UDC 004.4
DOI: 10.25140/2411-5363-2018-4(14)-84-94

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MULTIBODY SYSTEMS AND SIMULATION IN MATLAB

Urgency of the research. *Computer modeling changes the teaching methodology, the way of thinking and the possibilities of applications. It helps to move from external to internal properties and from individual to related properties. The development of the product is accelerated by experimenting with a computer model.*

Target setting. *Kinematic analysis in Matlab and MSC Adams View. The aim is to investigate the rotation of individual members of the robotic system and to determine the spatial movement of the end effector.*

Actual scientific researches and issues analysis. *MSC Adams represents dynamic simulators of virtual prototypes of mechanical systems. Virtual prototypes allow to model, analyze and optimize the future products and to examine their properties before building a real prototype. This approach is suitable for developing miniature mechatronic elements as well as complex systems.*

Uninvestigated parts of general matters defining. *Virtual prototypes represent a suitable resource for testing of control and regulation procedures.*

The research objective. *Compilation of a virtual prototype of a mechanical system that has all the decisive features and is computationally stable.*

The statement of basic materials. *Virtual model is a mathematical representation of real-world structures, simulating all its physical properties virtually.*

Conclusions. *The aim was to determine the kinematic properties and also to evaluate the influence of the parameters of the mechanism which influence these kinematic properties. The matrix method was used. The process of the solution consisted of determining the transformation matrices of the coordinate systems, the kinematic analysis of the industrial robot and the graphical representation of the effector handling space.*

Keywords: *virtual model; open kinematic chain; robotic system; software simulation; end-effector; transformation matrices.*

Fig.: 11. References: 17.

Introduction. The development of technology and mechanization has led to the development of the theory of planar and spatial mechanisms. Spatial mechanisms are used in various production machines, for example, in robots and manipulators. Analytical analysis of mechanisms describes the movement of driven members or some points of these members depending on the known or prescribed movement of the driving members. It means the determination of the position, speed and acceleration of the studied members and points depending on the movement of the driving member. It is possible to use the vector method for kinematic solution of spatial mechanisms, which was described by V. A. Zinovev. This method, however, is quite complicated for scalar notation of vector equations. More suitable is the usage of the matrix notation. The fourth order matrices were introduced by J.Denavit and R.S.Hartenberg. Similarly, G.S.Kalicin solved some problems of planar and spherical mechanisms by the matrix notation. The possibility of using quaternions or biquaternions in kinematics of the rigid bodies was pointed out by J. Novák. General methods of analytical analyses were studied by S.G. Kislicin and J. F. Moroshkin. The czech author V. Brat introduced into practice the usage of a matrix notation in analysis of kinematics of spatial mechanisms. Individual simultaneous movements can be described by matrix equations. There are relationships derived for both simple and simultaneous movements. The suitability and widespread usage of the matrix method is given not only by the possibility to describe the directly the space of the individual members, but it is also appropriate for use in computers with advanced methods of numerical solution of systems of equations.

This paper presents the application of the matrix method in the kinematic analysis of a simple manipulator model. Manipulators are composed of open kinematic chains. Matlab and MSC Adams -View computer programs were used in their analysis.

Model of manipulator with 2 degrees of freedom of movement R-R.

The mechanical system representing the open kinematic chain consists of two members 2 and 3 and the base 1 (Fig. 1). The member 2 with length l_2 rotates around the axis $z_1 \equiv z_2$ by the angle φ_2 and the member 3 with length l_3 rotates around the axis z_3 by the angle φ_3. We investigate the absolute motion of the member 3 and its point M, determine the position

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vector $\mathbf{r}_{1M}$ (position of the point M relative to the base 1) using the matrix method, using the transformation matrices of the basic movements. We also express the velocity $\mathbf{v}_{1M}$ and the acceleration $\boldsymbol{a}_{1M}$ of point M relative to the base 1.

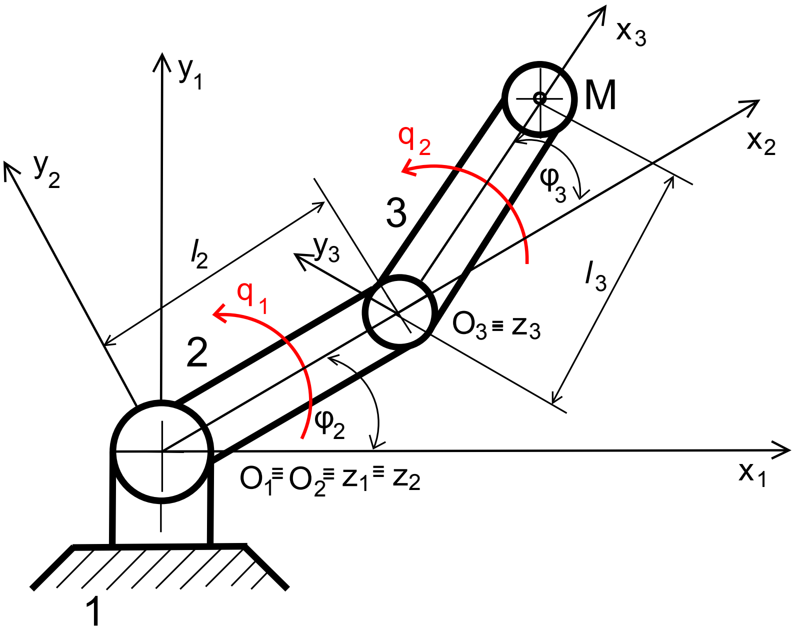


Fig. 1. Coordinate systems of the manipulator with 2 DOF ($q_1=\varphi_2$, $q_2=\varphi_3$)

We introduce the coordinate systems of individual members (Fig. 1). The movement of the member 2 with respect to the base 1 is rotational, the coordinate system O_2, x_2, y_2, z_2 of the member 2 is rotated with respect to the base coordinate system O_1, x_1, y_1, z_1 by the angle φ_2 around the base axis while $z_1 \equiv z_2$. The coordinate system O_3, x_3, y_3, z_3 of the member 3 is shifted by the length of the first element l_2 along the x_2 axis and rotated by angle φ_3 around the z_3 axis. Generalized coordinates for rotational movement of members are: $q_1=\varphi_2$ and $q_2=\varphi_3$. We search: $\mathbf{r}_{1M}$, $\mathbf{v}_{1M}$, $\boldsymbol{a}_{1M}$.

