Synthesis of the Manipulator for the Scraper of a Press Manure Removal

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ABSTRACT

This paper reviews the literature dealing with the press manure removals and describes its structure. To specify the dimensions of the scraper’s manipulator in the structure of the press manure removal the mathematical and virtual modeling based method of synthesis the scraper’s manipulator is developed. This method is divided into three parts: composition of virtual model of the manipulator in arbitrary positions on the computer screen, solution of the problems of optimization of the positions of the manipulator and verification the reaching optimal positions of manipulator by simulation its working process. These problems are solved separately for return and working strokes. The solution of the first problem is based on the exact solution of the system of quadratic equations in special form and on the using the possibilities computer graphics. The stated problems of optimization the positions of the manipulator during one cycle of motion are solved numerically with high accuracy. The motions of the scraper’s manipulator on the return and on the working strokes are joined together into one motion, which is simulated then in the environment of computer program Mathcad. Several frames of composed video clips are illustrating the working process of a manipulator reaching its optimal positions.

The results of this paper are useful for the designers of manipulators for press manure removals, for the specialists of computer graphics and for the users of computer package Mathcad.

Keywords: agriculture, machinery, manure, technology, simulation, computer graphics, Mathcad, synthesis, manipulator, scraper, experiment.

1. THE BACKGROUND OF THE STUDY

There are exists different manure removal systems, which are intend to remove manure from a cowshed and store it into a dung pit. One of them is the press manure removal that is intended to remove manure from a cowshed and store it by pressing through a manure pipe into a heap of muck. Fig. 1 shows a principal scheme of a manure press removal.

Figure 1. A principal scheme of the press manure removal, 1 – one-sided scraper; 2 – hydraulic cylinder; 3 – oil pipe; 4 – valve; 5 – electric engine; 6 – manure pipe; 7 – heap of muck

The principle of work of the press manure removal in Fig. 1 is the following. The manure scraper, driven by a hydraulic cylinder 2, transports the portions of manure to the manure pipe and presses these by the first manipulator of the manure scraper through the pipe 6 into a heap of muck 7. After the working stroke the valve 4 changes the direction of flow of oil in the oil pipes 3 and the scraper moves back to the initial position. By repeating this working cycle a large heap of muck will be structured. Press manure removal is economical and environmentally sound. A press manure removal can be in use in a small farm with 20 – 50 cows.

The manure scraper in Fig 2 is used as the working tool of the manure press removal in Fig. 1. A principal scheme of a one-sided manure scraper in the working stroke (a) and in the return stroke (b) is shown in Fig. 2, where the working vanes of the scraper have vertical axes of rotation.

The working vanes of the manure scraper are foursquare and can rotate freely around its vertical (or horizontal) axis under the resistance forces, applied to vane in the manure ply. Scrapers in Fig 2 are, for example, in the structure of press manure removals Paskervilleri 8000 (1997), and Schauer (2001). The disadvantage of the scraper in Fig. 2 is the lugging of manure by the manure scraper on its return stroke (Fig. 2b).

Merivirta Oy (1998) and Paskervilleri 4000 (1999) have used the forced driven system for rotation of the working vanes of the manure scraper. This system is complicated but guarantees the stable rotation of the working vanes from working position (Fig. 4) to the position of return stroke (Fig. 5) and opposite.

The scientific group, headed by Professor Emeritus Vambola Veinla, in Estonian Agricultural University have created novel manure scraper for press manure removal in which the first working vane (Fig. 2) was clamped to the forced driven manipulator (Fig. 3).
The structure of Scraper’s manipulator in Fig. 3 is shown in Fig. 4.

Veinla, Leola (2001, 2003) have made experimentally thorough study the press manure removal in Fig. 1 with manure scraper in Fig. 3. The purpose of their experimental study of the manure press removal was to measure the

- resistance force, applied to the working vane by manure in the manure pipe,
- pressure, applied to the walls of the manure pipe,
- pressure inside of the heap of muck,

and to study the dependence the height of the heap of muck on the resistance pressure of manure in the manure pipe. Fig. 5 shows the device for study the press manure removal experimentally.
The authors of this paper had not detected any papers on theoretical study of the manure press removals. The methods of synthesis of linkages had been developed, for example, by Norton (1999) and by Frolov (1987). At that Norton had developed the graphical methods and Frolov analytical methods of synthesis a linkages by two or three positions. Theory of manipulators had been considered shortly by Frolov (1987). The authors of this paper did not find any study, considering the optimization of manipulators by its positions.

