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Cartridge Lifting Mechanism

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Abstract The paper gives a basic division of planar mechanisms especially lifting mechanisms. It deals with the analysis of the lifting mechanism of a cartridge. The mechanism is first analyzed analytically using the vector method. The equations of the motion are assembled. Subsequently, the lifting mechanism model is simulated in MSC Adams. The result of the analysis is the graphical representation of calculated kinematic quantities, their dependencies and the evaluation of the results.

Keywords: *planar mechanism, equation of motion, analytic analysis, vector method, computer simulation*

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1. Introduction

A huge amount of material, either new or re-used, has to be loaded into the melting furnaces in the high-pressure die-casting plant during continuous operation. It is quite difficult for a worker to do this. As a consequence replacing this activity introduces a lifting mechanism that makes the process more efficient. The cartridge of the lifting mechanism is filled continuously by a forklift, as the mechanism is on a platform approximately one meter high and works semi-automatically with participation of a worker. When the cartridge is full, the worker lowers the mechanism to the unloading position and if necessary directs the material by the appropriate tools to the melting furnace opening. It is very important that the cartridge position is correct and the material moves in the right direction. The kinematic analysis of the cartridge lifting mechanism is therefore performed.

Firstly we present the division of different mechanisms and an overview of methods of analytic analysis of their kinematics. The most suitable approach is then selected for the subsequent analysis. Computer simulation in MSC Adams is then carried out. The results of both approaches are then compared and evaluated.

2. Mechanisms

By a mechanism we mean a mechanical device that is used either to transfer forces or to transform the movement (i.e., to change one type of motion to another).

Mechanisms of various kinds are known [1]. Different machines and devices use different kinds of mechanisms but their basic functions are the same [2].

2.1. Planar Mechanisms

Two members which are in contact and can move relative to each other form a kinematic pair [3]. The contact of the members can be in a point, a curve or a surface. These are also the elements of the pair. There are so called lower kinematic pairs (the contact of the members is an area) and higher (the contact is in form of a point or a curve).

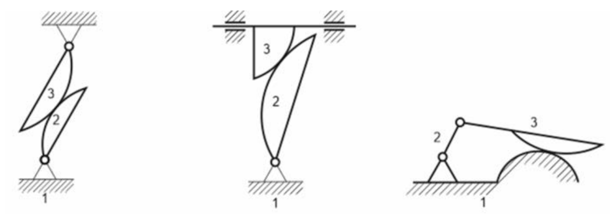

Figure 1. Three-member mechanisms

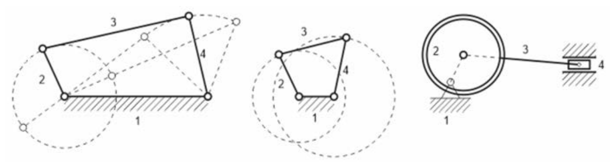

Figure 2. Four-member mechanisms

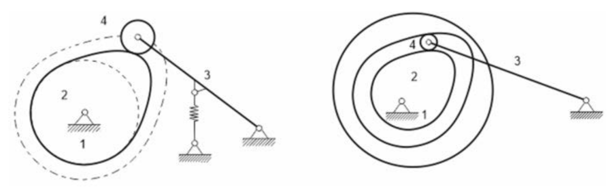

Figure 3. Cam mechanisms

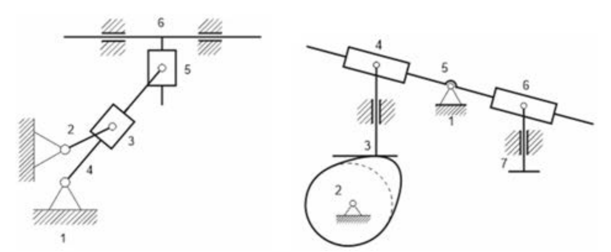

Figure 4. a) Slot mechanism with a characteristic rapid reverse motion of the member 6, b) kinematic diagram of the OHV mechanism

