

MULTIPARAMETRIC SYNTHESIS OF THE MANIPULATOR OF THE SCRAPER OF THE PRESS MANURE REMOVAL

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ABSTRACT. This paper presents the results of solving the following problem of multiparametric synthesis: determining 4 parameters of the manipulator of the scraper of press manure removal and finding out their values as the manipulator takes the prescribed positions and has equal angular velocities at the beginning and end of its turning. The solution to this multiparametric synthesis problem is based on the methods of the Machine and Mechanism Theory. The results of this paper can be useful for the designers of manipulators for press manure removals.

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

Introduction

There exist different manure removal systems, which 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 it through a manure pipe into a heap of muck. Figure 1 shows a principal scheme of a manure press removal.

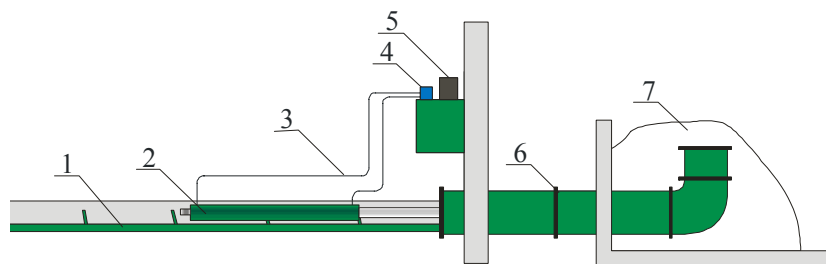


Figure 1. A principal scheme of the press manure removal. 1 – one-sided scraper; 2 – hydraulic cylinder; 3 – oil pipe; 4 – hydraulic station; 5 – electric engine; 6 – manure pipe; 7 – heap of muck

The working principle of the press manure removal in Figure 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 the 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 its initial position. By repeating this working cycle, a large heap of muck will be structured. The press manure removal is economical and environmentally sound. The press manure removal can be used for loading the manure to the storage which is situated nearby the barn (2–10 m) (Figure 1).

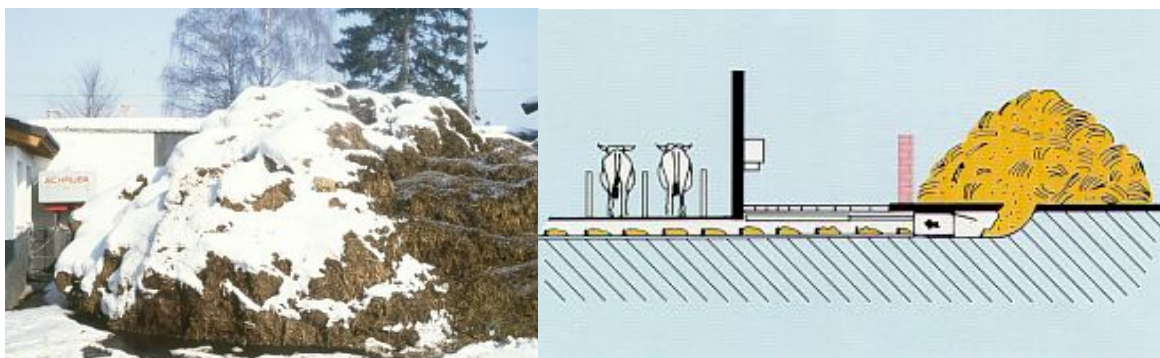


Figure 2. A press manure removal of a small farm by Schauer (2001)

The manure scraper in Figure 3 is used as the working tool of the manure press removal in Figure 1. The principal scheme of a one-sided manure scraper in the working stroke (a) and in the return stroke (b) is shown in Figure 3, where the working vanes of the scraper have vertical axes of rotation.

