Two link manipulator model using Controls Toolkit in MSC Adams with application for industry

Darina Hroncová[1]
Erik Prada[2]
Michal Kelemen[3]
Ľubica Miková[4]
Ivan Virgala[5]
Martin Varga[6]

[1] Technical University of Kosice, Letná 9, 042 00 Košice, Slovakia; darina.hroncova@tuke.sk
[2] Technical University of Kosice, Letná 9, 042 00 Košice, Slovakia; erik.prada@tuke.sk
[3] Technical University of Kosice, Letná 9, 042 00 Košice, Slovakia; michal.kelemen@tuke.sk
[4] Technical University of Kosice, Letná 9, 042 00 Košice, Slovakia; lubica.mikova@tuke.sk
[5] Technical University of Kosice, Letná 9, 042 00 Košice, Slovakia; ivan.virgala@tuke.sk
[6] Technical University of Kosice, Letná 9, 042 00 Košice, Slovakia; martin.varga.2@tuke.sk

Abstract In this paper, the authors focus on using MSC Adams in simulation of the motion of a two link manipulator model. The goal of the presented paper is to compile a two link model of the manipulator and to control the movement of the basket mounted on its end-effector. Attention is paid to kinematic and dynamic analysis of the manipulator, its modeling and control. The capability of MSC Adams Control Toolkit is used to design a control system which keeps the basket of the end-effector in horizontal position. Finally, the results obtained by computer simulation of the model are evaluated.

Keywords Two link manipulator, simulation, kinematic and dynamic analysis, controller

1. INTRODUCTION

A significant advantage of computer simulation of prototype models is the ability to immediately visualize modifications of design variants as well as the consequences of these changes on the behavior of the entire system.

Computer simulation allows to create a virtual prototype of a device and adjust it or create new variants of it without actually producing the real device. The change of behavior of these different variants of the model can be studied. By simulation we can also display the proposed model in its work cycle thus revealing possible collisions of its elements and evaluate different parameters of interest and visualize them in the software. The operation of the model can understood and subsequently verified its efficiency. During the simulation the values of different parameters can be checked in respective output displays of the simulated model in real time [3-7].

2. MODEL OF MANIPULATOR

The aim of the paper is to analyze the compiled model of a two link manipulator shown in the figure (Fig.1). From the kinematic point of view the manipulator structure is represented by an open kinematic chain [1,2].
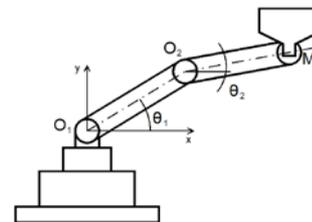

Figure 1. Model of the manipulator

The manipulator consists of two arms mounted on a solid base. The base ensures the manipulator stability in operation. The working tool, which in our case is a basket, is firmly attached to the end-effector of the manipulator. The manipulator then performs a working cycle with the basket. Our goal is to describe the motion of the end-effector. The next chapters describe the kinematic analysis of the motion of the end-effector [1,2].

The next figure (Fig. 2) shows the model of a two link manipulator created in MSC Adams. It consists of two links of length l_1 and l_2, with weights m_1 and m_2 [3-7]. We consider two degrees of freedom of movement. The arms are connected by rotating kinematic pairs to each other and by another rotating kinematic pair to the base. The drives are placed in respective kinematic pairs. The angle of rotation in kinematic pairs is denoted by angles θ_1 and θ_2. Kinematic equations describing the position of the end point M of the manipulator (Fig. 2) depending on the angles of rotation θ_1 and θ_2 are expressed as follows [2]:

$$x_M = l_1\cos\theta_1 + l_2\cos(\theta_1+\theta_2) \qquad (1)$$

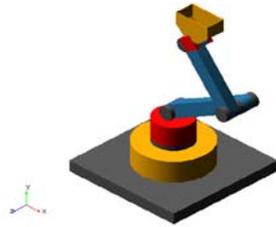$$y_M = l_1\sin\theta_1 + l_2\sin(\theta_1+\theta_2) \qquad (2)$$

Figure 2. Model of the two link manipulator in MSC Adams/View

The driving torques M_1 and M_2 are triggered by servo drives in individual kinematic pairs. They ensure the movement of the manipulator arms. The notation of dynamic equations of motion of the manipulator (Fig.1) can be briefly written according to [3-7]:

$$M(\theta)\ddot{\theta} + V(\theta,\dot{\theta}) + G(\theta) = \tau \qquad (3)$$

where $M(\theta)$ is the inertia matrix, $V(\theta,\dot{\theta})$ is the Coriolis-centripetal vector, $G(\theta)$ is the gravity vector and τ is vector of actuator torques.