The motion of the member 3 with respect to the base 1 is determined by the movement of the point M and described by the equation:

$$\mathbf{r}_{1M} = \prod_{i=1}^{2} \mathbf{T}_{i,i+1} \cdot \mathbf{r}_{3M} \tag{1}$$

the relative spherical motion is described by the transformation matrix:

$$\mathbf{T}_{13} = \prod_{i=1}^{2} \mathbf{T}_{i,i+1} \tag{2}$$

The matrix equation of the trajectory of the point M relative to the coordinate system of the base 1 is:

$$\mathbf{r}_{1M} = \mathbf{T}_{12} \cdot \mathbf{T}_{23} \cdot \mathbf{r}_{3M} \tag{3}$$

where:

$$\mathbf{T}_{12} = \mathbf{T}_{Z6}(\varphi_2) \tag{4}$$

$$\mathbf{T}_{23} = \mathbf{T}_{Z6}(\varphi_3)\,\mathbf{T}_{Z1}(l_2) \tag{5}$$

and:

$$\mathbf{r}_{3M} = \begin{bmatrix} l_3 & 0 & 0 & 1 \end{bmatrix}^T \tag{6}$$

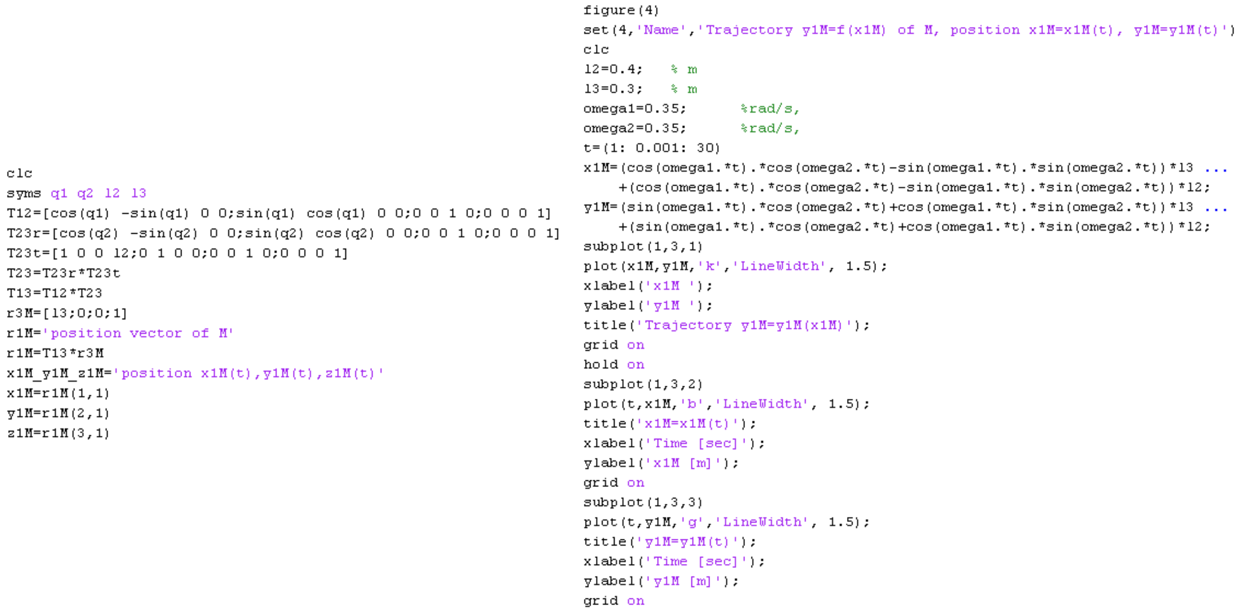
then

$$\mathbf{r}_{1M}=\mathbf{T}_{12}\cdot\mathbf{T}_{23}\cdot r_{3M}=\mathbf{T}_{Z6}\left(\varphi_2\right).\ \mathbf{T}_{Z6}\left(\varphi_3\right).\mathbf{T}_{Z1}\left(l_2\right).\mathbf{r}_{3M}=$$
$$=\begin{bmatrix} c\ \varphi_2 & -s\ \varphi_2 & 0 & 0\\ s\ \varphi_2 & c\ \varphi_2 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix} c\ \varphi_3 & -s\ \varphi_3 & 0 & 0\\ s\ \varphi_3 & c\ \varphi_3 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix} 1 & 0 & 0 & l_2\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix} l_3\\ 0\\ 0\\ 1\end{bmatrix}=$$
$$=\begin{bmatrix} c\,\varphi_2\,c\,\varphi_3-s\,\varphi_3\,s\,\varphi_3 & -c\,\varphi_2\,s\,\varphi_3-s\,\varphi_2\,c\,\varphi_3 & 0 & c\,\varphi_2\,c\,\varphi_3\,l_2-s\,\varphi_2\,s\,\varphi_3\,l_2\\ s\,\varphi_2\,c\,\varphi_3+c\,\varphi_2\,s\,\varphi_3 & -s\,\varphi_2\,s\,\varphi_3+c\,\varphi_2\,c\,\varphi_3 & 0 & s\,\varphi_2\,c\,\varphi_3\,l_2+c\,\varphi_2\,s\,\varphi_3\,l_2\\ 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}\cdot\begin{bmatrix} l_3\\ 0\\ 0\\ 1\end{bmatrix}= \tag{7}$$
$$=\begin{bmatrix}(c\,\varphi_2\,c\,\varphi_3-s\,\varphi_2\,s\,\varphi_3)\,l_3+c\,\varphi_2\,c\,\varphi_3\,l_2-s\,\varphi_2\,s\,\varphi_3\,l_2\\ (s\,\varphi_2\,c\,\varphi_3+c\,\varphi_2\,s\,\varphi_3)\,l_3+s\,\varphi_2\,c\,\varphi_3\,l_2+c\,\varphi_2\,s\,\varphi_3\,l_2\\ 0\\ 1\end{bmatrix}$$

Position vector of point M with respect to the base coordinate system O_1, x_1, y_1, z_1:

$$\mathbf{r}_{1M}=\begin{bmatrix} x_{1M}\\ y_{1M}\\ z_{1M}\\ 1\end{bmatrix}==\begin{bmatrix}(c\,\varphi_2\,c\,\varphi_3-s\,\varphi_2\,s\,\varphi_3)\,l_3+c\,\varphi_2\,c\,\varphi_3\,l_2-s\,\varphi_2\,s\,\varphi_3\,l_2\\ (s\,\varphi_2\,c\,\varphi_3+c\,\varphi_2\,s\,\varphi_3)\,l_3+s\,\varphi_2\,c\,\varphi_3\,l_2+c\,\varphi_2\,s\,\varphi_3\,l_2\\ 0\\ 1\end{bmatrix}. \tag{8}$$