It is impossible to guarantee the optimal positions of the scraper’s manipulator on the working process only by experimentation. To specify the dimensions of the scraper’s manipulator in the structure of the press manure removal the mathematical and virtual modeling based method of synthesis the scraper’s manipulator, taking optimal positions on the working process, is developed below.

2. THE STATEMENT OF THE SYNTHESIS

Fig. 6 images the virtual model for theoretical treatment of the scraper’s manipulator in Fig. 4. This model consists of rigid link OACED, slider B and connecting rod AB, joined together by pivots O, A and B. The points C, E, D are corresponding to the characteristic points on the contour of the rib 5 (Fig. 4).

![Virtual model of the scraper’s manipulator](image)

Figure 6. Virtual model of the scraper’s manipulator in Fig 4,
O, A – pivots; B – pivot with a large tolerance; OACED – rigid link

The virtual model of manipulator in Fig. 6 consists of the link OACED, slider B and connecting rod AB. Let us assume that the co-ordinates of the pivots O, A, B and the points C, E, D of the link OACED are determinable in the local system of co-ordinates Oxy (Fig. 6) with an origin at the pivot O, rigidly clamped to the case 1 (Fig. 4). The local axis Ox is supposed to be directed from origin O vertically upwards and local axis Oy - from origin O horizontally to the left. At the initial moment of the time \( t = 0 \) the global and the local coordinate systems coincide.

The virtual model of manipulator in Fig. 6 has the following dimensions: \( \rho_{AB} \) – the length of the connecting rod AB, \( \rho_{OE} \) – the distance between pivot O and the point E, \( \rho_{CA} \) – the distance between point C and pivot A, \( \rho_{EC} \) – the distance between points E and C, \( \rho_{DC} \) - the distance between points D and C, \( \rho_{AE} \) - the distance between pivot A and point E, \( \rho_{OC} \) - the distance between pivot O and point C. The parameters \( \delta \) – the vertical distance of pivot O from track of the pivot B and \( \rho_{AO} \) – the length of the link AO we consider as variable.

Unfortunately it is impossible to create the manipulator, which takes exactly the requested by constructor positions, only by experimentation. That is why the synthesis of virtual manipulator by using computer is needed.

Heinloo, Leola, Veinla, (2004) have composed the mathematical model for numerical study the motion of the manipulator in Fig. 6.

The purposes of the synthesis are
- to create the method of automatic imagination on a computer screen a virtual manipulator in arbitrary position during one cycle of its motion,
- to optimize the positions of the virtual manipulator,
- to simulate the working process of the virtual manipulator during one cycle.

The approach of this paper is useful for the
- designers of manipulators for press manure removals,
- specialists of computer graphics and machinery,
- users of computer package Mathcad,
- students of Agricultural Engineering.

3. THE STROKES AND STAGES OF THE SLIDER B

Full cycle of the working process of the slider 7 in Fig. 4 (slider B in Fig. 6) consists of working and return strokes. The slider 7 in Fig. 4 moves to the right in the return stroke and to the left in the working stroke.

The return stroke of the slider 7 (Fig. 4) consists of three stages. First stage: \( (0 \leq t \leq t_0) \) the pin 4 moves in the oval hole (Fig. 4) of the connecting plate 6 and the slider 7 doesn’t move the rib with a vane. Second stage: \( (t_0 < t \leq t_1) \) the slider B turns the rib with a vane clockwise from the working position to the position of return stroke. Third stage: \( (t_1 < t \leq t_2) \) the slider 7 moves the manipulator together with the scraper to the beginning of the working stroke. The working stroke has analogical stages that returns the vane with the rib with a vane back to the initial position. First stage: \( (0 < t' \leq t'_0) \) the pin 4 moves in the oval hole of the connecting plate 6 and the slider 7 doesn’t move the rib with a vane. Second stage: \( (t'_0 < t' \leq t'_1) \) the

slider B turns the rib with a vane anticlockwise from the position of return stroke to the working position. Third stage: \((t_1' < t' \leq t_2')\) the slider 7 moves the manipulator together with the scraper to the initial position of the cycle. Here \(t', t_0', t_1', t_2'\) are the times, counted from the beginning of the working stroke.

