Rapid Prototyping of a Manipulator Mechanism Using Hardware in the Loop (HIL) Simulators and Comparing the Results

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Abstract: In this paper dynamic and static analysis of five bar linkage mechanism are studied using different engineering software. The results are compared with each other and it's attempted to optimize the mechanism to perform an accurate action such as drawing a complicated path. This methodology leads us to analyze, design and implement robot control design very fast. It is solely rely on hardware in the loop (HIL) method

Keywords: Five bar mechanism, software, dynamic and static analysis, HIL robot

Introduction

In recent years, computer simulation plays a vital role in design, analysis and even implementation of systems. It makes possible to do many tests with reliable results, which is not affordable in real world. We will simulate a mechanism and study its results in this article. At first, a five bar linkage which has many application in industrial robots (Fig.1) is introduced.

Also the robot END EFFECTOR behavior is computed. The mechanism is modeled using Solidworks® and then dynamically analyzed with Cosmos® and MSC.Adams® software. The derived model in Solidwork® is converted to Simmechanic® model using Solidwork® to Simulink® converter software. Then it is analyzed in Simulink® environment easily as well.

Next the strength of each link is analyzed using Cosmos®, Ansys® and MSC.Nastran®. The performance of the mentioned methods in different conditions, such as different wind speeds is compared through Cosmos® and Fluent® packages.

Finally the bandwidth of this manipulator is computed by MSC.Adams®. The organization of this paper is as follows; section 1 describes the five bar linkage mechanism and its kinematics and dynamic equation. Section 2 deals with Solidwork® model of the given mechanism. Section 3 and 4 illustrate dynamic analysis and Simulink® model of the given mechanism. Static studies and flexible links modeling results are brought in section 5, 6 and 7 respectively. Section 8 is a brief description of implementation issues and it is followed by concluding remarks with future works.
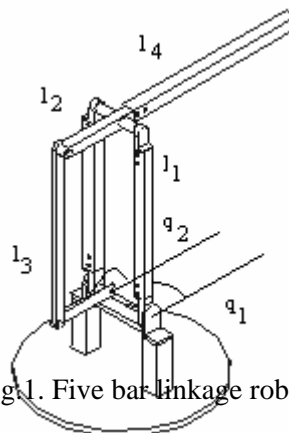

Fig.1. Five bar linkage robot schematic

1- Five Bar Mechanism

The mentioned five bar mechanism which is used in this study is shown in Fig.2. The point O is the base and the parameters α, β

are the control factors. The Links D and E shape a single bar and are connected to the bars, A and C. All the above joints are of the revolute type joint.
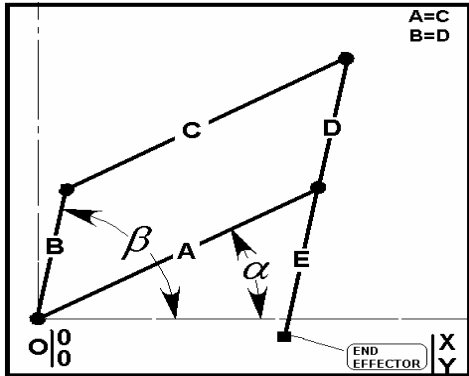

Fig.2. Five bar linkage schematic

1.1 Kinematics and Dynamic Equations

The end effector coordinates can be obtained by the following forward kinematics equation [1].:

$$\begin{bmatrix} x_{end} \\ y_{end} \end{bmatrix} = \begin{bmatrix} l_2 \cos(q_2) \\ l_1 \sin(q_1) \end{bmatrix} + \begin{bmatrix} l_4 \cos(q_2) \\ l_4 \sin(q_2) \end{bmatrix} \begin{matrix} (1) \\ (2) \end{matrix}$$

The inverse kinematics equations are also available [1].

