MECHATRONIC MODEL FOR THE DYNAMIC ANALYSIS OF A ROBOTIC SYSTEM

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Abstract: *The present paper discusses the co-simulation methodology for a robotic system, which is used in the spray pyrolysis process on a planar surface. Robot bodies, joints and rotors are modelled as a rigid multi-body system. The MBS software environment ADAMS was used to develop the dynamic model of a robotic system, while the control system model is developed in MATLAB/Simulink. The purpose is to verify the mode in which the control system (of the DC motors) is able to describe the trajectories of the end-effector, which are previously used to obtain the motion laws in the motor joints (through the inverse kinematic analysis as multi-body system).*

Key words: *co-simulation, spray pyrolysis, robotic system, dynamic model.*

1. Introduction

Today, spraying is used for depositing coatings onto various articles. Spray pyrolysis deposition is an aerosol process used to form a variety of materials in powder from including ceramics, superconductors and nanostructured materials. The spray pyrolysis is defined as a deposition technique whereby heat is used to break molecules into elemental sources that are then spray deposited on a substrate.

Spray Pyrolysis Deposition (SPD) is consists of four main steps: 1) generation of spray fro a precursor by a droplet generator, 2) spray transport by an air flow during which solvent evaporation occurs, 3) thermolysis of the precipitated particles at higher temperatures to form nano particles, 4) extraction of the particles from the gas flow [5]. The advantages of the SPD technique are offer a better uniformity in chemical composition, a better regularity in shape, a lower cost for the preparation of thin films with a larger area [7].

Robots are used for spraying application because of the repeatability of the resulting surface finishing, inclusive the benefit of removing humans from a hazardous environment. Their application gives a better quality of deposited surfaces due to the property of accurate control of robot [9].

The nozzle direction generation method is similar to the generation of the normal of a plane and the nozzle direction is the opposite direction of the normal of the plane. The nozzle velocity is determined by optimizing the spraying process of a plane surface. The nozzle velocity can be calculated as a function of the overlap distance for a thickness.

The relevance of this paper is represented by the importance for the field of thin film. This paper is structured as follows: Section

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2 presents the ADAMS model, Section 3 contains the MATLAB/Simulink control scheme of the robotic system, Section 4 presents some simulation results and finally, Section 5 contains concluding remarks.

2. Dynamic Model of the Robotic System

The robots are complex electro-mechanical systems, where various electric drives are used to control the movement of the articulated structures. For the model it was used joints (brushless DC motors) connected to the robot structure by speed reducer. The whole electrical part of the motor is represented in Figure 1 by the block "controller - motor".
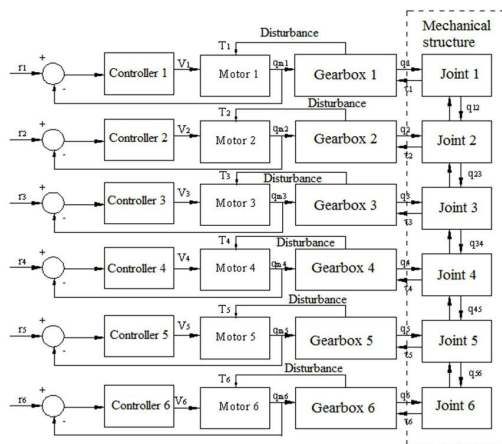

Fig. 1. *The control system of a robotic system*

Blocks "gearboxes" contain mechanical part of motors and of their speed reducers. The torque in the air gap drives rotor to the motor. Robot bodies, joints and rotors are modelled as a rigid multi-body system. The ADAMS software was used to develop the dynamic model of a robotic system.

This model was then supplied under MATLAB/Simulink environment to be analyzed. The model is used in the control scheme to predict the behavior of the system using a PD (Proportional Derivative) controller for position.

ADAMS and MATLAB/Simulink were interfaced to benefit a powerful tool to model the dynamic behavior of robotic system [4]. The need of a better design of the system like in robotics has led to the development of methods for the dynamic analysis as multi-body systems (MBS), which facilitate the self-formulating algorithms.