The matlab script (Fig.2a) for the calculation of the position vector in symbolic form and the matlab script (Fig.2b) to determine the trajectory of point M:



```
clc
syms q1 q2 l2 l3
T12=[cos(q1) -sin(q1) 0 0;sin(q1) cos(q1) 0 0;0 0 1 0;0 0 0 1]
T23r=[cos(q2) -sin(q2) 0 0;sin(q2) cos(q2) 0 0;0 0 1 0;0 0 0 1]
T23t=[1 0 0 l2;0 1 0 0;0 0 1 0;0 0 0 1]
T23=T23r*T23t
T13=T12*T23
r3M=[l3;0;0;1]
r1M='position vector of M'
r1M=T13*r3M
x1M_y1M_z1M='position x1M(t),y1M(t),z1M(t)'
x1M=r1M(1,1)
y1M=r1M(2,1)
z1M=r1M(3,1)
```

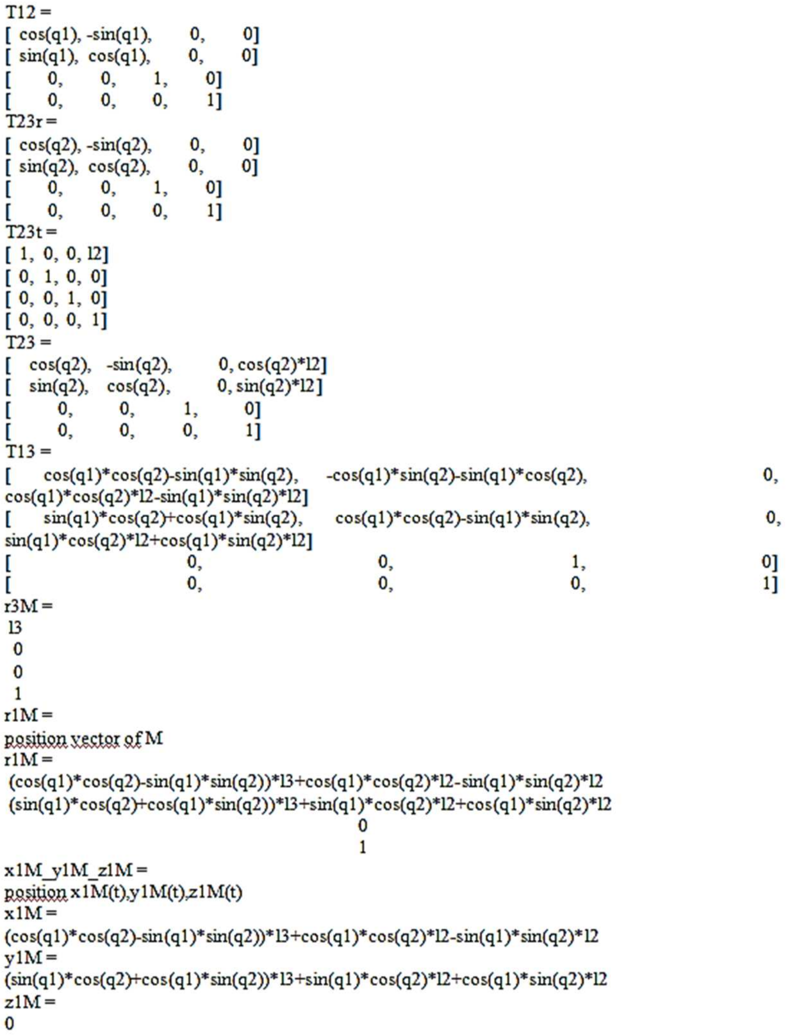
a

```
figure(4)
set(4,'Name','Trajectory y1M=f(x1M) of M, position x1M=x1M(t), y1M=y1M(t)')
clc
l2=0.4;   % m
l3=0.3;   % m
omega1=0.35;      %rad/s,
omega2=0.35;      %rad/s,
t=(1: 0.001: 30)
x1M=(cos(omega1.*t).*cos(omega2.*t)-sin(omega1.*t).*sin(omega2.*t))*l3 ...
    +(cos(omega1.*t).*cos(omega2.*t)-sin(omega1.*t).*sin(omega2.*t))*l2;
y1M=(sin(omega1.*t).*cos(omega2.*t)+cos(omega1.*t).*sin(omega2.*t))*l3 ...
    +(sin(omega1.*t).*cos(omega2.*t)+cos(omega1.*t).*sin(omega2.*t))*l2;
subplot(1,3,1)
plot(x1M,y1M,'k','LineWidth', 1.5);
xlabel('x1M ');
ylabel('y1M ');
title('Trajectory y1M=y1M(x1M)');
grid on
hold on
subplot(1,3,2)
plot(t,x1M,'b','LineWidth', 1.5);
title('x1M=x1M(t)');
xlabel('Time [sec]');
ylabel('x1M [m]');
grid on
subplot(1,3,3)
plot(t,y1M,'g','LineWidth', 1.5);
title('y1M=y1M(t)');
xlabel('Time [sec]');
ylabel('y1M [m]');
grid on
```

b

Fig. 2. M – file for a) position vector of the manipulator r_{1M} ,b) trajectory of the manipulator y_{1M} =y_{1M} (x_{1M}) and position x_{1M} = x_{1M} (t), y_{1M} = y_{1M} (t)

Solution of the position vector r_{1M}, position x_{1M} *and* y_{1M} in symbolic form in Matlab are shown in Figure 3.



```
T12 =
[ cos(q1), -sin(q1),      0,      0]
[ sin(q1),  cos(q1),      0,      0]
[      0,      0,      1,      0]
[      0,      0,      0,      1]
T23r =
[ cos(q2), -sin(q2),      0,      0]
[ sin(q2),  cos(q2),      0,      0]
[      0,      0,      1,      0]
[      0,      0,      0,      1]
T23t =
[ 1,  0,  0, l2]
[ 0,  1,  0,  0]
[ 0,  0,  1,  0]
[ 0,  0,  0,  1]
T23 =
[   cos(q2),   -sin(q2),        0, cos(q2)*l2]
[   sin(q2),    cos(q2),        0, sin(q2)*l2]
[        0,         0,        1,         0]
[        0,         0,        0,         1]
T13 =
[     cos(q1)*cos(q2)-sin(q1)*sin(q2),     -cos(q1)*sin(q2)-sin(q1)*cos(q2),                    0,
cos(q1)*cos(q2)*l2-sin(q1)*sin(q2)*l2]
[     sin(q1)*cos(q2)+cos(q1)*sin(q2),      cos(q1)*cos(q2)-sin(q1)*sin(q2),                    0,
sin(q1)*cos(q2)*l2+cos(q1)*sin(q2)*l2]
[                          0,                            0,                          1,                    0]
[                          0,                            0,                          0,                    1]
r3M =
 l3
  0
  0
  1
r1M =
position vector of M
r1M =
 (cos(q1)*cos(q2)-sin(q1)*sin(q2))*l3+cos(q1)*cos(q2)*l2-sin(q1)*sin(q2)*l2
 (sin(q1)*cos(q2)+cos(q1)*sin(q2))*l3+sin(q1)*cos(q2)*l2+cos(q1)*sin(q2)*l2
                                    0
                                    1

x1M_y1M_z1M =
position x1M(t),y1M(t),z1M(t)
x1M =
(cos(q1)*cos(q2)-sin(q1)*sin(q2))*l3+cos(q1)*cos(q2)*l2-sin(q1)*sin(q2)*l2
y1M =
(sin(q1)*cos(q2)+cos(q1)*sin(q2))*l3+sin(q1)*cos(q2)*l2+cos(q1)*sin(q2)*l2
z1M =
0
```

