Offset-Slider Crank Mechanism

(ME748 – Computer Aided Simulation of Machines)

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Submitted by

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Section 1: Model Specification

Section 1.1: Pictorial Depiction

Figure 1: Front View of actual prototype mechanism and Figure 2 shows pictorial view of Kinematic mechanism used for analysis in ADAMS.

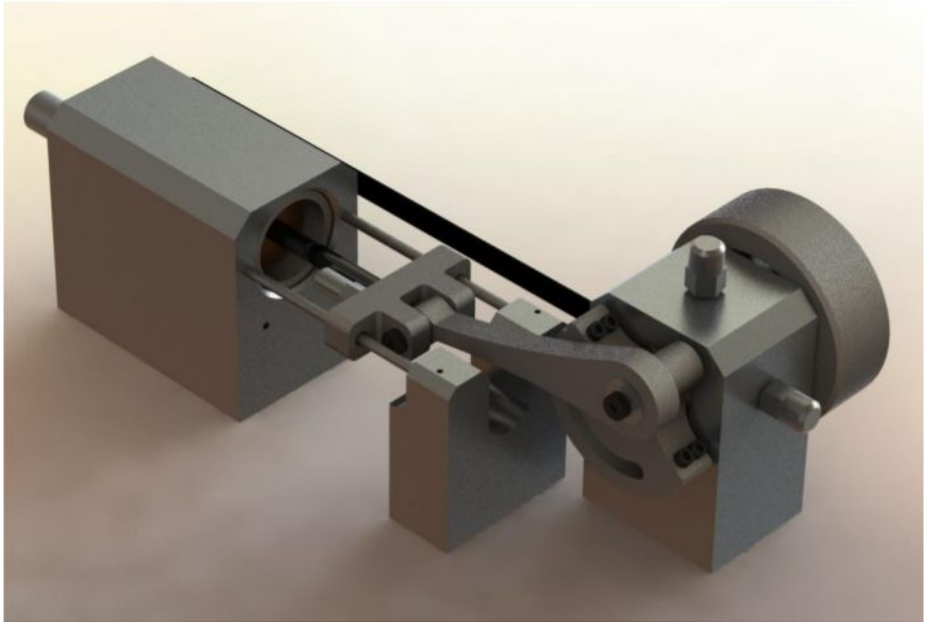

Figure 1:Front View of Actual Mechanism

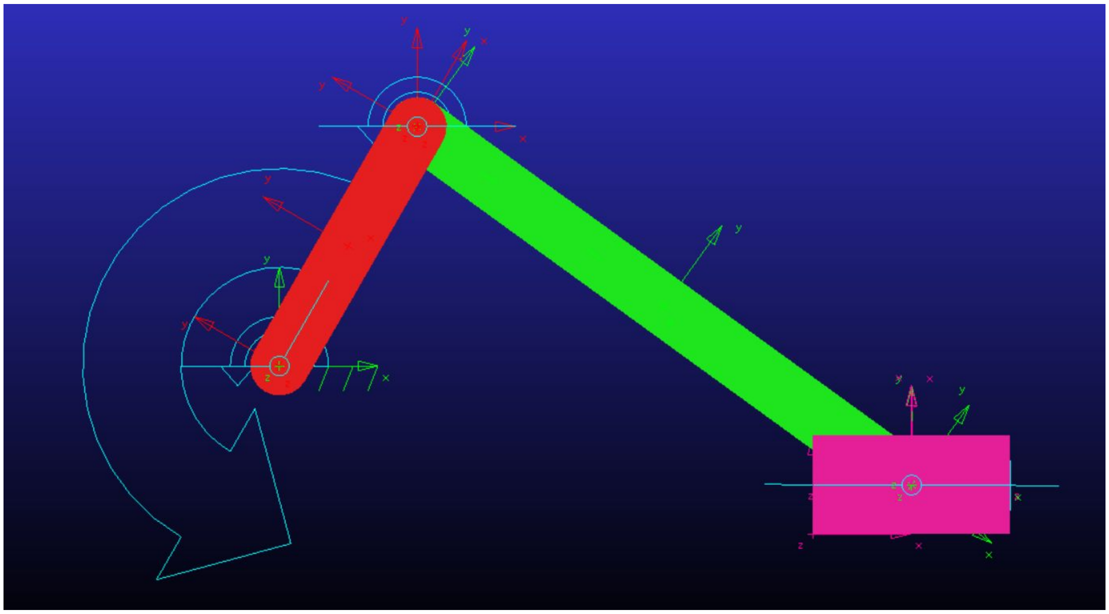

Figure 2:Mechanism used for analysis in Adams

Section 1.2: Geometry and Material

Material Used: All the links and joints are made up of mild steel (Density 7800 kg/m^3).

Depth of planar components is kept constant for simplicity.