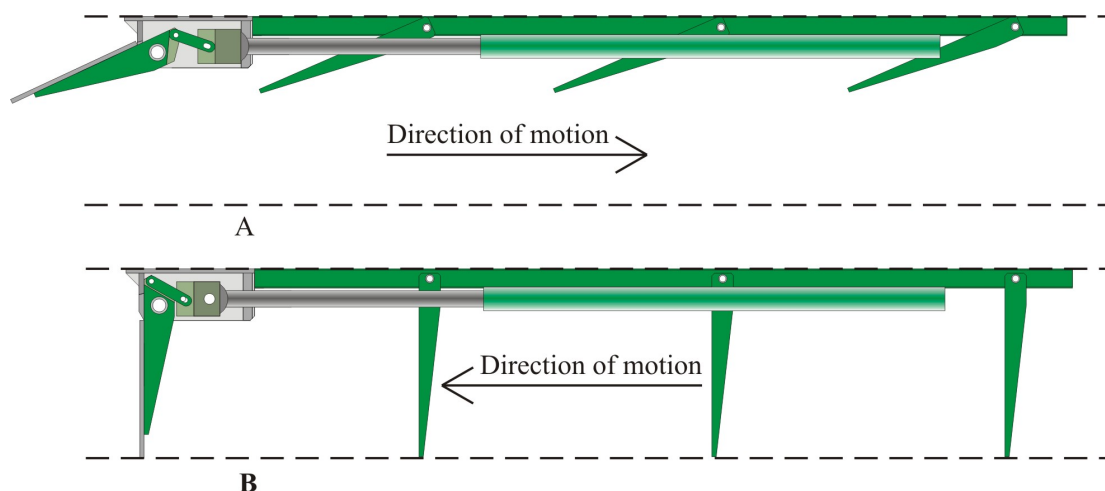


Figure 3. A principal scheme of a one-sided manure scraper in the working stroke (a) and in the return stroke (b)

The working vanes of the manure scraper in Figure 3 are four-square and can rotate freely around their vertical (or horizontal) axis under the resistance forces, applied to the vane in the manure pile. Scrapers in Figure 3 are, for example, in the structure of press manure removals Paskervilleri 8000 (1997), and Schauer (2001). The disadvantage of the scraper in Figure 3a is the lugging of manure by the manure scraper on its return stroke (Figure 3b).

Merivirta Oy (1998) and Paskervilleri 4000 (1999) have used the force-driven system for the rotation of the working vanes of the manure scraper. Although the system is complicated, it guarantees the stable rotation of the working vanes from the working position to the position of the return stroke and the other way round.

The scientific team, led by V. Veinla at Estonian University of Life Sciences have created a novel manure scraper for press manure removal in which the first working vane (Figure 4) was clamped to the force-driven manipulator.

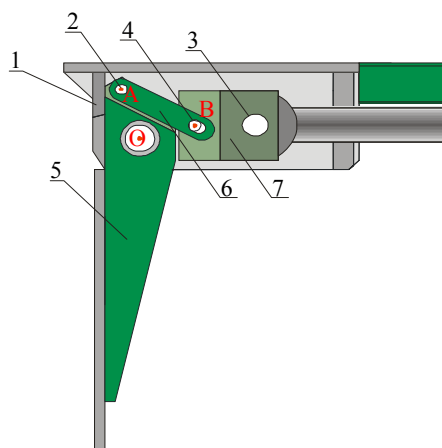


Figure 4. The scheme of designed manipulator 1 – case; 2, 3 – pivots; 4 – pivot with a large slack; 5 – rib with a vane, 6 – connecting plate; 7 – slider

Veinla and Leola (2001, 2003) have experimentally made a thorough study of the press manure removal in Figure 1 with manure scraper in Figure 4. The purpose of their experimental study of the press manure 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 of the height of the heap of muck on the resistance pressure of manure in the manure pipe. Figure 5 shows the device for studying the press manure removal experimentally.



