KINEMATIC ANALYSIS OF PARALLEL TRANSFER MECHANISM

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Abstract. The parallel transfer mechanism (patent LV 15506B) consists of links in form of two parallelograms with one common horizontal link and parallel to it opposite links of equal length, and the links of side edges of the parallelograms the lengths of which are equal in pairs, respectively. The common link of the parallelograms is formed as a guide for a slider to which two links are connected corresponding to the lengths of the side edge links of the parallelograms. The other ends of these elements are connected to the side edge links forming a rhomboid contour. The links of this planar linkage are connected by pin joints. For cyclic operation of the parallel transfer mechanism the hydraulic actuator is connected to the slider and attached to the common link. If the lower parallelogram link is the ground link, the output link will be the upper link, which parallel transfer movement will be ensured. The purpose of the work is kinematic analysis of this innovative mechanism. The side members with a length of 0.5 m and a hydraulic actuator with a speed 0.2 $m \cdot s^{-1}$ of movement are selected as a sample of the mechanism. Kinematic parameters as displacement, velocity and acceleration of the upper output link were determined using the Mathcad program for an idealized mechanism ignoring friction. These maximum values were 1 m, 0.985 $m \cdot s^{-1}$ and 0.508 $m \cdot s^{-2}$ accordingly. If the displacement of the output link is reduced, avoiding singularities and ensuring stability of mechanism, the maximum displacement, velocity and acceleration values will be reduced to 0.65 m, 0.55 $m \cdot s^{-1}$ and 0.10 $m \cdot s^{-2}$, accordingly. By changing the input parameters, it is possible using this Mathcad calculation method to obtain the values of the kinematic parameters for other size mechanisms.

Keywords: agroengineering, linkage mechanisms, parallel transfer.

Introduction

Parallel transfer or motion mechanisms contain the output link, which parallel transfer movement is provided. The movement of the output link is more often in the vertical plane, but it can be used for horizontal parallel displacement. The relevance of such mechanisms is evidenced by a recently issued patent [1] for a mechanism that contains a double parallelogram vertical lifting device comprising a linkage mechanism and a pushing device. Parallel displacement is obtained for several lifting mechanisms using a double parallelogram linkage [2] or single parallelogram [3] linkage. The application of the pantograph mechanism, which contains a parallelogram [4] allows to easily control the manipulator in 3D space. Slider movement accuracy in parallel displacement is one of the most important indicators for evaluating the operation of press mechanisms. This is significantly influenced by the synchronized movement [5] of two toggle mechanisms. If a mathematical model of the press mechanism [6] is established, multi-objective optimization will be available. The aim of this research is to determine the kinematic relationship between the input and output links of innovative [7] parallel transfer mechanism. Planning the application of this mechanism in leveling the position of the boom of agricultural sprayers, it is necessary to obtain numerical results of kinematic parameters. The design of a machine or a mechanism or any moving mechanical system always starts with a consideration of kinematics because kinematics is the study of the geometry of motion. That is, kinematics deals [8] with the functional relationships between the parts interconnected. Using Mathcad program for parallel transfer mechanism kinematic modelling allows to find the relationship between the mechanism input and output link displacement, velocity and acceleration. The numerical solution is performed according to the selected mechanism dimensions and the drive actuator speed. By changing these input parameters, it is possible to obtain the values of the kinematic parameters for the changed mechanism.

Materials and methods

The parallel transfer mechanism [7] in Fig. 1. consists of links in form of two parallelograms with one common side link 1 and parallel to it opposite side links 2 and 3 of equal length, and the links of side edges 4 and 4’ of the parallelograms, and 5 and 5’, the lengths of which are equal in pairs, respectively. The common link of the parallelograms 1 is formed as a guide for a slider 6, to which are connected the links 4” and 5”, corresponding to the lengths of the side links 4 and 5 of the parallelograms. The other ends of the elements 4” and 5” are connected to the side links 4 and 5, forming a rhomboid contour. The links of this planar linkage are connected by pin joints. For cyclic operation of the parallel transfer mechanism the hydraulic actuator 10 is connected to the slider 6 and attached to the

DOI: 10.22616/ERDev.2023.22.TF037

common link 1. If the lower parallelogram link 2 is the ground link, the output link will be link 3 which parallel transfer movement will be ensured.

