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PLANAR KINEMATICS ANALYSIS METHOD OF SEVEN-BAR MECHANISM USING VECTOR LOOPS AND THE VERIFICATION OF RESULTS EXPERIMENTALLY

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ABSTRACT
Planar kinematics analysis is based on vectorial algebra. First is required to describe vectorial & scalar equations for each simple planar mechanisms, either closed-chain or open-chain. Solution of vectorial/scalar equations is done using MathCAD software. Results are verified experimentally using Working Model 2D software.
Keywords: mechanism, kinematics, vectorial, scalar, loop.

1. INTRODUCTION
Kinematics study of mechanisms using plans and graphic methods is known that permissive error which is around 1%. To avert this error is required use of analytic methods, especially for dynamic study of smart mechanisms, where error is not allowed. In despite of hard work during calculations which are required for analytic study, for smart mechanisms this method is required. Except that, using analytic method can be achieved required exactness, which can't be arrived using other two methods.
Usually, by using analytic study is determined relations of kinematics parameters of guided and guide links.
Methods for analytic study are too many, but in view are presented only method of vectors loop for planar mechanism.

2. USING OF VECTORS LOOP OF MECHANISM
This represents one general study method, which is based on vectorial algebra. Based on this method, start & end connection points of each link represent the vectors with length same as link have, direction is determined according in the motion of mechanism.
In view is represented example of usage of this method for seven-bar mechanism.

Basic data of links of mechanism (Figure 1):

O_2A=40 *mm*; O_5C=84 *mm*; BP=117 *mm*; AB=172 *mm*;

BD=240 *mm*; R_{w2}=59 *mm*; R_{w5}=118 *mm*; CB=177 *mm*;

AP=111 *mm*;

Driver motion: $\theta_2 = \pi \cdot t + \pi \cdot (1 + 22/180)\ rad$.

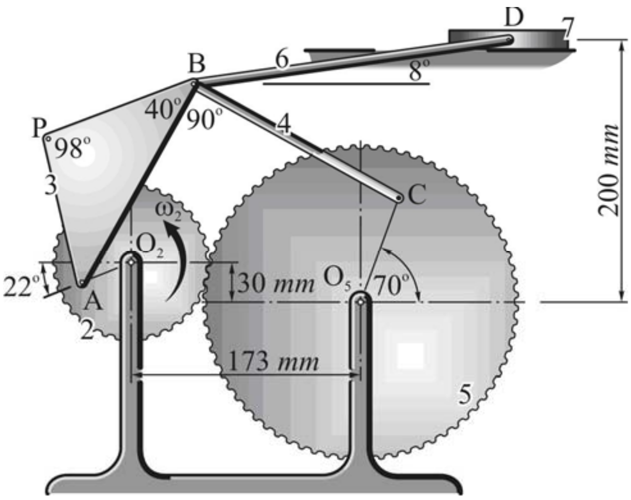


Figure 1. Seven-bar planar mechanism

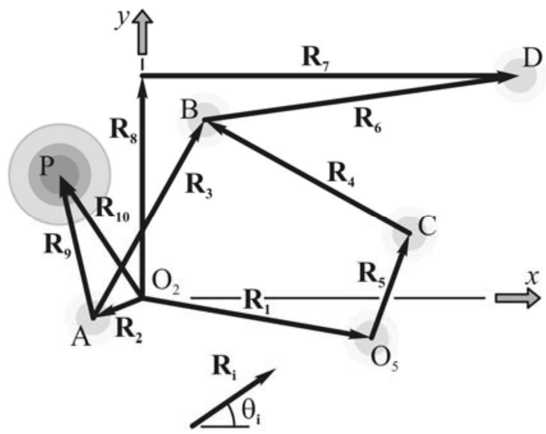


Figure 2. Scheme of vectors loop

In Fig. 2 can be seen three vector loops which represent three vectorial equations, as in view:

$$\mathbf{R_2} + \mathbf{R_3} = \mathbf{R_1} + \mathbf{R_5} + \mathbf{R_4}\,; \tag{1}$$

$$\mathbf{R_2} + \mathbf{R_3} + \mathbf{R_6} = \mathbf{R_7} + \mathbf{R_8}\,; \tag{2}$$

$$\mathbf{R_2} + \mathbf{R_9} = \mathbf{R_{10}}; \tag{3}$$

Hence, are presented components of equations (1), (2) and (3) in horizontal (x) and vertical (y) direction:

$$\left.\begin{aligned} R_2\cos\theta_2 + R_3\cos\theta_3 &= R_1\cos\theta_1 + R_5\cos\theta_5 + R_4\cos\theta_4 \\ R_2\sin\theta_2 + R_3\sin\theta_3 &= R_1\sin\theta_1 + R_5\sin\theta_5 + R_4\sin\theta_4 \end{aligned}\right\} \tag{4}$$

