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FINITE ELEMENT ANALYSIS OF AN INDUSTRIAL ROBOT WITHIN THE MSC.ADAMS SOFTWARE

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Abstract: *The paper presents a concept for the modelling and simulation of an industrial robot by using finite element analysis (FEA). The FE analysis was accomplished to simulate an environment close to reality by flexibilities in the robot. The industrial robot was designed in the CAD (Computer Aided Design) software CATIA, the 3D-model being then transferred to the MBS (Multi-Body Systems) environment ADAMS/View. The strain calculation of the three elements/links from the robot was made also by FEA. The conversion of the rigid components in flexible element has been performed through ADAMS/AutoFlex.*

Key words: *industrial robot, finite element method, flexible element.*

1. Introduction

The purpose of the paper is to investigate by finite element method the mechanical behavior of three elements/links of the IRB2400L ABB robot using MSC.ADAMS (Automatic Dynamic Analysis of Mechanical System), which is a multi-body system software environment [14].

Multi-body System Simulation (MBS) and Finite Element Analysis (FEA) are both practices in computational engineering.

Multi-body analysis was focused on the nonlinear dynamics of the system that has been designed through rigid bodies and linkages. The FEA method was used to analyze deformation and stresses in the mechanical system. The ADAMS/Flex is a software product that combines advantages of the MBS analysis and FEA solvers [1].

The industrial robot (ABB IRB2400L) was used in deposition to obtain of thin layers, which can be used in solar energy conversion systems. In this case, the robotic system is devices with six degrees of freedom (6-DOF), which are comply with 6 axes of the robot.

The virtual environment of the mechanical system is designed by the use of CATIA software environment (CAD - Computer Aided Design) [1], [4].

This model is imported in the dynamic analysis environment ADAMS/View through the standard for the exchange of product model data (STEP) file format. In ADAMS/View, there have been modeled the connections (joints) between the solid bodies, and the actuating elements. In this way, the MBS model of the mechanical device of the robotic system (IRB2400L robot) has been developed, which is shown in Figure 1.a.

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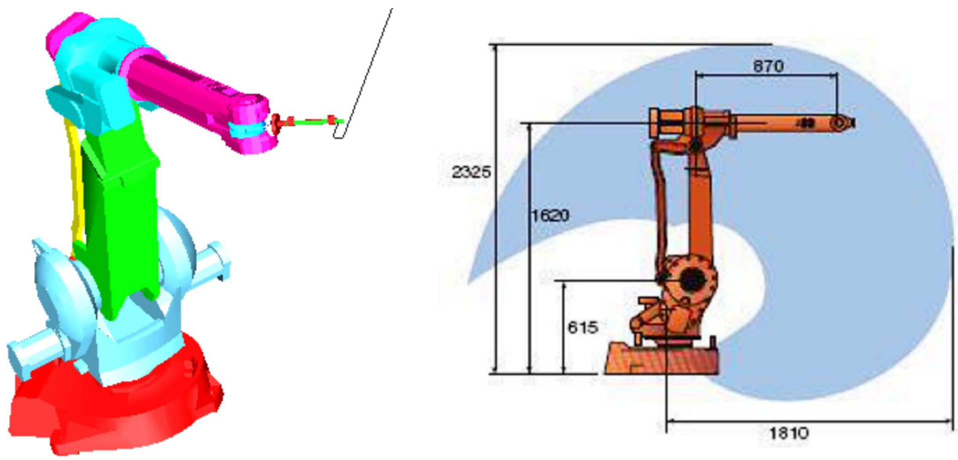

a. Virtual model *b. Physical model* [14]

Fig. 1. The virtual IRB2400L robot

The overall dimensions and workspace of the manipulator is shown in Figure 1b.

MSC.ADAMS software package includes the ADAMS/AutoFlex module, which combines simulations and results of the MBS and FEA analyses. The aim of this study is to simulate and analyze the robot with multi-axis, including behavior of the flexible bodies.

The paper is structured as follows: Section 2 presents the setup of the mechanical device (including the MBS model, and the FEM model); Section 3 shows the results of the simulation; Section 4 discusses the main research findings.

2. Setup of the MBS and FEM Models

In this case, the IRB2400L robot (see Figure 1) was used in the simulations. The CAD software was applied for obtaining the solid bodies (geometrical model) of the robotic system [10], [13]. The solid model contains information about rigid parts meaning the mass and inertia properties [2], [6], [8]. The dynamic model is modelled under ADAMS software in order to analyse the dynamic behaviour of the mechanical device.