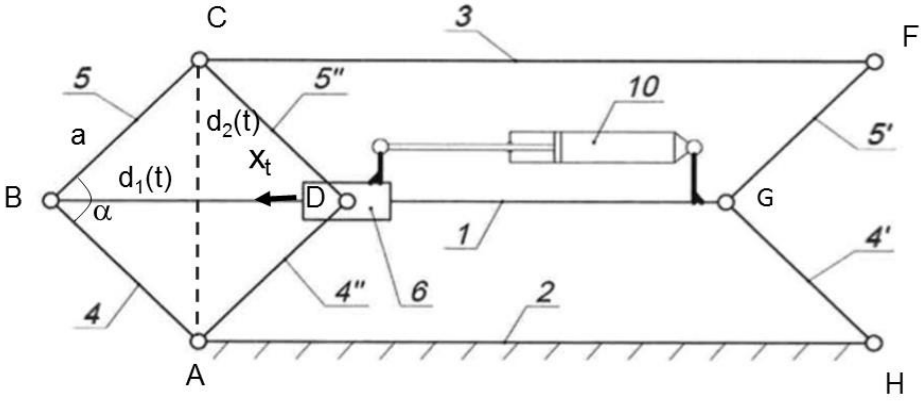

Fig. 1. **Parallel transfer mechanism**

The innovative features of this mechanism are included in the claims of the patent LV 15506 (B). The most important of these is the movement of the link 3 in Fig. 1 strictly perpendicularly to the base link 2 without transverse movement. Such movement is important in the vertical lifting and lowering of massive agricultural sprayer booms. The maximal vertical displacement of the parallel transfer output link 3 depends on the size of the rhomboid link a. For ideal mechanism it equals 2a. According to the agricultural precision requirements, the distance from the sprayer boom nozzles to the crops [9] should be kept between 50 cm to 70 cm. If a = 0.5 m is selected for the sample mechanism, then the maximal vertical displacement 1 m will be obtained for ideal linkage. The necessary sprayer boom leveling displacement is less than 1 m and could be determined during modeling. The speed (velocity) of the hydraulic cylinder actuator 10 is selected 0.2 $\mathrm{m \cdot s^{-1}}$ for smooth lifting and lowering of the spray boom. Flow control valves are included in the hydraulic circuit (Fig. 2) of the actuator drive to set the speed of the actuator. Hydraulic accumulators prevent pressure spikes during transition processes. Hydraulic schematic symbols correspond to ISO 1219-1: 1996-03.

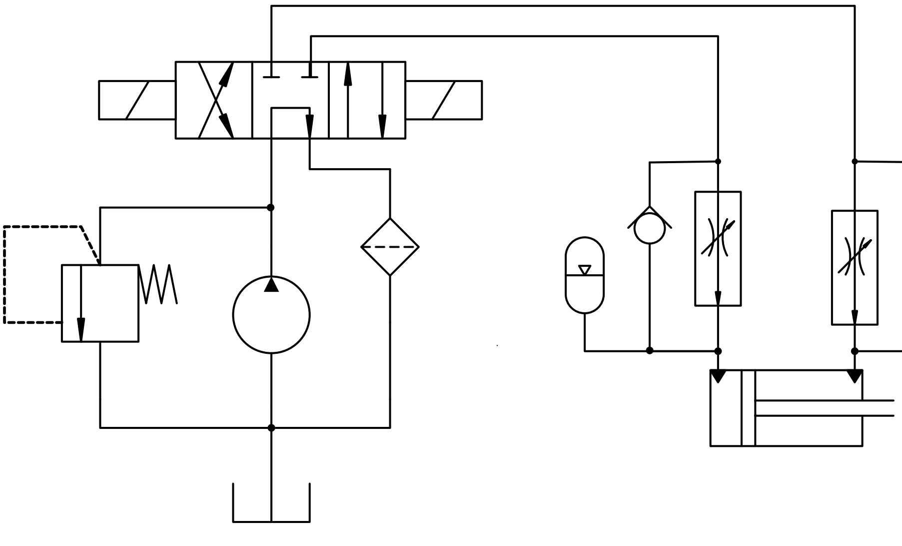

Fig. 2. **Hydraulic cylinder actuator drive circuit**

Fig. 1 shows that the size of the rhombus diagonals $d_1(t)$ and $d_2(t)$ of the mechanism unambiguously determines the position of the output link 3. The mutual perpendicularity of the diagonals of the rhombus is important for the calculation of displacements. Formulas used in MathCad calculations are derived from the geometric relationships between $d_1(t)$ and $d_2(t)$. The time for the actuator displacement 1m with the velocity 0.2 $\mathrm{m \cdot s^{-1}}$ is 5 s. We select the time t series in the Mathcad program (in dm, 1 ds equals 1 $\mathrm{s \cdot 10^{-1}}$):

$$t = 0...50 \text{, ds;} \tag{1}$$

Then the extension displacement of the actuator (in dm, 1 dm equals 1 m·10^{-1}):

$$x(t) = 0.2 \cdot t \text{, dm;} \tag{2}$$

Size of the diagonal $d_1(t)$ during actuator extension:

$$d_1(t) = 2 \cdot a - x(t) \tag{3}$$

Size of the diagonal $d_2(t)$ during actuator extension:

$$d_2(t) = \left| \sqrt{4 \cdot a^2 - \left|(2 \cdot a - x(t))^2\right|} \right| \tag{4}$$