Figure 5. The device of the press manure removal, created for experiments by the idea of V. Veinla

To specify the parameters of the manipulator in Figure 5, Heinloo, Leola, Veinla (2005) have developed a method based on mathematical and virtual modeling for the synthesis of the virtual manipulator (Figure 7), created on the worksheet of the Computer Package Mathcad according to the scheme in Figure 6. Heinloo, Leola, Veinla (2005) found out such a length for link AO and for the x-co-ordinate δ of the pivot B (Figure 6) which guarantees the position in Figure 6 of the manipulator before it turns clockwise and the position in Figure 7 after the turning.

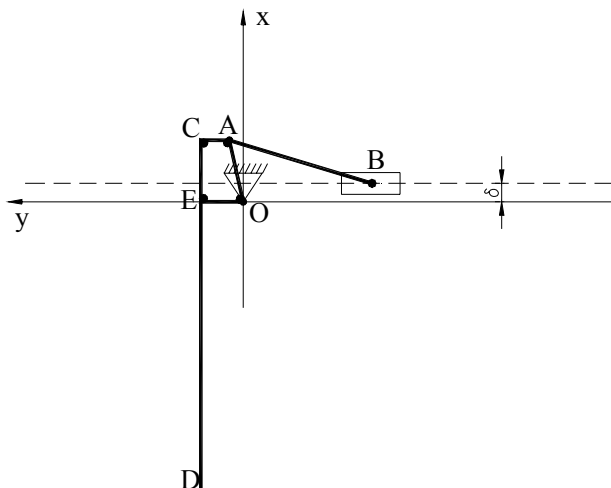


Figure 6. The computational scheme of the manipulator in Figure 4, O, A – pivots; B – pivot with a large tolerance; OACED – rigid link

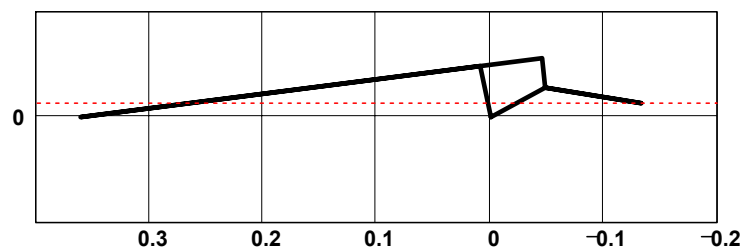


Figure 7. A virtual model of a manipulator in Figure 4, composed on the Mathcad worksheet

This paper deals with the solving of the following problem of multiparametric synthesis: finding out such lengths ρ_{AO} , ρ_{AB} , ρ_{OE} of the links AO, AB and the side OE of the link OACED and the x-co-ordinate δ of the pivot B (Figure 6) which can guarantee the optimal position in Figure 6 before turning the link OACED clockwise and the position in Figure 7 after this turning and satisfaction the condition of equality of the angular velocity of the link OACED at the positions in Figure 6 and in Figure 7.

Prescribed restrictions to the motion of the manipulator

Let us and suppose that the prescribed restrictions to the motion of the manipulator (Figure 6) are:

- At the interval of the time $0 \leq t \leq t_0$, where $t_0 = L/v_r = 0.0263$ s ($L = 0.006$ m – tolerance caused free stroke of the slider B before moving the link OACED; $v_r = 0.2285$ m/s – velocity of the slider B in the moving to the negative direction of y-axis) the link OACED is immovable.
- At the interval of the time $t_0 \leq t \leq t_1$, where $t_1 = h/v_r = 0.3632$ s ($h = 0.0830$ m – full stroke of the slider B in the system Oxy) the link OACED turns around the pivot O clockwise from working position in Figure 6 to the return position in Figure 8.
- At the interval of the time $t_1 \leq t \leq t_2$, where the time $t_2 = 6$ s is given, the link OACED is traversing to the final position.
- At the interval of the time $t_2 \leq t \leq t_2 + t'_0$, where $t'_0 = L/v_l = 0.0431$ s ($v_l = 0.1393$ m/s – the velocity of the slider B in the moving to the positive direction of y-axis of the system Oxy), due to the tolerance at the pivot B the link OACED is immovable.
- At the interval of the time $t_2 + t'_0 \leq t \leq t_2 + t'_1$, where t'_1 is the local time, the link turns around the pivot O anticlockwise the position in Figure 8 to the position in Figure 6.
- At the interval of the time $t_2 + t'_1 \leq t \leq t_2 + t'_2$, where t'_2 is the local time, the link is traversing and reaches the initial position at the moment $t = t_2 + t'_2$ of the time.
- Slider B can move only along its track and the x-co-ordinate of the pivot B is fixed (Figure 6)