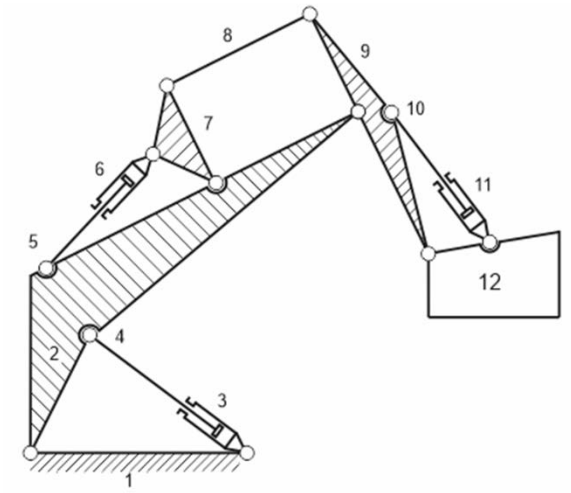

Figure 5. Hydraulic Excavator Mechanism

The planar kinematic pairs include rotary, sliding, rolling and general pairs. Different types of mechanisms are showed in (Figure 1), (Figure 2) and (Figure 3) [4].

Composite mechanisms with different applications are in (Figure 4) and (Figure 5) [5].

2.2. Lifting Mechanisms

Some types of planar lifting mechanisms are shown next - the hydraulic lifting mechanism of a truck (Figure 6), the tilting mechanism driven by a hydraulic cylinder (Figure 7) and the mechanism of a load-moving device (Figure 8) [6,7].

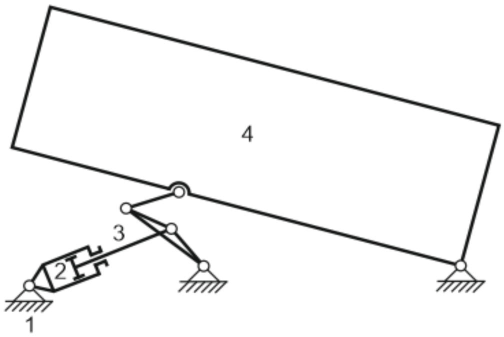

Figure 6. Hydraulic lifting mechanism of a truck

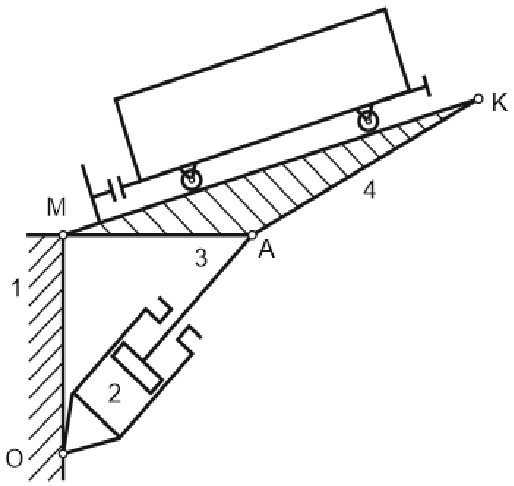

Figure 7. Tilting mechanism driven by hydraulic cylinder

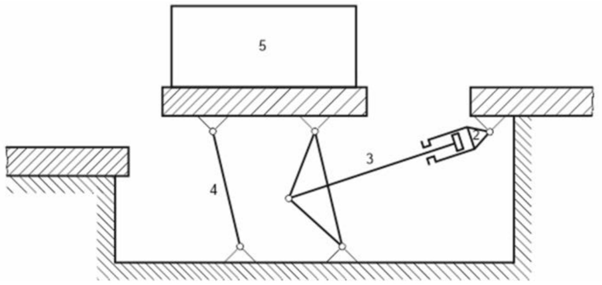

Figure 8. Mechanism of a load-moving device

2.3. Cartridge Lifting Mechanism

The goal is to solve the movement of the cartridge center of gravity and the overall movement of the lifting mechanism as shown in the following (Figure 9) and (Figure 10).

