Вісник Тернопільського національного технічного
університетуhttps://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2021, № 2 (102) https://doi.org/10.33108/visnyk_tntu2021.02
ISSN 2522-4433. Web: **visnyk.tntu.edu.ua**

UDC 621.9, 621.914.1

TECHNOLOGICAL SYSTEMS INVESTIGATION MACHINE'S TOOLS WITH PARALLEL STRUCTURE KINEMATICS

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Summary. *In the article examines the structure of technological systems with a parallel kinematic structure. The path location optimization problem consists of three sets, namely a set of design variables, a set of objective functions, and a set of design constraints. Accordingly, the optimization task is aimed at identifying design variables, such as hexapod, tripod, triglide, and others, that characterize the surface fabrication path in order to minimize or maximize objective functions subject to design constraints. The Hexapod mathematical model includes inverse and direct kinematic problems. The solution of the inverse kinematic problem for hexapods is tied to calculating the length of the racks and the location of the hinges at a given position of the movable platform. The spectral characteristics and qualitative and quantitative indicators of the processed samples were measured. Calculations were also performed on the ratio of initial parameters, cutting modes, and obtaining quality characteristics of Ra and T for each of the 25 samples. Kinematic pairs by class are reviewed and their functional and structural characteristics are determined, which makes it possible to estimate the degree of freedom for mechanisms with parallel structure kinematics. For Structural Simplification and reduction of time and complexity when choosing a PSKM scheme, they are shown in the graphical form of kinematic structures. To assess the quality of the system, as well as its ability to perform the functions assigned to it in the basic state, a table of output data was compiled, as well as a sample from which a data matrix was compiled to cover the entire possible range of output parameters, which significantly affects the result. The graphs show the spectral characteristics of technological systems with PSKV for the sections of the treated surfaces of samples No. 1, No. 2 and No. 3.*

Key words: *parallel mechanisms, PSKV, PSKM, samples, neural network, milling, roughness, precision.*

https://doi.org/10.33108/visnyk_tntu2021.02.037 *Received 30.04.2021*

Statement of the problem. One the main's methods processing's parts in a singling production that have a complex profile or are bodies of rotation with complex structural elements is the use of CNC machines or machining centers, which can relate and combine several machine groups. From year to year, the issue of introducing innovative methods, equipment and devices for performing mechanical processing operations using modern equipment becomes more acute. These processes affect the relevance of using machines with parallel structure kinematics (PSKM). To increase the efficiency manufacturing parts is necessary to use technological equipment namely machines with parallel structure kinematics and the latest high-speed tools (for high-speed processing). As the quality and complexity of geometric shapes and structural elements increases, the requirements for the transitions performed and parts in general increase.

Analysis of the available investigations. Parallel mechanisms have attracted attention for using high speed and positioning accuracy due of conceptual potentials of high dynamics and motion accuracy combined with low mass/inertia properties, high structural rigidity (i.e., stiffness – to-mass ratio) due to their closed kinematic links [1–5]. As for determining the optimal location of a pre-determined path in the manufacture working's surfaces of gearbox parts, it includes a set of functions that directly affect the kinematic and dynamic characteristics of PSKM and PSKV machines, components of PSKV.

The Objective of the work is the studying the spectral wave characteristics of the studied samples. To identify the behavior of the system and graphically represent the Tensor model of the machine system, work out the system characteristics at various output parameters.

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Statement of the task. The optimizing task the location of a path consists of three sets, namely: a set of design variables, a set of objective functions, and a set of design constraints. Accordingly, the optimization task is aimed at identifying design variables, such as hexapod, tripod, triglide, and others, that characterize the surface fabrication path in order to minimize or maximize objective functions subject to design constraints.