In the simulation, the end-effector (sprayer) was moved from its original position to other position according to an imposed trajectory (Figure 2). Getting the joint motion necessary to described trajectory of the end-effector is actually solving the inverse kinematic problem [7].

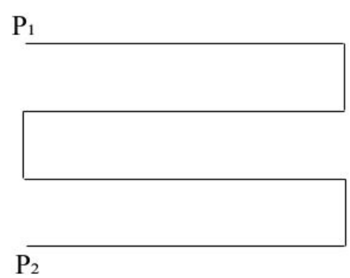

Fig. 2. *The imposed trajectory of the robot*

The MBS software solution ADAMS is used for the kinematic and dynamic analysis & simulation of the mechanical system. This is an efficient alternative for the numerical simulation of the dynamic behaviour of the industrial robot. The geometrical and dynamic parameters of the robot are presented in table 1.

Table 1

Parameter	Mass [kg]	Moment of inertia [Kg.m^2]
Link 1	m_1=80.9	$I_{xx}=4.29\cdot10^6$ $I_{yy}=2.96\cdot10^6$ $I_{zz}=1.62\cdot10^6$
Link 2	m_2=93.79	$I_{xx}=5.18\cdot10^6$ $I_{yy}=3.47\cdot10^6$ $I_{zz}=3.12\cdot10^6$
Link 3	m_3=39.3	$I_{xx}=2.02\cdot10^6$ $I_{yy}=1.99\cdot10^6$ $I_{zz}=1.82\cdot10^5$
Link 4	m_4=34.5	$I_{xx}=1.95\cdot10^6$ $I_{yy}=1.95\cdot10^6$ $I_{zz}=4.2\cdot10^4$
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

The dynamic model of the robot is shown in Figure 3; the model is used to evaluate the dynamic behaviour.

FEA software is used to model the flexibilities in the system, which allows the accurate simulation of the dynamic behaviour of the mechanical system with flexible components (bodies). FEA software determines the tension of each component of the mechanical system [3].

In the communication between the MBS and FEA software environments, the MBS analysis returns the state of motion and loads of the mechanical system, while FEA gives the state of the flexibility of the components. In this way, it is possible to accurately evaluate the kinematic and dynamic behaviour of the mechanical system [5], [9], [11, 12].

Figure 3 shows the flexible elements for the three components of the robot (these are the elements that generate the position of the end-effector). In this case study, only the components that define the position of the end-effector have been taken into consideration.

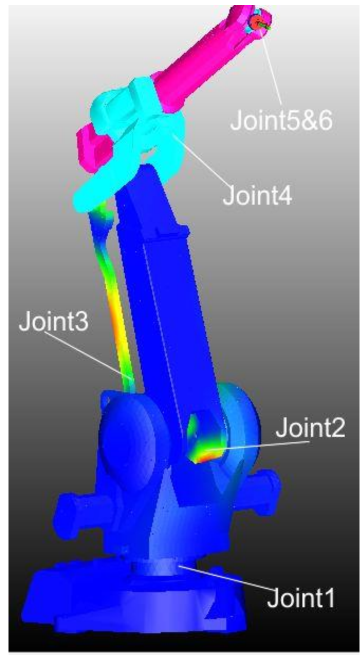

Fig. 3. *Finite elements model of the robot*

The conversion of the rigid bodies in flexible bodies was realized by the use of ADAMS/AutoFlex. Total number of brick elements was 22846, for the joint 1, joint 2 and joint 3 respectively. Steel material has been used for the bodies connected by these joints. The material properties of the bodies are imported into the virtual model by library packages.

3. Results and Discussion

In this study has been analysed the behaviour of the manipulator IRB 2400L, only the first three elements which determine the position of the effector were converted in flexible components. Therefore it was studied only the first three joints of the robot.

This model has six motors. The rotor of the motor is driven by the torque in the air gap.

The strain, displacement and torque plots are important to evaluate the mechanical system. To analyse the design of the system, it is important to obtain the information about strain and displacement. Also, information about torque is necessary to decide dimension of the motor for the system.

In the studied model, was taken into account the information about inertia and weight of the elements.

Table 2 presents the difference between the rotation of the reference industrial robot and the rotation of the virtual robot.