Fig. 3. Solution in Matlab of the position vector r_{1M} of the manipulator

The trajectory of the manipulator $y_{1M}=y_{1M}(x_{1M})$, position $x_{1M} = x_{1M}(t)$, $y_{1M} = y_{1M}(t)$ of the point M is shown in Figure 4.

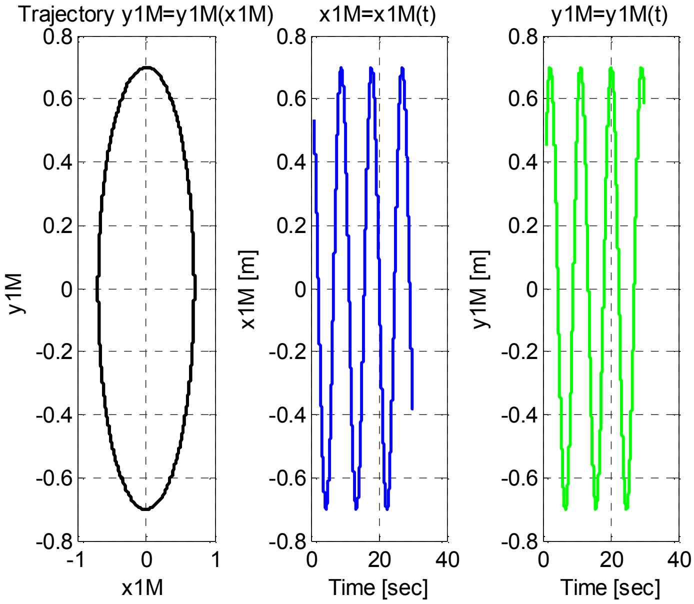


Fig. 4. Trajectory of the manipulator $y_{1M}=y_{1M}(x_{1M})$, position $x_{1M} = x_{1M}(t)$, $y_{1M}= y_{1M}(t)$

Model of manipulator with 3 degrees of freedom of movement.

The manipulator in Fig. 5 is an open kinematic chain of four members 1, 2, 3, and 4. The chain is four-dimensional with 3 degrees of freedom of movement. The member 2 is rotated about the z_1 axis, the member 3 is moved along the member 2 in the $z_2 \equiv z_3$ direction and the member 4 moves along the member 3 in the direction of the axis $x_3 \equiv x_4$. We investigate the absolute movement of the member 4 and its point M. The movement of the member 4 is expressed by means of the basic decomposition to the reference point M. It is necessary to determine by the matrix method, by means of transformation matrices of basic movements the position vector $\mathbf{r}_{1M}$ (position of point M relative to base 1) velocity $\mathbf{v}_{1M}$ and acceleration $\mathbf{a}_{1M}$ of the point M relative to base 1.

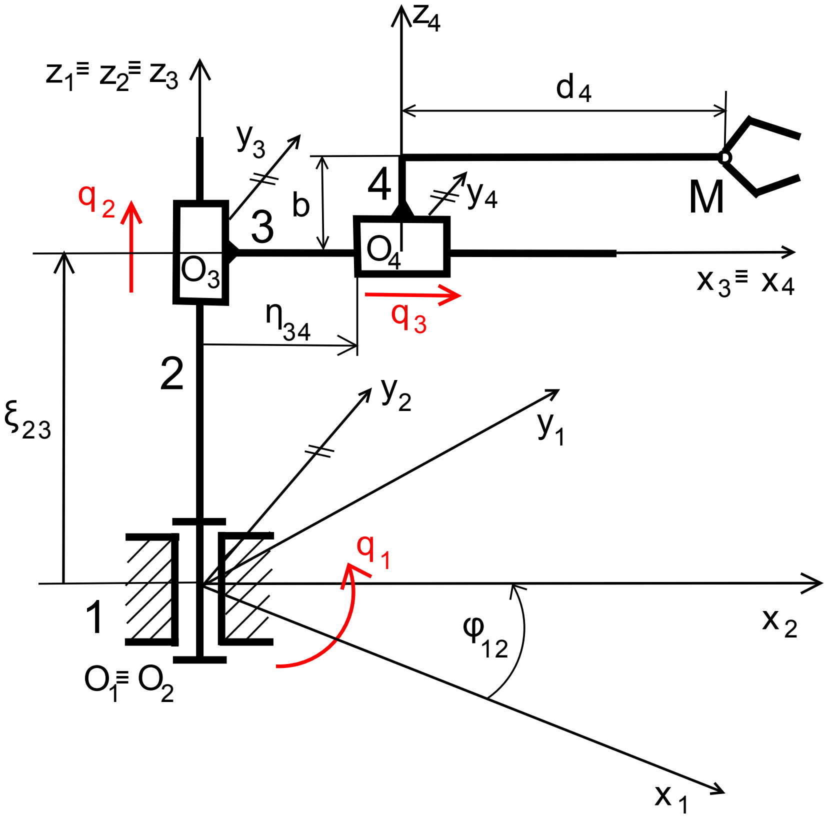


Fig. 5. Model of the manipulator with 3 DOF

We introduce the coordinate systems of individual members (Fig 5). The movement of the member 2 with respect to the base 1 is rotational, the coordinate system O_2, x_2, y_2, z_2 of the member 2 is rotated with respect to the base coordinate system O_1, x_1, y_1, z_1 by the angle φ_{12} around the axis $z_1 \equiv z_2$. The coordinate system O_3, x_3, y_3, z_3 of the member 3 is offset by the value ξ_{23} in the direction of the z_2 axis of the member 2. The member 4 moves on the member 3 by the value η_{34} in the x_3 direction of the member 3. The length of the member 4 is d_4 and the goal is to determine the movement of the end point M.

