10TH INTERNATIONAL CONFERENCE

«X UKRAINIAN-POLISH SCIENTIFIC DIALOGUES»

11-15 June 2024

ACTUAL PROBLEMS OF MODERN SCIENCE

Khmelnitsky | Bydgoszcz

ACTUAL PROBLEMS OF MODERN SCIENCE 2024

Edited by

Matiukh Serhii
Khmelnitskiy National University, Ukraine

Musial Janusz
Kazimierz Wielki University, Poland

Polishchuk Oleh
Khmelnitskiy National University, Ukraine

Macko Marek
Kazimierz Wielki University, Poland

ISBN: 978-83-938655-7-4

Bydgoszcz - Khmelnytskyi, 2024r.

TABLE OF CONTENT

SIMULATION OF SPATIAL MECHANISMS OF TECHNOLOGICAL MACHINES OF LIGHT INDUSTRY

Dvorzhak V.[1], Rubanka M.[1], Polishchuk O.[2], Zhlali Zh.[1]
[1]Kyiv National University of Technologies and Design, Ukraine
[2]Khmelnytskyi National University, Ukraine

Abstract. In modern productions of light industry, there is a constant need to improve technological equipment for the manufacture of various products. This process requires the development of new mechanisms with accurate reproduction of complex work trajectories, including spatial ones, during technological operations. The design of such mechanisms, in particular spatial hinge-lever mechanisms, requires an accurate calculation of their kinematic characteristics. The analytical methods of kinematics research used in the work allow obtaining more accurate results compared to traditional methods. Also the work examines the kinematics of links of spatial mechanisms of technological machines of light industry using the vector method of coordinate transformation. On the example of the needle mechanisms and loopers of sewing machines for performing class 500 stitches, a structural analysis was carried out, geometric parameters were determined, and structural and vector diagrams of these mechanisms were developed. Calculations were made for each link of the spatial mechanisms of the investigated sewing machine. The results of the study are presented in the form of visualization graphs of kinematic schemes of spatial mechanisms of the needle and loopers of the sewing machine, graphs of trajectories and laws of movement of the characteristic points of the working bodies of the spatial mechanisms of the needle and loopers of the sewing machine depending on the angle of rotation of the main shaft in Mathcad. The obtained results make it possible to carry out a more accurate assessment of the functionality of the mechanisms and the detection of inertial loads based on the values of the maximum accelerations. This will make it possible to identify possible design flaws during the design of new mechanisms or the study of existing ones in the garment industry. The calculation presented in the paper allows for mathematical modeling of the spatial mechanisms of sewing machines using CAE programs, for example, Mathcad, which is an effective tool for design and research modern high-speed sewing machines.
Keywords: sewing machine, spatial mechanism, needle mechanism, looper mechanism, vector method of coordinate transformation.

Introduction

The park of technological machines of light industry has various types of machines for the production of sewing, knitted, footwear and other products. Modern productions of light industry require the development of new technological equipment with improved mechanisms that can accurately reproduce complex trajectories of working bodies, in particular spatial ones, during the implementation of the technological process. This create a need in the use of spatial mechanisms as part of technological machines. In the implementation of a complex of technical solutions for the creation of such mechanisms, scientific researches as well as development aimed at achieving high standards of product manufacturing quality, machine and result products efficiency which all put together have the crucialest part in success of manufacturing. One of the most important stages of this process is the design of the main mechanisms, especially the most common such as spatial hinge-lever mechanisms.

When designing spatial hinge-lever mechanisms, a key aspect is the calculation of their kinematic characteristics. The accuracy of these calculations determines the reliability of further analyzes of dynamic processes, technological processes, etc. In the special literature on the design and research of sewing machine mechanisms, simplified calculation methods are used that do not take into account the peculiarities of spatial movements and loads [1]. This highlights the need for new methods to accurately determine the kinematic characteristics of complex spatial mechanisms that provide higher accuracy compared to traditional methods.

The way to solve this problem is to use analytical methods of kinematics research [5, 6, 7, 8, 9, 10, 11], in particular, the method of vector transformation of coordinates [2, 3, 4, 12].

The goal is to study the kinematics of the links of spatial mechanisms of technological machines of light industry by the vector method of coordinate transformation, in particular spatial mechanisms of sewing machines using the example of needle mechanisms and loopers of a sewing machine for performing class 500 stitches.

Research results

At the first stage of the research, a structural analysis of the needle and looper mechanisms was carried out, the geometric parameters of their links were determined, the peculiarities of their connections (type and class of kinematic pairs to be more precise) were established, and structural as same as vector diagrams of the spatial mechanisms of the needle and loopers were developed (Fig. 1, Fig. 2).

Structure of mechanisms and their equations of motion. In a class 500 sewing machine, all working bodies receive movement from the main shaft 1 (Fig. 1), on which the driving links of the space mechanisms of the needle and loopers under investigation are fixed. The instantaneous position of the main shaft is determined by the angle φ_1. The angular positions of the driving links of the corresponding mechanisms directly depend on the angle φ_1.

The diagram (Fig. 1) shows the following links of the needle mechanism: 1 – main shaft; 2 – the crank of the needle mechanism, made in the form of a crankshaft with a spherical pin 3; 4 – connecting rod with spherical heads; 6 – rocker arm with spherical trunnion 5; 7 – rocker shaft; 8 – rocker arm 6; 9 – connecting rod with forked heads; 10 – the leash of the needle driver 11 with a sewing needle 12. Links 2 – 3, 4 – 6 form kinematic pairs of the third class; link 11 forms a translational kinematic pair of the fifth class with the riser; links 8 - 9 form a rotational kinematic pair of the fifth class; links 2 and 6 form rotational kinematic pairs of the fifth class with the riser.