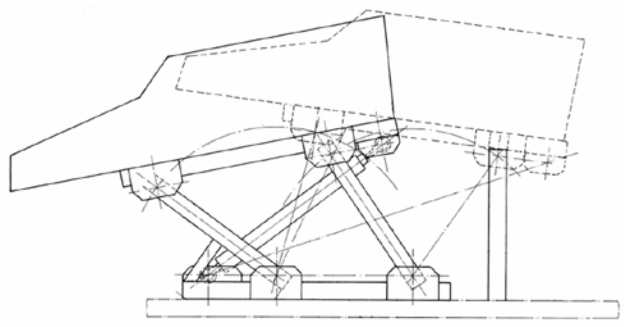

Figure 9. Cartridge lifting mechanism used in production

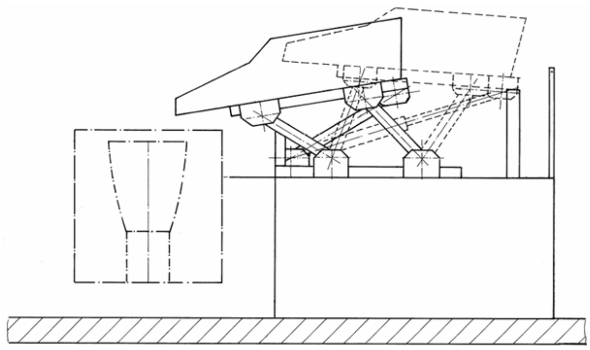

Figure 10. The lifting mechanism in the position when the material is loaded into the melting furnace

3. Analytic Analysis

Kinematic analysis of a mechanism describes the motion of each member and its characteristic points resulting of the movement of the driven members [8].

It is necessary to determine the dependency of position, speed and acceleration of the examined members and points on the position of the driven members or on time, and other dependencies derived from them [4]. The analytic analysis is carried out on a planar lifting mechanism (Figure 10).

3.1. Vector Method

The vector method is a general method that is useful for kinematic investigation of planar mechanisms. This method characterizes the kinematic scheme of the mechanism by means of vector polygons and thus provides general guidance on how to proceed to equations describing the position, velocity and acceleration of the mechanism [4].

If the mechanism is simple it is described by one vector polygon. In case of complex ones, several polygons are required [5]. The individual sides of the polygon are vectors oriented one after the other so that the closure condition for the polygon stands.

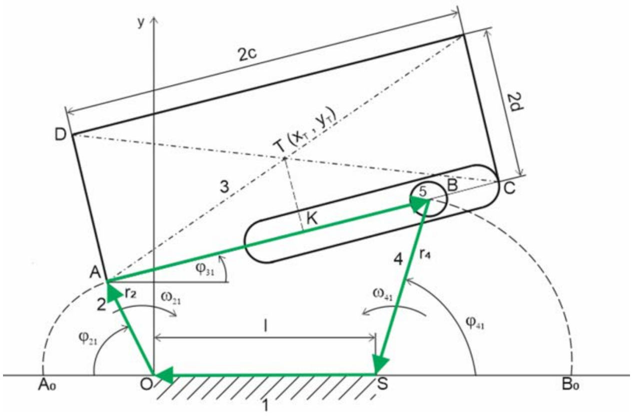

Figure 11. Schema of the lifting mechanism

After defining the vectors in the graphical model of the mechanism (Figure 11) and the vector polygons, vector equations are then created [9]. These are then rewritten into two scalar equations. Then a substitution is introduced which simplifies the solution and makes it more transparent. First we determine the angle of rotation of the cartridge φ_{31}, mark the length AB = l^*. The lifting mechanism has 2 degrees of freedom. Analysis is based on the OABS shape closure condition.

For the polygon (Figure 11) the vector equation applies:

$$\overline{OA} + \overline{AB} + \overline{BS} + \overline{SO} = \overline{0} \qquad (1)$$

Rewriting the vector equation in the x and y axes:

$$-r_2 \cos\phi_{21} + l^* \cos\phi_{31} - r_4 \cos\phi_{41} - l = 0 \qquad (2)$$

$$r_2 \sin\phi_{21} + l^* \sin\phi_{31} - r_4 \sin\phi_{41} = 0. \qquad (3)$$

We need to specify the angle φ_{31}, so we transform the equations as follows:

$$l^* \cos\phi_{31} = l + r_4 \cos\phi_{41} + r_2 \cos\phi_{21} \qquad (4)$$

$$l^* \sin\phi_{31} = r_4 \sin\phi_{41} - r_2 \sin\phi_{21}. \qquad (5)$$

By modification:

$$l^{*2} \left(\cos\phi_{31}\right)^2 = \left(l + r_4 \cos\phi_{41} + r_2 \cos\phi_{21}\right)^2 \qquad (6)$$

$$l^{*2} \left(\sin\phi_{31}\right)^2 = \left(r_4 \sin\phi_{41} - r_2 \sin\phi_{21}\right)^2. \qquad (7)$$