The generalized coordinate of the rotational motion of the member 2 is $q_1=\varphi_{12}$ and the generalized coordinate of the translational motion of the member 3 is $q_2=\xi_{23}$ and the generalized coordinate of the translational motion of the member 4 is $q_3= \eta_{34}$. In the initial position, the coordinate systems of members 1, 2, 3, 4 coincide $q=[0 \ \ 0 \ \ 0]^T$.

The position $\mathbf{r}_{1M}$, the velocity $\mathbf{v}_{1M}$ and the acceleration $\mathbf{a}_{1M}$ of the point M relative to the base coordinate system are investigated.

The motion of the member 4 with respect to the base 1 is determined by the motion of the point M and described by the equation:

$$\mathbf{r}_{1M} = \prod_{i=1}^{3} \mathbf{T}_{i,i+1} \cdot \mathbf{r}_{4M} \tag{9}$$

The relative spherical motion is described by the transformation matrix:

$$\mathbf{T}_{14} = \prod_{i=1}^{3} \mathbf{T}_{i,i+1} \tag{10}$$

We express the individual transformation matrices using the basic matrices. In each member, we introduce coordinate systems (Fig. 5) and mark the dimensions and coordinates. Then we write the transformation matrices using the transformation matrices of the basic movements in the form:

$$\mathbf{T}_{12} = \mathbf{T}_{Z6}(\varphi_{12}) \tag{11}$$

$$\mathbf{T}_{23} = \mathbf{T}_{Z3}(\xi_{23}) \tag{12}$$

$$\mathbf{T}_{34} = \mathbf{T}_{Z1}(\eta_{34}) \tag{13}$$

Then we obtain the equation of the trajectory of the point M of member 4 in the coordinate system of the base 1 by means of the basic matrices:

$$\mathbf{r}_{1M} = \mathbf{T}_{12} \,.\, \mathbf{T}_{23} \,.\, \mathbf{T}_{34} \,.\, \mathbf{r}_{4M} \tag{14}$$

where

$$\mathbf{r}_{4\mathrm{M}} = [d_4 \;\; 0 \;\; b \;\; 1]^{\mathrm{T}} \tag{15}$$

and

$$\begin{aligned}
\mathbf{r}_{1M} &= \mathbf{T}_{Z6}\,(\varphi_{12})\,.\,\mathbf{T}_{Z3}(\xi_{23})\,.\,\mathbf{T}_{Z1}(\eta_{34})\,.\,\mathbf{r}_{4M} = \\
&= \begin{bmatrix} \cos\,(\varphi_{12}) & -\sin\,(\varphi_{12}) & 0 & 0 \\ \sin\,(\varphi_{12}) & \cos\,(\varphi_{12}) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \xi_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 & \eta_{34} \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} d_4 \\ 0 \\ b \\ 1 \end{bmatrix} = \\
&= \begin{bmatrix} \cos\,(\varphi_{12}) & -\sin\,(\varphi_{12}) & 0 & \eta_{34}\cos(\varphi_{12}) \\ \sin\,(\varphi_{12}) & \cos\,(\varphi_{12}) & 0 & \eta_{34}\sin(\varphi_{12}) \\ 0 & 0 & 1 & \xi_{23} \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} d_4 \\ 0 \\ b \\ 1 \end{bmatrix} = \begin{bmatrix} d_4\cos\,(\varphi_{12}) + \eta_{34}\cos(\varphi_{12}) \\ d_4\sin\,(\varphi_{12}) + \eta_{34}\sin(\varphi_{12}) \\ b + \xi_{23} \\ 1 \end{bmatrix}
\end{aligned} \tag{16}$$

Position vector of point M with respect to the base coordinate system O$_1$, x$_1$, y$_1$, z$_1$:

$$\mathbf{r}_{1M} = \begin{bmatrix} x_{4M} \\ y_{4M} \\ z_{4M} \\ 1 \end{bmatrix} = \begin{bmatrix} d_4\cos\,(\varphi_{12}) + \eta_{34}\cos(\varphi_{12}) \\ d_4\sin\,(\varphi_{12}) + \eta_{34}\sin(\varphi_{12}) \\ b + \xi_{23} \\ 1 \end{bmatrix} \tag{17}$$

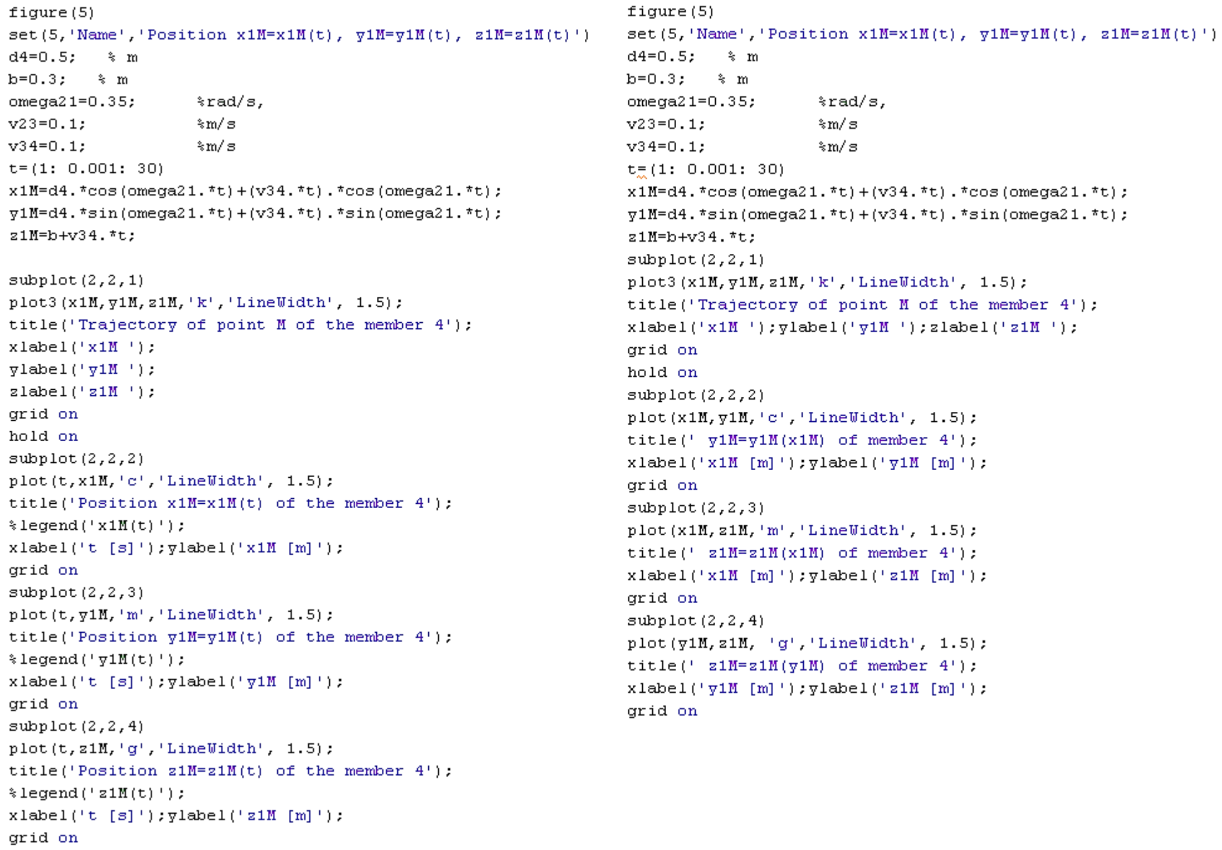
Velocity vector of point M with respect to the base coordinate system O$_1$, x$_1$, y$_1$, z$_1$:

$$\mathbf{v}_{1M} = \dot{\mathbf{r}}_{1M} = \begin{bmatrix} \dot{\eta}_{34}\,.\,\cos(\varphi_{12}) - (d_4 + \eta_{34})\,.\,\dot{\varphi}_{12}\,.\sin\,(\varphi_{12}) \\ \dot{\eta}_{34}\,.\,\sin\,(\varphi_{12}) + (d_4 + \eta_{34})\,.\,\dot{\varphi}_{12}\,.\cos\,(\varphi_{12}) \\ \dot{\xi}_{23} \\ 0 \end{bmatrix} \tag{18}$$

Acceleration vector of point M with respect to the base coordinate system O$_1$, x$_1$, y$_1$, z$_1$:

$$\mathbf{a}_{1M} = \dot{\mathbf{v}}_{1M} = \ddot{\mathbf{r}}_{1M} = \begin{bmatrix} \ddot{\eta}_{34}\,.\,\cos(\varphi_{12}) - \dot{\eta}_{34}\,\dot{\varphi}_{12}\sin\,(\varphi_{12}) - \left(\ddot{\varphi}_{12}\,(d_4 + \eta_{34}) + \dot{\varphi}_{12}\,.\dot{\eta}_{34}\right)\sin\,(\varphi_{12}) - \dot{\varphi}_{12}^2(d_4 + \eta_{34}).\cos\,(\varphi_{12}) \\ \ddot{\eta}_{34}\,.\sin\,(\varphi_{12}) + \dot{\eta}_{34}\,\dot{\varphi}_{12}\cos\,(\varphi_{12}) + \left(\ddot{\varphi}_{12}\,(d_4 + \eta_{34}) + \dot{\varphi}_{12}\,.\dot{\eta}_{34}\right)\cos\,(\varphi_{12}) - \dot{\varphi}_{12}^2(d_4 + \eta_{34}).\sin(\varphi_{12}) \\ \ddot{\xi}_{23} \\ 0 \end{bmatrix} \tag{19}$$

Solution of the position of the point M in the Matlab program is performed by m-files (Fig.6a, b):



```
figure(5)
set(5,'Name','Position x1M=x1M(t), y1M=y1M(t), z1M=z1M(t)')
d4=0.5;   % m
b=0.3;   % m
omega21=0.35;       %rad/s,
v23=0.1;            %m/s
v34=0.1;            %m/s
t=(1: 0.001: 30)
x1M=d4.*cos(omega21.*t)+(v34.*t).*cos(omega21.*t);
y1M=d4.*sin(omega21.*t)+(v34.*t).*sin(omega21.*t);
z1M=b+v34.*t;

subplot(2,2,1)
plot3(x1M,y1M,z1M,'k','LineWidth', 1.5);
title('Trajectory of point M of the member 4');
xlabel('x1M ');
ylabel('y1M ');
zlabel('z1M ');
grid on
hold on
subplot(2,2,2)
plot(t,x1M,'c','LineWidth', 1.5);
title('Position x1M=x1M(t) of the member 4');
%legend('x1M(t)');
xlabel('t [s]');ylabel('x1M [m]');
grid on
subplot(2,2,3)
plot(t,y1M,'m','LineWidth', 1.5);
title('Position y1M=y1M(t) of the member 4');
%legend('y1M(t)');
xlabel('t [s]');ylabel('y1M [m]');
grid on
subplot(2,2,4)
plot(t,z1M,'g','LineWidth', 1.5);
title('Position z1M=z1M(t) of the member 4');
%legend('z1M(t)');
xlabel('t [s]');ylabel('z1M [m]');
grid on
```

a

```
figure(5)
set(5,'Name','Position x1M=x1M(t), y1M=y1M(t), z1M=z1M(t)')
d4=0.5;   % m
b=0.3;   % m
omega21=0.35;       %rad/s,
v23=0.1;            %m/s
v34=0.1;            %m/s
t=(1: 0.001: 30)
x1M=d4.*cos(omega21.*t)+(v34.*t).*cos(omega21.*t);
y1M=d4.*sin(omega21.*t)+(v34.*t).*sin(omega21.*t);
z1M=b+v34.*t;
subplot(2,2,1)
plot3(x1M,y1M,z1M,'k','LineWidth', 1.5);
title('Trajectory of point M of the member 4');
xlabel('x1M ');ylabel('y1M ');zlabel('z1M ');
grid on
hold on
subplot(2,2,2)
plot(x1M,y1M,'c','LineWidth', 1.5);
title(' y1M=y1M(x1M) of member 4');
xlabel('x1M [m]');ylabel('y1M [m]');
grid on
subplot(2,2,3)
plot(x1M,z1M,'m','LineWidth', 1.5);
title(' z1M=z1M(x1M) of member 4');
xlabel('x1M [m]');ylabel('z1M [m]');
grid on
subplot(2,2,4)
plot(y1M,z1M, 'g','LineWidth', 1.5);
title(' z1M=z1M(y1M) of member 4');
xlabel('y1M [m]');ylabel('z1M [m]');
grid on
```

b

Fig. 6. M – file of the trajectory and a) position $x_M = x_M(t)$, $y_M = y_M(t)$, and $z_M = z_M(t)$, b) position $y_M = y_M(x_M)$, $z_M = z_M(y_M)$, $z_M = z_M(x_M)$

The trajectory and position $x_{1M}=x_{1M}(t)$, $y_{1M}=y_{1M}(t)$, $z_{1M}=z_{1M}(t)$ of the point M is shown in Fig. 7.

