23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

MODELLING AND SIMULATION RESEARCHES OF DYNAMICS OF TRANSLATIONAL PARALLEL MECHANISM

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Abstract: *The paper presents a method of modeling and simulation research of translational parallel mechanisms with three degrees of freedom and linear actuators. The analyzed mechanisms are characterized by their platform, which can move translationally with respect to the base keeping a constant orientation. Simulation researches were carried out in a computer multibody dynamic analysis system. The simulation model for the given system was built. The control system was chosen, parameters of controllers were matched. Simulation researches of the dynamics (the simple and inverse issues) were made in order to determine the basic characteristics of the system (driving forces, forces in joints, the accuracy of the actuators excitations and execution of trajectory.*

Keywords: Translational parallel mechanism, Dynamics, Simulation researches, Control system.

1. Introduction

Parallel mechanisms are systems with a closed kinematic chain structure, in which the driven link is connected with the base through several independent chains. Due to their many advantages, such mechanism find progressively wider application in industry as machine tools, positioners or manipulators (Merlet, 2000 and Tsai, 1999). Translational parallel mechanisms are peculiar systems in which the platform can move only translationally relative to the base (Bałchanowski, 2016a and Tsai, 2000).

In this paper, the subject of study is a translational parallel mechanism mt-utu (Tsai, 2000 and Bałchanowski, 2016a, 2016b). The topology and geometry of that system were determined in the Mechanical Engineering Faculty at Wrocław University of Science and Technology (Bałchanowski, 2016a), where the researches on parallel mechanisms were conducted (Fig. 1).

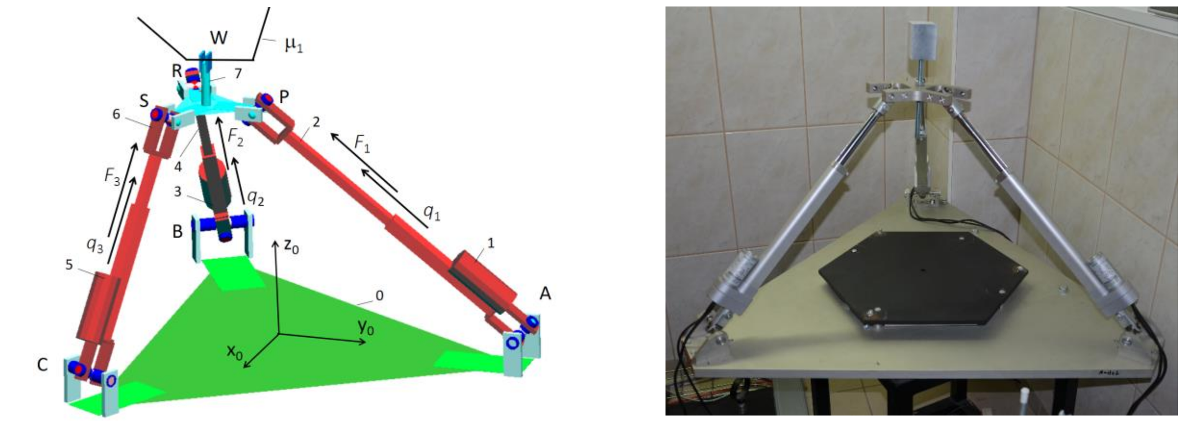

Fig. 1: The mt-utu translational parallel mechanism: numerical model and view of real system.

In the system mt-utu motion of the links is enforced by three linear actuators. The proper control of actuator excitations in order to carry out the given trajectory requires the development of a dedicated control system (Tsai, 1999; Bałchanowski et al., 2008, 2010, Bałchanowski, 2016a). Thus one of the main

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objectives of research carried out in this work was to develop computational models of the mechanism and the model of control system for realization of simulation researches. The results of simulation were the basis for the development of a mechanism with the control system (Fig. 1).

2. Methods of modelling and simulations

It was assumed, that analyses of the mt-utu mechanism carried out in this paper, were made using the computer simulation (Bałchanowski et al., 2008, 2010, Bałchanowski, 2016a). For this purpose computational models of the mechanism and the control system were built. Studies of the dynamics relied on performed numerical simulations of typical working movements of the mechanism. LMS DADS system was chosen to be used for carried simulation. It is a computer program for dynamic analysis of multibody system.