4. LAW OF MOTION THE SLIDER B ON THE RETURN STROKE

Let us assume that the slider B (Fig. 6) is moving according to the law

\[
x_B = \delta, \quad y_B(t) = y_{BO} - v_i(t - t_0), \quad (t \geq t_0 > 0)
\]

where \(\delta\) is the distance between the pivot O and the track of the slider B (Fig. 6), \(v_i = \frac{4Q}{\pi(D^2 - d^2)}\) – the velocity of the slider at its return stroke, \(Q\) is the flow of the hydraulic pump, \(D\) – diameter of the piston 7 (Fig 4), \(d\) – diameter of the piston rod, \(\pi = 3.1416, y_{BO}\) – the y-coordinate of the pivot B at the moment of time \(t_0 = \frac{L}{v_i}\), here \(L\) – the distance, covered by the slider B at the beginning of the return stroke without moving the manipulator because of large tolerance in the pivot B (Figs. 4, 6).

5. EXACT SOLUTION OF THE SYSTEM OF QUADRATIC EQUATIONS OF SPECIAL TYPE

The system of quadratic equations \(x^2 + y^2 = a^2, (x - b)^2 + (y - c)^2 = d^2\) has the following two exact solutions:

\[
x_1(a, b, c, d) = B(a, b, c, d) + \frac{1}{2A(b, c)}\sqrt{B(a, b, c, d)^2 - 4A(b, c)C(a, b, c, d)},
\]

\[
y_1(a, b, c, d) = \frac{1}{2c}(-2x_1(a, b, c, d)b + b^2 + c^2 - d^2 + a^2)
\]

and

\[
x_2(a, b, c, d) = B(a, b, c, d) - \frac{1}{2A(b, c)}\sqrt{B(a, b, c, d)^2 - 4A(b, c)C(a, b, c, d)},
\]

\[
y_2(a, b, c, d) = \frac{1}{2c}(-2x_2(a, b, c, d)b + b^2 + c^2 - d^2 + a^2).
\]

Here \(A(b, c) = \frac{1}{c^2}(c^2 + b^2), B(a, b, c, d) = \frac{1}{c^2}I(a^2 + b^2 + c^2 - d^2)\), \(C(a, b, c, d) = \frac{1}{4c^2}[a^2 + b^2 + c^2 - d^2]^2 - 4a^2c^2]\).

This exact solution will be used for solution the systems equations, which determine the law of motion of pivots O, A, B and characteristic points C, E, D of the manipulator.

6. LAWS OF MOTION THE POINTS AND PIVOTS OF THE VIRTUAL MANIPULATOR ON THE SECOND STAGE OF THE RETURN STROKE

The law of the motion

\[ x_A(t, \delta, \rho_{AO}) = x_1(\rho_{AO}, \delta, y_B(t), \rho_{AB}), \]
\[ y_A(t, \delta, \rho_{AO}) = y_1(\rho_{AO}, \delta, y_B(t), \rho_{AB}) \]  \hspace{1cm} (4)

of pivot A, where \( y_B(t) \) is determined by the formula (1), was found out from exact solution in the part 3 for the system of the non-linear equations
\[ x_A^2 + y_A^2 = \rho_{AO}^2, \hspace{0.5cm} (x_A - \delta)^2 + (y_A - y_B(t))^2 = \rho_{AB}^2. \]