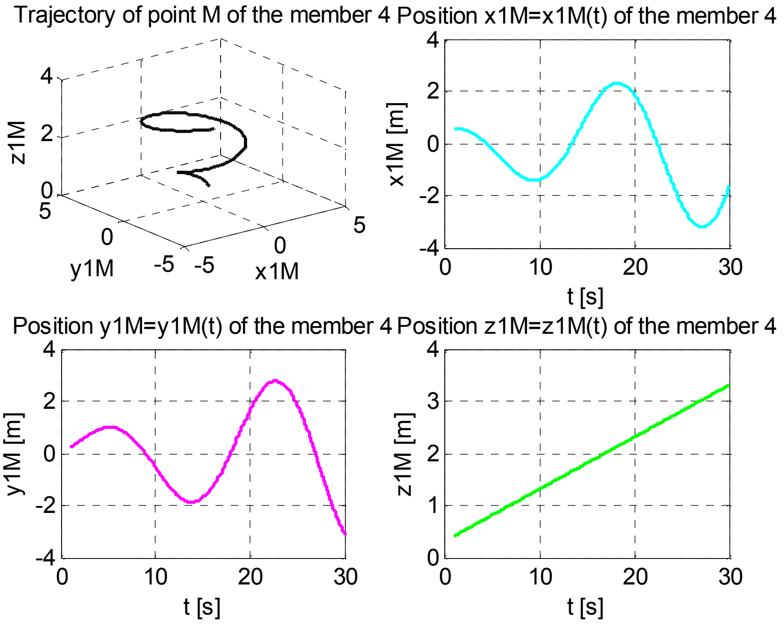


Fig. 7. Trajectory and position $x_{1M} = x_{1M}(t)$, $y_{1M} = y_{1M}(t)$, $z_{1M} = z_{1M}(t)$ of the manipulator

The trajectory and position $y_{1M}=y_{1M}(x_{1M})$, $z_{1M}=z_{1M}(x_{1M})$, $z_{1M}=z_{1M}(y_{1M})$ of the point M is shown in Figure 8.

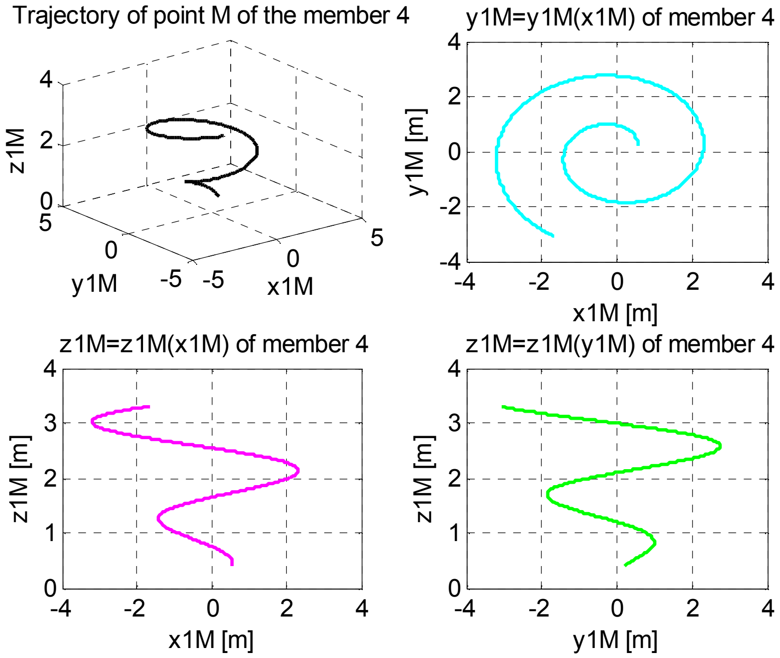
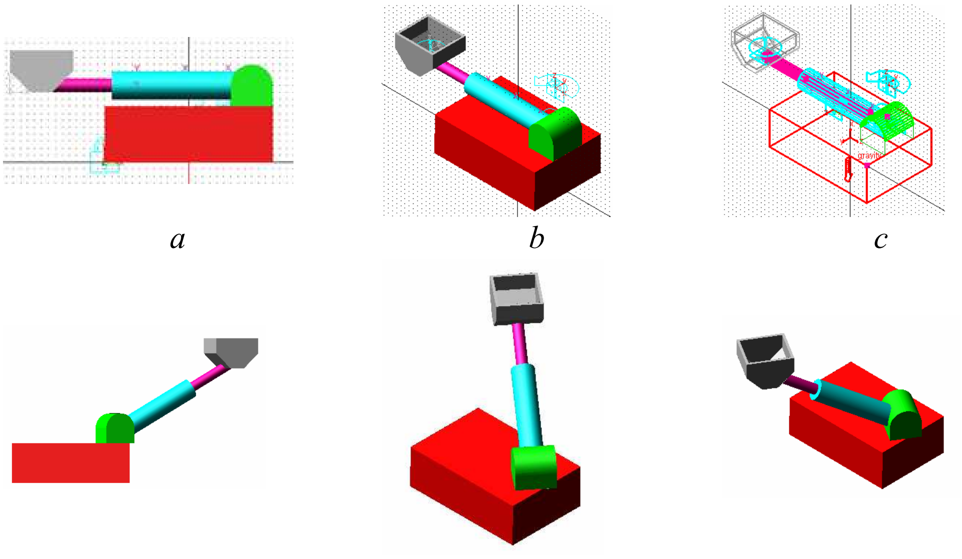


Fig. 8. Trajectory and position $y_{1M} = y_{1M}(x_{1M})$, $z_{1M} = z_{1M}(x_{1M})$, and $z_{1M} = z_{1M}(y_{1M})$ of the manipulator

Computer simulation in MSC Adams software. An example of how to use Adams to simulate the movement of a R-R-T-R model manipulator is in the following section.

We create a model of the R-R-T-R manipulator with the basket according to Fig. 9a)-c) using modeling elements and procedures for building body, geometric and kinematic links in MSC.ADAMS/View and verifying its functionality. The manipulator consists of the base part on which is mounted the stand. There is an arm with a basket at the end. Once the model is assembled, another task is to investigate the endpoint movement. The solution is shown in graphical form. A preview of the assembled model of the manipulator and the simulation of its movement is shown in Fig. 9a)-f).



a *b* *c*

d *e* *f*

Fig. 9. Models of the manipulator in MSC Adams- View

The trajectory of the end-effector during the simulation is shown in the Fig. 10.