2.1. The development of a computational model of mt-utu mechanism

For this purpose of parametric calculation computational model of the mechanism was built. The model included all the basic geometric parameters of the links and the ranges of the kinematic and dynamic excitations of the actuators (Fig. 1). The assumed basic parameters of the systems were:

$$AB = BC = CA = 0.96\text{ m};\ PS = PR = RS = 0.2\text{ m};\ m_1 = m_3 = m_5 = 1.52\text{ kg};\ m_2 = m_4 = m_6 = 0.85\text{ kg};$$
$$m_7 = 6.3\text{ kg},\ 0.45\text{ m} < q_i < 0.85\text{ m};\ F_i < F_{max} = 250\text{ N, for } i = 1, 2, 3.$$

The study of the point W motion, associated with the platform, relative to the global coordinate system $x_0y_0z_0$ enforced by F_1, F_2 and F_3 forces in linear actuators q_1, q_2 and q_3 was considered in the paper.

2.2. Design of control system

Motion of mechanism is realized by the control system, which for the setpoint (excitations of linear actuator) q_{iz} generates the active forces F_i necessary to enforce the displacement along of the preset trajectory. General conceptual scheme of the mechanism control system is shown in Fig. 2. The forces F_i are output parameters from the control system and input to the model of dynamic of the mechanism. The kinematic parameters q_i, v_i, a_i of the motion of mechanism's parts are output parameters from the model of the dynamics and input to the control system. The mt-utu mechanism have three DOFs, therefore in order to unequivocally determine the position of the system's links one should calculate independent variables q_1, q_2, q_3 describing the kinematic excitations of linear actuators 1, 2 and 3. It was assumed that the classic PID controllers will be used in the control system of the mechanism (Szrek, 2016). The control process of one linear actuator in the mechanism is based on the determination of the control signal, which is the active force $F_i(t)$ (i = 1, 2, 3 – number of actuator), determined according to the formula (Gessing, 2001):

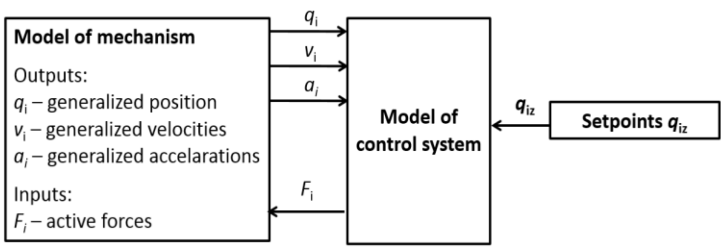

Fig. 2: Conceptual scheme of model of mechanism with control system.

$$F_i(t) = K_P e_i(t) + K_I \int_0^t e_i(t)dt + K_D \frac{de_i(t)}{dt} \quad (1)$$

where: $e_i = q_i(t) - q_{iz}(t)$ – the error value, the process variable, the setpoint,
K_P, K_I, K_D – the proportional, integral, derivative gains.

Considering the character of the object, the complete control system of mechanism was divided into three separate blocks with PID controllers, one for each actuator (Fig. 3). Computer models were built in LMS DADS and combined with the models of the mechanism in order to investigate the system dynamics.

For the purpose of this research, the parameter values were matched using a numerical procedure based on the modified Ziegler-Nichols method (Ziegler et al., 1942). The procedure consisted of an assumption of parameter values K_P subjected with the object to unit excitations and observing the responses. Parameter K_P in this simulation (for K_D, K_I = 0) was being increased until critical values K_{Pcr}

(K_{Pcr} = 1.9 x 10^4), was reached. The system response q_1 in the form of cyclic oscillations with period T_{cr} = 0.61 s (Fig. 4a) was the criterion for reaching the critical values. The initial values of the parameters for PID controller were calculated with the formula (Gessing, 2001 and Ziegler et al., 1942):

$$K_P = 0.6\,K_{cr} = 1.14\times10^4;\quad K_I = 2\,K_P/\mathrm{T_{cr}} = 3.8\times10^6;\quad K_D = K_P\,T_{cr}\,/\,8 = 8690 \qquad (2)$$