1.2 Dynamic Equation

In the following the dynamic equation of the five bar linkage mechanism is illustrated[1].

$$T_1 = ((M)_{11} + I_h^1)\ddot{q} + (M)_{12}\ddot{q}_2 + \frac{\partial(M)_{12}}{\partial q_2} \times \dot{q}_2^2 + g(m_1 l_{c1} + m_3 l_{c3} + m_4 l_1)C_{q1} \quad (3)$$

$$T_2 = ((M)_{22} + I_h^2)\ddot{q} + (M)_{12}\ddot{q}_1 + \frac{\partial(M)_{12}}{\partial q_1} \times \dot{q}_1^2 + g(m_2 l_{c2} + m_3 l_2 - m_4 l_{c4})C_{q2} \quad (4)$$

$$(M)_{11} = I_{11}^1 + I_{11}^3 + m_1 l^2_{c1} + m_3 l_{c3}^2 + m_4 l_1^2 \quad (5)$$

$$(M)_{22} = I_{11}^2 + I_{11}^4 + m_2 l^2_{c2} + m_4 l_{c4}^2 + m_3 l_2^2 \quad (6)$$

$$(M)_{12} = (m_3 l_{c3} l_2 - m_4 l_{c4} l_1)C_{q_1 - q_2} \quad (7)$$

2 Solidworks Model

The five bar mechanism is modeled with Solidworks (Fig.4). Note that the mechanism can rotate around the base axes. Therefore,
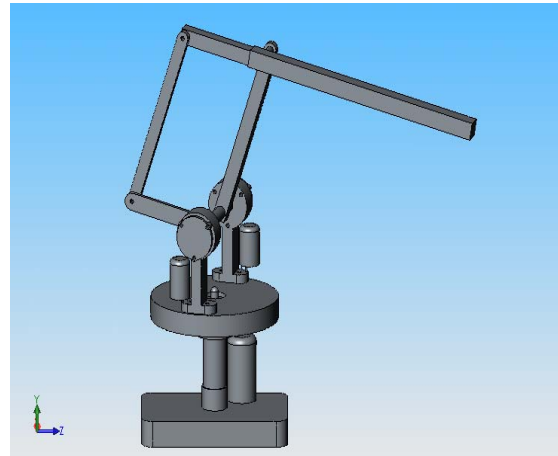
the mechanism has 3 degrees of freedom (DOF).

Fig.4.Model in Solidworks

3 Dynamic Analyses

Dynamic analysis is performed using Cosmos® and MSC.Adams®[3,4] packages. Results for standard inputs i.e., reference trajectory are shown in Fig.5, 6, 7, 10, and 12. The behavior of specified joints (Fig.8) helps designer to choose the appropriate motor specifications.
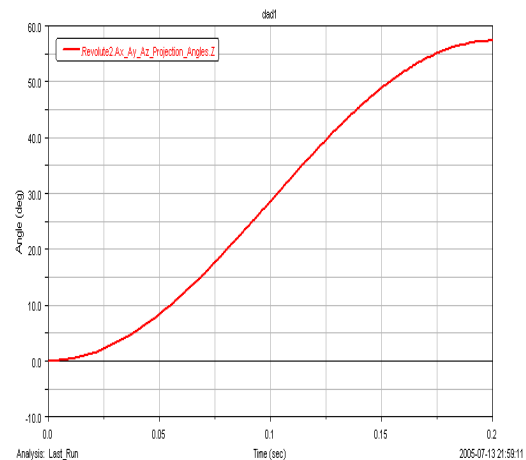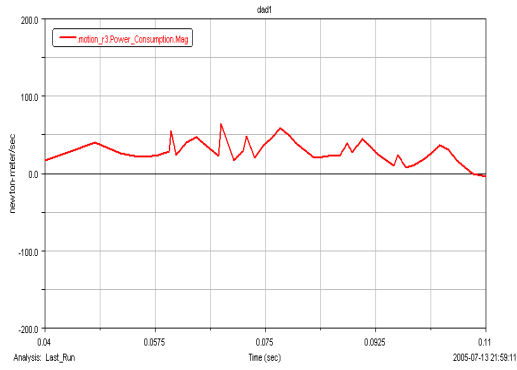

Fig.5 Reference trajectory

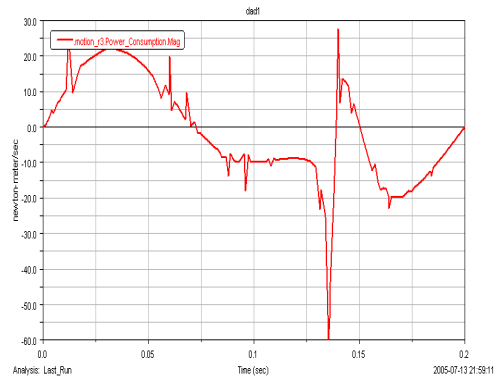Fig.6 Power requirement for the motor 1
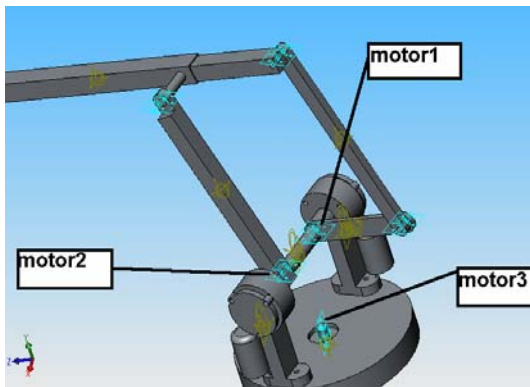