In this approach, complex virtual prototypes can be developed, which exactly replicate the structure and the operating conditions of the real physical products. Virtual prototyping, a new way of defining dynamic simulations is more compliant with time and budget constraints [6]. Mostly, a virtual prototyping platform integrates the following software solutions [1-3]: CAD (Computer Aided Design), MBS (Multi-Body Systems), FEA (Finite Element Analysis) and DFC (Design for Control). The CAD model improve the model accuracy by the automatic calculation of the inertia properties of the all the parts of the robot.

The CAD software is needed for creating the geometrical model (solid model) of the system. This model contains information about the mass and inertia properties of the rigid parts. In modeling using CATIA, CAD software, robot model is divided into 11 parts. To import the designer model to ADAMS, the first step is to save each of the parts of the robot in "stp" format, since this format is recognized in ADAMS. The next step is to import the model into ADAMS. After transferring model, inertial parameters of the parts are recorded in software database.

The ADAMS software presents an alternative to derive numerically the dynamic model for system. In Table 1 is shown the geometric and dynamic characteristics of the robotic system. A design is modeled under ADAMS (Figure 2), and the dynamic model is determined in order to investigate the dynamic behavior.

Inertia parameters of the system   Table 1

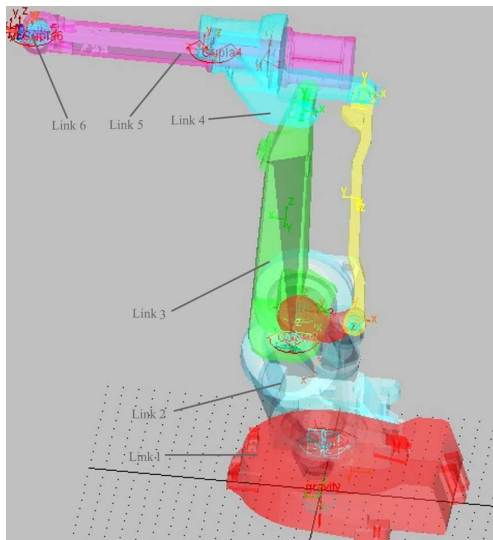| Parameter	Mass [kg]	Moment of inertia [Kg.m^2]
Link 1	$m_1 = 93.8$	$I_{xx} = 5.18 \cdot 10^6$ $I_{yy} = 3.48 \cdot 10^6$ $I_{zz} = 3.13 \cdot 10^6$
Link 2	$m_2 = 35.4$	$I_{xx} = 2.02 \cdot 10^6$ $I_{yy} = 2 \cdot 10^6$ $I_{zz} = 1.83 \cdot 10^5$
Link 3	$m_3 = 14.6$	$I_{xx} = 2.82 \cdot 10^5$ $I_{yy} = 2.6 \cdot 10^5$ $I_{zz} = 2 \cdot 10^5$
Link 4	$m_4 = 20$	$I_{xx} = 1.95 \cdot 10^6$ $I_{yy} = 1.95 \cdot 10^6$ $I_{zz} = 4.2 \cdot 10^4$
Link 5	$m_5 = 0.3$	$I_{xx} = 184.9$ $I_{yy} = 116.03$ $I_{zz} = 107.7$
Link 6	$m_6 = 0.12$	$I_{xx} = 112.8$ $I_{yy} = 112.5$ $I_{zz} = 15.8$

Fig. 2. *ADAMS model of the robotic system*

In this study it was been used a system with six inputs (control torques), respectively twelve outputs (the angle and angular velocity) (see Figure 3), where w_i is the velocity, *Tetha$_i$* represent the angular position and T_i is the torque, for $i = 1…6$.

The objective of co-simulation is to make

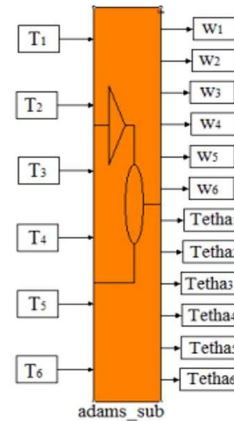a connection so that any change in one of the programs affects the other one [8].