And after addition:

$$l^* = \sqrt{\begin{bmatrix} \left(l + r_4 \cos\phi_{41} + r_2 \cos\phi_{21}\right)^2 \\ + \left(r_4 \sin\phi_{41} - r_2 \sin\phi_{21}\right)^2 \end{bmatrix}}. \qquad (8)$$

From equations (4) and (5) we determine the angle φ_{31}.

For determination of the position of the center of gravity the vector equation applies:

$$\overline{OA} + \overline{AK} + \overline{KT} = \overline{TO}. \qquad (9)$$

Rewriting the vector equation in the x and y axes:

$$x_T = -r_2 \cos\phi_{21} + c \cos\phi_{31} - d \sin\phi_{31} \qquad (10)$$

$$y_T = r_2 \sin\phi_{21} + c \sin\phi_{31} + d \cos\phi_{31}. \qquad (11)$$

There are the equations (10) and (11) of center of gravity positions x_T and y_T. The location of the cartridge center in time (t=1 second) is in (Table 5). After derivation we obtain the equations of x and y components of the velocities and the acceleration of the center of gravity in (Table 5) [5].

4. Computer Simulation

MSC Adams gives engineers the opportunity of verifying the design on a computer model reducing design cost and increasing work efficiency [12]. This simulation can evaluate and control complex interactions between bodies including their movement [10]. The modeling of the mechanism and the evaluation of the results are shown in successive steps in the following chapters.

4.1. Modeling of the Mechanism

We simulated the mechanism according to its exact dimensions. First we created the cranks 2 and 4 (Figure 11a), then the roller and finally the cartridge which consists of three smaller parts (Figure 12b).

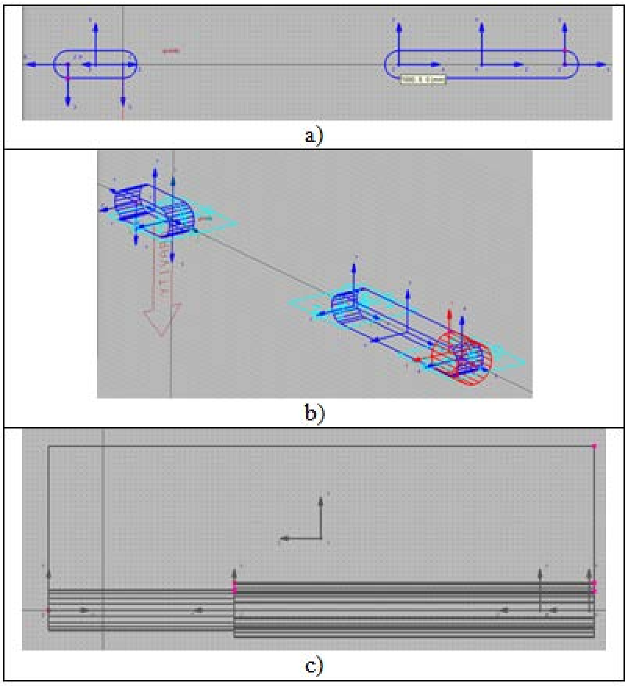

Figure 12. Modeling steps

We used rotational and sliding links to connect the respective parts (Figure 13a,b). Finally we defined the actuators (Figure 13c) and verified the model [11].