The speed value of the tool Vertex is constant on the path. Therefore, for given path sizes, the position vector $F_p = [x_{Pp} \cdot y_{Pp} \cdot z_{Pp}]^T$ and the velocity vector $v_{Fp} = [\dot{x}_{Pp} \cdot \dot{y}_{Pp} \cdot \hat{z}_{Pp}]^T$ in the frame, paths can be evaluated as a function of time. The position and velocity vectors defined in F_p can be expressed in F_b using a transformation matrix defined as:

$$\begin{bmatrix} x_{p_b} \\ y_{p_b} \\ z_{p_b} \\ 1 \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta & 0 & x_{p_o} \\ sin\theta & cos\theta & 0 & y_{p_o} \\ 0 \quad 0 & & 1 & z_{p_o} \\ 0 \quad 0 & & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} x_{p_p} \\ y_{p_p} \\ z_{p_p} \\ 1 \end{bmatrix} \quad \begin{bmatrix} \dot{x}_{p_b} \\ \dot{y}_{p_b} \\ \dot{z}_{p_b} \\ 1 \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta & 0 & x_{p_o} \\ sin\theta & cos\theta & 0 & y_{p_o} \\ 0 \quad 0 & & 1 & z_{p_o} \\ 0 \quad 0 & & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \dot{x}_{p_p} \\ \dot{y}_{p_p} \\ \dot{z}_{p_p} \\ 1 \end{bmatrix} \tag{1}$$

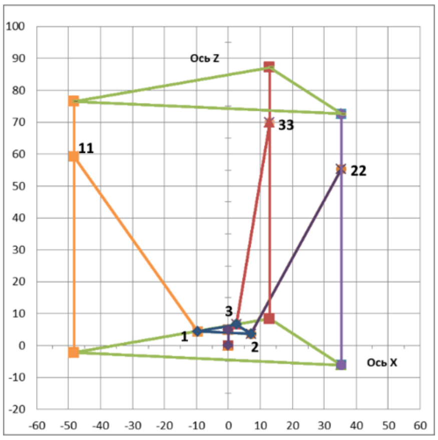
For $x = [x_{Op} \cdot y_{Op} \cdot z_{Op} \cdot \phi]^T$ – s the variable vector for solving the optimization problem. For simplicity, we assume that the path consists of four independent line segments.

The Hexapod mathematical model includes inverse and direct kinematic problems. The solution of the inverse kinematic problem for hexapods is tied to calculating the length of the racks and the location of the hinges at a given position of the movable platform [6].

Analysis of results. The review of kinematic pairs by class and the determination of their functional and structural characteristics makes it possible to estimate the degree of freedom for mechanisms with parallel structure kinematics. For Structural Simplification and reduction of time and complexity when choosing a PSKM scheme, they are shown in the graphical form of kinematic structures [7].

For a better understanding of dependencies in kinematics, and therefore the design of PSKM, we will build a 3D mathematical model of PSKM using Excel, based on formulas for determining the spatial position of each of the model points in space (fig. 1).

When turning around (Q_X; Q_Y; Q_Z) = (80°; 0°; 15°), we have:



11 (X; Y; Z) = (-50,00; 0,00; 62,45)
22 (X; Y; Z) = (25,00; 43,30; 62,45)
33 (X; Y; Z) = (25,00; 43,30; 62,45)

1 (X; Y; Z) = (-10,00; 0,00; 5,00)
2 (X; Y; Z) = (5,00; -8,66; 5,00)
3 (X; Y; Z) = (5,00; 8,66; 5,00)

Figure 1. Coordinates of articulated joints of the mathematical model

To assess the quality of the system, as well as its ability to perform the functions assigned to it in the basic state, a table of output data was compiled, as well as a sample from which a data matrix was compiled to cover the entire possible range of output parameters, which significantly affects the result. First, the equipment parameters were determined (table. 1). Taking into account the parameters, the mode part was selected over the entire possible range (table. 1).