Also, the diagram (Fig. 1) shows the following links of the looper mechanism: 13 – the crank of the looper mechanism with a spherical pin 14; 15 – connecting rod with spherical heads; 17 – a rocker arm with a spherical head 16; 18 – shaft; 20 – the second arm of the rocker-holder looper 21; 19 – shaft; 22 – the third arm of the rocker arm; 23 – double connecting rod; 24 – rocker arm axis 25; 26 – the second arm of the rocker arm-loop holder 27. Links 13 – 15, 15 – 17 form kinematic pairs of the third class; links 22 – 23, 23 – 25 form rotational kinematic pairs of the fifth class; links 13, 17, 24 form rotational kinematic pairs of the fifth class with the riser.

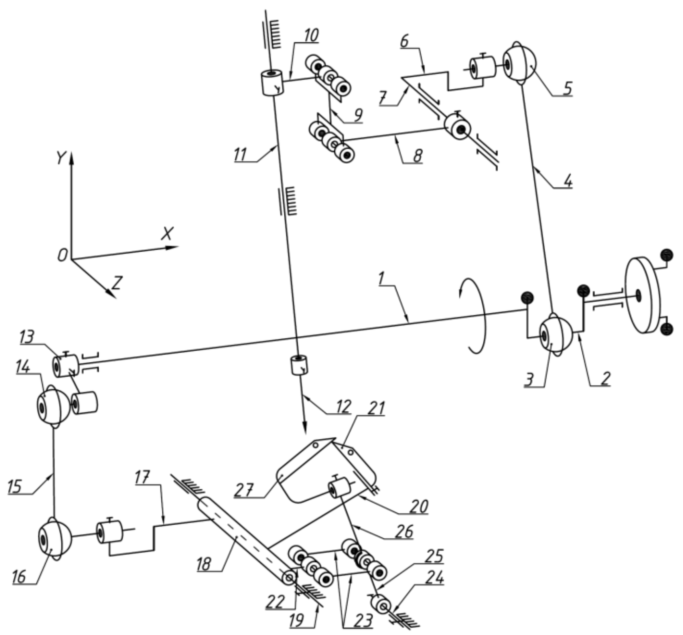

Fig. 1. Structural diagram of the spatial mechanisms of the needle and loopers of the sewing machine

For a kinematic study, let’s depict the mechanisms of the needle and loopers in the form of free vectors (Fig. 2), which are built on its links, and we will call these vectors “link vectors”. The starting and ending points of the vector-links are set in the geometric centers of the kinematic pairs formed by the corresponding links of the mechanisms. Link vectors are denoted as $P_{i\text{-}j}$, where the index “*i*” indicates the beginning of the vectors, and the index “*j*” indicates its end. We place the coordinate system so that the abscissa axis is oriented along the geometric axis of the main shaft 1 to the right, the ordinate axis is up perpendicular to the abscissa axis, and the applied axis is so that a right coordinate system is formed. The radius vectors that determine the centers of kinematic pairs and characteristic points of mechanisms in the specified coordinate system are denoted by P_i, where the index “*i*” indicates the number of the kinematic pair or characteristic point according to the designations in fig. 2.

To study the needle mechanism, the input metric parameters are the lengths of link vectors (modules)$|P_{12\text{-}13}|$, $|P_{13\text{-}14}|$, $|P_{15\text{-}14}|$, $|P_{16\text{-}17}|$, $|P_{17\text{-}18}|$, $|P_{18\text{-}19}|$, length of the area, which determines constructing features – $|P_{15\text{-}16}|$, $|P_{19\text{-}20}|$, crank riser coordinates P_{12}, coordinates of the riser of the needle guide, the angle between the arms of the rocker arm *6 – 8*, the angle between the leash 10 and the needle guide 11, the coordinates of the riser 7.

Since the needle of the mechanism moves in the plane *X'OY'*, which is inclined relative to the vertical plane *XOY* by an angle *α*, convenient it will be to perform the calculation of the needle mechanism in the hatched coordinate system *X'Y'Z'*, rotated around the *X* axis by an angle α clockwise.

The vector-link crank $P'_{12\text{-}13}$, which depends on the angle of rotation of the main shaft 1, is obtained from the expression:

$$P'_{12-13}(\varphi_1) = \begin{vmatrix} 0 \\ |P_{12-13}| \cdot \cos(\varphi_1 + \varphi_{0-1}) \\ |P_{12-13}| \cdot \sin(\varphi_1 + \varphi_{0-1}) \end{vmatrix}, \qquad (1)$$

where $\varphi_{0\text{-}1}$ – The initial angle of the needle mechanism.