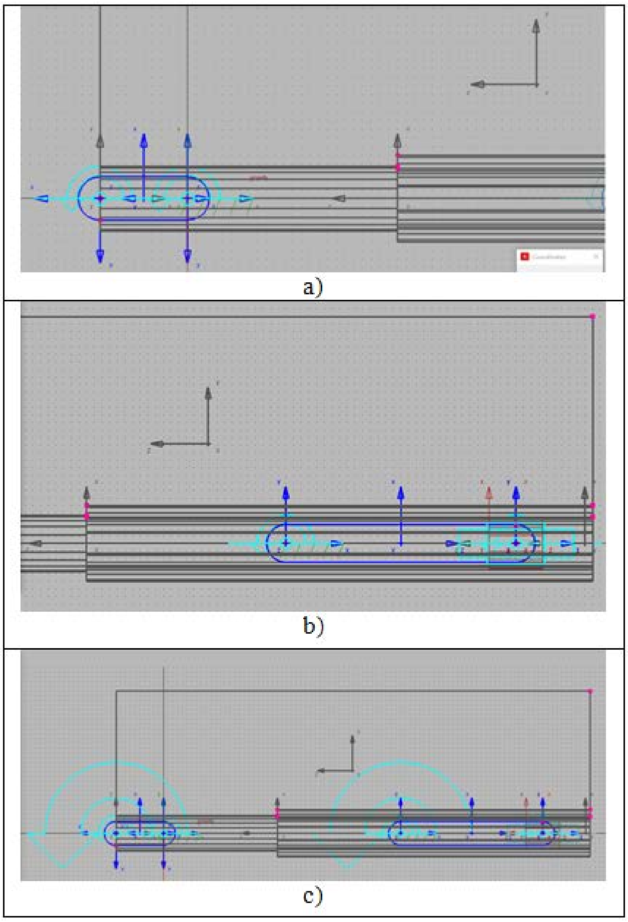

Figure 13. Modeling steps

The mechanism performed the predicted motion. As an example we are giving an overview of some modeling steps in picture (Figure 14a, b).

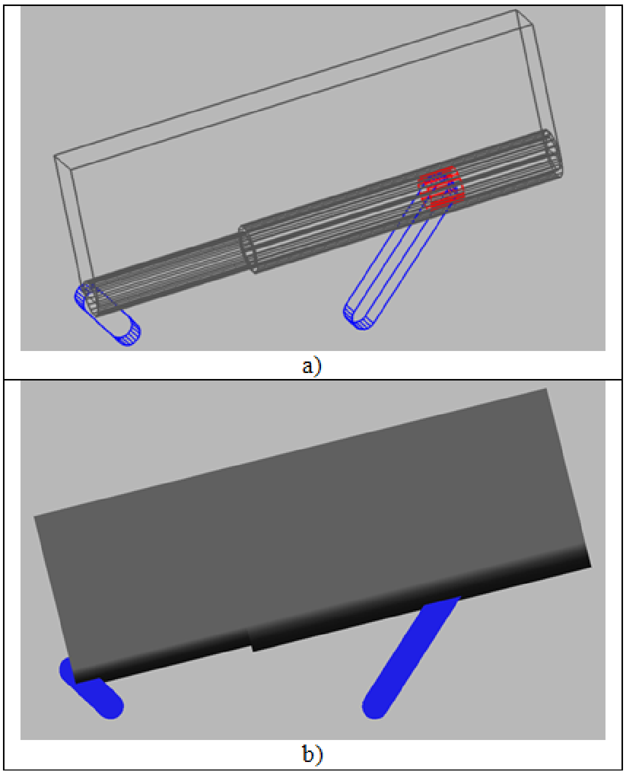

Figure 14. Model of the mechanism

5. Simulation Results

Numerical results of the simulation can be acquired from the model by using so called “meters”. They provide the kinematic and dynamic quantities in respective members of the model. These quantities for selected model parts are shown in the following picture (Figure 15).