Section 1.2.1: Dimensions of components

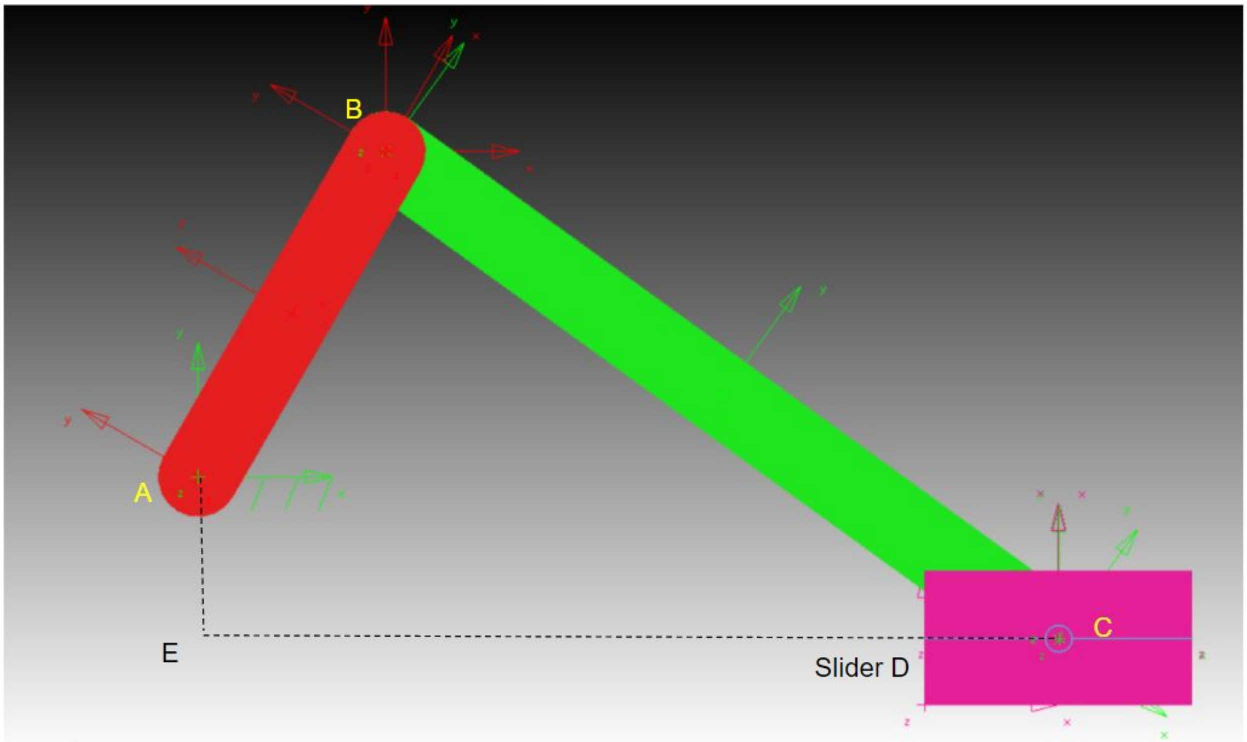

Figure 3:Front view for Link Lengths

Link lengths of all the links as below:

Sr.No.	Link	Length (mm)	Width (mm)	Depth (mm)
1	AB	140	30	20
2	BC	310	30	20
3	Slider D	100	50	50

Section 1.2.2: Mass of every component

Mass is calculated based on density mentioned above. Mild steel density =7800 kg/m^3. Mass of each component is listed in below table:

Sr.No.	Link	Mass (kg)
1	AB	0.764
2	BC	1.56
3	Slider D	1.95

Section 1.2.3: Moment of inertia of every component

Moment of Inertia of each component is calculated using Adams software. Also, the same values are confirmed by using analytical calculations.

Moment of inertia of each component is listed below:

Sr.No.	Link	M_{xx} (kg-mm^2)	M_{yy} (kg-mm^2)	M_{zz} (kg-mm^2)
1	AB	1758.88	1729.192	80.607
2	BC	14559.33482	14496.4	166.808
3	Slider D	2031.51	2031.51	812.6041

Section 1.3: Constraints

- AEC forms the fixed ground link. In ADAMS, point A is fixed to ground.
- ABCDEA forms the offset slider crank mechanism where EA is the offset.
- AB is the crank connected to the ground through a revolute joint.
- All joints, viz. A, B and C are revolute joints.
- Slider D is connected through a prismatic/translatory joint with the ground link AEC.
- The slider D will translate along EC which is at a distance AE = 60mm.

Section 1.4: Motion Transmission

Section 1.4.1: Driving component

Link AB (crank) is the driving component. A motor is fixed at A, which rotates the link AB at a constant angular velocity of 300rpm or 31.416 rad/s considering the case of the vibrating sieve which also corresponds to medium speed of crank as per various applications.

So, Normal speed can be considered between 31.416 rad/s for conducting fair dynamic analysis at a later point in time.

Section 1.4.1: Component which gives output of interest

Slider D is the component of interest. The simulation is run with the crank at 0° (corresponding to 0s) initially with the horizontal and runs for 0.2 second(which is also equal to cycle time.

Section 2: Kinematic Simulations

Section 2.1: Output Component

- The slider D is of interest as its trajectory and rate of motion define the movement of the vibrating sieve.
- Displacement and acceleration are calculated and collected at center of gravity of slider D (i.e. point C).
- Independent axis i.e. X-axis in this case is parameterized as time in sec. Other parameters like displacement, velocity and acceleration are plotted on Y-axis.

Section 2.1.1: Simulated and expected displacement profile of the output component