$$x_B(t) = \delta. \quad (1)$$

- The y-co-ordinate changes in the system Oxy according to the law

$$y_B(t) = y_{B0} - v_r(t - t_0), (t_1 \geq t \geq t_0) \quad (2)$$

when the slider B is moving in this system to the negative direction of y-axis and according to the law

$$y'_B(t') = y_B(t_1) + L + v_l(t' - t'_0), (t'_1 \geq t' \geq t'_0) \quad (3)$$

when the slider B is moving to the positive direction of y-axis. Here t – the current time; t' – the local current time, counted from reaching the link OACED the final position; $y_{B0} = 0.0550$ m – the fixed y-co-ordinate of the pivot B directly before moving the link OACED at the moment of the time t_0 .

Basic equations

Co-ordinates of the points C, E, D and pivots A, B are determined in the local system of co-ordinates Oxy (Figure 6) by the following system of equations:

$$\begin{aligned} x_A^2 + y_A^2 &= \rho_{AO}^2, (x_A - \delta)^2 + [y_A - y_B(t)]^2 = \rho_{AB}^2, \\ (x_E - x_A)^2 + (y_E - y_A)^2 &= \rho_{AE}^2, x_E^2 + y_E^2 = \rho_{OE}^2, \\ x_C^2 + y_C^2 &= \rho_{OC}^2, (x_C - x_E)^2 + (y_C - y_E)^2 = \rho_{EC}^2, \\ x_D &= \frac{\rho_{DC}}{\rho_{EC}} \left[x_E + \left(\frac{\rho_{EC} - \rho_{DC}}{\rho_{DC}} \right) x_C \right], y_D = \frac{\rho_{DC}}{\rho_{EC}} \left[y_E + \left(\frac{\rho_{EC} - \rho_{DC}}{\rho_{DC}} \right) y_C \right]. \end{aligned} \quad (4)$$

A possible analytical solution of the system (1) had been derived by Leola, Veinla, Heinloo (2004).

By differentiation the system (4) by the time t one can find the following linear system of equations for the determination of velocities $v_{Ax}, v_{Ay}, v_{Cx}, v_{Cy}, v_{Ex}, v_{Ey}, v_{Dx}, v_{Dy}$, of points C, E and D and pivots A and B.

$$\begin{aligned} x_A v_{Ax} + y_A v_{Ay} &= 0, (x_A - \delta) v_{Ax} + [y_A - y_B(t)] (v_{Ay} + v_r) = 0, \\ x_E v_{Ex} + y_E v_{Ey} &= 0, (x_E - x_A) (v_{Ex} - v_{Ax}) + (y_E - y_A) (v_{Ey} - v_{Ay}) = 0, \\ x_C v_{Cx} + y_C v_{Cy} &= 0, (x_C - x_E) (v_{Cx} - v_{Ex}) + (y_C - y_E) (v_{Cy} - v_{Ey}) = 0, \\ v_{Dx} &= \frac{\rho_{DC}}{\rho_{EC}} \left[v_{Ex} + \left(\frac{\rho_{EC} - \rho_{DC}}{\rho_{DC}} \right) v_{Cx} \right], v_{Dy} = \frac{\rho_{DC}}{\rho_{EC}} \left[v_{Ey} + \left(\frac{\rho_{EC} - \rho_{DC}}{\rho_{DC}} \right) v_{Cy} \right]. \end{aligned} \quad (5)$$

Systems of equations (4) and (5) are valid in the case of motion of the slider B to the negative direction of y-axis of the local system Oxy (Figure 5). To obtain the velocities of points C, E and D and pivots A and B in the case, when the slider B moves to the positive direction of y-axis of the local system Oxy one have to change in the systems (4) and (5) $y_B(t)$, determined by the formula (2), to $y'_B(t')$, determined by the formula (3), the local velocity v_r to the local velocity v_l and the time t to the local time t' .