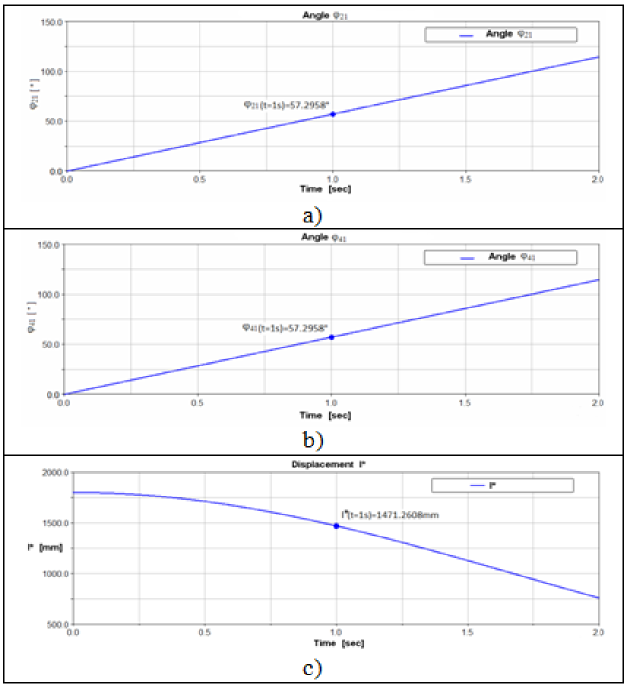

Figure 15. Rotations and distances a) angle of crank 2, b) angle of crank 4, c) displacement *l**

Our goal is to investigate the movement of the center of gravity of the cartridge. After inserting the appropriate meter we obtain its position, velocity and acceleration. Respective quantities are shown in the picture (Figure 16).

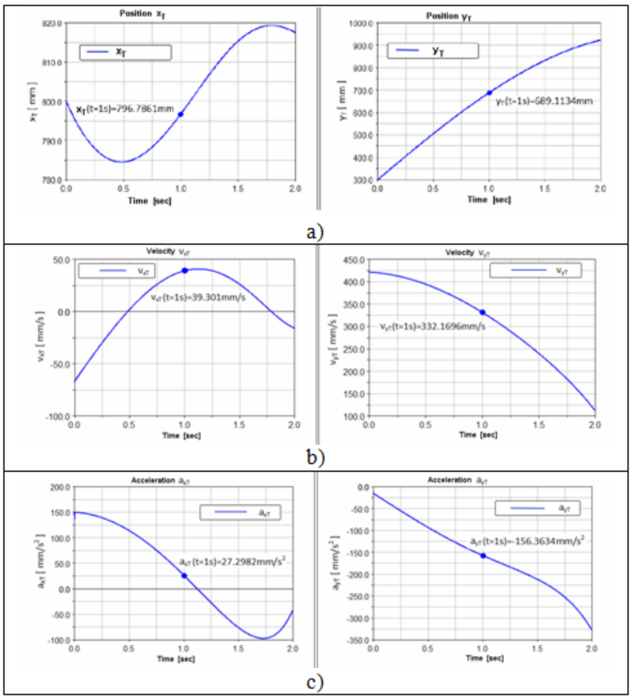

Figure 16. The result parameters a) position x_T and y_T, b) velocity v_{xT} and v_{yT}, c) acceleration a_{xT} and a_{yT}