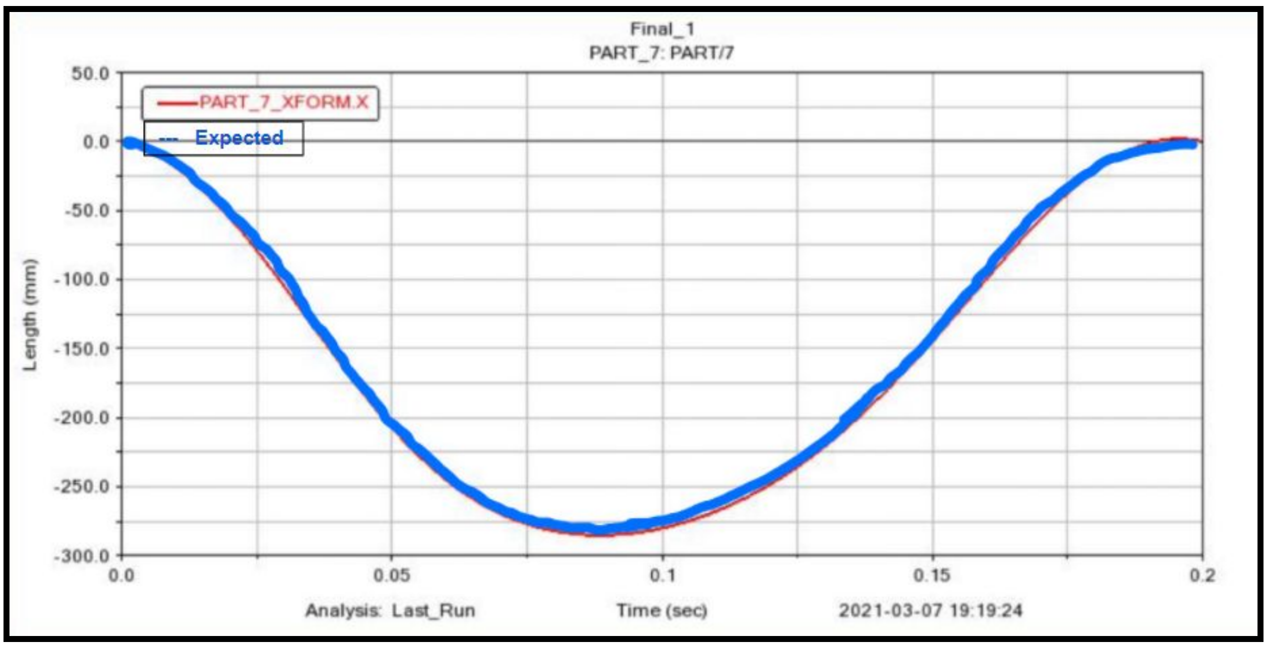

Figure 4: X-Component of Displacement of Slider D

Section 2.1.2: Simulated and expected Velocity profile of the output component

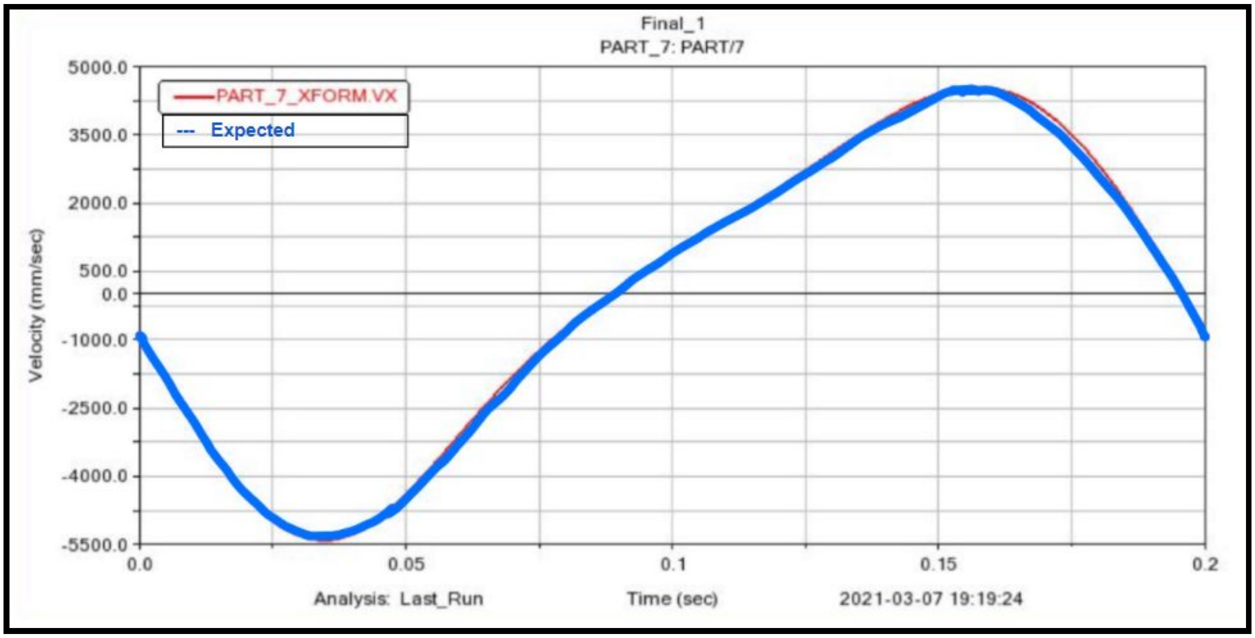

Figure 5: X-Component of Velocity of Slider D

Section 2.1.3: Simulated and expected Acceleration profile of the output component

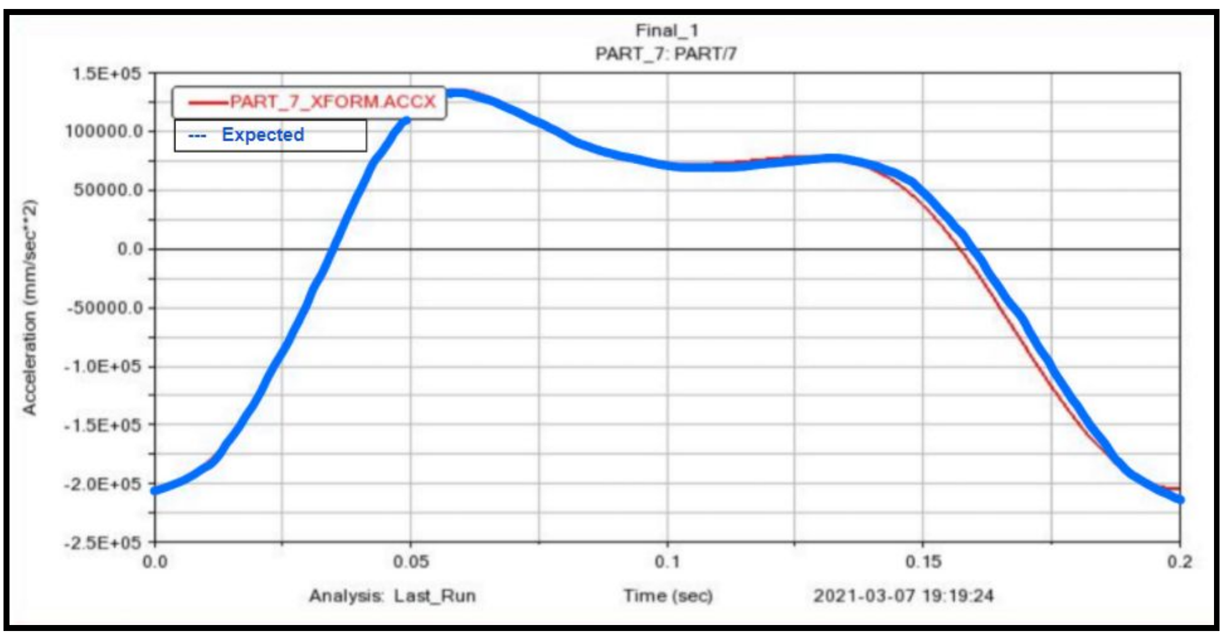

Figure 6: X-Component of Acceleration of Slider D

Section 2.1.4: Comments

- The expected curves do not exactly match the curves shown here, as the acceleration and velocity curves which were obtained during the actual motion of the slider certainly involve the data that can differentiate both quantitatively.
- X displacement of A is a type of oscillating function and becomes zero after every full crank cycle or 360°. Since, there is an offset present in this mechanism which provides a quick return motion to the slider. For the two extreme positions of the slider, the velocity will become zero and the acceleration at these points will be maximum. Such positions have been achieved in both the curves but the slopes cannot be exactly matched at each point due to unknown behavior of mass and size effects.
- During the simulation of the mechanism, two toggle positions of crank and connecting rod(that are also extreme positions for the slider) can not be located accurately while the estimation of the kinematic constraints associated with the mechanism.