By differentiation on time t the equations $x_A(t) = \rho_{AO}\sin(\varphi)$, $y_A(t) = \rho_{AO}\cos(\varphi)$, where φ – is the angle between the positive direction of y-axis of the system and the link AO, and by simple transformations one can derive the following formula for determination of the angular velocity ω_{AO} of the link OACED

$$\omega_{AO} = -\frac{v_{Ay}}{x_A}. \quad (6)$$

Solution of the problem of synthesis

Let us consider the time t , the dimensions ρ_{AO} , ρ_{AB} , ρ_{OE} and the x-co-ordinate δ of the pivot B as variables. Then the coordinates x_A , y_A , x_C , y_C , x_E , y_E , x_D , y_D , the velocities v_{Ax} , v_{Ay} , v_{Cx} , v_{Cy} , v_{Ex} , v_{Ey} , v_{Dx} , v_{Dy} and the angular velocity ω_{AO} have to be considered as functions of t , δ , ρ_{AO} , ρ_{AB} , ρ_{OE} .

The synthesis problem of this paper needs to solve the following system of equations

$$\begin{aligned} x_D(t_1, \delta, \rho_{AO}, \rho_{AB}, \rho_{OE}) &= 0 \text{ m}, \\ y_D(0s, \delta, \rho_{AO}, \rho_{AB}, \rho_{OE}) - y_C(0s, \delta, \rho_{AO}, \rho_{AB}, \rho_{OE}) &= 0 \text{ m}, \\ \omega_{AO}(t_1, \delta, \rho_{AO}, \rho_{AB}) - \omega_{AO}(0s, \delta, \rho_{AO}, \rho_{AB}) &= 0 \frac{1}{s}. \end{aligned} \quad (7)$$

The lengths

$$\rho_{EC} = 0.0560 \text{ m}, \rho_{DC} = 0.4110 \text{ m}, \rho_{AE} = 0.0622 \text{ m}, \rho_{OC} = 0.0718 \text{ m} \quad (8)$$

were considered as given. To solve the system of nonlinear equations (7) relative to parameters δ , ρ_{AO} , ρ_{AB} , ρ_{OE} one has to give the initial values of these parameters. For initial values

$$\delta = 0.0200 \text{ m}, \rho_{AO} = 0.0500 \text{ m}, \rho_{AB} = 0.0900 \text{ m}, \rho_{OE} = 0.0500 \text{ m}. \quad (9)$$

The correspondent values, found out by applying the solve block of the Computer Package Mathcad, are

$$\delta' = 0.0198 \text{ m}, \rho'_{AO} = 0.0604 \text{ m}, \rho'_{AB} = 0.0830 \text{ m}, \rho'_{OE} = 0.0493 \text{ m}. \quad (10)$$

Figure 9 shows the dependency of angular velocity ω_{AO} on time t , when the parameters δ , ρ_{AO} , ρ_{AB} , ρ_{OE} have the initial values (9) (dotted line) and found out values (10) (solid line).