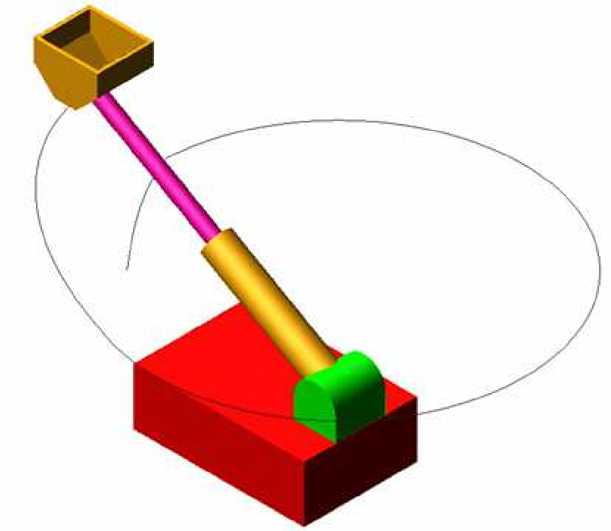


Fig. 10. Model of the manipulator- trajectory of the end-effector

Movement is depicted using the Postprocessor in Fig. 11.

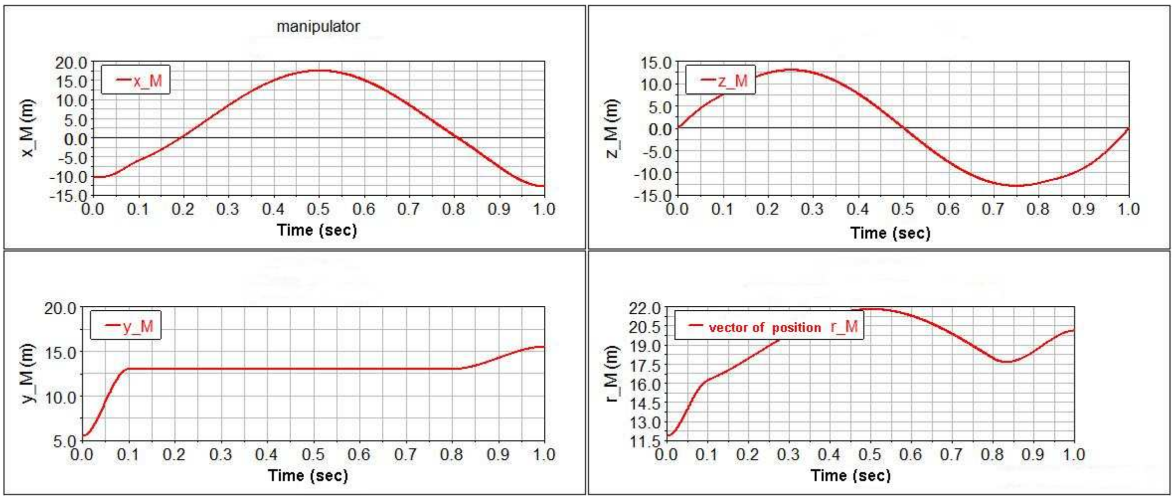


Fig. 11. Position x_M, y_M, z_M and position vector r_M of the end effector

The position $x_M=x_M(t)$, $y_M=y_M(t)$, $z_M=z_M(t)$ and magnitude of the position vector $\mathbf{r}_M=\mathbf{r}_M(t)$ of the point M of the end effectors in Postprocessor is shown in Figure 11.

Conclusion. This work deals with the problem of kinematic analysis of an open kinematic chain of an industrial robot. The aim was to determine the kinematic properties and also to evaluate the influence of the parameters of the mechanism which influence these kinematic properties. The matrix method was used. The process of the solution consisted of determining the transformation matrices of the coordinate systems, the kinematic analysis of the industrial robot and the graphical representation of the effector handling space. The analysis also includes graphical representations of the kinematic properties of the mechanical system.

Acknowledgement.

This work was supported in part by the Ministry of Education of the Slovakia Foundation under grant projects VEGA No. 1/0872/16, grant projects KEGA No. 018TUKE-4/2018, grant projects KEGA No. 049TUKE-4/2017, grant projects VEGA No. 1/0389/18, grant projects VEGA No. 1/0731/16 and FGV/2016 supported by Faculty of Mech. Eng. at Technical University of Kosice.

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УДК 004.4

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БАГАТОКОМПОНЕНТНІ СИСТЕМИ ТА МОДЕЛЮВАННЯ В MATLAB

Актуальність теми дослідження. *Комп'ютерне моделювання змінює методику навчання, спосіб мислення й можливості застосування. Це допомагає перейти від зовнішніх до внутрішніх властивостей і від індивідуальних до зв'язаних властивостей. Розробка продукту прискорюється проведенням експериментів із комп'ютерною моделлю.*

Постановка проблеми. *Кінематичний аналіз в Matlab і MSC Adams View. Мета полягає в тому, щоб досліджувати обертання окремих елементів роботизованої системи й визначити просторовий рух виконавчого органу.*

Аналіз останніх досліджень і публікацій. *MSC Adams представляє динамічні симулятори віртуальних прототипів механічних систем. Віртуальні прототипи дозволяють моделювати, аналізувати і оптимізувати майбутні продукти і вивчати їхні властивості, перш ніж створювати реальний прототип. Цей прийом підходить для розробки мініатюрних мехатронних елементів, а також складних систем.*

Виділення недосліджених частин загальної проблеми. *Віртуальні прототипи становлять собою відповідний ресурс для тестування процедур контролю і регулювання.*

Постановка завдання. *Компіляція віртуального прототипу механічної системи, яка має всі вирішальні особливості і є стабільною з точки зору обчислень.*

Виклад основного матеріалу. *Віртуальна модель – це математичне представлення структур реального світу, що віртуально відтворює всі його фізичні властивості.*

Висновки відповідно до статті. *Мета полягала в тому, щоб визначити кінематичні властивості, а також оцінити вплив параметрів механізму, які впливають на ці кінематичні властивості. Був використаний матричний метод. Процес рішення складався з визначення матриць перетворення систем координат, кінематичного аналізу промислового робота і графічного представлення простору маніпулювання виконавчого пристрою.*

Ключові слова: *віртуальна модель; відкритий кінематичний ланцюг; роботизована система; програмне моделювання; виконавчий пристрій; матриці перетворення.*

Рис.: 11. Бібл.: 17.

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