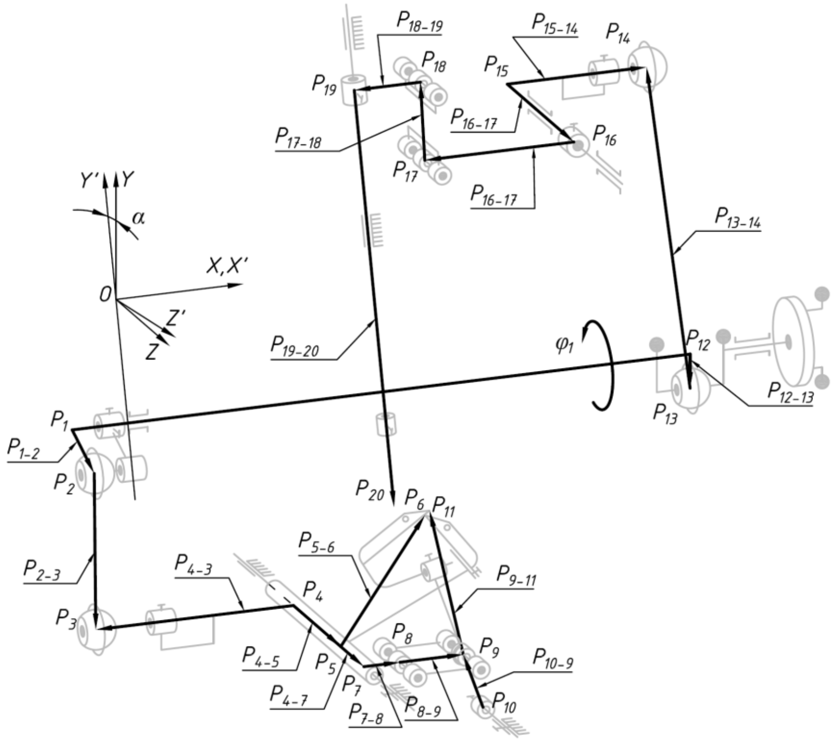

Fig. 2. Vector scheme of the spatial mechanisms of the needle and loopers of the sewing machine

The radius vector of the kinematic pair P_{13}, which depends on the angle of rotation of the main shaft 1, is obtained from the expression:

$$P'_{13}(\varphi_1) = \begin{vmatrix} P_{12_{X'}} \\ P_{12_{Y'}} \\ P_{12_{Z'}} \end{vmatrix} + P'_{12-13}(\varphi_1)\,. \tag{2}$$

We determine the auxiliary free vector P'_{15-13} of variable length and direction, which depends on the angle of rotation of the main shaft 1, as the difference between the radius vectors P'_{13} and P'_{15}:

$$P'_{15-13}(\varphi_1) = P'_{13}(\varphi_1) - \begin{vmatrix} P'_{15_{X'}} \\ P'_{15_{Y'}} \\ P'_{15_{Z'}} \end{vmatrix}. \tag{3}$$

Imagine the vector link of the rocker arm P'_{15-14}, which depends on the angle of rotation of the main shaft 1, as the product of its orth e'_{15-14} on the modulus of the vector-link of the rocker arm $|P_{15-14}|$:

$$P'_{15-14}(\varphi_1) = e_{'15-13}(\varphi_1) \cdot |P_{15-14}|\,. \tag{4}$$

The expressions obtained in [12] are used to determine the components of the orte$'_{15-14}$ in the hatched coordinate system *X'Y'Z':*

$$e'_{15-14}(\varphi_1)_{X'} = \frac{\left(\begin{array}{c} \frac{|P'_{15-13}(\varphi_1)|^2+|P_{15-14}|^2-|P_{13-14}|^2}{2\cdot|P_{15-14}|} \cdot P'_{15-13}(\varphi_1)_{X'} - \\ -P'_{15-13}(\varphi_1)_{Y'} \cdot \sqrt{\begin{array}{c}(P'_{15-13}(\varphi_1)_{X'})^2+(P'_{15-13}(\varphi_1)_{Y'})^2- \\ -\left(\frac{|P'_{15-13}(\varphi_1)|^2+|P_{15-14}|^2-|P_{13-14}|^2}{2\cdot|P_{15-14}|}\right)^2\end{array}} \end{array} \right)}{(P'_{15-13}(\varphi_1)_{X'})^2+(P'_{15-13}(\varphi_1)_{Y'})^2}; \tag{5}$$

$$e'_{15-14}(\varphi_1)_{Y'} = \frac{\left(\begin{array}{c}\frac{|P'_{15-13}(\varphi_1)|^2+|P_{15-14}|^2-|P_{13-14}|^2}{2\cdot|P_{15-14}|}\cdot P'_{15-13}(\varphi_1)_{Y'}+ \\ +P'_{15-13}(\varphi_1)_{Y'}\cdot\sqrt{\begin{array}{c}(P'_{15-13}(\varphi_1)_{X'})^2+(P'_{15-13}(\varphi_1)_{Y'})^2- \\ -\left(\frac{|P'_{15-13}(\varphi_1)|^2+|P_{15-14}|^2-|P_{13-14}|^2}{2\cdot|P_{15-14}|}\right)^2\end{array}}\end{array}\right)}{(P'_{15-13}(\varphi_1)_{X'})^2+(P'_{15-13}(\varphi_1)_{Y'})^2}. \quad (6)$$

It should be noted that the component of the orth $e'_{15\text{-}14}$ in the hatched coordinate system *X'Y'Z'*, which determines its projection on the axis of the applicator, is zero, because the line of the rocker 6, which we determine vector-link $P_{15\text{-}14}$, perpendicular to the axis of the shaft 7, so $e'_{15-14}(\varphi_1)_{Z'} = 0$.

Determine the radius vector of the kinematic pair P'_{14}, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P'_{15} and $P'_{15\text{-}14}$:

$$P'_{14}(\varphi_1) = \begin{vmatrix} P'_{15_{X'}} \\ P'_{15_{Y'}} \\ P'_{15_{Z'}} \end{vmatrix} + P'_{15-14}(\varphi_1)\,. \quad (7)$$

Determine the vector link of the connecting rod, which depends on the angle of rotation of the main shaft 1, as the difference between the two radius vectors P'_{14} and P'_{13}:

$$P'_{13-14}(\varphi_1) = P'_{14}(\varphi_1) - P'_{13}(\varphi_1)\,. \quad (8)$$

Determine the vector-link the second arm of the rocker arm $P'_{16\text{-}17}$, which depends on the angle of rotation of the main shaft 1, in the hatched coordinate system:

$$P'_{16-17}(\varphi_1) = \begin{vmatrix} P'_{15-14}(\varphi_1)_{X'}\cdot\cos(\propto_1) - P'_{15-14}(\varphi_1)_{Y'}\cdot\sin(\propto_1) \\ P'_{15-14}(\varphi_1)_{X'}\cdot\sin(\propto_1) + P'_{15-14}(\varphi_1)_{Y'}\cdot\cos(\propto_1) \\ 0 \end{vmatrix}\cdot\frac{|P_{16-15}|}{|P'_{15-14}(\varphi_1)|}. \quad (9)$$