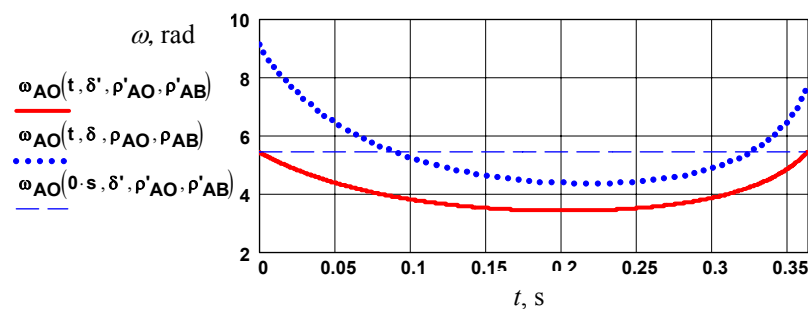


Figure 8. The dependency of angular velocity ω_{AO} on time t , when the parameters δ , ρ_{AO} , ρ_{AB} , ρ_{OE} have the initial values (9) (dotted line) and found out values (10) (solid line)

Figure 9 shows the positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters δ , ρ_{AO} , ρ_{AB} , ρ_{OE} have the initial values (9).

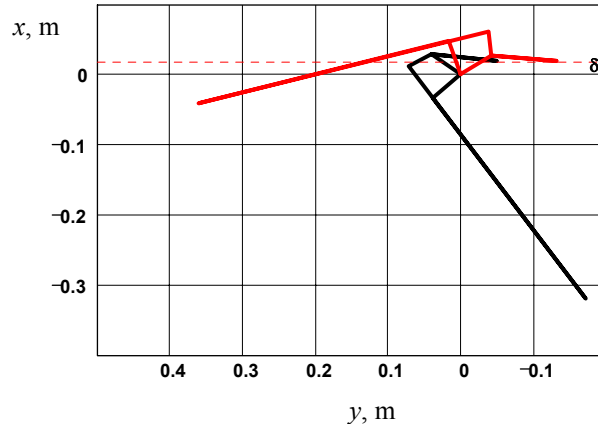


Figure 9. The positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the initial values (9)

Figure 10 shows the positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the found out values (10).

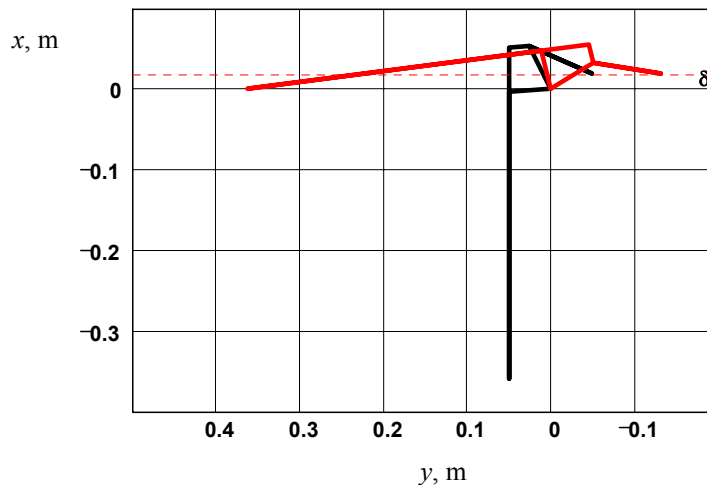


Figure 10. The positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the found out values (10)

While the system (7) has 3 equations for the determination of 4 parameters then its solution (10) is not unique. For initial values

$$\delta = 0.0100 \text{ m}, \rho_{AO} = 0.0600 \text{ m}, \rho_{AB} = 0.1000 \text{ m}, \rho_{OE} = 0.0600 \text{ m} \quad (11)$$

the system (7) gives a correspondent solution

$$\delta' = 0.0101 \text{ m}, \rho'_{AO} = 0.0583 \text{ m}, \rho'_{AB} = 0.0834 \text{ m}, \rho'_{OE} = 0.0479 \text{ m}. \quad (12)$$

Figure 11 shows the dependency of angular velocity ω_{AO} on time t , when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the initial values (11) (dotted line) and found out values (10) (solid line).