$$\left.\begin{aligned} R_2\cos\theta_2 + R_3\cos\theta_3 + R_6\cos\theta_6 &= R_7 \\ R_2\sin\theta_2 + R_3\sin\theta_3 + R_6\sin\theta_6 &= R_8 \end{aligned}\right\} \tag{5}$$

$$\left.\begin{aligned} R_2\cos\theta_2 + R_9\cos\theta_9 &= R_{10}\cos\theta_{10} \\ R_2\sin\theta_2 + R_9\sin\theta_9 &= R_{10}\sin\theta_{10} \end{aligned}\right\} \tag{6}$$

From system of equations (4), (5) and (6) can be found all required expressions for positional analysis of mechanism.
Using first and second derivative of equations (4), (5) and (6) can be found required velocities and accelerations of characteristic points and links of mechanism.

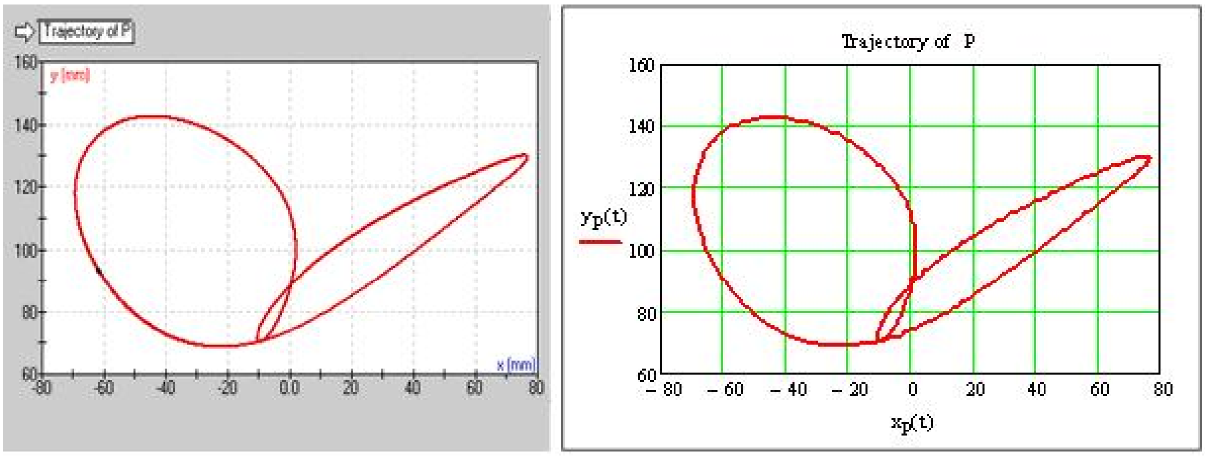
3. USING OF SOFTWARE'S WORKING MODEL 2D AND MATHCAD FOR SEVEN-BAR MECHANISM

3.1. Results – graphic diagrams

After is obtained system which describe the motion of mechanism, required kinematics parameters can be solved using MathCAD software, e.g. motion of arbitrary point P in one full circle. For point P are represented trajectory, velocity and acceleration diagram.
Results are verified in Working Model 2D.
Based on Figure 2 position of point P in data mechanism is:
$x_P(t) = R_{10}(t)\cdot\cos(\theta_{10}(t))$ and $y_P(t) = R_{10}(t)\cdot\sin(\theta_{10}(t))$

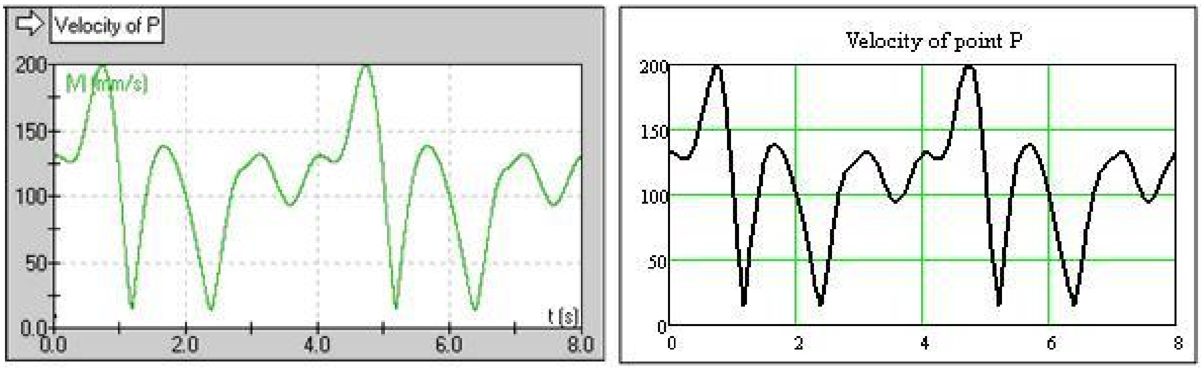
where: $R_{10}(t)$ and $\theta_{10}(t)$ can be found from equations (6).
Velocity and acceleration is calculated using firs and second derivatives of position:

$$v_P(t)=\sqrt{\left(\frac{d}{dt}x_P(t)\right)^2+\left(\frac{d}{dt}y_P(t)\right)^2}\ ,\quad a_P(t)=\sqrt{\left(\frac{d^2}{dt^2}x_P(t)\right)^2+\left(\frac{d^2}{dt^2}y_P(t)\right)^2}$$



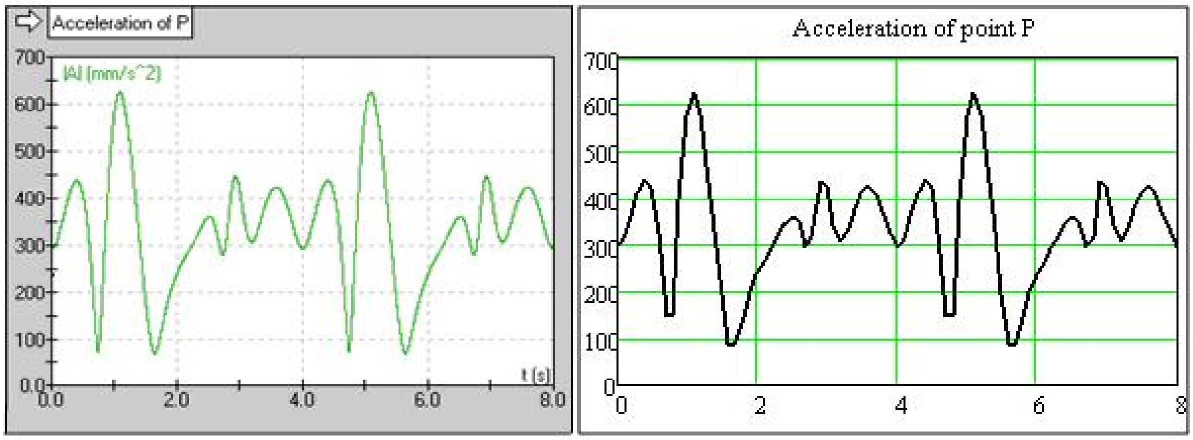
Working Model 2D *MathCAD*

Figure 3. Trajectory of point P



Working Model 2D *MathCAD*

Figure 4. Velocity of point P



Working Model 2D *MathCAD*

Figure 5. Acceleration of point P

3.2. Numerical Results

For comparisons of used software's in Table 1 are represented numerical results for two full circles.

Table 1. Results of kinematics parameters in MathCAD and Working Model 2D

t [s]	MathCAD				Working Model 2D			
	$x_P(t)$	$y_P(t)$	$v_P(t)$	$a_P(t)$	$x_P(t)$	$y_P(t)$	$v_P(t)$	$a_P(t)$
0	-61.516	93.277	130.695	293.43	-61.515	93.277	9.369	293.431
0.001	-61.448	93.165	130.729	293.363	-61.447	93.165	130.729	293.362
1	68.750	121.387	118.926	572.083	68.75	121.386	118.927	572.066
2	0.989	89.267	102.900	235.336	0.989	89.267	102.902	235.329
3	-2.826	118.579	127.406	423.857	-2.826	118.578	127.407	423.903
4	-61.516	93.277	130.695	293.430	-61.515	93.277	130.695	293.429
5	68.750	121.387	118.926	572.083	68.75	121.386	118.927	572.066
6	0.989	89.267	102.900	235.336	0.989	89.267	102.902	235.329
7	-2.826	118.579	127.406	423.857	-2.826	118.578	127.407	423.903
8	-61.516	93.277	130.695	293.430	-61.515	93.277	130.695	293.429

4. CONCLUSIONS

Based on results can be concluded that Working Model in comparison with MathCAD need less time and less **theoretical knowledge's** to have exact results of any engineering models generally, especially any 2D or 3D model of mechanisms.

From Table 1, we see difference on results (especially velocity in start for t=0). Difference shows advantage of use of Working Model, because results from this software are **more realistic** in comparison with results from MathCAD which are theoretical – ideal, received by strict calculations.

In second circle, motion of mechanism is stabilized. Results from both software's are identically.

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