Determine the radius vector of the kinematic pair P'_{17}, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P'_{16} and $P'_{16\text{-}17}$:

$$P'_{17}(\varphi_1) = P'_{16} + P'_{16-17}(\varphi_1)\,. \quad (10)$$

Determine the vector link of the connecting rod $P_{17\text{-}18}$, which depends on the angle of rotation of the main shaft 1:

$$P'_{17-18}(\varphi_1) = \begin{vmatrix} P'_{17-18'}(\varphi_1)_{X'}\cdot\cos(\propto_2(\varphi_1)) - P'_{17-18'}(\varphi_1)_{Y'}\cdot\sin(\propto_2) \\ P'_{17-18'}(\varphi_1)_{X'}\cdot\sin(\propto_2) + P'_{17-18'}(\varphi_1)_{Y'}\cdot\cos(\propto_2) \\ 0 \end{vmatrix}\cdot\frac{|P_{17-18}|}{|P'_{17-18'}(\varphi_1)|}, \quad (11)$$

where $P'_{17-18'}(\varphi_1) = \begin{vmatrix} -P'_{N1-N2_Y} \\ P'_{N1-N2_Y} \\ 0 \end{vmatrix}\cdot\frac{\left|\left(P'_{17-N1}(\varphi_1)\times Ort(P'_{N1-N2})\right)_Z\right|}{|P'_{N1-N2}|}$ – is the vector, which is built on a perpendicular, which is drawn from the kinematic pair P_{17} right to the line point P_{18} moves by (Fig. 3); denoted line is determined by the vector $P'_{N1'\text{-}N2'}$: $P'_{N1'-N2'} = P_{N2'} - P_{N1'}$;

$\propto_2(\varphi_1) = arccos\left(\frac{\left|\left(P'_{17-N1'}(\varphi_1)\times Ort(P'_{N1'-N2'})\right)_Z\right|}{|P_{17-18}|}\right)$ – an angle between the vectors $P'_{17\text{-}18'}$ and $P'_{17\text{-}18}$, which depends on rotation angle of the main shaft 1; $P'_{17\text{-}N1'}$ – auxiliary vector, the one that is defined as the difference of radius vectors $P'_{N1'}$ and P'_{17}: $P'_{17-N1'}(\varphi_1) = P'_{N1'} - P'_{17}(\varphi_1)$.

Determine the radius-vector of the kinematic pair P'_{18}, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P'_{17} and $P'_{17\text{-}18}$:

$$P'_{18}(\varphi_1) = P'_{17}(\varphi_1) + P'_{17-18}(\varphi_1)\,. \tag{12}$$

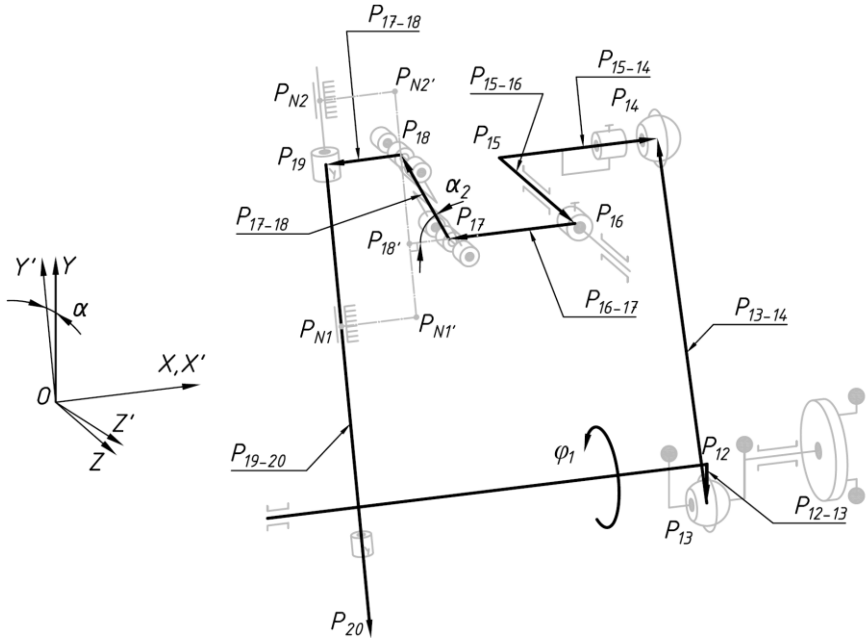

Fig. 3. Vector diagram of the spatial mechanism of the needle sewing machine

Determine the vector link of the leash $P'_{18\text{-}19}$:

$$P'_{18-19} = \begin{vmatrix} -|P_{18-19}| \\ 0 \\ 0 \end{vmatrix}. \tag{13}$$

Determine the radius vector of the kinematic pair P'_{19}, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P'_{18} and $P'_{18\text{-}19}$:

$$P'_{19}(\varphi_1) = P'_{18}(\varphi_1) + P'_{18-19}\,. \tag{14}$$

Determine the free vector $P'_{19\text{-}20}$, which characterizes the position of the working point of the needle P'_{20} relative to the radius vector P'_{19}:

$$P'_{19-20} = \begin{vmatrix} -|P'_{N1-N2}| \\ 0 \\ 0 \end{vmatrix} \cdot \frac{|P_{19-20}|}{|P'_{N1-N2}|}. \tag{15}$$

