26th International Conference
ENGINEERING MECHANICS 2020
Svratka, Czech Republic May 11– 14,2020

DETERMINATION OF THE RELATIONSHIP BETWEEN KINEMATIC QUANTITIES OF A MECHANICAL SYSTEM WITH DAMPING

Darina Hroncová, Ingrid Delyová, Peter Sivák

1. Introduction

In practice, we often encounter mechanisms in installations where the rotational motion is transformed to sliding. The requirement for their accuracy, functionality and performance are constantly increasing. The aim of the article is to get acquainted with analysis of such bound mechanical systems. We focus on the dynamic analysis with MSC Adams software (Frankovský et al., 2012, Delyová et al., 2014). The bound mechanical system consists of a kinematic chain of rigid bodies interconnected by bonds. The part of the model solution is therefore the compilation of basic dynamic equations of rigid bodies. Depending on the system and according to the specifications, the equations should take into account other effects, such as friction and gravity compensation, if available (Swevers et al., 2007, Khalil and Dombre, 2002). The first part of the paper deals with dynamic analysis. Dynamic equations of motion were compiled using Lagrange equations of mixed type. Based on this method of dynamic analysis, a mathematical model is built. Since we get a complex mathematical model, dynamic analysis is performed by MSC Adams software (Mickoski et al., 2018). Simulation software like MSC Adams are a great help in the dynamic analysis of various complex bound mechanical systems by making it faster and more efficient. It allows us to evaluate the results in graphical form (Tedeschi et al., 2017). In the final part of the paper we evaluate the results of the dynamic analysis.

2. Analytical analysis of a system with damping

Dynamic analysis examines the movement of the mechanism invoked by action forces. The mechanism or bound mechanical system consists of several connected rigid bodies. The joints can be sliding (telescopic) or rotating (pin, hinge). By changing the position of the joint, it is possible to change the position and / or orientation of the tool. A complete kinematic model is one that has the ability to assign a tool position to the common positions of any kinematic manipulator. Ultimately, the model must contain the required number of independent kinematic parameters (Vavro jr. et al., 2017, Delyová et al., 2013).

A model of a four-joint mechanism was selected (Fig. 1) to analyze the kinematic quantities using MSC Adams. The dimensions of the individual members were chosen for the given mechanism. The spring has a free length l and in the free state it is perpendicular to the rocker arm No. 1. The value of the angle φ_1 was entered in the equilibrium position. Angles φ_1, φ_2, φ_3 are chosen as the coordinates for describing the movement of the mechanism. These coordinates are interdependent, as the four-joint mechanism has only one degree of freedom of motion. For an analytical solution, Lagrange equations of the mixed type are a suitable tool for compiling equations of motion. These are equivalent to Newton's second law. However, their formulation for more complex mechanisms is simpler, as they are compatible with any coordinate system as well as dependent coordinates. With a proper choice of coordinates, we can greatly simplify the problem from a mathematical point of view.
For our system, the equations of motion for the coordinates φ_j, j = 1, 2, 3 have the form:

$$\frac{d}{dt}\frac{\partial E_k}{\partial \dot{\varphi}_j} - \frac{\partial E_k}{\partial \varphi_j} = Q_j + \lambda_1 \frac{\partial f_1}{\partial \varphi_j} + \lambda_2 \frac{\partial f_2}{\partial \varphi_j} \tag{1}$$

where E_k is the kinetic energy, φ_j generalized coordinates, Q_j generalized force, λ_1, λ_2 Lagrange multipliers.

The kinetic energy of the whole mechanism is expressed by the relation:

$$E_k = \frac{1}{2}\left[I_1\dot{\varphi}_1^2 + I_{2T}\dot{\varphi}_2^2 + I_3\dot{\varphi}_3^2 + m_2(\dot{x}_2^2 + \dot{y}_2^2)\right] \tag{2}$$

where I_1, I_3 are the moments of inertia of the rockers to the axes of rotation, m_2 mass of connecting rod - member 2 of the system, I_{2T} moment of inertia of the connecting rod to the center of gravity. The first three members in relation (2) represent the kinetic energies of the rotational motion of the members of the mechanism and the fourth member represents the kinetic energy of the translational motion of the connecting rod.

