

Kinematics and Simulation of a Hybrid Mechanism: MATLAB/SimMechanics

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Abstract. Kinematic analysis and simulation of hybrid drive system are addressed in this study. A seven link mechanism with two degrees of freedom is selected as the configuration of the system. Kinematic analysis is performed by loop closure equations and required inputs of servo motor are given to get desired ram motion scenario. MATLAB/SimMechanics platform is used to model the hybrid driven mechanical system mechanism characteristics. The simulation results are presented herein.

1. Introduction

The interest in hybrid driving systems is started many years ago [1]. The main principle in hybrid driven systems is to use the conventional motors with a flywheel and the servo motors via a mechanical linkage mechanism. A 2DOF (degree of freedom) link mechanism is driven by a combined input; an ordinary motor with a mechanism coupled to a servo motor (SM) adjusting ram motion. While ordinary motor provides high torque, SM performs the desired motion scenarios. This is presented as an example in flexible manufacturing systems under the assumption of power optimization which is important for selection of useful mechanism. Many different studies are then seen in hybrid configurations in industry. Some related with press operations are taken here [2-5]. The hybrid systems include the advantages of both driving systems. While the existence of conventional motor is to obtain power and torque requirement, SM is used to make system as a flexible motion provider. The basic principle of hybrid systems is to bring together the motion of a large constant velocity motor (CM) with a small SM via a mechanical linkage mechanism. In these systems the CM provides the main torque and motion requirements while the SM assists the modulations on the present motion. The CM undertakes a big amount of workload and the SM is like a real time regulator to change the task. Hybrid systems can be classified as hybrid actuator and hybrid mechanism. An intelligent box having two inputs and one output is considered as the hybrid actuator. The box is driven by a SM and a CM and it provides a programmable output which may be coupled to a mechanism or a load. However, a hybrid mechanism is one that has at least two degrees of freedom. The mechanism has two input links which are coupled to a SM and a CM [6].

The main purpose of this study is to present hybrid mechanism idea with related kinematics and simulation. Reviews on the related works are given as background. A hybrid seven bar (2 DOF) mechanism is taken here. Its kinematics is studied with inverse issues. One of the required ram (slider) motion is explained. A hybrid press alternative is presented. A SimMechanics model is built with the chosen configuration. Simulation results are then given for further studies.



2. Background of the Hybrid Machine

Hybrid machine systems are currently presented many ongoing studies [7-8]. Hybrid machine (HM) systems are employed in common industrial applications including cutting, printing, and stamping. Since the idea is providing a hybrid actuation, this is called hybrid machines. Different studies are seen in hybrid configurations with a five bar, slider crank, and seven bar for example. Motion ranges can be changed and more complicated paths may be produced. A recent study on hybrid systems are summarized in a thesis [8]. Studies on the subject more than two decades are searched. They are given with remarks and things to be added for coming studies. It is composed of three main parts; hybrid machine configurations, hybrid machine synthesis, modelling and control and hybrid machine applications. Optimal synthesis of possible configurations was carried out with the system control.

In hybrid machine applications, control of the machine is carried out in two stages. The first one is the control of SM, the second one is the control of CM to provide its actuation synchronously with the SM. In the studies completed, the proposed configurations are modelled mathematically and different PID control techniques; adaptive control, genetic algorithms (GA), particle swarm optimization (PSO) and sliding mode control (SMC) techniques are applied on them. Main concentration is done its modelling and simulation issues in this study.

3. Hybrid Configuration

A hybrid driven mechanical system is presented in figure 1. The system is composed of a planar five bar mechanism ABDEF and a dyad of CD. All joints except one are revolute joints. The exception is a prismatic joint used in translational motion between the slider and ground. The lengths of the links are represented by r_1, r_2, r_3, r_4, r_5 and r_6 as shown in figure 1. The crank r_5 is driven by a CM. The crank r_2 is driven by a SM. The link r_1 is the ground link and Θ is the orientation angle of it. The coordinate axes are fixed at point F. The BDC is the Bottom Dead Center point of the slider in which r_4, r_5 and r_6 are lined up in a straight line. The starting point of the slider is assumed as BDC. In addition to all, Top Dead Center of the slider is TDC point. In this mechanism, while EF link is driven by a CM, AB link is driven by a SM.