Section 2.2: Sensitivity Analysis

The dimensions of links AB and BC are changed one at a time keeping others unchanged. The new lengths are 150mm and 320mm respectively.

Section 2.2.1: Variation in Displacement Profile of Slider D

Section 2.2.1.1: Variation in displacement Profile when Length of crank i.e. AB is changed from 140mm to 150mm

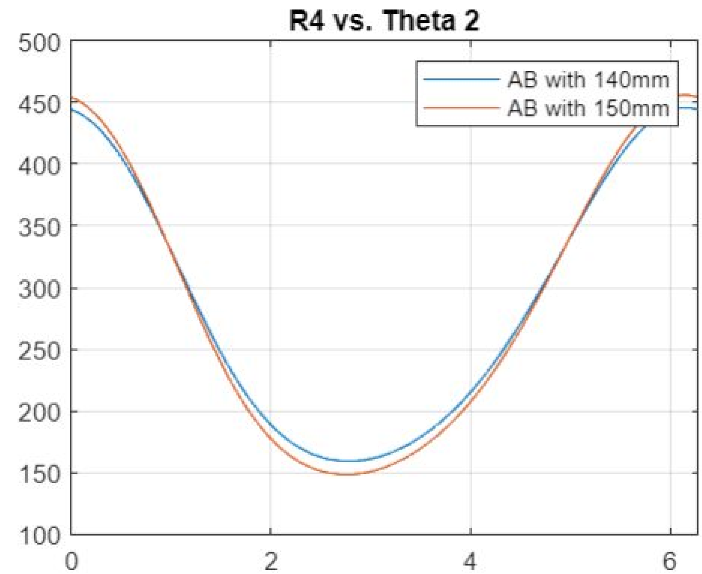

Figure 7: Sensitivity for length of AB on X-Displacement

Section 2.2.1.2: Variation in displacement Profile when Length of BC is changed from 310mm to 320mm

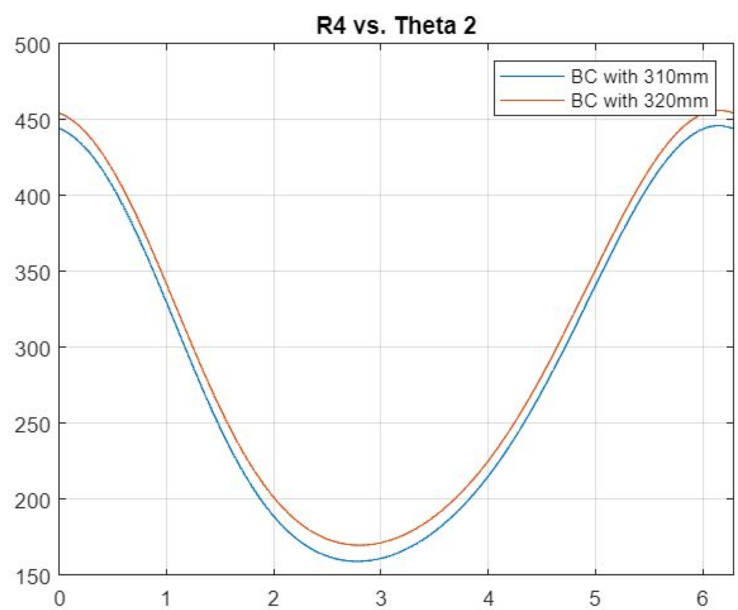

Figure 8: Sensitivity for length of BC on X-Displacement

Section 2.2.2: Variation in Velocity Profile of Slider D

Section 2.2.2.1: Variation in Velocity Profile when Length of crank i.e. AB is changed from 140mm to 150mm

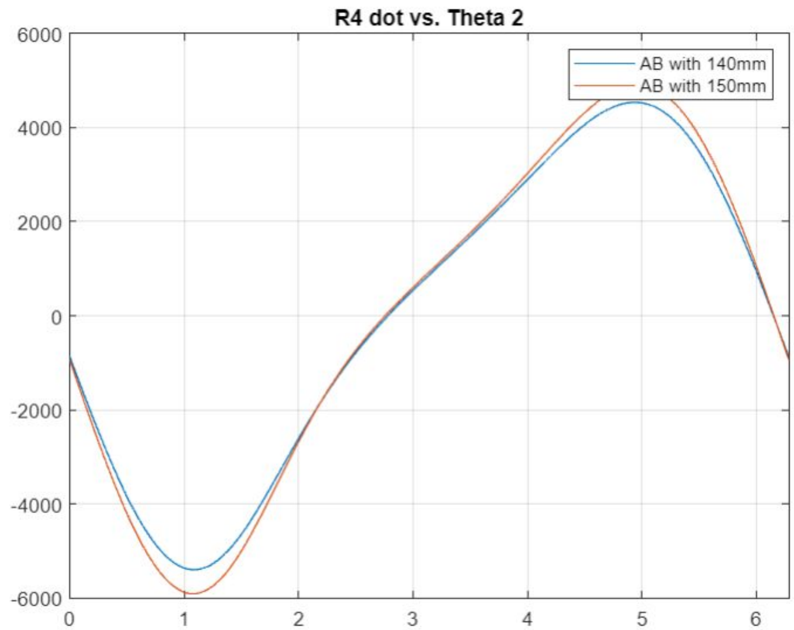

Figure 9: Sensitivity for length of AB on X-Velocity

Section 2.2.2.2: Variation in Velocity Profile when Length of BC is changed from 310mm to 320mm