Equation (3) in our case represents a model with 2° of freedom of motion, a system of two 2nd order differential equations. The motion of the mechanism of the two link manipulator takes place in vertical plane, for this reason the influence of gravity is also taken into account. The equations of motion do not take into account the laxity and friction effects in the individual kinematic pairs nor the elastic deformations of the individual arms of the manipulator [15-18]. We consider the change of the weight of the basket due to the load of material present in the basket [19,20].

3. COMPUTER SIMULATION

A 3D computer model of a two link manipulator is created in MSC Adams. Modelling elements and procedures for the creation of bodies and their kinematic bonds were used. After proposing the model, the functionality is verified and the simulation is started Fig.3 [7-9].
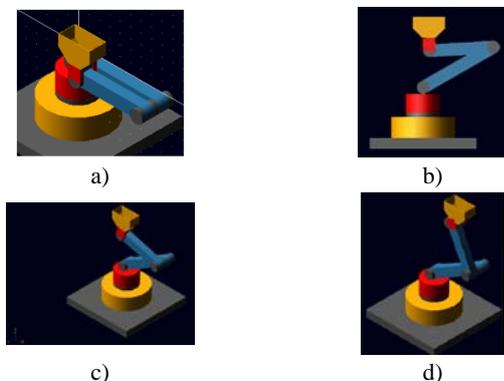

a)   b)

c)   d)

Figure 3. Views of the rendered model a) the view with visible links in 0 sec, b) the front view with visible links, c) the isometric view, d) the view of the model in motion

Next we focus on controlling the position of the basket during the motion. The basket can be used for manipulation of materials of various kinds, namely solid, bulk or liquid. The control was performed in MSC Adams. It offers the possibility of creating a control system using different types of controllers. In our case, we use a proportional controller with gain Kp.

The stability of the basket is ensured with a control circuit by means of a balancing torque which stabilizes the basket during the motion. A feedback control circuit is provided, i.e. a torque controller to keep the basket in horizontal position during the motion of the arm [3]. There is a diagram of a closed feedback basket position control system with a proportional controller K_p in the next picture (Fig. 4) [15-18,20].
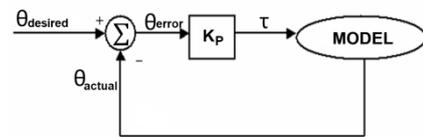

Figure 4. The control system with proportional feedback

The control system ensures that the compensating torque keeps the end-effector in horizontal position and the loss of stability of the basket during the motion of the manipulator is prevented. The control circuit of the system is designed according to the diagrams in Fig.4 and Fig.5.

Figure 5. Scheme of control system with proportional controller

The mechanical system is controlled by the variable u according to the following equation:

$$u = K_p . e \qquad (4)$$

where in the diagram in Fig.5:

u – torque control action variable (torque_gain) for compensating torque (SFORCE_1),
x – desired angle (theta_desired = 0°),
y – measured controlled variable (theta_actual),
e – difference (error) in the adding block:
    theta_sum = theta_desired - theta_actual,
z – fault quantity (prescribed movement of the mechanical system).

After compiling the block diagram of the control system we need to define the following elements:

1. Design Variable
2. State Variable
3. Measure

We define the control system in MSC Adams using the Controls Toolkit. Its control blocks menu is shown in Fig.6 [20].
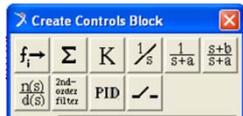
Figure 6. Controls Toolkit – Create Controls Block

The first input signal to the summation block is the desired value of the angle ($\theta_{desired}$) between the x axis defined on the end-effector and the axis of the base reference system, which is zero. In the Create Control Blocks dialog box (Fig. 6) we select the input signal f_i and define the desired input variable (*theta_desired*). We set the required value of the angle to 0°.

The control difference between the desired and the actual angle is defined in the *summing junction block* ($\sum$). Subtracting the current angle value from the desired angle of the basket during the motion is *theta_error* and is written to the *Database Navigator*.