The strain is the relative displacement of a point on a body from an undeformed state to a deformed one. In Figure 4 is shown the diagram of the strain energy of the second element of the manipulator.

Table 2

Axes	Robot specification		Computed rotation
	1 s	0.1 s	
Joint 1	150^0	15^0	14.9^0
Joint 2	150^0	15^0	14.8^0
Joint 3	150^0	15^0	14.9^0

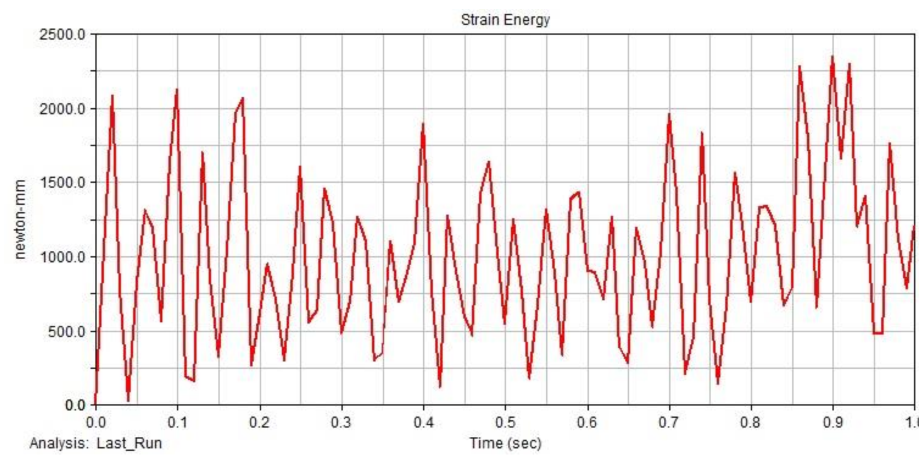

Fig. 4. *Strain energy of the second element*

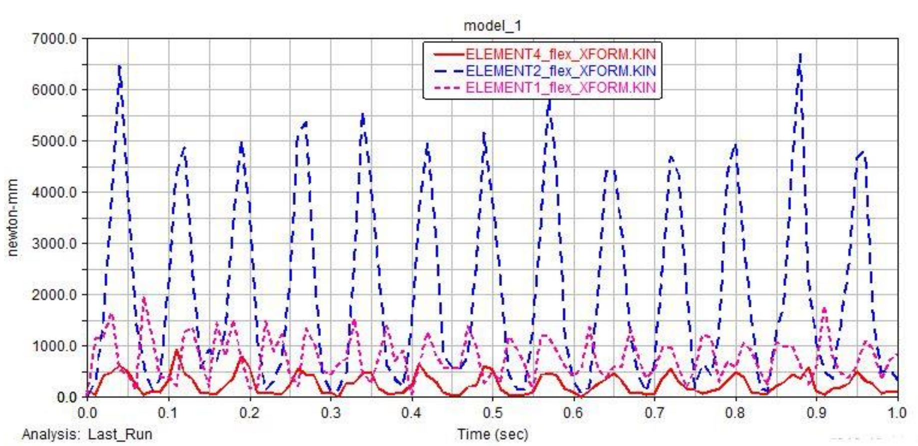

Fig. 5. *Kinetic energy of the first three elements of the robot*

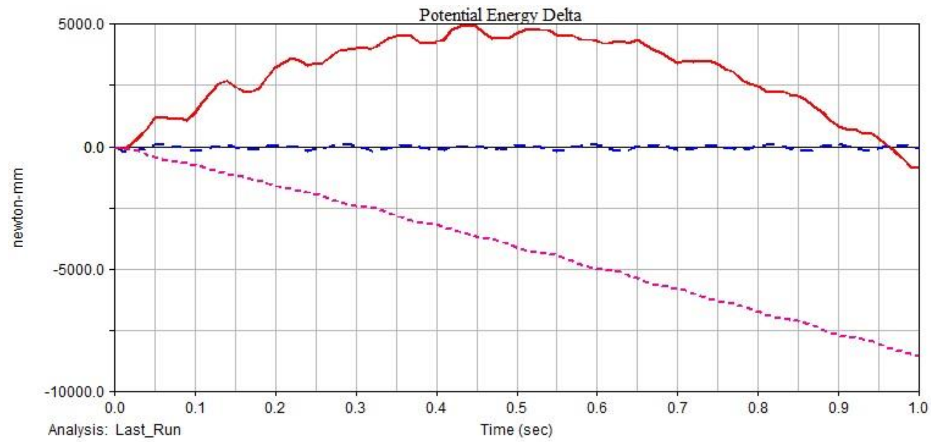

Fig. 6. *Potential energy of the first three elements of the robot*

Figure 5 shows the time history variation of the kinetic energy of the first three elements of the robot IRB 2400L (links 1, 2, and 3). In figure 6, there is shown the potential energy of the same three elements of the 6-DOF robot. From the two figures, it is possible to conclude that the second element (link 2) has the highest values, in terms of kinetic and potential energy.