Determine the radius vector of the working point of the needle P'_{20}, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P'_{19} and $P'_{19\text{-}20}$:

$$P'_{20}(\varphi_1) = P'_{19}(\varphi_1) + P'_{19-20}\,. \tag{16}$$

To translate the coordinates of the link vectors and the radius vectors of the characteristic points of the mechanism from the hatched coordinate system *X'Y'Z'* into not hatched *XYZ* the desired coordinates of the link vectors and radius vectors in the hatched coordinate system by the $M_Z(\alpha)$, rotation matrix should be multiplied to the right, the arguments of the guide cosines of which are the angle of inclination α:

$$M_Z(\propto) = \begin{vmatrix} \cos(\propto) & -\sin(\propto) & 0 \\ \sin(\propto) & \cos(\propto) & 0 \\ 0 & 0 & 1 \end{vmatrix}. \quad (17)$$

For example, to determine the radius vector of the operating point P_{19} in a non-hatched coordinate system, the following expression should be made:

$$P_{20}(\varphi_1) = M_Z(\propto) \cdot P'_{20}(\varphi_1)\,. \quad (18)$$

Similarly, we determine the other radius vectors of the characteristic points of the needle mechanism.

For example, to determine the vector-link, the $P_{17\text{-}18}$ connecting rod in a non-hatched coordinate system should be as follows:

$$P_{17-18}(\varphi_1) = M_Z(\propto) \cdot P'_{17-18}(\varphi_1)\,. \quad (19)$$

Similarly, we define other vectors-links of the needle mechanism.

To study the mechanism of loopers (Fig. 1, Fig. 2) the input metric parameters are the lengths of the vectors-links (modules) $|P_{1\text{-}2}|$, $|P_{2\text{-}3}|$, $|P_{4\text{-}3}|$, $|P_{5\text{-}6}|$, $|P_{7\text{-}8}|$, $|P_{8\text{-}9}|$,$|P_{10\text{-}9}|$, $|P_{9\text{-}11}|$ the length of the sections that determine the design features of the mechanism - $|P_{4\text{-}5}|$, $|P_{4\text{-}7}|$, crank riser coordinates P_1, coordinates of rocker arms risers P_5, P_7, P_{10}, angles between the shoulders of the rocker arm17 - 20, 17 – 22, 25 - 26.

Vector-link crank $P_{1\text{-}2}$, which depends on the angle of rotation of the main shaft 1, get from the expression:

$$P_{1-2}(\varphi_1) = \begin{vmatrix} 0 \\ |P_{1-2}| \cdot \cos(\varphi_1 + \varphi_{0-2}) \\ |P_{1-2}| \cdot \sin(\varphi_1 + \varphi_{0-2}) \end{vmatrix}, \quad (20)$$

where $\varphi_{0\text{-}2}$ – The initial angle of the crank mechanism of the needle.

The radius vector of the kinematic pair P_2, which depends on the angle of rotation of the main shaft 1, is obtained from the expression:

$$P_2(\varphi_1) = \begin{vmatrix} P_{1X} \\ P_{1Y} \\ P_{1Z} \end{vmatrix} + P_{1-2}(\varphi_1)\,. \quad (21)$$

We define the auxiliary free vector $P_{4\text{-}2}$ of variable length and direction, which depends on the angle of rotation of the main shaft 1, as the difference between the radius vectors P_2 and P_4:

$$P_{4-2}(\varphi_1) = P_2(\varphi_1) - \begin{vmatrix} P_{4X} \\ P_{4Y} \\ P_{4Z} \end{vmatrix}. \quad (22)$$

Let's imagine the rocker link vector $P_{4\text{-}3}$, which depends on the angle of rotation of the main shaft 1, as a product of its orth $e_{4\text{-}3}$ by the module of the rocker link vector $|P_{4\text{-}3}|$:

$$P_{4-3}(\varphi_1) = e_{4-3}(\varphi_1) \cdot |P_{4-3}|\,. \quad (23)$$

To determine the components of orta $e_{4\text{-}3}$ in the unshaded XYZ coordinate system, the expressions obtained in [12] were used:

$$e_{4-3}(\varphi_1)_X = \frac{\left(\begin{gathered}\frac{|P_{4-2}(\varphi_1)|^2+|P_{4-3}|^2-|P_{2-3}|^2}{2\cdot|P_{4-3}|}\cdot P_{4-2}(\varphi_1)_X+\\ +P_{4-2}(\varphi_1)_Y\cdot\sqrt{\begin{gathered}(P_{4-2}(\varphi_1)_X)^2+(P_{4-2}(\varphi_1)_Y)^2-\\ -\left(\frac{|P_{4-2}(\varphi_1)|^2+|P_{4-3}|^2-|P_{2-3}|^2}{2\cdot|P_{4-3}|}\right)^2\end{gathered}}\end{gathered}\right)}{(P_{4-2}(\varphi_1)_X)^2+(P_{4-2}(\varphi_1)_Y)^2}\ ; \qquad (24)$$

$$e_{4-3}(\varphi_1)_Y = \frac{\left(\begin{gathered}\frac{|P_{4-2}(\varphi_1)|^2+|P_{4-3}|^2-|P_{2-3}|^2}{2\cdot|P_{4-3}|}\cdot P_{4-2}(\varphi_1)_Y-\\ -P_{4-2}(\varphi_1)_Y\cdot\sqrt{\begin{gathered}(P_{4-2}(\varphi_1)_X)^2+(P_{4-2}(\varphi_1)_Y)^2-\\ -\left(\frac{|P'_{4-2}(\varphi_1)|^2+|P_{4-3}|^2-|P_{2-3}|^2}{2\cdot|P_{4-3}|}\right)^2\end{gathered}}\end{gathered}\right)}{(P_{4-12}(\varphi_1)_X)^2+(P_{4-2}(\varphi_1)_Y)^2}\ . \qquad (25)$$

The orthogonal component $e_{4\text{-}3}$ in the unshaded XYZ coordinate system, which determines its projection onto the applique axis, is zero, since the rocker line 17, which is defined by the link vector $P_{4\text{-}3}$, is perpendicular to the shaft axis 4, so $e_{4-3}(\varphi_1)_Z = 0$.