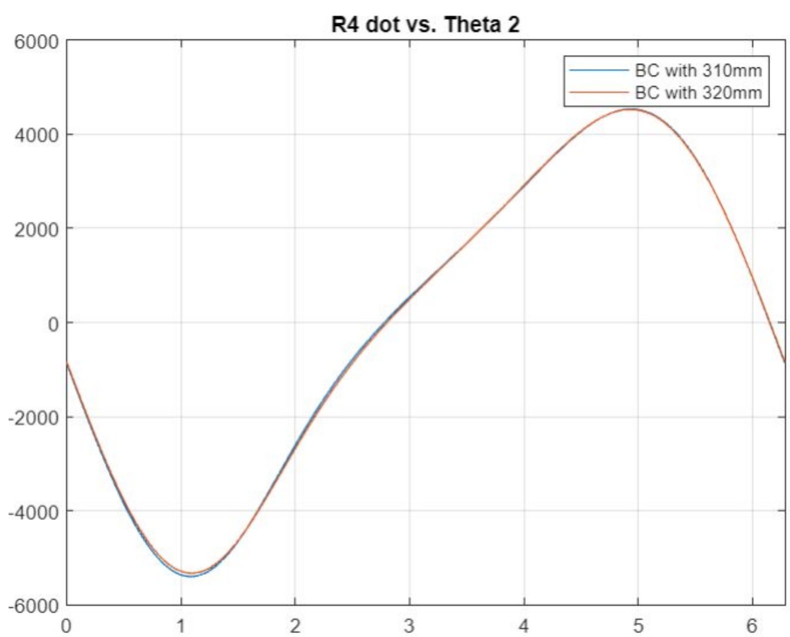

Figure 10: Sensitivity for length of BC on X-Velocity

Section 2.2.3: Variation in Acceleration Profile of Slider D

Section 2.2.3.1: Variation in Acceleration Profile when Length of crank i.e. AB is changed from 140mm to 150mm

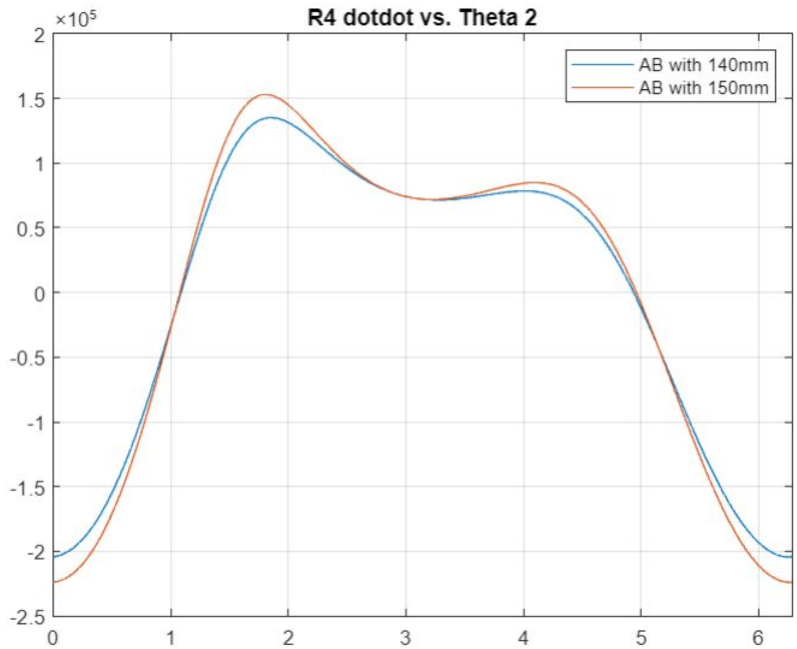

Figure 11: Sensitivity for length of AB on X-Acceleration

Section 2.2.3.2: Variation in Acceleration Profile when Length of BC is changed from 310mm to 320mm

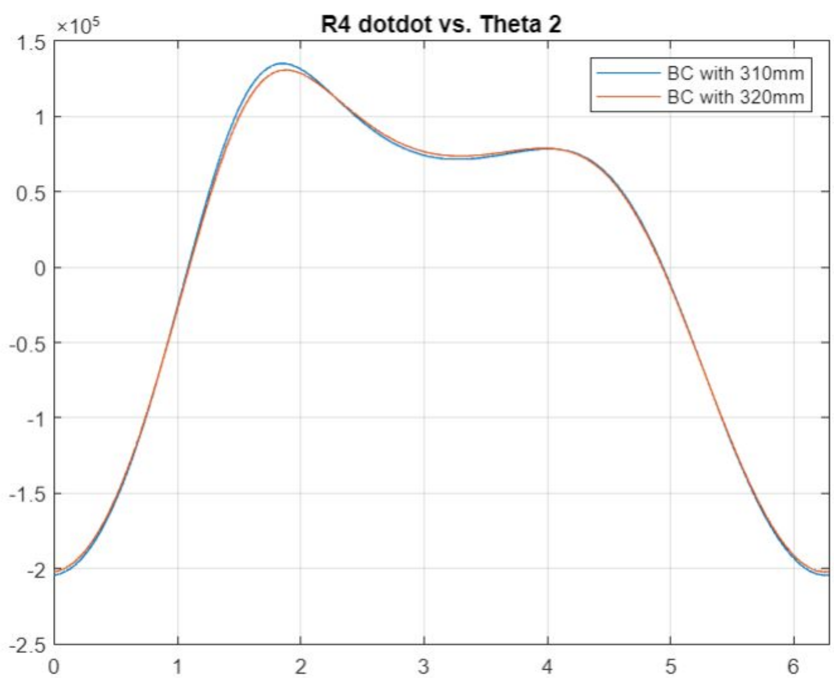

Figure 12: Sensitivity for length of BC on X-Acceleration

Section 2.3: Analysis of Joint Clearance

A clearance of 1mm has been introduced in the revolute joint at B and its effects are studied at high(400rpm) and low(30rpm) speeds. Displacement plots of both higher and normal (low) speeds are plotted on the same graphs as displacement remains the same regardless of speed. There is very little effect on displacement plots as shown.