4. Related Kinematics

Kinematics analysis and main configuration of a 2-DOF controllable hybrid driven mechanism are presented in this section. A seven bar configuration is taken here. The inverse kinematics analysis is included. Linkage synthesis criteria's are given. The equations of inverse kinematics are derived. From the sketch of the mechanism given in figure 1, two loop closure equations [7-8] are written. Loops 1 and 2 are given as;

$$\vec{r}_5 + \vec{r}_6 = \vec{FG} + \vec{GC} + \vec{r}_4 \quad (1)$$

$$\vec{r}_5 + \vec{r}_6 = \vec{r}_1 + \vec{r}_2 + \vec{r}_3 \quad (2)$$

These two equations can be written in Euler form [8-9]. When Equations of (1) and (2) are written in Euler form and separated into two parts, Loop 1 and Loop 2 can be written as below;

$$r_5 \sin \theta_5 + r_6 \sin \theta_6 = S_0 + s + r_4 \sin \theta_4 \quad (3)$$

$$r_5 \cos \theta_5 + r_6 \cos \theta_6 = e + r_4 \cos \theta_4 \quad (4)$$

$$r_5 \cos \theta_5 + r_6 \cos \theta_6 = X_A + r_2 \cos \theta_2 + r_3 \cos \theta_3 \quad (5)$$

$$r_5 \sin \theta_5 + r_6 \sin \theta_6 = Y_A + r_2 \sin \theta_2 + r_3 \sin \theta_3 \quad (6)$$

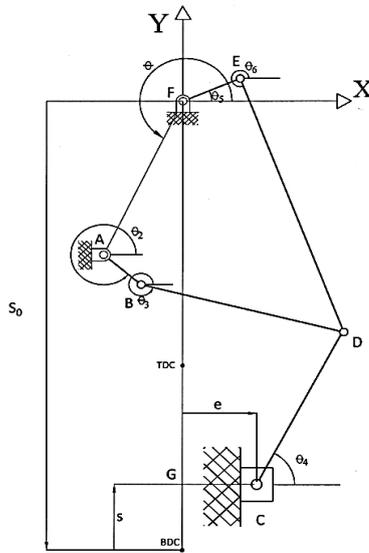


Figure 1 Schematic representation of hybrid driven mechanical system.

$$|\overline{AF}| = r_1, |\overline{AB}| = r_2, |\overline{BD}| = r_3, |\overline{CD}| = r_4, |\overline{FE}| = r_5, |\overline{ED}| = r_6$$

By taking 1st and 2nd derivatives of equations (3-6), the angular velocities and accelerations of each linkage are found [8-10]. Angular displacement, velocity and acceleration expressions are included in a thesis [8]. In order to satisfy different motion characteristics of the slider, the input link r_2 and r_5 must make complete rotations. In a previous study, Li [3] has given the classifications of hybrid five-bar linkages by using the unrestraint double-crank type. The input link r_2 and r_5 are unrestraint cranks. Therefore, the inequality constraints are defined as follows:

$$r_1 + r_2 + r_5 < r_3 + r_6 \tag{7}$$

$$r_2 + r_5 + r_6 < r_1 + r_3 \tag{8}$$

$$r_2 + r_3 + r_5 < r_1 + r_6 \tag{9}$$

The following inequality constraints should be satisfied to provide slider mobility condition in figure 1. It is required that $r_4 > X_D - e$, where e is the coordinate of point D in x direction. Link length condition; in order to have appropriate link lengths, the link lengths inequality constraints are given as follows:

$$r_{i \min} \leq r_i \leq r_{i \max} \quad r_i = 1, 2, \dots, 6 \tag{10}$$

When these constraints of mechanism are taken into account, the link dimensions of the hybrid driven mechanism are found and tabulated in table 1. All dimensions are in mm. The orientation angle, Θ is given in degrees.