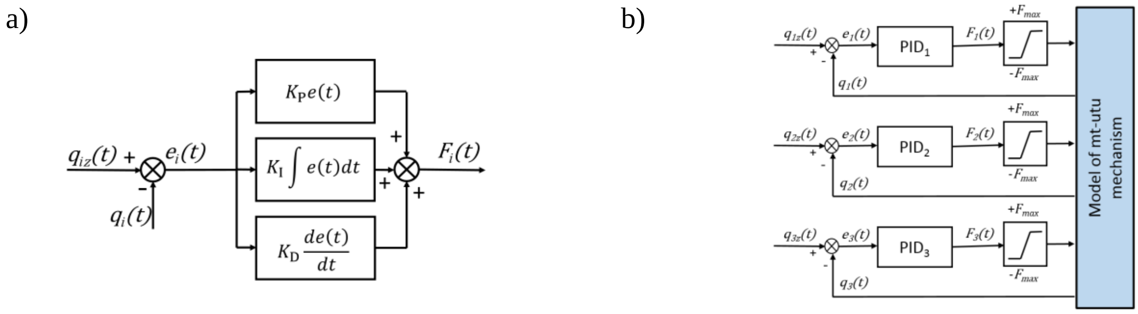

Fig. 3: a) The scheme of PID controller; b) The scheme of control system of the mt-utu mechanism.

The verifying simulation was performed for parameters from Eq. (2). The obtained response signal q_1 have small over-regulations with long time of stabilization t_s < 0.4 s (Fig. 4b - curve a). The next step of the matching parameters procedure was to adjust the values of parameters K_I, K_D. Those values were iteratively changed until the system responded without over-regulations and time t_s < 0.1 s was obtained (Fig. 4b - curve b, c). Finally the received parameter values of PID as a result of the simulations were the following (Fig. 4b – curve c):

$$K_P = 1.14\times10^4,\quad K_I = 8.1\times10^3,\;\; K_D = 3200 \qquad (3)$$

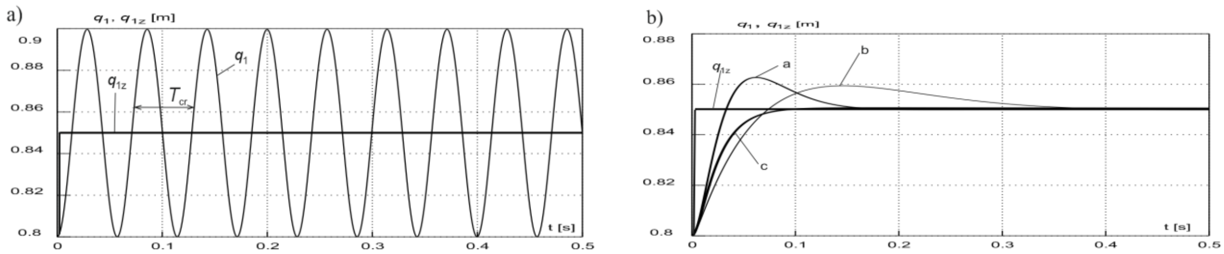

Fig. 4: a) Response q_1 for unit excitations q_{1z} for critical gain K_{Pcr}; b) Response q_1 for parameters from Eq. (2) – curve a; for parameters from Eq. (1) –curve c.

3. Results of simulation researches

In order to determine the basic dynamic properties of the mechanism and to verify the control parameter matching, simulations of the motion were carried out. The simulation consisted of the enforcement of point W motion on the platform along the selected trajectory μ_1. The general view of analyzed trajectory is presented in the Fig. 1 and the change of coordinates x_W, y_W, z_W of point W in Fig. 5a. The setpoint values for control system were the actuators settings q_{1z}, q_{2z}, q_{3z} which were calculated for the assumed trajectory μ_1 by solving the inverse problem of kinematics for the mt-utu mechanisms (Bałchanowski, 2014) (Fig. 5b).