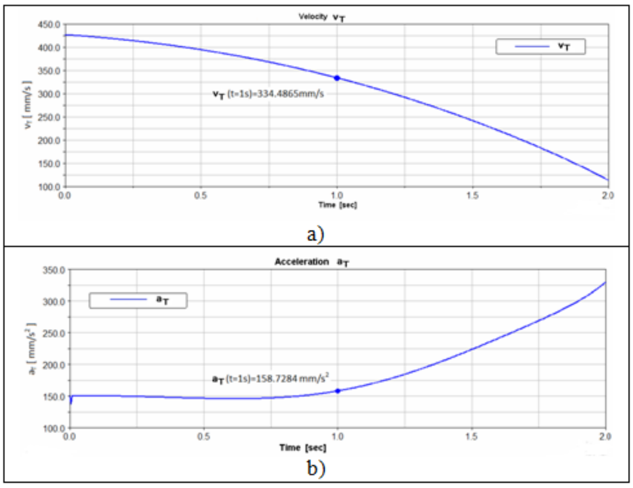

Figure 17. The result parameters a) velocity v_T, b) acceleration a_T

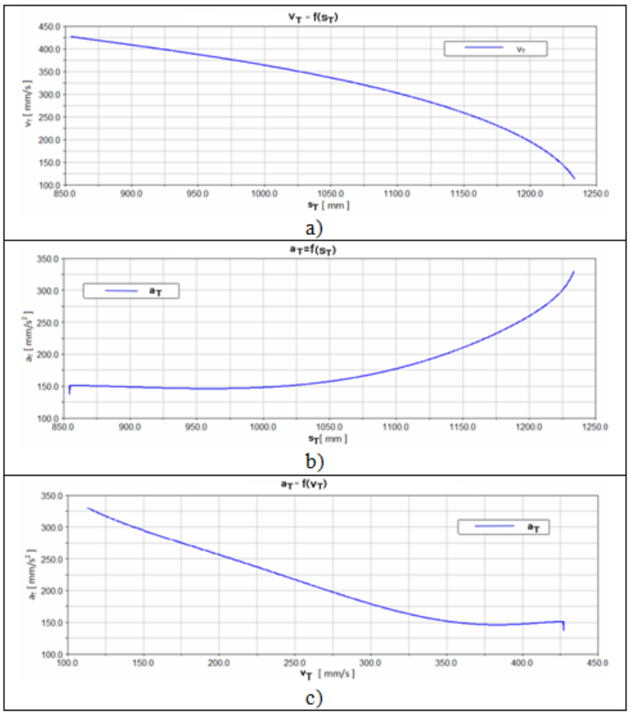

Figure 18. The result parameters a) velocity v_T=f(s_T), b) velocity a_T=f(s_T), c) acceleration a_T=f(v_T)

Table 1. Results of the computer simulation

Time [sec]	Angle φ_{21} [°]	Angle φ_{41} [°]	Position x_T [mm]	Position y_T [mm]	AB=l* [mm]
0.0	0.0	0.0	800.0	300.0	1800.0
0.1	5.7296	5.7296	794.0833	342.1216	1796.4472
0.2	11.4592	11.4592	789.6463	383.9359	1785.8223
0.3	17.1887	17.1887	786.6403	425.2842	1768.2248
0.4	22.9183	22.9183	784.9927	466.0098	1743.8197
0.5	28.6479	28.6479	784.6079	505.9596	1712.8353
0.6	34.3775	34.3775	785.3679	544.9854	1675.5605
0.7	40.1070	40.1070	787.1335	582.9453	1632.3418
0.8	45.8366	45.8366	789.7456	619.7038	1583.5791
0.9	51.5662	51.5662	793.0273	655.1334	1529.7214
1.0	57.2958	57.2958	796.7861	689.1134	1471.2608

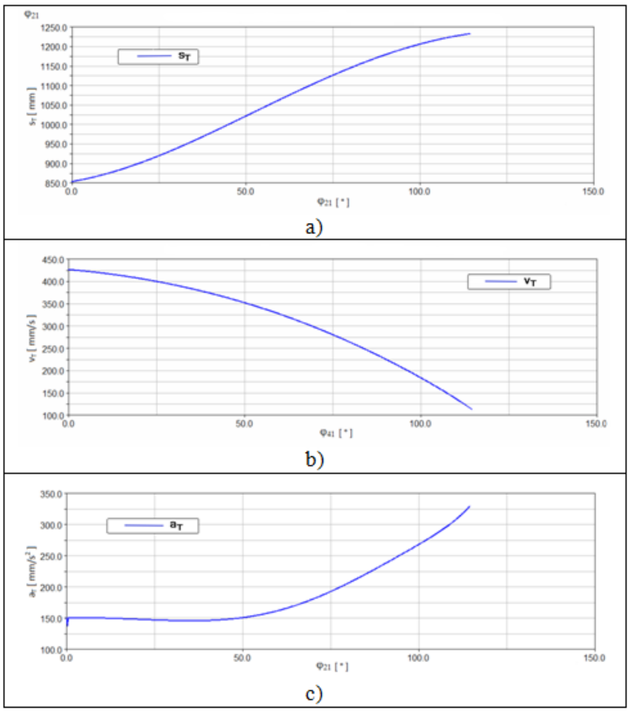

Figure 19. The result parameters a) position s_T=f(φ_{21}), b) velocity v_T=f(φ_{41}), c) acceleration a_T=f(φ_{21})