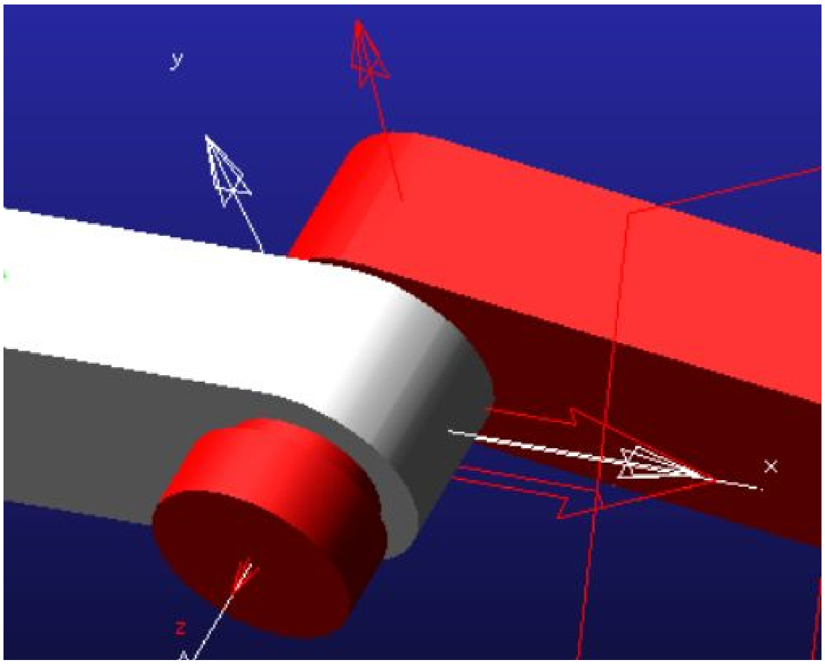

Figure 13: Clearance of 1 mm

Section 2.3.1: Variation in Displacement Profile of Slider D

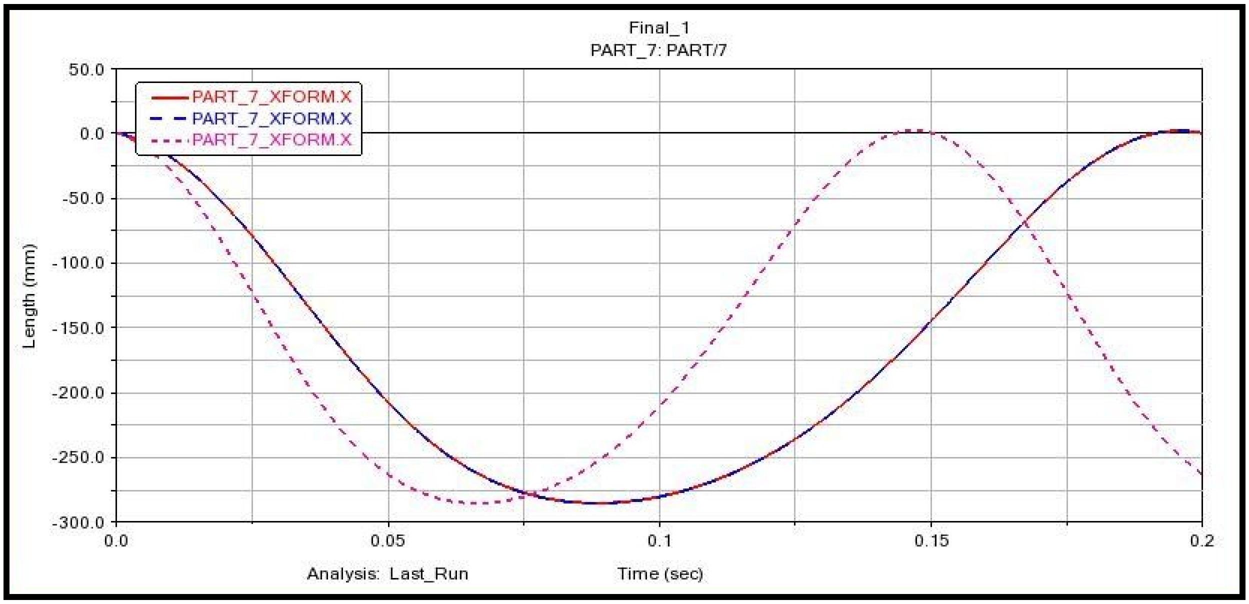

Figure 14: Variation with High Speed (Pink), Normal(low) Speed (Red), Without Clearance (Blue)

Section 2.3.2: Variation in Velocity Profile of Slider D

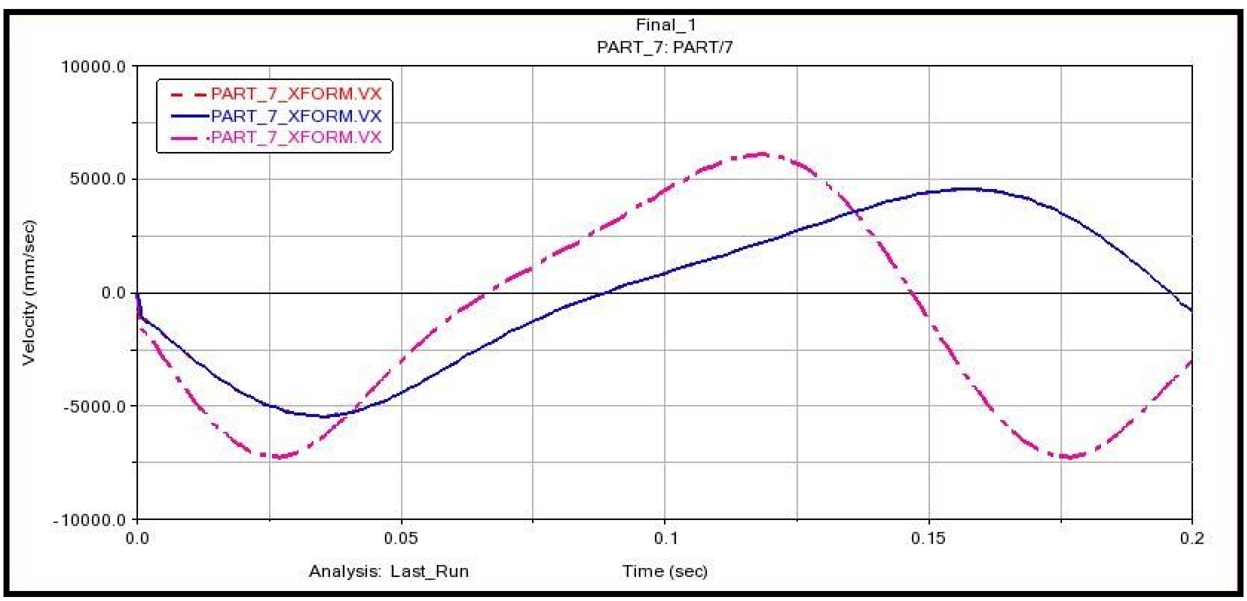

Figure 15: Variation with High Speed (Pink), Normal(low) Speed (Blue), Without Clearance (Red dotted)