We determine the radius vector of the kinematic pair P_3, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P_4 and $P_{4\text{-}3}$:

$$P_3(\varphi_1) = \begin{vmatrix} P_{4_X} \\ P_{4_Y} \\ P_{4_Z} \end{vmatrix} + P_{4-3}(\varphi_1)\ . \qquad (26)$$

We define the link vector of the connecting rod, which depends on the angle of rotation of the main shaft 1, as the difference of two radius vectors P_3 and P_2:

$$P_{2-3}(\varphi_1) = P_3(\varphi_1) - P_2(\varphi_1)\ . \qquad (27)$$

We determine the vector link of the second arm of the rocker arm $P_{5\text{-}6}$, which depends on the angle of rotation of the main shaft 1:

$$P_{5-6}(\varphi_1) = \begin{vmatrix} P_{4-3}(\varphi_1)_X\cdot\cos(\propto_3) - P_{4-3}(\varphi_1)_Y\cdot\sin(\propto_3) \\ P_{4-3}(\varphi_1)_X\cdot\sin(\propto_3) + P_{4-3}(\varphi_1)_Y\cdot\cos(\propto_3) \\ 0 \end{vmatrix}\cdot\frac{|P_{5-6}|}{|P_{4-3}(\varphi_1)|}, \qquad (28)$$

where α_3 – the angle between the arms of the rockers 17 and 20.

We determine the radius vector of the kinematic pair P_6, which depends on the angle of rotation of the main shaft 1 and determines the position of the working point of the looper 21, as the sum of the vectors P_5 and $P_{5\text{-}6}$:

$$P_6(\varphi_1) = P_5 + P_{5-6}(\varphi_1)\ . \qquad (29)$$

We determine the link vector of the third arm of the rocker arm $P_{7\text{-}8}$, which depends on the angle of rotation of the main shaft 1:

$$P_{7-8}(\varphi_1) = \begin{vmatrix} P_{4-3}(\varphi_1)_X\cdot\cos(\propto_4) - P_{4-3}(\varphi_1)_Y\cdot\sin(\propto_4) \\ P_{4-3}(\varphi_1)_X\cdot\sin(\propto_4) + P_{4-3}(\varphi_1)_Y\cdot\cos(\propto_4) \\ 0 \end{vmatrix}\cdot\frac{|P_{7-8}|}{|P_{4-3}(\varphi_1)|}, \qquad (30)$$

where α_4 – the angle between the shoulders of rockers 17 and 22.

We determine the radius vector of the kinematic pair P_8, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P_7 and $P_{7\text{-}8}$:

$$P_8(\varphi_1) = P_7 + P_{7-8}(\varphi_1)\ . \qquad (31)$$

We define the auxiliary variable vector $P_{10\text{-}8}$, which depends on the angle of rotation of the main shaft 1, as the difference of two radius vectors P_8 and P_{10}:

$$P_{10-8}(\varphi_1) = P_8(\varphi_1) - P_{10}\,. \tag{32}$$

We determine the auxiliary variable angle α_5 between the vectors $P_{10\text{-}8}$ and $P_{10\text{-}9}$, which depends on the angle of rotation of the main shaft 1:

$$\propto_5 (\varphi_1) = arccos\left(\frac{|P_{10-8}(\varphi_1)|^2 + |P_{10-9}|^2 - |P_{8-9}|^2}{2\cdot|P_{10-8}(\varphi_1)|\cdot|P_{10-9}|}\right). \tag{33}$$

We determine the link vector rocker arm $P_{10\text{-}9}$, which depends on the angle of rotation of the main shaft 1:

$$P_{10-9}(\varphi_1) = \begin{vmatrix} P_{10-8}(\varphi_1)_X \cdot \cos(\propto_5) - P_{10-8}(\varphi_1)_Y \cdot \sin(\propto_5) \\ P_{10-8}(\varphi_1)_X \cdot \sin(\propto_5) + P_{10-8}(\varphi_1)_Y \cdot \cos(\propto_5) \\ 0 \end{vmatrix} \cdot \frac{|P_{10-9}|}{|P_{10-8}(\varphi_1)|}. \tag{34}$$

We determine the radius vector of the kinematic pair P_9, which depends on the angle of rotation of the main shaft 1, as the sum of the vectors P_{10} and $P_{10\text{-}9}$:

$$P_9(\varphi_1) = P_{10} + P_{10-9}(\varphi_1)\,. \tag{35}$$

We define the link vector of the connecting rod $P_{8\text{-}9}$, which depends on the angle of rotation of the main shaft 1, as the difference of two radius vectors P_9 and P_8:

$$P_{8-9}(\varphi_1) = P_9(\varphi_1) - P_8(\varphi_1)\,. \tag{36}$$

We determine the vector link of the second rocker arm $P_{9\text{-}11}$, which depends on the angle of rotation of the main shaft 1:

$$P_{9-11}(\varphi_1) = \begin{vmatrix} P_{10-9}(\varphi_1)_X \cdot \cos(\propto_6) - P_{10-9}(\varphi_1)_Y \cdot \sin(\propto_6) \\ P_{10-9}(\varphi_1)_X \cdot \sin(\propto_6) + P_{10-9}(\varphi_1)_Y \cdot \cos(\propto_6) \\ 0 \end{vmatrix} \cdot \frac{|P_{9-11}|}{|P_{10-9}(\varphi_1)|}, \tag{37}$$

where α_5 – angle between arms of rockers 25 and 26.