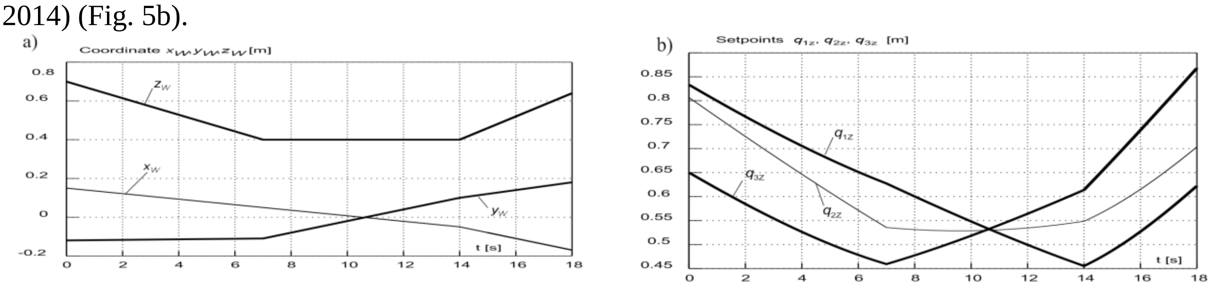

Fig. 5: Runs of x_w, y_w, z_w coordinates of analysed trajectory μ_1 of point W and runs of setpoints q_{1z}, q_{2z}, q_{3z} of actuators forcing motion along trajectory μ_1.

Simulations were made for the mechanism loaded by mass forces of the links. The results of the simulations researches of the mechanism are presented below. Errors Δq_1, Δq_2, Δq_3 in the execution of the actuators settings q_{1z}, q_{2z}, q_{3z} are presented in the Fig. 6. The actuators execution settings accuracy of below 0.35 mm for mechanisms was achieved. The errors Δx_W, Δz_W in the execution of the assigned trajectory μ_1 by the mechanism are presented in Fig. 7a. The achieved trajectory of the execution accuracy is below 0.33 mm. The control systems swiftly respond to interference (Figs. 6a and 6b – the points for $t = 7$ *s* and 14 *s*) and short stabilization time. The runs of actual active forces F_1, F_2, F_3 in actuators for mechanism mt-tuu are presented in Fig. 7a and runs of resultant forces F_A, F_P in joints A, P in Fig 7b. The active force margin in the actuators (F_{max}=150 N) relative to the required forces (F_i < 85 N - Fig. 7a) contributes to the quick stabilization.

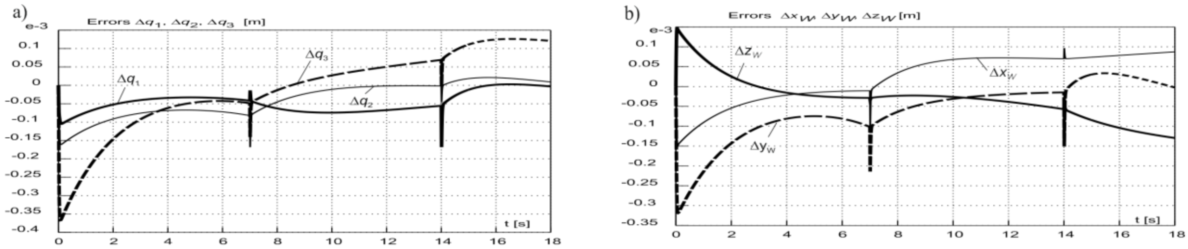

Fig. 6: Runs errors Δq_1, Δq_2, Δq_3 of drives forcing motion along trajectory μ_1 and runs of errors Δx_w, Δy_w, Δz_w of point W on the platform.

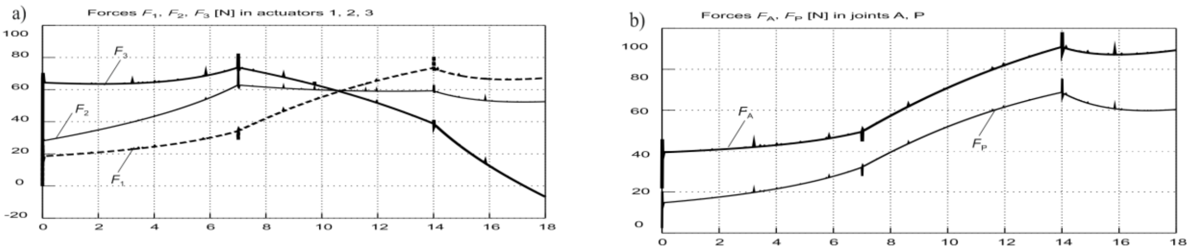

Fig. 7: Runs of actual forces F_1, F_2, F_3 in actuators and runs of resultant forces F_A, F_P in joints A, P for mechanism mt-tuu.

4. Conclusion

The basic dynamic and kinematic properties of the translational parallel mechanisms mt-utu were determined through simulation studies. The simulations confirmed that the control system structure was correct and the controller parameters were adjusted properly. The obtained numerical results can be used to design and develop real mechanisms (Bałchanowski, 2016a, Bałchanowski et al., 2010).

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