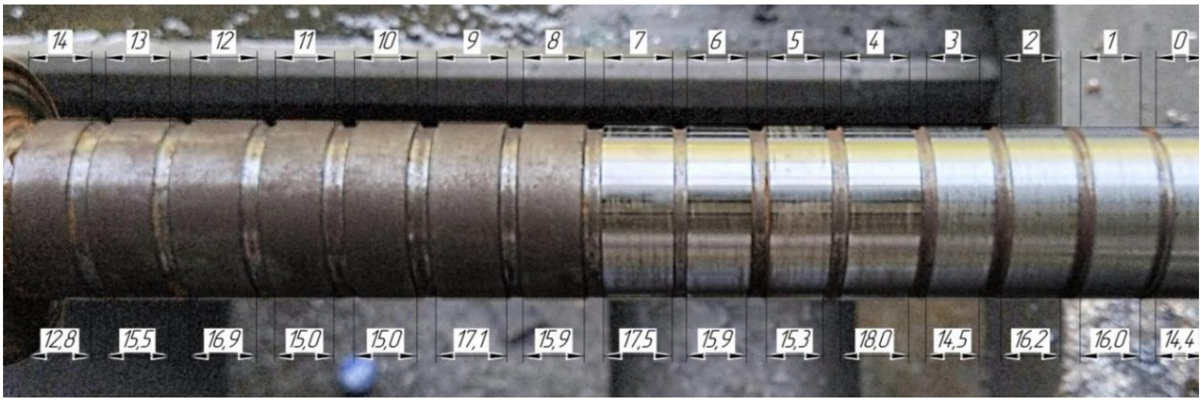
Table 1

Ranges and pitch of possible output parameters

№	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
n, m/min.	200	250	315	400	500	630	800	100	1250	1600	2000	-	-	-
S, mm/rev.	0,14	0,15	0,17	0,195	0,21	0,23	0,26	0,28	0,3	0,34	0,39	0,43	0,47	0,52

Research results. A round rolled steel sample was selected as the test sample, which was divided into segments of different lengths (fig. 2). A total of 15 measurement positions were obtained, each position from which is separated from the previous or subsequent one by a constant-width groove over the entire sample segment for 15 positions.

The experiment is performed on the testing machine STM-100, characteristics of which are presented in fig. 3. General appearance of the machine is presented in Fig. 2.



(0-14-segment numbers and their length for The Matrix grid)

Figure 2. Test sample № 1

To perform neural network analysis, the measured results for processing sample No. 1 were used as a data file, in which studies were conducted on the effects of initial parameters on the dispersed States of the system, and taking into account which the qualitative characteristics of the processed 25 samples were obtained [8, 9].

In Fig. 3 shows graphs of the spectral States of the structural study of systems where, depending on the cutting modes, the surface roughness *Ra* and the accuracy of performing diametric dimensions *T* were obtained and measured.

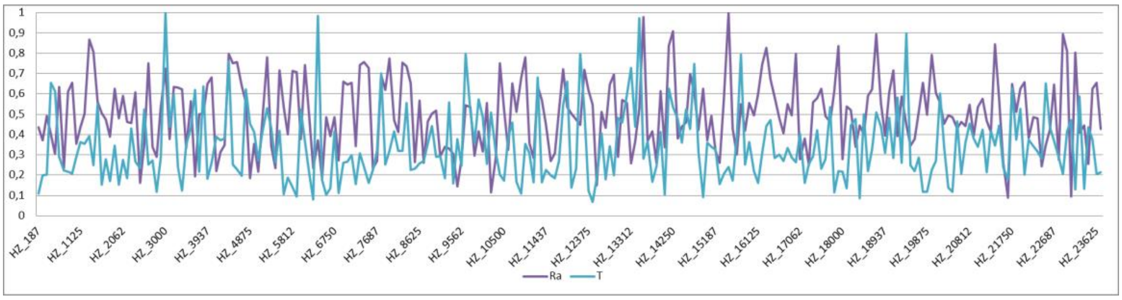


Figure 3. Graphs of the values of the state spectra of systems for the initial parameters of samples

Also, to compare technological systems with the structure of parallel kinematics, milling of sample No. 2 was performed (fig. 4) and sample No. 3 (fig. 5). Five samples were used to measure the roughness and accuracy of the surface design relative to the possibility of performing the necessary part parameters on the VKPS [10].