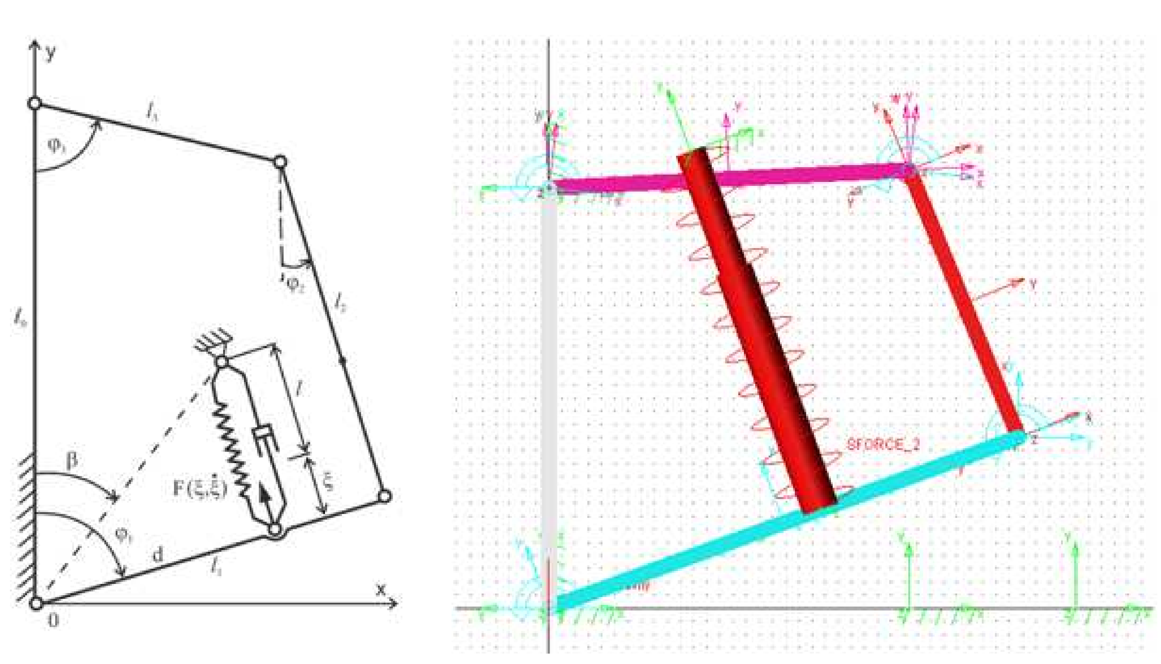

Fig. 1: *The diagram and the model of the four-joint mechanism*

The conversion of coordinates x_1,x_2 using generalized coordinates φ_1, φ_2 comes from the geometry in Fig.1:

$$x_2 = l_1 . sin(\varphi_1) - p . sin(\varphi_2) \tag{3}$$

$$y_2 = l_1 . cos(\varphi_1) + p . cos(\varphi_2) \tag{4}$$

Let the force in the elastic and damping member be $F(\xi, \dot{\xi})$. We calculate generalized forces Q_j from the relation:

$$\sum_{j=1}^{3} Q_j \delta\varphi_j = -F(\xi, \dot{\xi})\delta\xi \tag{5}$$

From the geometry of the image we can express one generalized force, the others are zero

$$Q_1 = -F(\xi, \dot{\xi})\frac{d\sqrt{l^2 + d^2}}{l + \xi} sin(\varphi_1 - \beta) \tag{6}$$

Three equations of motion and two equations of constraints are sufficient to calculate 3 unknown coordinates φ_1, φ_2, φ_3 and two Lagrange multipliers λ_1 and λ_2 as a function of time under known initial conditions. By solving the system, we get to the time diagram of kinematic quantities of the system.

3. Simulation with MSC Adams

The excitation force $F = 1N$, spring coefficient $k = 4$ N/mm and excitation coefficient $b = 0{,}2N$ (mm/s) were chosen for the simulation. Fig. 2 shows the time diagrams of the kinematic quantities, namely the speed, the acceleration of the centers of gravity of the individual members of the bound system and the angular velocity and the angular acceleration of the individual members of the system.