Table 1. Link dimensions of the hybrid driven mechanism.

r_1	r_2	r_3	r_4	r_5	r_6	e	Θ
530	200	650	900	170	800	6.73	245

5. Motion Applications in Industry

Hybrid machine systems are being used in cutting, stamping and pressing applications in industry. By changing the motion profiles, it is possible to obtain different trajectories and use in various applications in industry. Most of studies are taken on press application according to years of studies. The fifth order polynomials are used to design the motion. Curve Fitting Toolbox in Matlab© is used as a tool in this study to design the motion characteristics of the slider. The Curve Fitting Toolbox is not directly used in motion design operation [8, 11].

5.1. Ram Motion Scenarios

Figure 2 are the selected CM's angular displacement profile. Angular velocity of CM is a constant value (positive direction 1.0472 radian/sec).

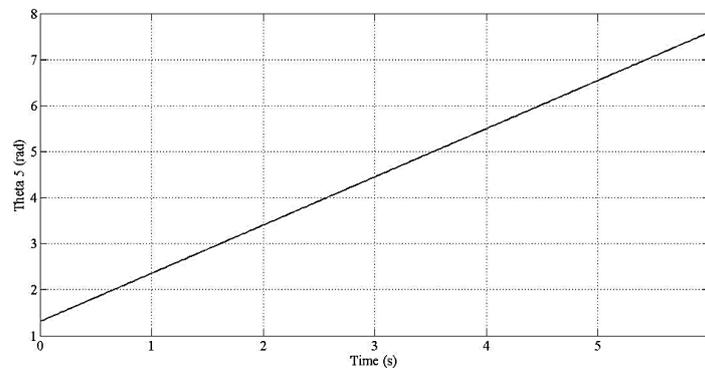


Figure 2. Angular displacement of CV motor.

The designed ram motion is a slow return-dwell and quick rise motion. Stroke of the slider is 687 mm and stroke/min is taken as 10. Figure 3 shows the designed ram motion which is composed of three segments. The kinematics specifications of each segment are illustrated in table 2. It is formed of segment number, time interval and initial and final values of position, velocity and acceleration of each segment.

When the kinematics data of the slider link (ram motion) and the fifth link driven by the CM are known, it is possible to reach the kinematics data of SM (Figure 1) by using the inverse kinematics analysis. The kinematic characteristics of the SM obtained are given in figure 4 (signal building view).

Table 2. Kinematics specifications of the segments

	Motion Time(s)	Position(mm)	Velocity(mm/s)	Acceleration (mm/s²)
I	$0 \leq t \leq 3.0$	687 , 0	0 , 0	0 , 0
II	$3 \leq t \leq 3.5$	0 , 0	0 , 0	0 , 0
III	$3.5 \leq t \leq 6.0$	0 , 687	0 , 0	0 , 0

6. Modelling MATLAB/SimMechanics

A multibody simulation environment is provided by using SimMechanics. It is an important simulation environment for solving many practical problems in industry. With this environment, forward dynamics, inverse dynamics, and kinematics can be done. Mechanisms can be modeled by solving motion equations in MATLAB/Simulink toolbox [12]. In SimMechanics, mechanism's bodies are defined as their coordinates for a one position. Its simulation can be shown directly as 2D or 3D. SimMechanics produces system model without deriving the equations of motion. The input parameters related systems are necessary [13]. SimMechanics model of the hybrid system is given in Figure 5 [11]. SimMechanics structure is designed for the position when Θ_5 is 30 deg. Input parameters are adapted according to that position. Body 7 indicates the slider of the mechanism and the model results of slider are obtained in two types that are "to file: as numerical" and "to scope: as visual". Figure 2 and figure 4 give the signal buildings of CM and SM respectively. Figure 6 presents the 3D simulation view of hybrid mechanism and figure 7 is kinematic outputs of slider link obtained by SimMechanics.