Table 2. Results of the computer simulation

Time [sec]	Velocity v_{xT} [mm/s]	Velocity v_{yT} [mm/s]	Velocity v_T [mm/s]
0.0	-66.6667	422.2222	427.453
0.1	-51.7071	419.9459	423.1172
0.2	-37.1139	416.077	417.729
0.3	-23.1274	410.6287	411.2795
0.4	-9.9828	403.6292	403.7526
0.5	2.0917	395.1213	395.1268
0.6	12.8777	385.1604	385.3756
0.7	22.1697	373.812	374.4688
0.8	29.7785	361.1481	362.3737
0.9	35.5361	347.2434	349.057
1.0	39.301	332.1696	334.4865

Table 3. Results of the computer simulation

Time [sec]	Acceleration a_{xT} [mm/s^2]	Acceleration a_{yT} [mm/s^2]	Acceleration a_T [mm/s^2]
0.0	150.6173	-14.8148	151.3441
0.1	148.1680	-30.7368	151.3225
0.2	143.2967	-46.6200	150.6896
0.3	136.0440	-62.2990	149.6300
0.4	126.4698	-77.6201	148.3896
0.5	114.6582	-92.4461	147.2847
0.6	100.7213	-106.6628	146.7029
0.7	84.8043	-120.1855	147.0929
0.8	67.0926	-132.9673	148.9353
0.9	47.8229	-145.0076	152.6900
1.0	27.2982	-156.3634	158.7284

Table 4. Angle, position, velocity and acceleration- results of the computer simulation

φ_{21} [°]	s_T [mm]	v_T [mm/s]	a_T [mm/s^2]
0.0000	854.4004	427.4530	151.3441
10.0841	874.5532	419.1185	150.8883
20.1681	903.6615	407.5012	148.9893
30.0230	938.8252	392.8902	147.0813
40.1070	979.4919	374.4688	147.0929
50.1911	1022.6724	352.3662	151.5925
57.2958	1053.4446	334.4865	158.7284
60.0460	1065.2564	327.0388	162.5086
701300	1107.2993	297.1644	181.3313
80.2141	1146.0351	263.2099	207.0333
90.0690	1179.1841	226.0722	236.4874
100.153	1206.9493	183.8742	268.7267
110.0079	1227.016	137.4597	305.5352
114.5916	1233.7571	113.1598	330.2312

5.1. Result Evaluation

Simulation in MSC Adams and results processing gave us the specific values which represent the movement of the center of the cartridge (Table 5).

The cranks 2 and 4 perform a rotary motion around the points we have defined and they rotate at the same angular speed. The roller (member 5) performs a sliding motion in the hollow cylinder that is part of the cartridge. The movement of the cartridge is composed of two rotating and one sliding movement. We've found that the cartridge's center of gravity performs an accelerated movement along a curve. Both the velocity (Tab.2) and acceleration (Tab.3) components in the y-axis direction are larger than the velocity and acceleration components in the x-axis direction, so it is obvious that the cartridge is more lifted than shifted. The fact that the cartridge is lifted follows from comparison of the coordinates x_T and y_T of the initial state and the state in the investigated position.

Table 5. Results of the analytic and computer simulation

Analytic solution	Solution in MSC Adams
x_T=796.7861121 [mm]	x_T=796.7861 [mm]
y_T=689.1134346 [mm]	y_T=689.1134 [mm]
v_{xT}=39.29930507 [mm/s]	v_{xT}=39.301 [mm/s]
v_{yT}=332.1686167 [mm/s]	v_{yT}=332.1696 [mm/s]
v_T=334.485314 [mm/s]	v_T=334.4865 [mm/s]
a_{xT}=27.29661494 [mm/s^2]	a_{xT}=27.2982 [mm/s^2]
a_{yT}=-156.3634126 [mm/s^2]	a_{yT}=-156.3634 [mm/s^2]
a_T=158.7281386 [mm/s^2]	a_T=158.7284 [mm/s^2]

6. Conclusion

We investigated the movement of the center of gravity and the overall movement of the lifting mechanism. The solution was accomplished by two methods, analytically and by computer simulation. The vector method was used as an analytic method. The computer simulation was performed by MSC Adams. The results of the simulation are presented in form of graphs and tables with quantities of the investigated model parts.

The results of both solutions match. The simulation in MSC Adams is however faster and so more effective.

Acknowledgements

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