The relation of angular velocity and the angle of rotation of member 1 is plotted in the Fig. 3a). Fig. 3b) shows the relation between the angular acceleration and the angle of rotation. Fig. 3c) shows the relation of the angular acceleration and the angular velocity. Finally, the Fig. 3d) shows the time diagram of the angle of rotation of member 1 of the system.

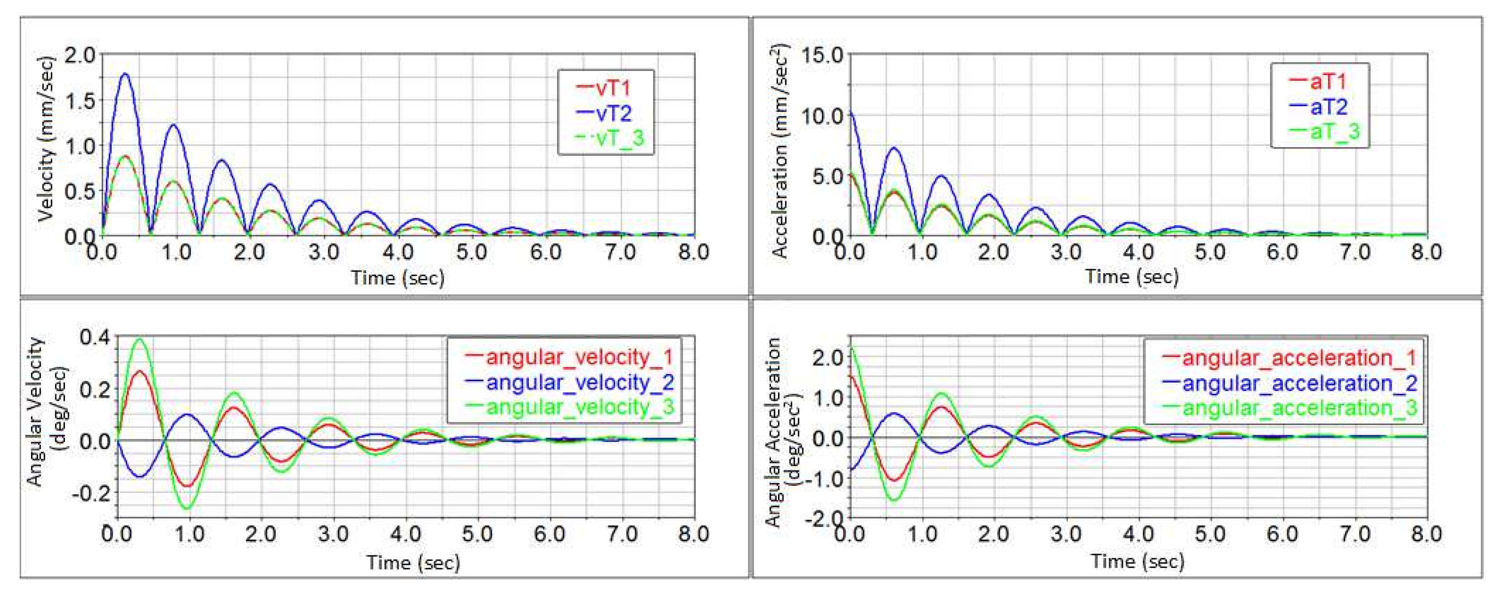

Fig. 2: *Time diagrams of kinematic quantities*