We determine the radius vector of the kinematic pair P_{11}, which depends on the angle of rotation of the main shaft 1 and determines the position of the working point of the looper 27, as the sum of the vectors P_9 and $P_{9\text{-}11}$:

$$P_{11}(\varphi_1) = P_9(\varphi_1) + P_{9-11}(\varphi_1)\,. \tag{38}$$

According to the obtained values of the radius vectors of the characteristic points of the needle and looper mechanisms P_1, P_2, P_3,P_4, P_5, P_6, P_7, P_8, P_9, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_{15}, P_{16}, P_{17}, P_{18}, P_{19}, P_{20} graphs of the visualization of the kinematic scheme of the spatial mechanisms of the needle and loopers (Fig. 4, Fig. 5, Fig. 6), graphs of the trajectories of the characteristic points of the working organs of the needle – P_{20}, loopers P_6 and P_{11} (Fig. 7), graphs of the dependence of absolute displacements were built in Mathcad as well as characteristic points P_{20}, P_6 and P_{11} (Fig. 8).

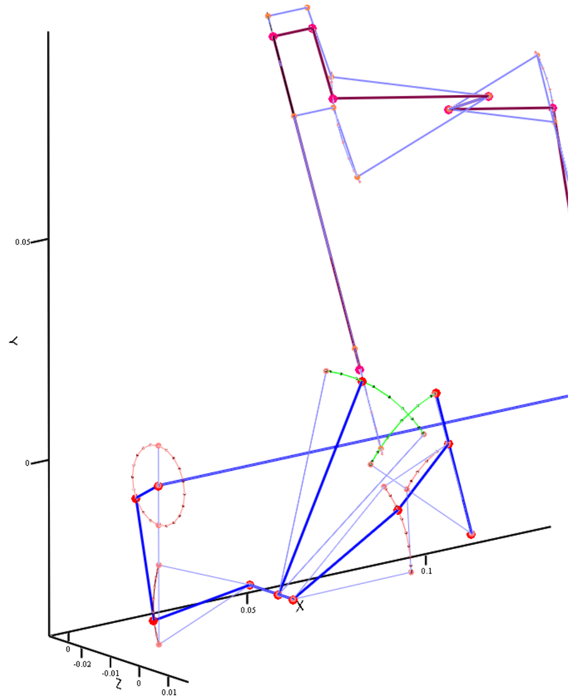

Fig. 4. Visualization graph of the kinematic scheme of the spatial mechanisms of the needle and loopers, combined with the trajectories of the characteristic points of the mechanisms in Mathcad

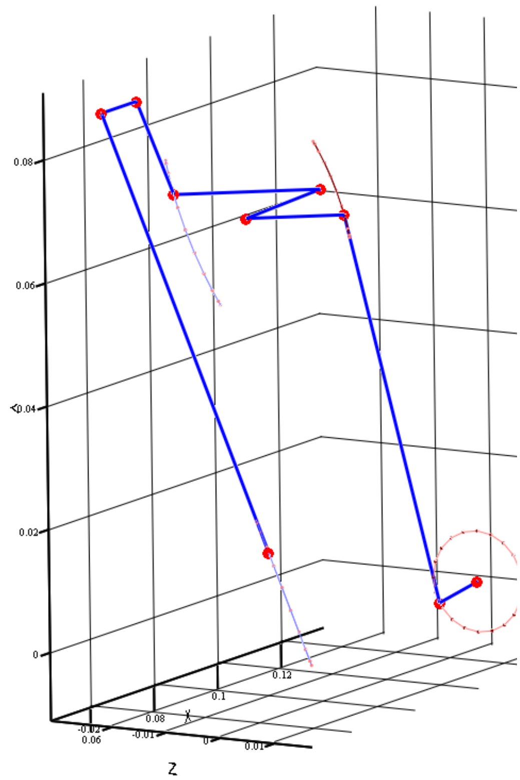

Fig. 5. Visualization graph of the spatial mechanism of the sewing machine needle, combined with the trajectories of the characteristic points of the mechanism in Mathcad

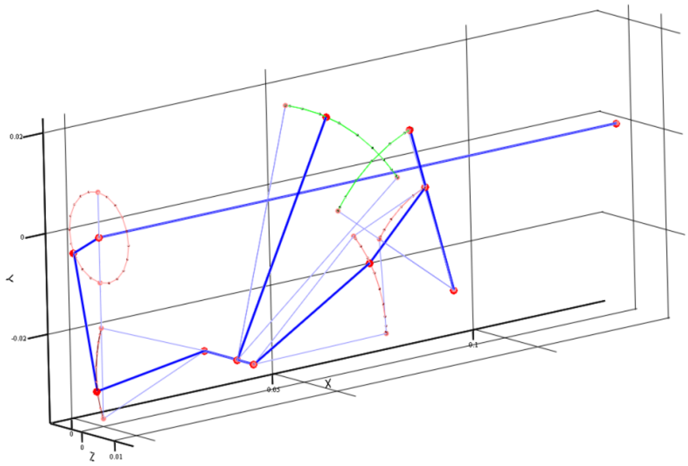

Fig. 6. Visualization graph of the spatial mechanism of the sewing machine loopers, combined with the trajectories of the characteristic points of the mechanism in Mathcad