It turned out that in the region of parameters, considered in this paper, the system of equations
\[ x_E^2 + y_E^2 = \rho_{OE}^2, \hspace{0.5cm} (x_E - x_A(t, \delta, \rho_{AO}))^2 + (y_E - y_A(t, \delta, \rho_{AO}))^2 = \rho_{AE}^2 \]
has two solutions. This is the reason why the law of motion of the point E must be presented in the following form:
\[ x_E(t, \delta, \rho_{AO}) = x_1(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}), \]  \hspace{1cm} (5)
\[
\text{if } y_1(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}) \leq y_2(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}), \text{ else}
\]
\[ x_E(t, \delta, \rho_{AO}) = x_1(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}). \]  \hspace{1cm} (6)

Similarly
\[ y_E(t, \delta, \rho_{AO}) = y_2(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}), \]  \hspace{1cm} (7)
\[
\text{if } y_1(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}) \leq y_2(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}), \text{ else}
\]
\[ y_E(t, \delta, \rho_{AO}) = y_1(\rho_{OE}, x_A(t, \delta, \rho_{AO}), y_A(t, \delta, \rho_{AO}), \rho_{AE}). \]  \hspace{1cm} (8)

The law of the motion
\[ x_E(t, \delta, \rho_{AO}) = x_1(\rho_{OC}, x_E(t, \delta, \rho_{AO}), y_E(t, \delta, \rho_{AO}), \rho_{EC}), \]  \hspace{1cm} (9)
\[ y_E(t, \delta, \rho_{AO}) = y_1(\rho_{OC}, x_E(t, \delta, \rho_{AO}), y_E(t, \delta, \rho_{AO}), \rho_{EC}) \]  \hspace{1cm} (10)
of pivot C was also found out from exact solution in the part 3 for the system of the non-linear equations
\[ x_E^2 + y_E^2 = \rho_{OC}^2, \hspace{0.5cm} (x_E - x_A(t, \delta, \rho_{AO}))^2 + (y_E - y_E(t, \delta, \rho_{OC}))^2 = \rho_{EC}^2. \]

The co-ordinates of the point D are determined by the formulae
\[ x_D(t, \delta, \rho_{AO}) = \frac{1}{\lambda}[x_E(t, \delta, \rho_{AO}) + (\lambda - 1)x_C(t, \delta, \rho_{AO})], \]  \hspace{1cm} (11)
\[ y_D(t, \delta, \rho_{AO}) = \frac{1}{\lambda}[y_E(t, \delta, \rho_{AO}) + (\lambda - 1)y_C(t, \delta, \rho_{AO})], \]  \hspace{1cm} (12)
where
\[ \lambda = \frac{\rho_{EC}}{\rho_{OC}}. \]
7. PROBLEM OF OPTIMIZATION ON THE RETURN STROKE

Let us state the following problem of two-positions optimization: Find such values for parameters \( \delta \) and \( \rho_{AO} \) that guarantee at the end of second stage of the return stroke the position of the point D on the y-axis and at the end of the second stage of the working stroke parallelism of the side CED to the x-axis. This optimization problem requires the solution of the following system of equations:

\[
\begin{align*}
&x_D(t, \delta, \rho_{AO}) = 0, \\
y_D(t, \delta, \rho_{AO}) = y_C(t, \delta, \rho_{AO}).
\end{align*}
\] (13)

Let the considered in this paper parameters have the following values: \( h = 0.0830 \) m – is the value of the return and working strokes of the slider B, \( Q = 0.0007 \) m\(^3\)/s, \( D = 0.0800 \) m, \( d = 0.0500 \) m, \( \rho_{AB} = 0.0837 \) m, \( \rho_{OE} = 0.0490 \) m, \( \rho_{CA} = 0.0270 \) m, \( \rho_{EC} = 0.0560 \) m, \( \rho_{DC} = 0.4110 \) m, \( \rho_{AE} = 0.0622 \) m, \( \rho_{OC} = 0.0718 \) m, \( L = 0.0060 \) m, \( y_{BO} = -0.0550 \) m. By solution of the system (13) the following optimal values of parameters \( \delta \) and \( \rho_{AO} \) were found out:

\[
\delta = 0.0177 \text{ m}, \quad \rho_{AO} = 0.0564 \text{ m}.
\] (14)