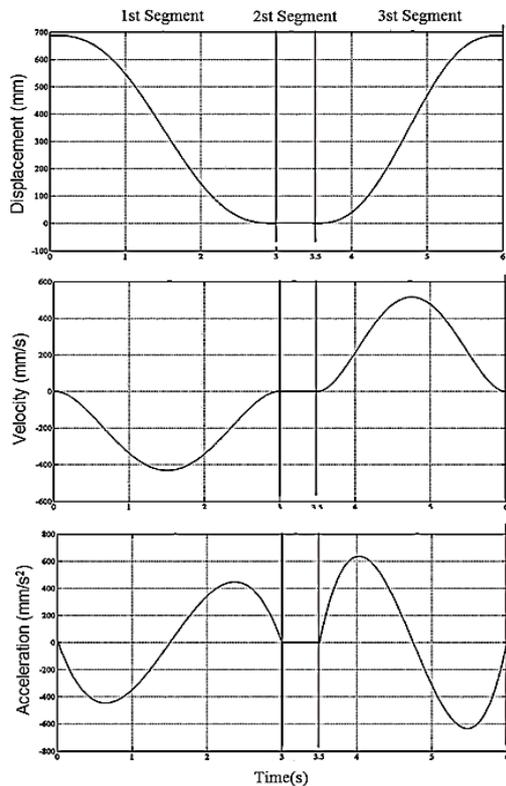


Figure 3. Desired and designed displacement, velocity and acceleration ram motion.