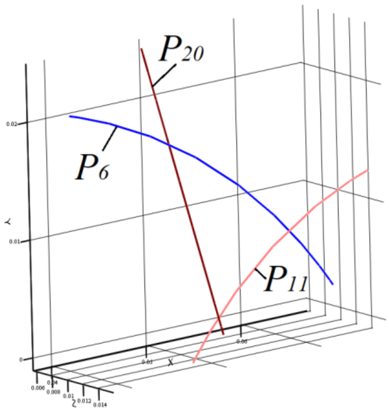

Fig. 7. Graphs of the trajectories of the characteristic points of the working bodies of the spatial mechanisms of the needle and loopers of the sewing machine in Mathcad

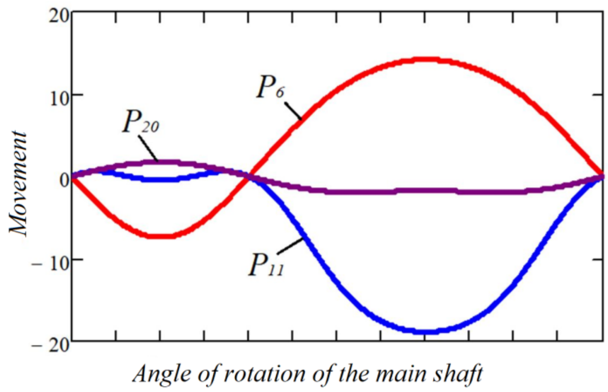

Fig. 8. Graphs of movements of the characteristic points of the working bodies of the spatial mechanisms of the needle and loopers of the sewing machine depending on the angle of rotation of the crank in Mathcad

Calculations were made for all links of the spatial mechanisms of the sewing machine under consideration. The obtained results make it possible to more accurately assess the performance of the mechanisms, identify inertial loads based on the values of maximum accelerations to identify possible structural violations during the design of new and research of existing sewing machine mechanisms.

Conclusion

The obtained results make it possible to effectively use the developed analytical dependencies for more accurate modeling of the movement characteristics of the spatial mechanisms of sewing machines. It is advisable to use the proposed approach in studies of the kinematics of spatial mechanisms of sewing machines.

The calculation given in the paper makes it possible to carry out mathematical modeling of spatial mechanisms of sewing machines using CAE-programs, for example, Mathcad, which is an effective tool for designing and researching modern high-speed sewing machines.

Bibliography

1. Pyshchykov, V. O., & Orlovskyi, B. V. (2007). Proektuvannia shveinykh mashyn [Design of sewing machines]. Kyiv: Format [in Ukrainian].
2. Bratchenko, O.V. (2014). Osoblyvosti vykorystannia metodu peretvorennia koordynat vdoslidzhenniakh kinematyky kryvoshypno-shatunnykh mekhanizmiv [Peculiarities of the use of the coordinate transformation method in the study of the kinematics of

crank-rod mechanisms]. Zbirnyk naukovykh prats Donetskoho instytutu zaliznychnoho transportu - Collection of scientific works of the Donetsk Institute of Railway Transport, 37, 115-120 [in Ukrainian].
3. Moroz, V. I., Bratchenko, O. V. & Hromov, V. I. (2016). Rozrakhunkove vyznachennia kinematychnykh kharakterystyk elementiv konstruktsii tekhnichnykh zasobiv transportu metodom peretvorennia koordynat [Calculated determination of kinematic characteristics of structural elements of technical means of transport by the method of coordinate transformation]. Zbirnyk naukovykh prats Ukrainskoho derzhavnoho universytetu zaliznychnoho transportu - Collection of scientific works of the Ukrainian State University of Railway Transport, 159, 118-125 [in Ukrainian].
4. Przytulski R., Zajaczkowski J. (2016). Kinematic analysis of the sewing mechanisms of an over edge machine. Fibres and Textiles in Eastern Europe. Vol. 14, Issue 1. P. 79–82.
5. Owczarek A.: ‘Computer models of selected mechanisms used in sewing machines (in Polish)’, M. Sc. thesis, Technical University of Łódź, 2002.
6. Zajączkowski J.: Komputerowe modelowanie maszyn włókienniczych. PAN, (2004).
7. Şafak Ş, Şaka Z, Özçelik Z. (2012). Modifcation of the Classical Needle Bar and Thread Take-Up Lever Mechanism in Sewing Machines. Fibres & Textiles in Eastern Europe. Vol. 20, Issue 4(93). P. 108-111.
8. Nejlaoui Mohamed, Najlawi Bilel and Affi Zouhaier (2017). Multi-objective design optimisation of four-bar mechanisms using a hybrid ICA-GA algorithm. International Journal Reasoning-based Intelligent Systems, Vol. 9, 1, P. 43-51.
9. Mechatronic design optimization of the mechanism in a sewing machine Proceedings of the Institution of Mechanical Engineers Part C Journal of Mechanical Engineering Science 1989-1996 (vols 203-210).
10. Saeed Ebrahimi, Pedram Payvandy Optimization of the link drive mechanism in a sewing machine using imperialist competitive algorithm International Journal of Clothing Science and Technology 26(3), pp. 247-260.
11. Gotlih, K., Lojen, D.Z. and Vohar, B. (2007). “Optimization of needle penetration velocity using thelink drive mechanism in a sewing machine”, Fibres & Textiles in Eastern Europe, Vol. 15, No. 1, pp. 66-71.
12. Dvorzhak V. M. (2016). Skhemotekhnichne modeliuvannia kinematychnykh skhem prostorovykh chotyrylankovykh kryvoshypno-koromyslovykh mekhanizmiv tekhnolohichnykh mashyn [Circuit simulation kinematic scheme of spatial four crankrocker mechanisms of technological machines]. Visnyk Kyivskoho natsionalnoho universytetu tekhnolohii ta dyzainu - Bulletin of the Kyiv National University of Technologies and Design, 2. 16-26 [in Ukrainian].