8. THE IMAGINATION THE VIRTUAL MANIPULATOR AT THE FIRST AND AT THE SECOND STAGE OF THE RETURN STROKE

To imagine the virtual manipulator on the worksheet of the computer program Mathcad let us compose the following vector functions

\[
s_x(t) = \begin{cases}
0 \text{ m} \\
x_E(t, \delta, \rho_{AO}) \\
x_D(t, \delta, \rho_{AO}) \\
x_C(t, \delta, \rho_{AO}) \\
x_A(t, \delta, \rho_{AO}) \\
\delta \\
0 \text{ m}
\end{cases}
\] if \( 0 \leq t \leq t_0 \) \hspace{1cm} (15)

and

\[
s_x(t) = \begin{cases}
0 \text{ m} \\
x_E(t, \delta, \rho_{AO}) \\
x_D(t, \delta, \rho_{AO}) \\
x_C(t, \delta, \rho_{AO}) \\
x_A(t, \delta, \rho_{AO}) \\
\delta \\
0 \text{ m}
\end{cases}
\] if \( (t_0 < t \leq t_1) \), \hspace{1cm} (16)

Similarly one can obtain

The formulas (1) – (18) present the mathematical model for synthesis of the virtual manipulator in Fig. 6 on the second stage of the return stroke.

The functions (15) – (18) can be used for creation the images of the virtual manipulator on the computer screen at an arbitrary position of the first and at the second stages on the return stroke. Fig. 7 shows these images at the beginning (dot line) and end (solid line) on the second stage of the return stroke before (a) and after (b) optimization positions of virtual manipulator.

\[
s_x(t) = \begin{cases} 
0 \text{ m} \\
y_E(t_0, \delta, \rho_{AO}) \\
y_D(t_0, \delta, \rho_{AO}) \\
y_C(t_0, \delta, \rho_{AO}) \\
y_A(t_0, \delta, \rho_{AO}) \\
y_B(t) \\
y_A(t_0, \delta, \rho_{AO}) \\
0 \text{ m}
\end{cases} \quad \text{if } 0 \leq t \leq t_0 \tag{17}
\]

and

\[
s_y(t) = \begin{cases} 
0 \text{ m} \\
y_E(t, \delta, \rho_{AO}) \\
y_D(t, \delta, \rho_{AO}) \\
y_C(t, \delta, \rho_{AO}) \\
y_A(t, \delta, \rho_{AO}) \\
y_B(t) \\
y_A(t_0, \delta, \rho_{AO}) \\
0 \text{ m}
\end{cases} \quad \text{if } (t_0 < t \leq t_1). \tag{18}
\]

for the first \((0 \leq t \leq t_0)\) and the second stages \((t_0 < t \leq t_1)\) of the return stroke of the slider B.

9. IMAGINATION THE VIRTUAL MANIPULATOR AT THE THIRD STAGE OF THE RETURN STROKE

To imagine the virtual manipulator in the global system of co-ordinates at the third stage of the return stroke let us define the vector-functions

\[ T_y(t) = s_y(t) \quad \text{if } 0 \leq t \leq t_1, \quad (19) \]

and

\[ T_y(t) = s_y(t_1) - v_y(t - t_1) \quad \text{if } t_1 < t \leq t_2, \quad (20) \]

where \( t_2 \) is the moment of time, when the third stage of the return stroke is ends, and the vectors

\[
\begin{align*}
    a_x &= \left[ u \leftarrow T_x(t_1) ight] \\
    &\quad \text{for } t \in t_1, t_1 + 0.5 \cdot s_2 \\
    a_y &= \left[ u \leftarrow T_y(t_1) ight] \\
    &\quad \text{for } t \in t_1, t_1 + 0.5 \cdot s_2 \\
    u &= \text{stack}(u, T_x(t)) \\
    &\quad \text{for } t \in t_1, t_1 + 0.5 \cdot s_2
\end{align*}
\]

(21)

as programs in the environment of computer package Mathcad. Here “stack (A, B)” is the operator of Mathcad, which returns a vector formed by placing A, B top to bottom.