Extension displacement of the actuator during retraction:

$$x(t) = 10 - 0.2 \cdot t \text{, dm} \tag{5}$$

Size of the diagonal $d_1(t)$ during actuator retraction:

$$d_1(t) = 0.2 \cdot t \tag{6}$$

Size of the diagonal $d_2(t)$ during actuator retraction:

$$d_2(t) = \left| \sqrt{4 \cdot a^2 - (0.2 \cdot t)^2} \right| \tag{7}$$

For time t series $t = 1...49$ ds the value of the rhombus angle α can be determined:

$$a(t) = 2 \cdot \arctan\left(\frac{d_2(t)}{d_1(t)}\right) \cdot \tag{8}$$

Results and discussion

Using the Mathcad program for calculation, the kinematic parameters of an idealized parallel transfer mechanism had been obtained. Displacement, velocity and acceleration values were determined for the actuator – $x(t)$, diagonals $d_1(t)$ and $d_2(t)$, because they determine the position of the output link 3.

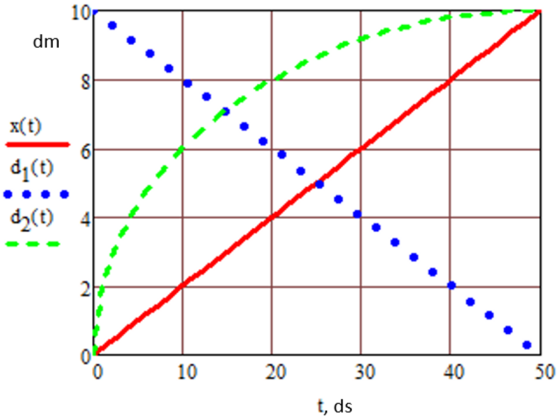

Fig. 3. **Displacements during lifting**

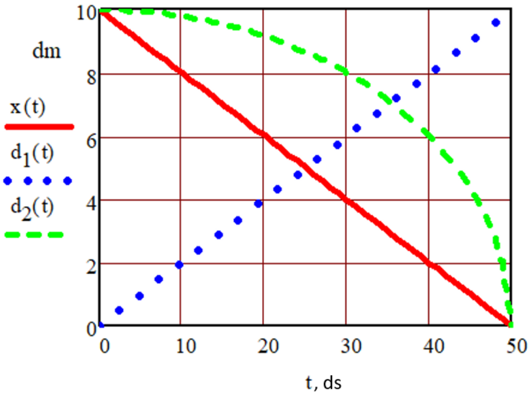

Fig. 4. **Displacements during lowering**

Since the sprayer boom is attached to the output link 3, the values of the kinematic parameters (Fig. 3 and Fig. 4) for the diagonal $d_2(t)$ correspond to the vertical movement of the sprayer boom. Directly proportional change in the actuator and horizontal diameter displacement corresponds to constant actuator speed. Since the side links of the mechanism 4 and 5, 4' and 5', 4"and 5" compose two toggle mechanisms on both sides, the diameter $d_2(t)$ change has a non-linear characteristic.

Fig. 5. and Fig. 6. show that velocities $dx(t)/dt$ and $d(d_1(t))/dt$ are constant. Velocity of the sprayer boom $d(d_2(t))/dt$ has the maximum value at the beginning of lifting and minimum value at the end of lowering 0.985 m·s^{-1}.