Fig. 3. *The dynamic model generated by ADAMS/Controls*

Once the model is finalized, the dynamic model is generated by ADAMS/Controls and exported under the MATLAB/ Simulink. The block *adams_sub* (Figure 4) is the file exported from ADAMS which is containing the dynamic model with all the simulation parameters.
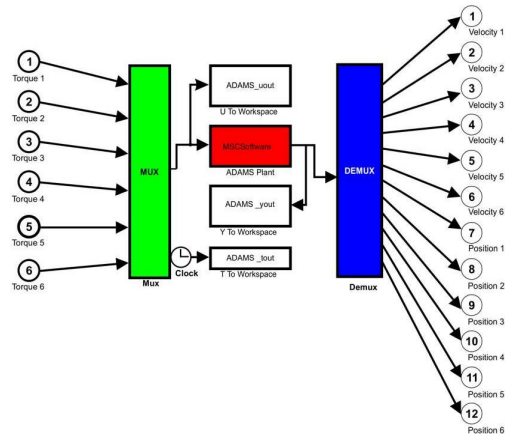

Fig. 4. *Architecture of the Adams_sub block*

The blocks: *ADAMS_uout*, *ADAMS_yout* and *ADAMS_tout* are the input and output variables, respectively the simulation time. *ADAMS Plant* is the dynamic model of the robotic system.

By having *Adams_sub* block in MATLAB/Simulink, the robot model is suitable for control and motion simulation as a defined system in MATLAB. The main objective of the research is to generate various paths on the planar and curved surfaces (for this paper, we have considered a planar trajectory). With other words, we intend to verify the mode in which the control system (of the DC motors) is able to describe the trajectories of the end-effector, which are previously used to obtain the motion laws in the motor joints (through the inverse kinematic analysis as multi-body system).

3. The Control Scheme

The robots are complex electrical and mechanical systems with electric drives which are used to control the movement of the articulated structures. For this study, the electric drives were facilitated by the Electric Drives library in MATLAB/ Simulink. This module can be used to model the motor drive, the speed reducer, the mechanical model of the arm and the controller. For each motor drive, a proportional-derivative (PD) controller is used. The control scheme used in this paper is present in Figure 5.
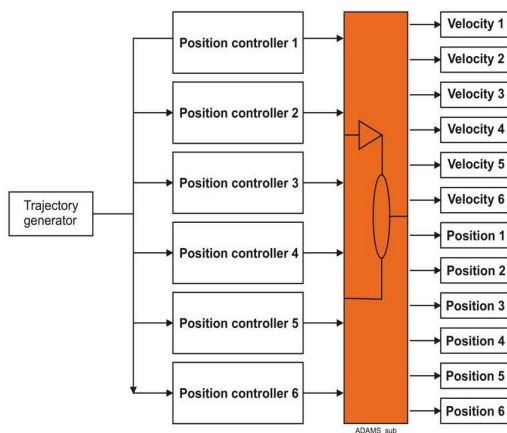
The advantage of the PD controller is that this does not require a deep knowledge of the dynamic model of the robotic system. In this paper, we will be interested in the PD controller. The PD control algorithm is given by:

$$\tau(t) = K_P e(t) + K_D \dot{e}(t), \qquad (1)$$

where $\tau(t)$ is the driving torque generated by the controller, K_P, K_D are the proportional and derivative gains, respectively, $e(t)$ is the position error and $\dot{e}(t)$ is the velocity error, they are calculated by:

$$e(t) = x_d - x(t); \quad \dot{e}(t) = \dot{x}(t) \qquad (2)$$

where x_d is the desired position and $x(t)$ is the actual position.

The control system used in this study is the type of control loops designed using Simulink blocks for each of the six control positions. The robot's axes are driven by DC motor that are modeled by permanent magnet synchronous motors. The speed reducers and the gearbox are needed to transmit torque from the motors to the joints. The motor is fed by a three phase inverter operating in current controlled mode.

The block model of the position controller is shown in Figure 6, with the following notations: *teta_ref* - the desired reference angle, *teta* - the current joint angle, *w* - the corresponding rotational velocity, *Kp* - proportional gain, *Kd* - derivative gain, *Nref* - the reference rotor speed. The Saturation block imposes upper and lower bounds on the signal.

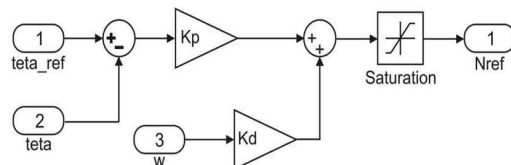Fig. 5. *The control scheme of the robotic system*

Fig. 6. *The PD scheme of the position controller*

For each of the six joints, we have considered the effect of the other links as a single load, reflecting to the joint a torque that is composed of three terms:

$$T_i = J_i \frac{d^2\theta_i}{dt^2} + C_i \frac{d\theta_i}{dt} + G_i\theta_i, \qquad (3)$$

where θ_i is joint position, J_i is inertia, C_i is centrifugal and Coriolis coefficient, G_i is gravitational coefficient. In this analysis, the parameters J_i, C_i, G_i are functions of joint positions.