The formulas (1) – (20), present the mathematical model for the virtual manipulator in Fig. 6 on the return stroke.

Fig. 8 shows the images of the virtual manipulator during the third stage of the return stroke in the global system of co-ordinates, when \( t_2 = 6 \) s.
10. LAW OF MOTION OF THE SLIDER B ON THE WORKING STROKE

Let us assume that the slider B (Fig. 6) is moving on the working stroke according to the law

\[ x_B = \delta, \quad y'_B(t) = y'_{BO} + v_w(t - t'_0), \quad (22) \]

where \( y'_{BO} = y'_B(t'_0) + L \) the y-co-ordinate of the pivot B at the moment of the local time \( t'_0 = \frac{L}{v_w} \), when the second stage on the return stroke is begins and \( t' \) – current time counted from the beginning of the working stroke, and \( v_w = \frac{4Q}{\pi D^2} \) - the velocity of the slider at its working stroke.

Because of large tolerance in the pivot B during the first stage of the working stroke of the slider B, the length of the link AB changes and the slider B moves without moving OACED. Before beginning the second stage of the working stroke of the slider B the link AB has the length

\[ \rho'_AB = \sqrt{[y'_{BO} - y_A(t'_1, \delta, \rho_{AO})]^2 + [\delta - x_A(t'_1, \delta, \rho_{AO})]^2}, \quad (23) \]

where \( t'_1 \) – is the local moment of the time, when the second stage of the return stroke is begins. The coordinates of pivots O, A, B and the points C, E, D of the link OACED in the local system of co-ordinates can be determined also by formulas (4) – (12) if

- all times are local, being counted from the beginning the first stroke of the working stroke,
- the law of motion the slider B and the length AB is being changed to \( y'_B(t') \), determined by formula (22),
- the length of connecting rod \( \rho_{AB} \) is being changed to \( \rho'_{AB} \), determined by formula (23).

11. PROBLEMS OF OPTIMIZATION ON THE WORKING STROKE

Let us state the first problem of optimization: Find such moment of local time \( t'_1 \), that guarantee at the end of second stage of the working stroke of the slider B the parallelism of the side ECD of the link OACED to the x-axis (Fig. 6). This optimization problem requires the solution of the following equation:

\[ y'_B(t'_1, \delta, \rho_{AO}) = y_C(t'_1, \delta, \rho_{AO}). \quad (24) \]

Equation (24) gives \( t'_1 = 0.6002 \) s.
Let us state the second problem of optimization: Find such moment of local time \( t'_2 \), that guarantee at the end of third stage of the working stroke of the slider B the initial position of the link OACED for the next cycle. This optimization problem requires the solution of the equation

\[ v_l t_2 = v_w t'_2 \]  

(25)

following from the condition that the working stroke and the return stoke of the slider B must be equal. Equality (25) gives \( t'_2 = 9.8462 \) s.

Fig. 9 shows the positions of virtual manipulator at the beginning (dot line) and at the end (solid line) of the second stage on the working stroke, when the local time \( t'_1 \) is determined from the equality \( t'_1 = h/v_w \) (a), where \( h \) is the stroke of the slider B in the local system of coordinates in Fig. 6 (stroke of the slider 7 inside the case 1 in Fig. 4), or by the optimum position condition (24) (b), and \( s'_x, s'_y \) denote the functions (15) – (18) at the return stroke.

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12. IMAGINATION THE VIRTUAL MANIPULATOR AT THE THIRD STAGE OF THE WORKING STROKE

