {in Ukrainian}

8. *Vanin V. V., Virchenko G. A., Volokha M. P., Yablonskyi P. M., Vorobiov O. M.* Influence of the geometric parameters of the arrow shaped paw on the energy indicators of the combined cultivator-coulter. *Applied geometry and engineering graphics*, 2023. Vol. 104. P. 30–37. DOI: 10.32347/0131-579x.2023.104.30-37 {in Ukrainian}

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СТРУКТУРНО-ПАРАМЕТРИЧНЕ ФОРМОУТВОРЕННЯ ГРУНТООБРОБНИХ ЗНАРЯДЬ

Одним із важливих напрямків сучасного розвитку наукової школи прикладної геометрії Національного технічного університету України «Київський політехнічний інститут імені Ігоря Сікорського» є методологія структурно-параметричного формоутворення різноманітних технічних об'єктів. У даній сфері за останні роки отримано вагомі теоретичні і практичні здобутки. Зокрема, це стосується виконаних впроваджень в авіаційну промисловість, загальне машинобудування та інші галузі народного господарства.

Нинішній важкий період життя в Україні пов'язаний із воєнними діями на її території. У таких умовах суттєвою складовою економіки нашої держави постає сільське господарство. Тому подальше вдосконалення зазначеного виробництва являє собою актуальну науково-прикладну проблему. Одним із шляхів успішного вирішення окреслених задач є, зокрема, покращення використовуваних грунтообробних знарядь. При цьому прогресивним вважається визначення раціональної форми та розмірів наведених технічних об'єктів. Указані фактори не тільки суттєво підвищують якість обробітку грунту, а і сприяють збереженню його родючості, зменшенню енергетичних витрат у відповідних технологічних процесах і т. д.

Застосування комп'ютерного структурно-параметричного геометричного моделювання дозволяє продуктивно та гнучко реалізувати в багатоаспектному плані аналіз великої кількості проєктних варіантів під час опрацювання промислових виробів. Такий підхід забезпечує проведення комплексної оптимізації, в тому числі й різноманітних грунтообробних знарядь. Важливий момент при цьому полягає у використанні інтегрованих узагальнених геометричних моделей, що охоплюють доволі широкі групи технічних об'єктів. Зазначена концепція дозволяє суттєвим чином підвищити ефективність наявних комп'ютерних інформаційних технологій.

У даній статті зроблено огляд деяких базових результатів, отриманих щодо структурно-параметричного формоутворення певної продукції сільськогосподарського машинобудування. Наприклад, це стосується грунтообробних дисків, стрілчастих і полицевих лап. У публікації подано також запропоновані нові способи і прийоми геометричного моделювання, окреслено напрямки їхнього розвитку, визначено перспективи здійснення відповідних подальших наукових досліджень.

Ключові слова: автоматизоване проєктування; геометричне моделювання; ґрунтообробні знаряддя; структурно-параметричне-формоутворення.