The gain block provides the u signal amplification for control of the basket position compensation torque (SFORCE_1). The input for the gain block is *theta_error* variable created in the previous section. After setting the amount of gain and its input, an element (*torque_gain*) is added to the *Database Navigator* (Fig.7).

After assigning the created function the variables are written and displayed in the *Database Navigator*. The content of the variables is in (Fig. 7):
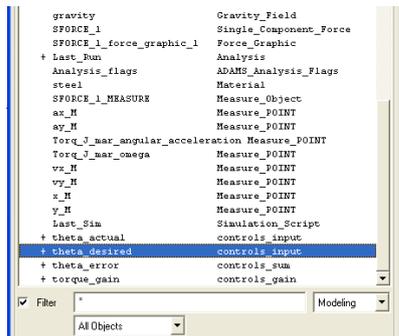

Figure 7. Database Navigator of the manipulator

The compensating torque in Fig. 8 is needed to control the current position of the basket with respect to the desired position during motion. The SFORCE_1 torque secures the position of the basket in a horizontal position and thus prevents the loss of stability during the motion.
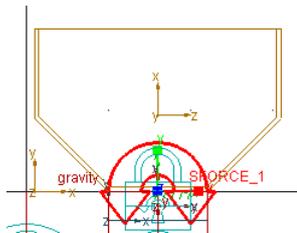

Figure 8. Compensating torque SFORCE_1

Fig.9 shows the simulation of the model with the compensating torque [14-16].

Figure 9. Views of the rendered model

Interactive simulation and visualization allows comfortable simulation of the model, model modifications and visualization of results. The graphs of output variables enable viewing the current values of the measured variables in real time during the actual simulation and its visualization (Fig.10).

Postprocessor is an integral part of the process of computer modeling of a prototype and it is a very comfortable tool for creating, processing, modifying and presenting the results of simulation in the form of graphs [8-14]. It is also possible to display the model in the current state and print the results prepared this way (Fig.10). It is also possible to create the output of the simulation in AVI format.
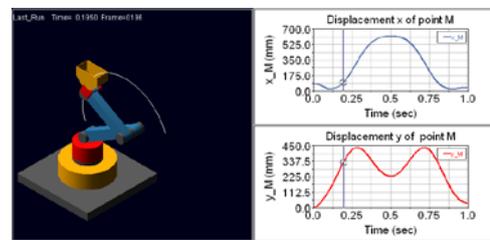

Figure 10. The animation of the simulation and displacement of the end efector

4.   RESULTING KINEMATIC PARAMETERS

The values of the calculated variables are displayed in a graphical form with the postprocessor. The magnitudes of the torques in rotating kinematic pairs when the weights of the arms are $m_1 = 9.9779$ kg, $m_2 = 7.1330$ kg and the weight of the basket $m_b = 0.9348$ kg are in Fig.11 to Fig.14.
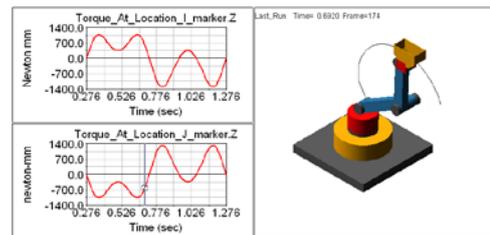

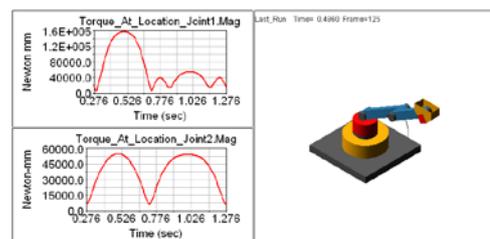Figure 11. The graph of the torque in the I_marker and J_Marker between basket and link

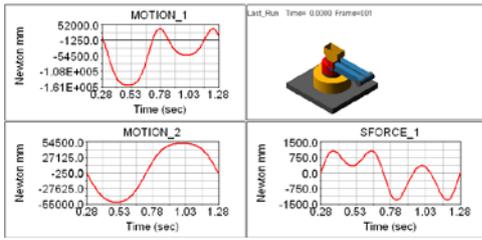Figure 12. The graph of the torque in the joint 1 and joint 2