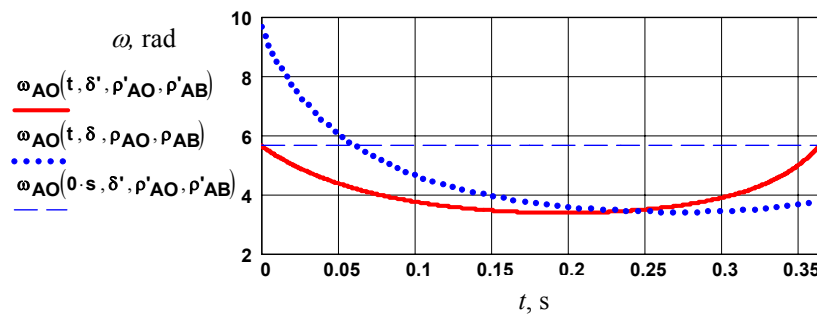


Figure 11. The dependency of angular velocity ω_{AO} on time t , when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the initial values (11) (dotted line) and found out values (12) (solid line)

Figure 12 shows the positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the initial values (11).

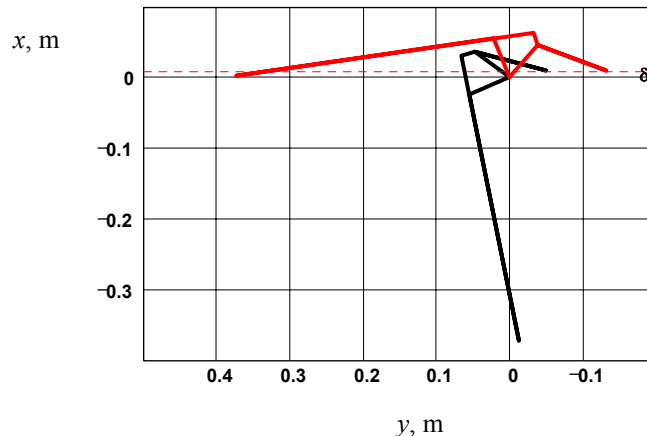


Figure 12. The positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the initial values (11)

Figure 13 shows the positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the found out values (12).

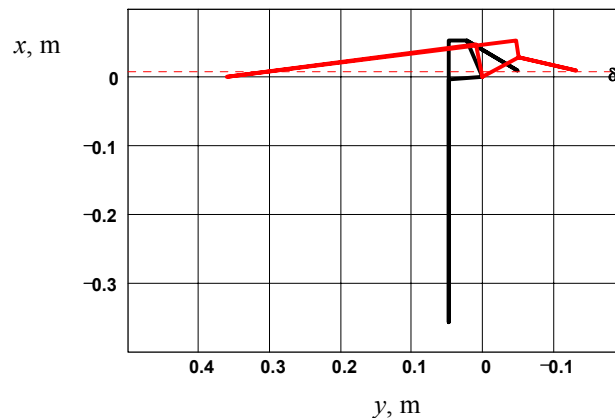


Figure 13. The positions of the link OACED at the moments of the times t_0 and t_1 (t'_0 and t'_1), when the parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ have the initial values (11)

It may happen that for some initial values of parameters $\delta, \rho_{AO}, \rho_{AB}, \rho_{OE}$ the system (7) have not any solution.

The motion of the link OACED at the interval $t_2 \geq t \geq t_2 + t'_2$ of the time t' can be studied analogically by Heinloo, Leola, Veinla (2005).

Conclusions

It has been shown that the problem of multiparametric synthesis stated in this paper is solvable for the case of the manipulator of the scraper of the press manure removal. It was convenient to compose a special programme for the solution of the stated problem on the worksheet of the computer package Mathcad. This programme easily allows to change the given dimensions and conditions of synthesis of the manipulator and can be used in the creation of press manure removals. The results of this paper confirm the world experience that the creation of virtual models of machine elements, their synthesis and simulation their motion might be more effective and precise than the creation of a machine element only by experimentation. If possible, it is reasonable to begin the creation of a real machine element after the creation of a virtual model, its synthesis and the simulation of its motion.

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