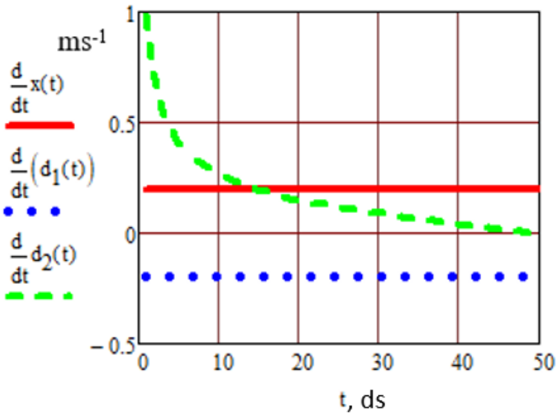

Fig. 5. **Velocity during lifting**

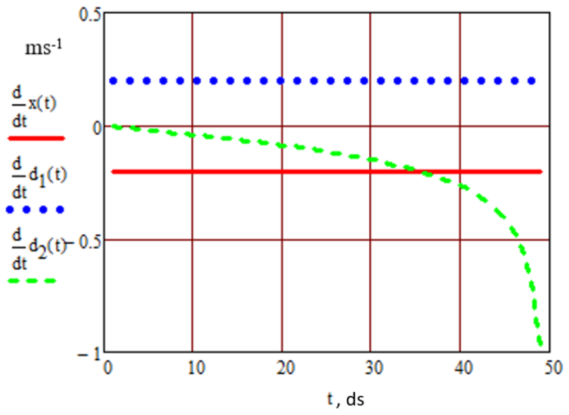

Fig. 6. **Velocity during lowering**

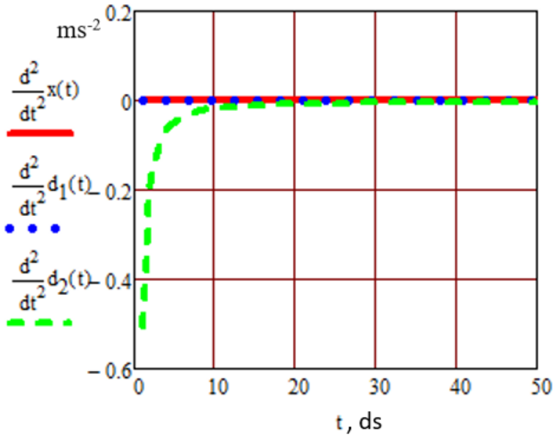

Fig. 7. **Acceleration during lifting**

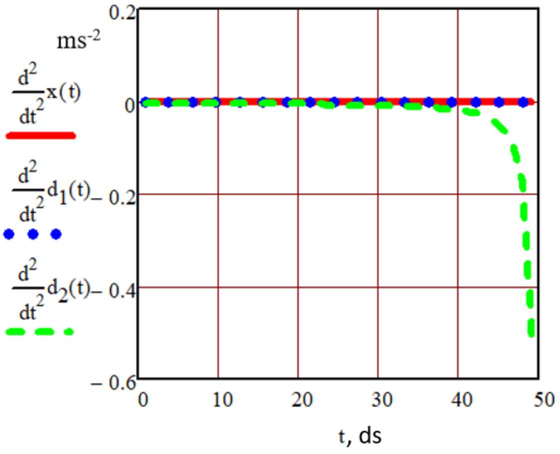

Fig. 8. **Acceleration during lowering**

Fig. 7. and Fig. 8 show that maximum negative values of the output link acceleration are at the beginging of lifting and at the end of lowering equal 0.508 ms^{-2}. It is necessary to avoid the mechanism being at or close to the singularity [10], a position in which the transmission performance of the mechanism is reduced. Therefore, it is important to control the rhombus links away from the two limit positions of parallel and vertical [10] during the movement. The position of rhombus links (Fig. 9) depends on the rhombus angle α. Using the mechanism for $t = 3...48$ ds, the corresponding angle is $\alpha = 40…175$º. Within the range of these angle positions singularities would be avoided.

Then the maximum displacement, velocity and acceleration values will be reduced to 0.65 m, 0.55 m·s^{-1} and 0.10 m·s^{-2} accordingly. By changing the input parameters, it is possible using this Mathcad calculation method to obtain the values of the kinematic parameters for other size mechanisms.

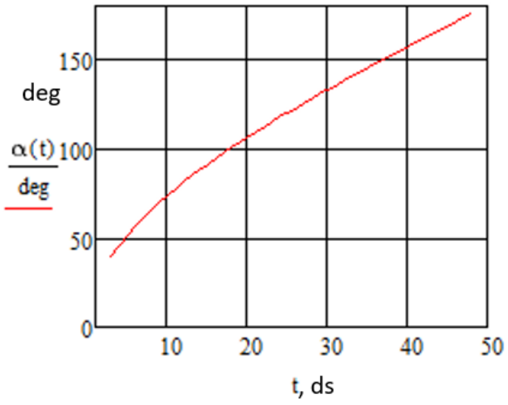

Fig. 9. **Rhomb angle in dependence of time**

Conclusions

1. Kinematic parameters as displacement, velocity and acceleration of the upper output link of the sprayer boom were determined using the Mathcad program for an idealized mechanism ignoring friction.
2. Maximum displacement, velocity and acceleration values were 1 m, 0.985 $m \cdot s^{-1}$ and 0.508 $m \cdot s^{-2}$.
3. Within the range of the angle α = 40…175 deg, position singularities would be avoided.
4. For the angle α = 40…175 deg, the maximum displacement, velocity and acceleration values will be reduced to 0.65 m, 0.55 $m \cdot s^{-1}$ and 0.10 $m \cdot s^{-2}$ accordingly.
5. By changing the input parameters, it is possible using this Mathcad calculation method to obtain the values of the kinematic parameters for other size mechanisms.

Author contributions

Conceptualization, E.K.; methodology, E.K.; software, M.S.; validation, M.S.; formal analysis, M.S.; investigation, E.K. and M.S.; writing – original draft preparation, E.K.; writing – review and editing, M.S. and E.K.; visualization, M.S. All authors have read and agreed to the published version of the manuscript.

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