Fig.7 Power requirement for the motor 3

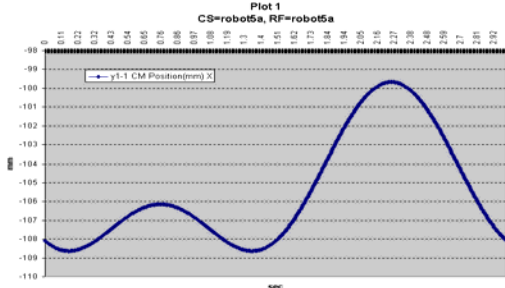Fig.8 Motors connection to the links in Solidwork® model
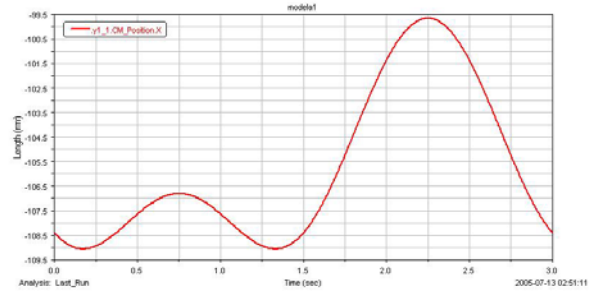

Fig.10 Cosmos result

Fig.12 MSC.Adams result

4 Simulink Model

Simulink® model for was obtained using Solidworks® to Simulink® converter [2, 5]. Simmechanic® is a toolbox of Simulink®(Fig.9). It is then examined with a standard input and the result is shown in Fig.11.
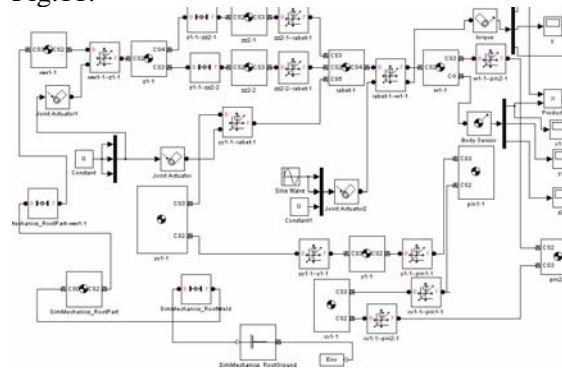

Fig.9 Simulink® model of the five bar linkage
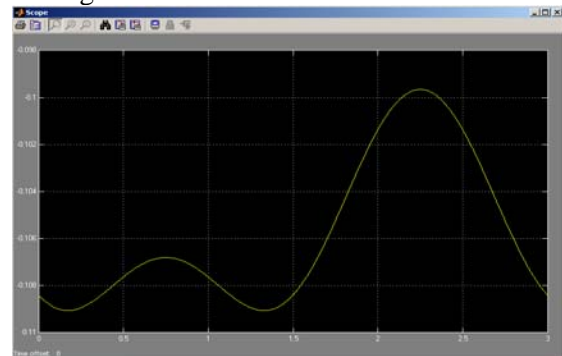
The results of standard inputs are shown in the Fig.11.