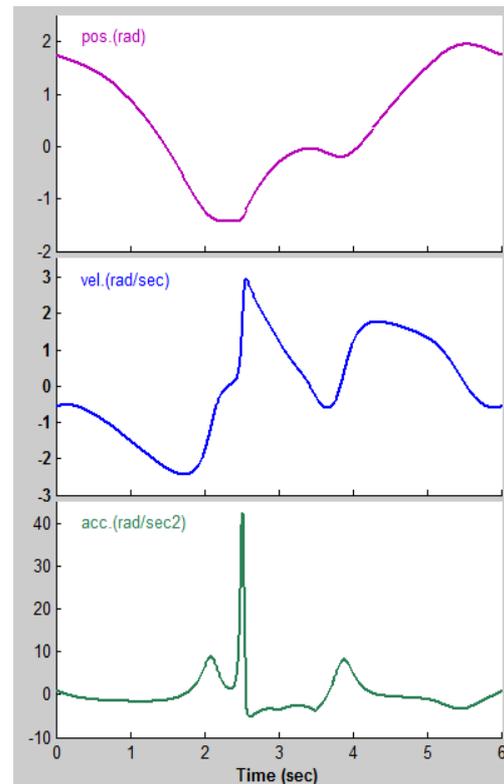


Figure 4. Angular displacement, velocity and acceleration of SM

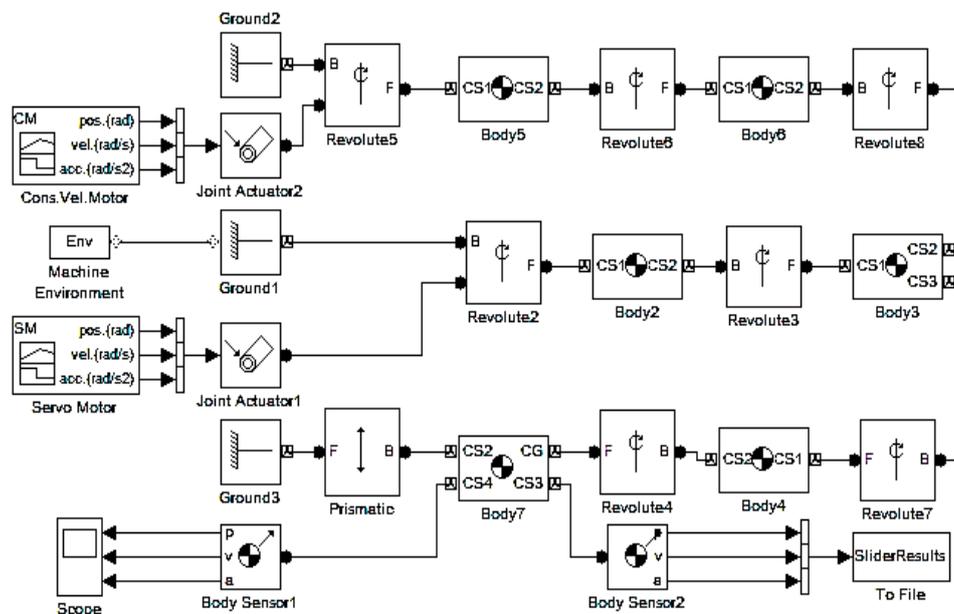


Figure 5. Hybrid mechanism kinematics model by Matlab/SimMechanics

7. Conclusions

A seven bar mechanism is given for hybrid system explanation. It is studied with its inverse kinematics issues. This configuration has advantages of traditional systems with flexible motion

output by using a servo motor. The kinematic modelling is facilitated by using SimMechanics and the results are interpreted easily. The results obtained from inverse kinematics are used as input parameters in SimMechanics. The scope of the model gives the expected ram motion output. Different ram motion scenarios can be implemented.

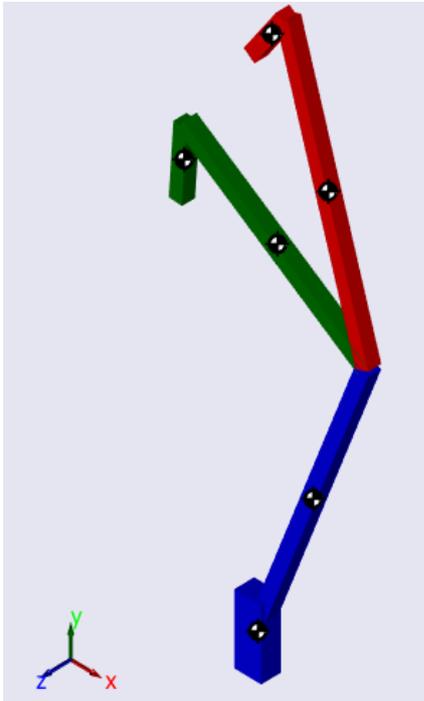


Figure 6. 3D SimMechanics simulation of the hybrid mechanism

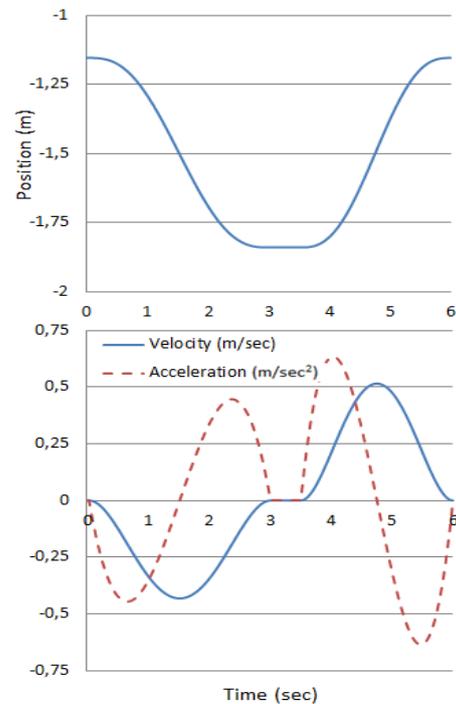


Figure 7. Displacement, velocity and acceleration of the slider (press ram)

8. Acknowledgment

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