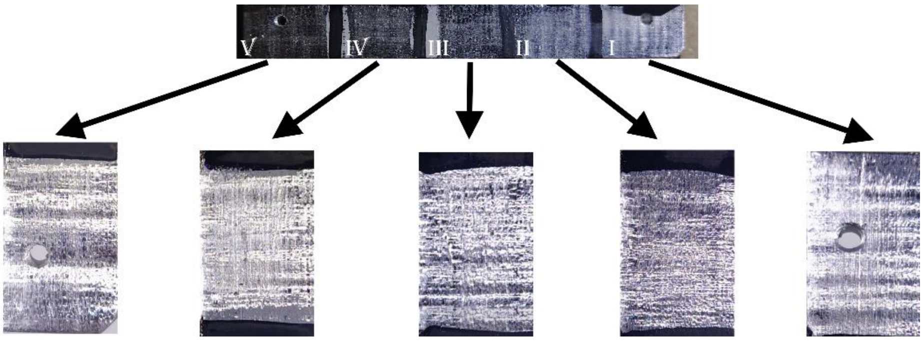


Figure 4. Test sample No. 2

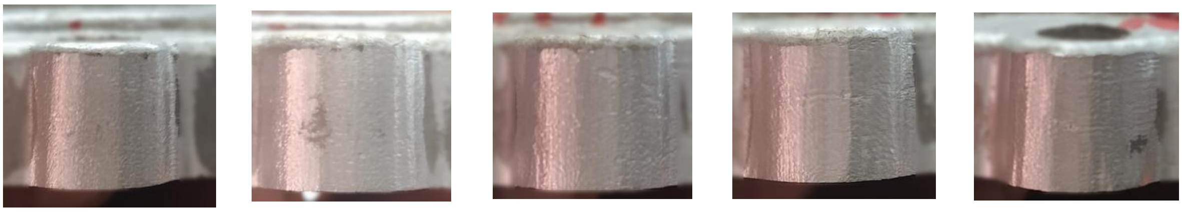


Figure 5. Test sample No. 3

In Fig. 6 presents graphs of the spectral characteristics of technological systems with MCPS for five sections of the treated surfaces of sample No. 2 and No. 3 by milling.

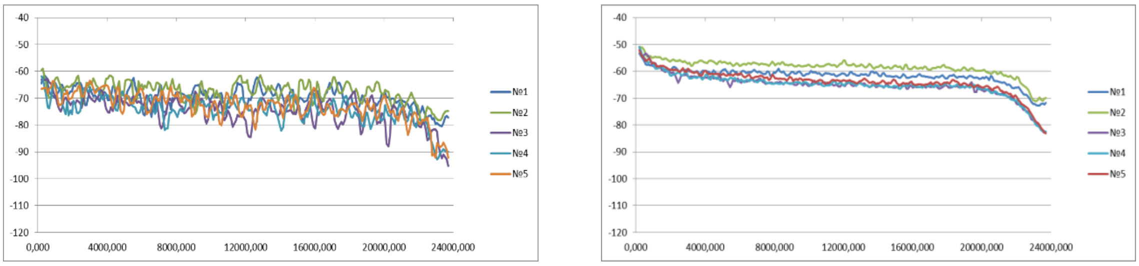


Figure 6. SD control and processing sample 2 PHD

In Fig. 7 graphs of roughness Ra and dimensional accuracy T are plotted for sample No. 1 and No. 2 there are slight improvements in processing sample No. 2 compared to sample No. 1, which are characterized by the equations:

$$Ra_1\ y = 9E - 0.8x^6 - 4E - 0.6x^5 - 2E - 0.5x^4 + 0.0027x^3 - 0.0414x^2 + 0.2124x + 0.3228$$

$$Ra_2\ y = -3E - 0.7x^6 - 3E - 0.5x^5 - 0.0009x^4 + 0.0156x^3 - 0.135x^2 + 0.5295x - 0.0215$$