Section 2.3.3: Variation in Acceleration Profile of Slider D

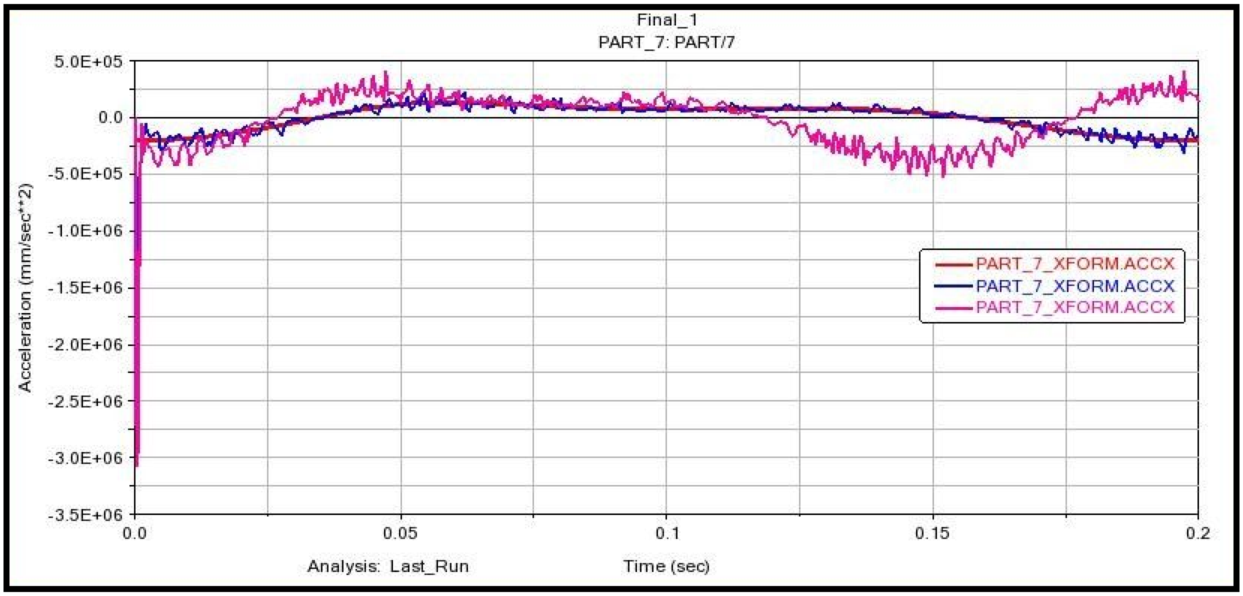

Figure 16: Variation with High Speed (Pink), Normal(low) Speed (Blue), Without Clearance (Red dotted)

Section 3: Validation of Kinematic Simulations

Section 3.1: Theoretical evaluation of Kinematic Parameters

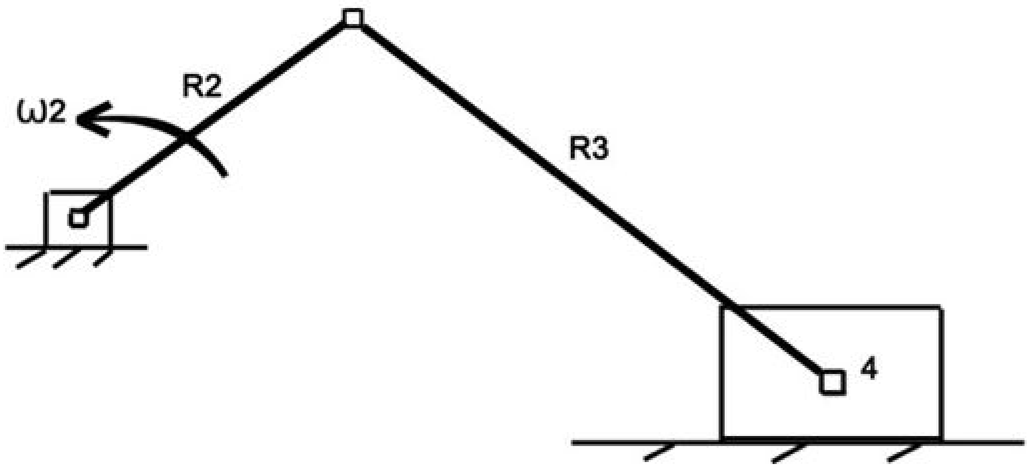

Figure 17: Kinematic Picture of Linkage used for analytical calculations

Given the lengths of the crank and link 3 (R_2 ,R_3), offset (R_1) and angular velocity of the crank (ω_2), the following part presents the methods that were used to find the position, velocity and acceleration components of an offset slider crank mechanism for all angles θ_2 in MATLAB.

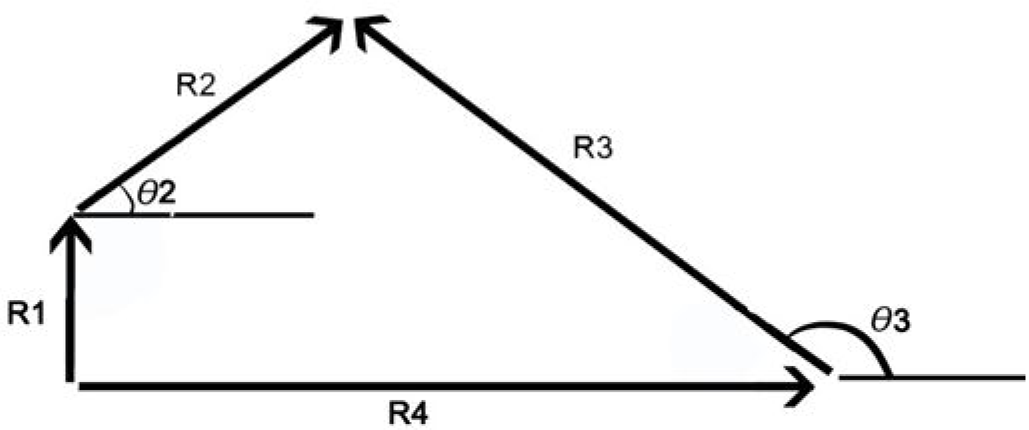

Figure 18: Vector Loop Closure Diagram

$R_1+R_2-R_3-R_4=0$ (1)

Equation (1) is the vector loop equation for Figure 2.