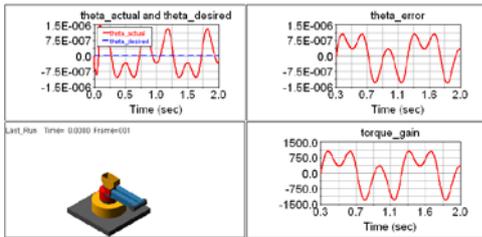Figure 13. The graph of the torque SFORCE_1 in the joint 3

Figure 14. The graph of the angle theta desired and angle theta actual

The magnitudes of the moments in rotating kinematic pairs with increased arm weight $m_1 = 4.5$ kg, $m_2 = 3.5$ kg and basket $m_b = 5$ kg are calculated next. Before starting the simulation a change of the magnitudes of individual moments in individual joints is expected, as well as change of the compensating moment of the end-effector [16,17]. The graphs obtained by the simulation are shown in (Fig. 15). Only the torques are plotted. Angular variables as acceleration, speed and trajectories are not changed by the load. The resulting graphs are in the following figures.

We also calculated the values of position, velocity and acceleration of the basket (Fig.16 - 19) [20].
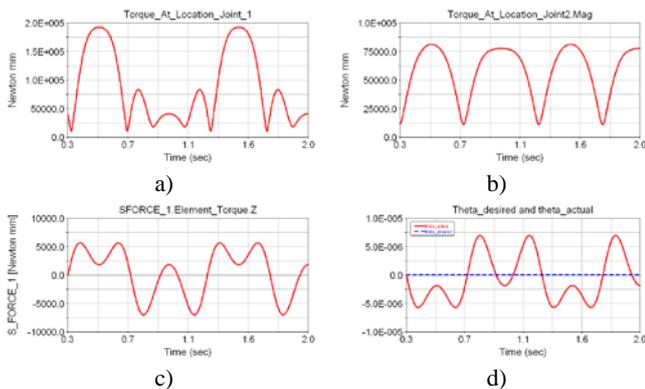

Figure 15. The graphs a) the torque in the joint 1, b) the torque in the joint 2 , c) the torque SFORCE_1 in the joint 3 , d) the angle theta desired and angle theta actual
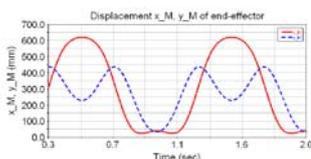

Figure 16. The graph of the position x_M and y_M of the end-effector
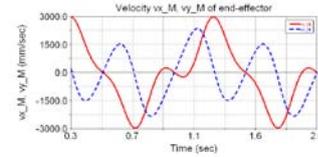

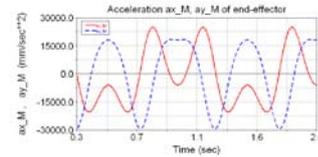Figure 17. The graph of the velocity v_{xM} and v_{yM} of the end-effector

Figure 18. The graph of the acceleration a_{xM} and a_{yM} of the end-effector

The aim was also to obtain results from the control of the end-effector and prove the ability and functionality of the proposed regulator for the compensating torque [20]. The obtained graphs of the actual and desired angle during the motion along the trajectory are shown in Fig.15 and Fig.18. The difference between these values is in negligible ranges in both cases which indicates a suitably designed and functional end-effector position control system.

5. CONCLUSION

The values obtained from both simulations confirmed the increase and decrease of the acting torques in the joints of the manipulator. An increase in the load also revealed an increase in the torque required to move the basket along the trajectory. The opposite is true when reducing the load.

MSC Adams works with a 3D model [20]. The advantage is the possibility to simulate the motion of the prototype model and its control in the program environment and verification of the functionality in the form of 3D visualization. Based on the results obtained from the simulation it is possible to build a real model and design the drives. When designing drives for a mechanical system it is necessary to pay attention to the maximum magnitudes of the forces when handling various loads and so it is necessary to design the drive with the appropriate parameters for the specific purpose of use of the manipulator.

The proposed control of the stability of the end-effector by selecting the appropriate control system and setting the controller parameters is an important aspect for maintaining stability and managing load transfer. Based on the results of the simulation it can be stated that the proposed control system is functional and maintains the necessary stability during the motion of the manipulator. Simulation software is a suitable tool for design, saving time and resources. It is also suitable for detailed research and investigation of mechanical systems in practice.

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