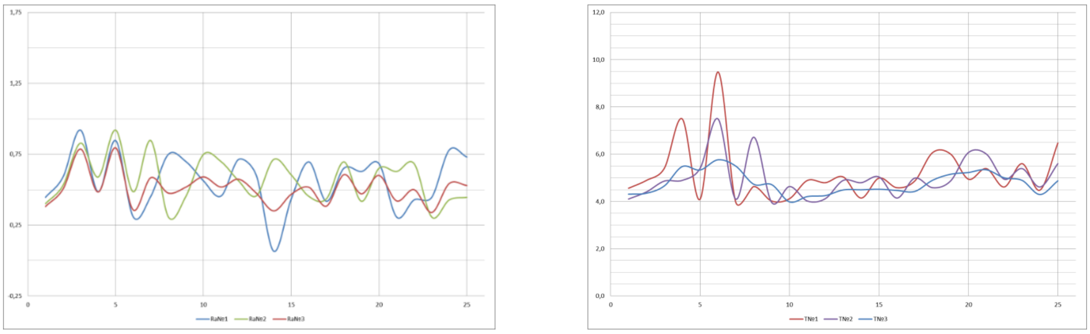
$$Ra_3\ y = -1E - 0.7x^6 + 1E - 0.5x^5 - 0.0048x^4 + 0.0082x^3 - 0.0794x^2 + 0.3339x + 0.01356$$

$$T_1\ y = 2E - 06x^6 - 0.0001x^5 - 0.0029x^4 - 0.0125x^3 - 0.1971x^2 + 1.6908x + 2.7897$$

$$T_2\ y = 3E - 0.6x^6 - 0.0002x^5 + 0.0063x^4 + 0.0767x^3 + 0.3681x^2 - 0.2481x + 3.9705$$

$$T_3\ y = 2E - 0.6x^6 - 0.0002x^5 + 0.047x^4 + 0.00549x^3 + 0.2341x^2 - 0.0011x + 3.9725$$

The use of these mechanisms in workbenches makes it possible to achieve high accuracy, low metal consumption and speed sufficient to process the workpiece at the maximum possible speeds with minimal time spent on manufacturing the Part [8].



a) results of surface roughness measurements of samples No. 1, No. 2 and No. 3

b) results of accuracy measurements of samples No. 1, No. 2 and No. 3

Figure 7. Sample measurement results No. 1 and No. 2

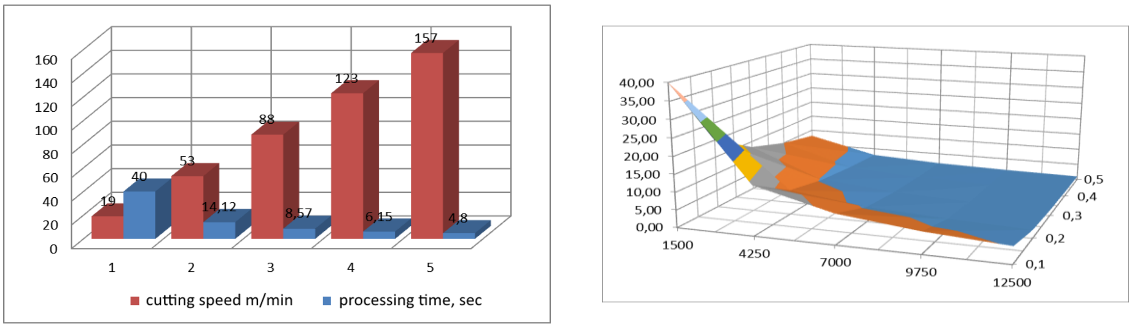


Figure 8. Processing results and volumetric Surface model of the relationship between tool Speed, Feed per revolution, and processing time