Fig.11 A MATLAB result

5 Static Analyses

In order to have a good factor of safety (FOS), finite element analysis (FEA) of the model is performed using Cosmos®, Ansys®, MSC.Nastran® and the results are shown in Fig. 13, 14 and 15 respectively. Also, the stress results are calculated and shown in Table (1).
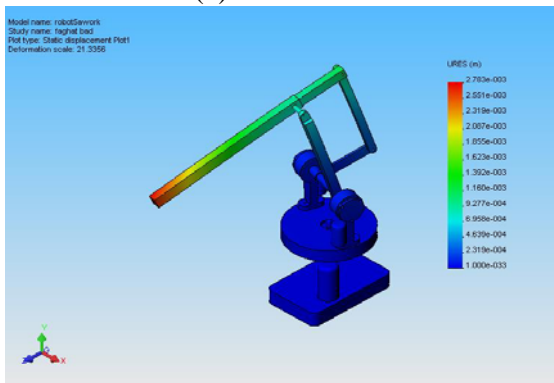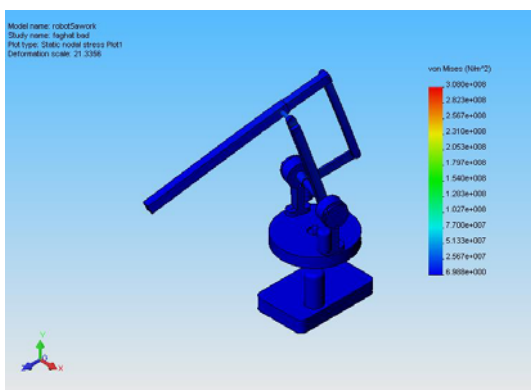

Fig.13.Deformation analyses by Cosmos
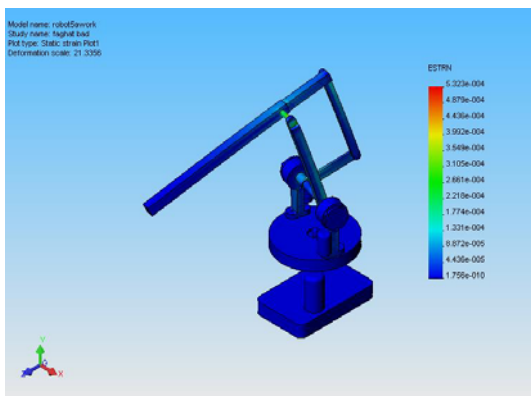

Fig.14.stress analyses by Cosmos

Fig.15.strain analyses result by Cosmos

Table 1 Comparing results in different conditions

Condition	Min stress	Max stress
Just load	0.2628	3.7e+007

	N/m^2	N/m^2
Load with wind in x direction	5.47 N/m^2	4.7e+007 N/m^2
Load with wind in y direction	2.07 N/m^2	4.57e+007 N/m^2
Load with wind in z direction	4.5 N/m^2	2.67e+007 N/m^2

6 Static Analyses in Different Conditions

The static analyses are performed in different conditions and different wind speeds using Cosmos® and Fluent® [packages (Fig.16). The results are shown in Table (1). It is revealed that in some cases, the wind is even decreasing the maximum of stress.
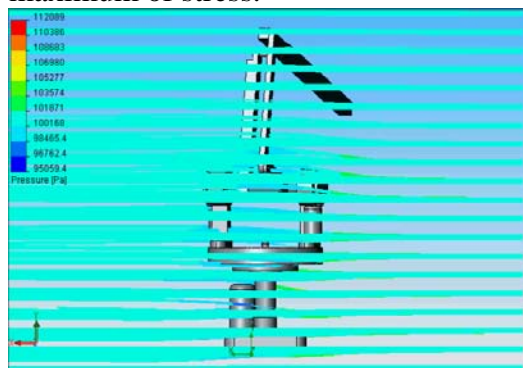

Fig.16.wind analysis in Cosmos

7 Flexible links and joints modeling

In the real world, there is no solely rigid body. Everything in our environment is flexible, so designer should consider the flexible parts into account for modeling. When we vibrate an object with some frequency, it can be observed that by increasing the frequency will decrease the body reaction. The flexible mechanism model is shown in Fig.17. and the related results of increasing frequency is shown in Fig.18.

Fig.17.flexible bodies

Fig.18. Implementation of 5-barlinkage in the lab

Fig.18. Body reaction due to increasing frequency

promising and reliable method to perform any test without having any lab.

The given mechanism could be tailored for many purposes such as welding, drilling and grinding. In the future, we will implement several AI algorithm using Simulink™ and RTWT® toolbox for teleoperation purposes. Moreover optimal design of this manipulator will be considered.

8 Implementation

Considering all the results we design and construct the lab model of 5bar linkage (Fig. 19). It is widely used for our future experiments.

9 Conclusion

In this paper several analyses was performed and studied on a five bar mechanism such as dynamic, static, and vibration using different pckages. Also comparing the results were carried out. It is found out that simulation could be a

References
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[2] www.Mathworks.com
[3] www.mscsoftware.com
[4] www.**cosmos**m.com
[5] www.**solidwork**s.co.il