4. Conclusions

By using the software environments for the simulation, analysis and optimization is decrease the cost of the product or the process and also is minimize the time of the design. In the same time, the quality of those products and processes is increase.

The application is an important example of the virtual prototyping of the industrial robot that is used to deposit thin films for the solar energy conversion systems.

In this study was been described the designing, simulation and analysis of the rigid and flexible bodies for the robot IRB2400L.

The FAE technique offers the possibility to analysis the robot with multi-axis as response to the dynamic model. To analyse by FEA a flexible model is necessary to determine number of flexible elements and also number of the nodes.

In the future work, it is intended to simulate and analyse the all components of the robot converted in flexible elements.

References

1. Alexandru, C., Comşiţ, M.: *Modeling the Tracking System of a Photovoltaic Platform using the ADAMS & EASY5 Software Solutions.* In: Proceedings of the 2-nd Conference on Sustainable Energy, Braşov, 2008, p. 109-114.
2. Cheraghpour, F., Vaezi, M. et al.: *Dynamic Modeling and Kinematic Simulation of Staubli TX40 Robot Using MATLAB/ADAMS Co-Simulation.* In: International Conference on Mechatronics, Instanbul, 2011, p. 386-391.
3. Du, H., Hitchings, D., Davies, G.A.O.: *A Finite Element structural Dynamics Model of a Beam with an Arbitrary Moving Base – Part I: Formulations*. In: Finite Elements in Analysis and Design, Vol. 12, Issue 2, 1992, p. 117-131.

4. Enescu, M.: *A Novel Spray Pyrolysis Deposition Procedure on Planar and Non-Planar Surfaces*. In: Sustainable Energy in the Built Environment – Steps Towards nZEB, 2014, p. 243-255.
5. Elsayed, Y., Vincensi, A. et al.: *Finite Element Analysis and Design Optimization of a Penumatically Actuating Silicone Module for Robotic Surgery Applications*. In: Soft Robotics, Vol. 2, 2014, p. 1-8.
6. Garcia de Jalón, J., Bayo, E., *Kinematic and Dynamic Simulation of Multibody Systems*. Springer, New York, 1994.
7. Guan, Y, Yokoi, K. et al.: *On Robotic Trajectory Planning Using Polynomial Interpolations*. In: Robotics and Biomimetics, 2006, p. 111-116.
8. Hroncová, D., Binda, M. et al.: *Kinematical Analysis of Crank Slider Mechanism Using MSC ADAMS/View*. In: Procedia Engineering, Vol. 48, 2012, p. 213-222.
9. Mon, T.T., Mohd Romlay, F.R., Tamin, M.N.: *Role of Finite Element Analysis in Designing Multi-Axes Positioning for Robotic Manipulators*. In: Advances in Robot Manipulators, 2010 INTECH, p. 565-588.
10. Pupăză, C., Constantin, G., Negrilă, Ş.: *Computer Aided Engineering of Industrial Robots*. In: Proceedings in Manufacturing Systems, Vol. 9, Issue 2, 2014, p. 87-92.
11. Podnos, E., Becker, E. et al.: *FEA Analysis of Silicone MCP Implant.* In Journal Biomech, 2006, p. 1217-1226.
12. Su, Y., Swevers, J.: *Finite-Time Tracking Control for Robot Manipulators with Actuator Saturation*. In: Robotics and Computer-Integrated Manufacturing, Vol. 30, Issue 2, 2014, p. 91-98.
13. Velicu, R., Moldovean, G., Gavrilă, C.C.: *Constructive Aspects on the Altitudinal System of a Solar Tracking PV Platform*. In: Proceedings of the 2nd Conference on Sustainable Energy, Braşov, 2008, p. 1194-1108.
14. https://www.robots.com/abb/irb-2400l. Accessed: 20.09.2016