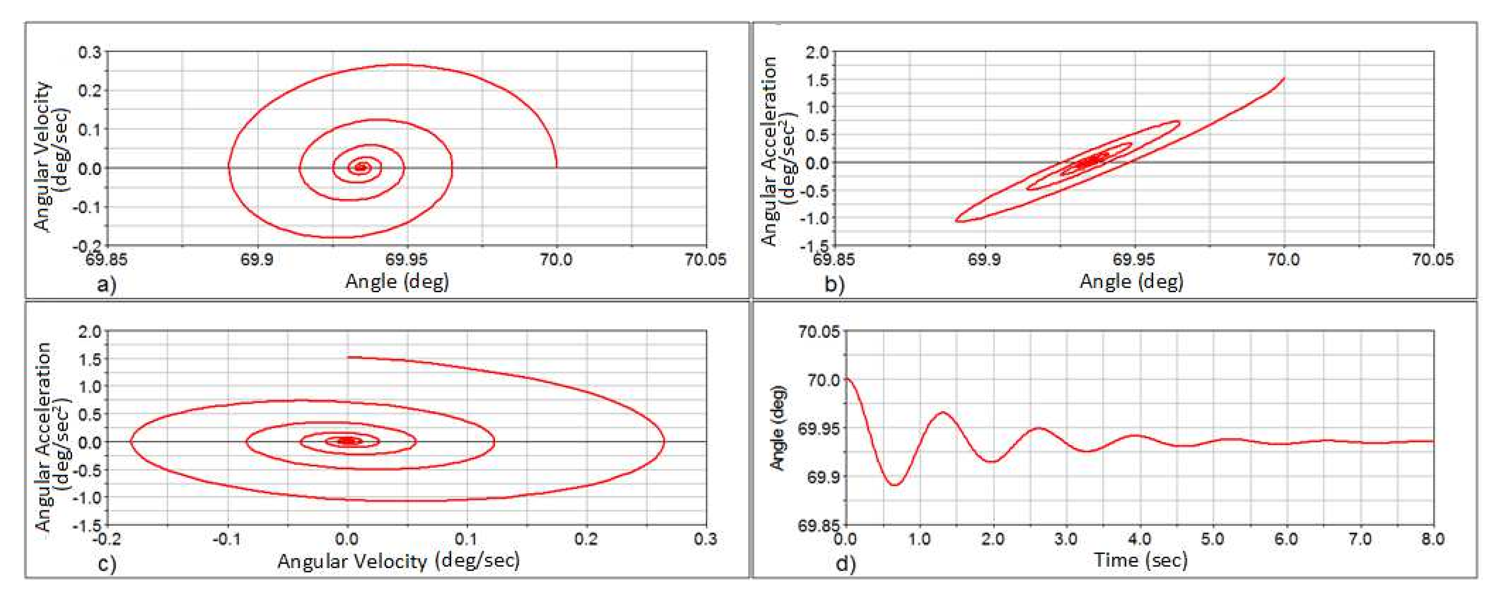

Fig. 3: *Relations of kinematic quantities of member 1 of the bound system*

The time diagram of the force in the spring is shown in Fig. 4a). The time diagram of the spring deformation is shown in Fig. 4b). The relation of the acceleration of the system member 1 on its speed is shown in Fig. 4c). The time diagram of the kinetic energy of individual members of the bound system is shown in Fig. 4d).