4. Simulation and Results

The robotic system is a robot with six degrees of freedom and has the parameters given in Table 1.

In the simulation, the inputs were required to move the end-effector (nozzle) from its original position to the new position following the described path. The simulation is performed using a time step of 45 seconds, and the responses of the simulation for six axes are shown on one scope connected to the output variables of the robot blocks. In the simulation the both of software are working in the same time, this fact leads to the possibility to obtain results in the both software. In this study the results (the angular velocity variation depending on time, the angular displacement depending on time) are obtain with MATLAB/Simulink and ADAMS software.

In Figures 7 and 8 are shown the diagrams were obtained by co-simulate released for the mechanical structure developed in MBS concept in ADAMS and the control system released in MALTAB/Simulink for the planar trajectory, the simulation was performed for 45 seconds.

In Figure 7 (*a* - result from MATLAB, *b* - result from ADAMS) are represented in the graphic mode the velocity of the first joint in the analyzed robotic system.
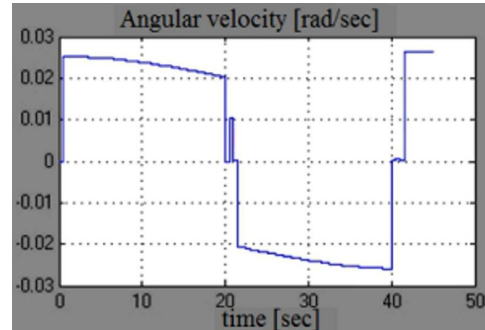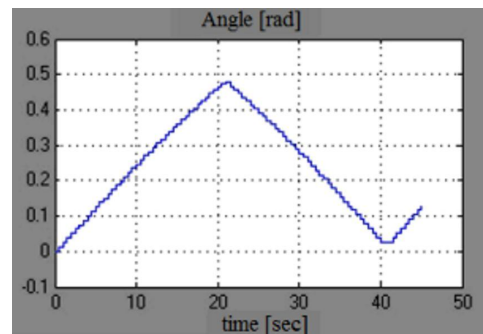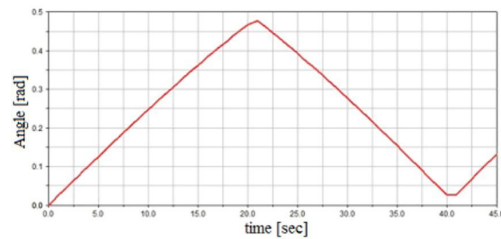

a)
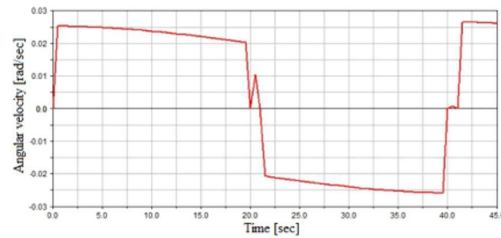
b)

Fig. 7. *The angular velocities of the system*

In Figure 8 (*a* - result from MATLAB, *b* - result from ADAMS), there are generated the position diagrams for the first joint of the robot with six degrees of freedom.

a)

b)

Fig. 8. *The angular position of the system*

5. Conclusions

In this paper, we developed the virtual prototyping of the robotic system. The robotic system was designed under ADAMS environment then its dynamic model was exported to MATLAB/Simulink for the co-simulation. The MBS model of the robotic system (shown in Figure 2) was integrated in the control system model (Figure 5). The mechanical model and the control system were been co-simulated (tested together). Different sets of dynamic parameters can be selected according to purpose without changing the model.

The physical robot exists within the Department of Renewable Energy Systems and Recycling, and the motion laws in joints (obtained by simulating the virtual prototype) will be implemented on the physical robot for generating the desired trajectory. Various trajectories will be tested to obtain a better uniformity of the film by different overlapping spraying cones, in order to achieve the desired deposited surface.

References

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