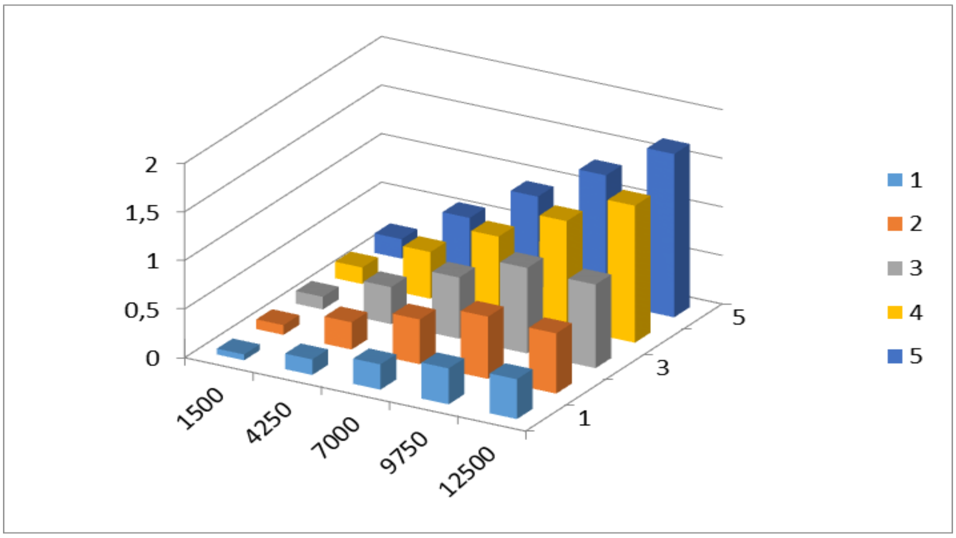


Figure 9. Dependence of spindle power on processing modes

Conclusions. Structural studies of technological systems with a parallel kinematics structure were carried out by measuring the spectral characteristics and qualitative and quantitative indicators of the processed samples.

After verifying the reliability and repeatability of testing the neural network model, Nm studies were performed for the relationship between the initial parameters, cutting modes, and obtaining qualitative characteristics of Ra and T for each of the 25 samples.

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УДК 621.9, 621.914.1

ДОСЛІДЖЕННЯ ТЕХНОЛОГІЧНИХ СИСТЕМ ВЕРСТАТІВ З КІНЕМАТИКОЮ ПАРАЛЕЛЬНОЇ СТРУКТУРИ

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Резюме. *Досліджено структуру технологічних систем з паралельною кінематичною структурою. Завдання оптимізації розташування шляху складається з трьох наборів, а саме: набору змінних конструкцій, набір цільових функцій та набір проектних обмежень. Відповідно, завдання оптимізації спрямоване на визначення змінних конструкцій, наприклад гексапод,* *трипод, триглайд та інші, що характеризують шлях виготовлення поверхні з метою мінімізації або максимізації цільових функцій, що підлягають обмеженням проектування. Математична модель гексапод включає в себе зворотну і пряму кінематичні завдання. Розв'язування зворотної кінематичної задачі для гексапод зав'язане на обчисленні довжини стійок і розташуванні шарнірів при даному положенні рухомої платформи. Проведено вимірювання спектральних характеристик, якісних і кількісних показників оброблених зразків. Також виконано розрахунки по співвідношенню вихідних параметрів, режимів різання й отримання якісних характеристик* Ra *і T для кожного з 25 зразків. Проведено огляд кінематичних пар за класами та визначення їх функціонально-структурних характеристик, що дає змогу оцінити ступінь свободи для механізмів з кінематикою паралельної структури. Для структурного спрощення, зменшення часу та складності при виборі схеми ВКПС їх зображено у графічному вигляді кінематичних структур. Для оцінювання якості системи, а також її можливості в базовому стані виконувати покладені на неї функції складено таблицю вихідних даних, а також проведено вибірку, з якою складено матрицю даних для охоплення всього можливо діапазону вихідних параметрів, що суттєво впливає на результат. На графіках показано спектральні характеристики технологічних систем з МКПС по ділянках оброблених поверхонь зразків № 1, № 2 та № 3.*

Ключові слова: *паралельні механізми, ВКПС, МКПС, зразок, нейронна мережа, фрезерування, шорсткість, точність.*

https://doi.org/10.33108/visnyk_tntu2021.02.037 *Отримано 30.04.2021*