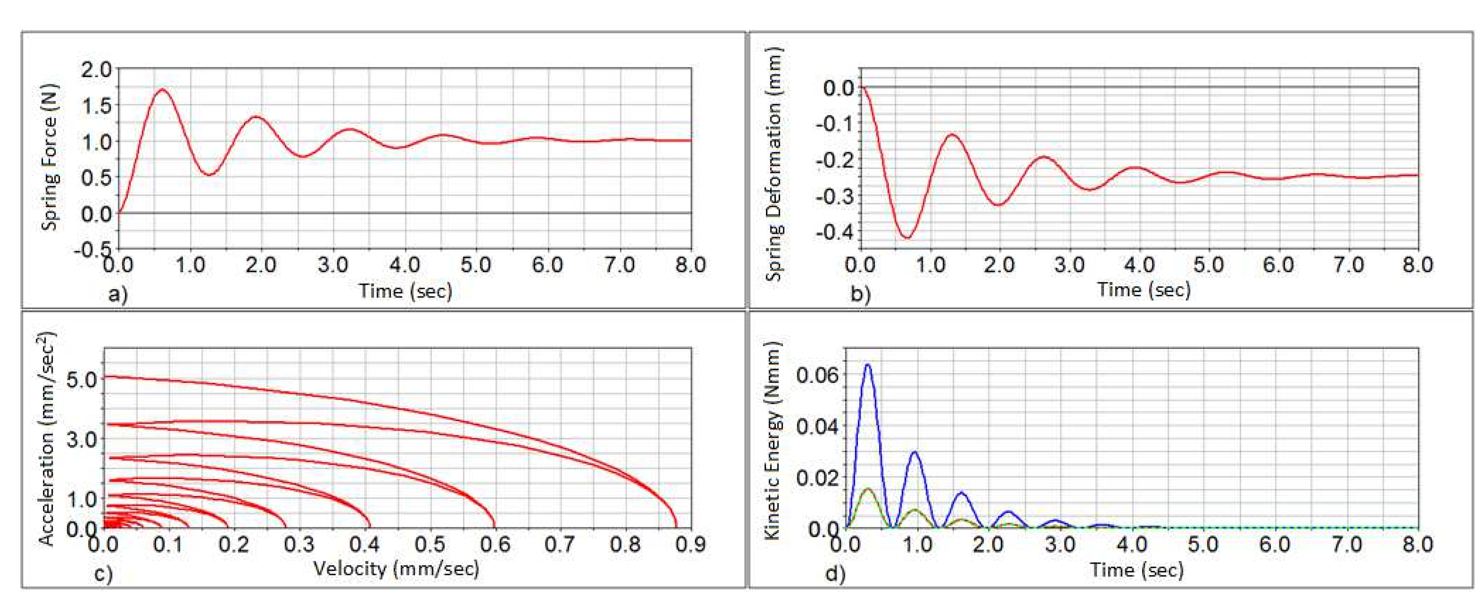

Fig. 4: *Time diagrams of the bound system with damping*

4. Conclusions

The article presented the kinematic analysis of a four-joint mechanism by simulation in MSC Adams. This software allows to simulate the motion of multibody mechanical systems. The results are obtained in the form of time diagrams of the required variables. MSC Adams provides tools for virtual prototyping, visualization of the model and easier evaluation of the obtained results. This makes it a suitable tool for teaching and practice. The contribution of this work is mainly didactic, especially in the field of applied mechanics and mechatronics, it presents the possibility of computer simulation.

Acknowledgement

This work was supported by the Ministry of Education of Slovakia Foundation under Grant project VEGA No.1/0290/18, VEGA No. 1/0389/18, VEGA No. 1/0500/20, KEGA No.018 TUKE - 4/2020 and KEGA No.030 TUKE - 4/2020.

References

Brát, V. (1981). Maticové metody v analýze a syntéze prostorových vázaných mechanických systémů. Academia Praha.

Delyová, I., Hroncová, D., Frankovský, P. (2014). Analysis of simple mechanism using MSC Adams. Manufacturing Technology, 14(2), 141-145.

Delyová, I., Hroncová, D., Sivák, P., Beliško, M. (2013). The dynamic analysis of cam mechanism. American Journal of Mechanical Engineering, 1(7), 266-270.

Frankovský, P., Hroncová, D., Delyová, I., Hudák, P. (2012). Inverse and forward dynamic analysis of two link manipulator. Procedia Engineering, 48, 158-163.

Hroncová, D., Delyová, I., Frankovský, P., Puzderová, A. (2013). Dynamic analysis of the shaping machine mechanism. American Journal of Mechanical Engineering, 1(7), 370-373.

Khalil, W., Dombre, E. (2002). Modeling, Identification and Control of Robots. London: Hermes Penton Ltd.

Mickoski, H., Mickoski, I., Djidrov, M. (2018). Dynamic modeling and simulation of three-member robot manipulator. Mathematical Models in Engineering, 4(4), 183-190.

Swevers, J., Verdonck, W., De Schutter, J. (2007). Dynamic model identification for industrial robots. IEEE control systems magazine, 27(5), 58-71.

Tedeschi, F., Carbone, G. (2017). Design of a novel leg-wheel hexapod walking robot. Robotics, 6(4), 40.

Vavro jr, J., Vavro, J., Kováčiková, P., Bezdedová, R., Híreš, J. (2017). Kinematic and dynamic analysis and distribution of stress in items of planar mechanisms by means of the MSC ADAMS software. Manufacturing technology, 17(2), 267-270.