To imagine the virtual manipulator in the global system of co-ordinates on the third stage of the return stroke let us define the vector-functions

\[ W_1'(t') = s'_1(t') - v_n(t'_{2} - t'_{1}) \text{ if } 0 \leq t'_{1} \leq t'_{2}, \quad (26) \]

and

\[ W_2'(t') = s'_2(t') - v_n(t'_{2} - t') \text{ if } t'_{1} < t' < t'_{2}, \quad (27) \]

\[ W_3'(t') = s'_3(t') \text{ if } t < t'_{1} \text{ and } W_3'(t') = s'_3(t'_{1}) \text{ if } t'_{1} < t' \leq t'_{2}, \quad (28) \]

where the functions \( s'_1(t') \) and \( s'_2(t') \) can be obtained from the corresponding functions \( s_1(t) \) and \( s_2(t) \) in the part 5 of this paper by changing \( t, t_0, t_1, t_2 \) to the correspondent local times \( t', t'_0, t'_1, t'_2 \); \( y_B(t) \) to \( y'_B(t') \) and \( \rho_{AB} \) to \( \rho'_{AB} \), and the vectors

\[
\begin{align*}
a'_x &= \left\{ u \leftarrow W'_x(t'_1) \right\} \\
    &\text{for } t \in t'_1, t'_1 + 0.2 \cdot s \ldots t'_1 + t'_2 \\
    \text{and } u \leftarrow \text{stack}(u, W_x(t)) \\

a'_y &= \left\{ u \leftarrow W'_y(t'_1) \right\} \\
    &\text{for } t \in t'_1, t'_1 + 0.2 \cdot s \ldots t'_1 + t'_2 \\
    \text{and } u \leftarrow \text{stack}(u, W_y(t)) \quad (29)
\end{align*}
\]

as programs in the environment of computer package Mathcad.

The formulas (2) – (12), (15) – (18), (19) – (29) present the mathematical model for synthesis of the virtual manipulator in Fig. 6 on the working stroke.

Fig. 10 shows the images of the virtual manipulator during the third stage on the working stroke in the global system of co-ordinates.

![Figure 10](image)

Figure 10. The images of the virtual manipulator during the third stage on the working stroke in the global system of co-ordinates

13. SIMULATION THE WORKING PROCESS OF THE VIRTUAL MANIPULATOR IN ONE CYCLE

To verify visually the reaching required optimal positions by the composed virtual manipulator it is reasonable to simulate its working process in the one cycle (0 ≤ t ≤ t'_{2}). Let us define the following functions

\[ P_1(t) = T_1(t) \text{ if } 0 \leq t \leq t_2 \text{ and } P_1(t) = W_1(t - t_2) \text{ if } t_2 < t \leq t'_{2} \]

\[ P_2(t) = T_2(t) \text{ if } 0 \leq t \leq t_2 \text{ and } P_2(t) = W_2(t - t_2) \text{ if } t_2 < t \leq t'_{2} \]

vectors

\[ a''_x := \begin{cases} u \leftarrow P_x(0 \cdot s) \\ for \ t \in 0 \cdot s, 0.0792s .. t_2 + t'_2 \\
\end{cases} \]
\[ a''_y := \begin{cases} u \leftarrow P_y(0 \cdot s) \\ for \ t \in 0 \cdot s, 0.0792s .. t_2 + t'_2 \\
\end{cases} \]
\[ u \leftarrow stack(u, P_x(t)) \]
\[ u \leftarrow stack(u, P_y(t)) \]

Fig. 11 shows several video frames in the global co-ordinate system from the composed video clip that simulates the working process of the link OACED in one cycle.

Figure 11. Video frames in the global co-ordinate system from the composed video clip that simulates the working process of the link OACED in one cycle.

14. CONCLUSION

The view of the press manure removals has cleared the background of the study of the press manure removal.

To specify the dimensions of the scraper’s manipulators in the structure of the press manure removal the mathematical and virtual modeling based method of synthesis the scraper’s manipulator, taking optimal positions on the working process, is developed. This problem of synthesis is successfully solved and the distances between characteristic points of optimal manipulator are specified. These specified distances might be used for creation manipulators type in optimal dimensions.

It was convenient to compose special program for solution stated problems in the environment of the computer package Mathcad. This program allows easy to change given dimensions and optimum conditions of the manipulator.

The results of this paper confirm the world experience that the creation of virtual models of machine elements, their optimization and simulation their motion might be more effective and precise than the creation of machine element only by experimentation. If possible, then it is reasonable to begin the creation real machine element after creation a virtual model, its optimization and simulation its motion.

15. REFERENCES