Derivation of Equations and Methods

1. Position Equations:
    a. X-component

    $$f_1=R_2 \cos(\theta_2)-R_3 \cos(\theta_3)-R_4 = 0 \quad (2)$$

    b. Y-component

    $$f_2=R_1+R_2 \sin(\theta_2)-R_3 \sin(\theta_3) = 0 \quad (3)$$

To solve for θ_3 and R_4 in Equation (2) and (3), the Newton-Raphson Method was used. The initial guess for θ_3 and R_4 used in the MatLab code was 180° and 40 respectively.

    c. Jacobian Matrix

$$J = \begin{bmatrix} \partial f_1/\partial \theta_3 & \partial f_1/\partial R_4 \\ \partial f_2/\partial \theta_3 & \partial f_2/\partial R_4 \end{bmatrix} = \begin{bmatrix} R_3 \sin(\theta_3) & -1 \\ -R_3 \cos(\theta_3) & 0 \end{bmatrix}$$

2.

2. Velocity Equations:

$$\frac{df_1}{dt}=-R_2 \omega_2 \sin(\theta_2)+R_3 \omega_3 \sin(\theta_3)-\dot{R}_4=0 \quad (4)$$

$$\frac{df_2}{dt}=R_2 \omega_2 \cos(\theta_2)-R_3 \omega_3 \cos(\theta_3)=0 \quad (5)$$

From Equation (5), an equation for ω_3 was found to be:

$$\omega_3=\frac{R_2 \cos(\theta_2) \omega_2}{R_3 \cos(\theta_3)} \quad (6)$$

From Equation (4), an equation for $\dot{R}_4$ was found to be:

$$\dot{R}_4=R_3 \sin(\theta_3) \omega_3-R_2 \sin(\theta_2) \omega_2 \quad (7)$$

3. Acceleration Equations:

$$\frac{d^2 f_1}{dt^2}=-R_2 (\omega_2)^2 \cos(\theta_2)+R_3 (\omega_3)^2 \cos(\theta_3)+R_3 \alpha_3 \sin(\theta_3)-\ddot{R}_4=0 \quad (8)$$

$$\frac{d^2 f_2}{dt^2}=-R_2 (\omega_2)^2 \sin(\theta_2)+R_3 (\omega_3)^2 \sin(\theta_3)-R_3 \alpha_3 \cos(\theta_3)=0 \quad (9)$$

From Equation (9), an equation for α_3 was found to be:

$$\alpha_3=\frac{R_3 \sin(\theta_3) (\omega_3)^2-R_2 \sin(\theta_2) (\omega_2)^2}{R_3 \cos(\theta_3)} \quad (10)$$

From Equation (10), an equation for $\ddot{R}_4$ was found to be:

$$\ddot{R}_4 = R_3 \cos(\theta_3)(\omega_3)^2 + R_3 \sin(\theta_3)\alpha_3 - R_2 \cos(\theta_2)(\omega_2)^2 \quad (11)$$

MATLAB Code

```
clear all, close all, clc
%
% Script to compute position, velocity and acceleration of an offset slider crank
%%Input Parameters
R1 = 60;       % Offset
R2 = 140;      % Crank length
R3 = 310;      % Link 3 length
omeg2 = 31.416;  % Angular velocity of crank (rad/s)
size = 200;  % Resolution of plots

% Allocating memory
th3=nan(1,size);
R4=nan(1,size);
omeg3=nan(1,size);
R4dot=nan(1,size);
alph3=nan(1,size);
R4dotdot=nan(1,size);
```

```
i=1; % index counter
for x=linspace(0,2*pi,size)

        %Position Solution
        th30=180*pi/180;  % Initial guesses
        R40=40;

        %Position functions
        f1=R2*cos(x)-R3*cos(th30)-R40;
        f2=R1+R2*sin(x)-R3*sin(th30);

        while norm([f1;f2])> 1E-6

        % Set up the Jacobian matrix
        J=[R3*sin(th30) -1;-R3*cos(th30)  0];

        % compute the update
        upd=J\[-f1;-f2];
        th30=th30+upd(1);
           R40=R40+upd(2);
```

```
% Re-evaluate the function to check for convergence

f1=R2*cos(x)-R3*cos(th30)-R40;

f2=R1+R2*sin(x)-R3*sin(th30);

end


% Storing position solutions

th3(i)=th30;

R4(i)=R40;


% Velocity Solution

omeg3(i) = (R2*cos(x)*omeg2) / (R3*cos(th3(i)));

R4dot(i) = R3*sin(th3(i))*omeg3(i) - R2*sin(x)*omeg2;


% Acceleration Solution

alph3(i) = ((R3*sin(th3(i))*omeg3(i)^2)-(R2*sin(x)*omeg2^2)) / (R3*cos(th3(i)));

R4dotdot(i) = R3*cos(th3(i))*omeg3(i)^2 + R3*sin(th3(i))*alph3(i) - R2*cos(x)*omeg2^2;


th2(i)=x; % Stores Theta 2 values

i=i+1;
```

```
end


% Plotting the position, velocity and acceleration solution vs th2 values.

subplot(3,2,1)

plot(th2,th3)

title('Theta 3 vs. Theta 2')

xlim([0 2*pi])


subplot(3,2,2)

plot(th2,R4)

title('R4 vs. Theta 2')

xlim([0 2*pi])


subplot(3,2,3)

plot(th2,omeg3)

title('Omega 3 vs. Theta 2')

xlim([0 2*pi])


subplot(3,2,4)

plot(th2,R4dot)

title('R4 dot vs. Theta 2')
```

```
xlim([0 2*pi])


subplot(3,2,5)

plot(th2,alph3)

title('Alpha 3 vs. Theta 2')

xlim([0 2*pi])


subplot(3,2,6)

plot(th2,R4dotdot)

title('R4 dotdot vs. Theta 2')

xlim([0 2*pi])
```

The above matlab code can be used to obtain various results for one complete revolution(not only for just 4 points) of the crank AB. In order to plot for a particular number of data points, the variable "size" can be altered to obtain the analytical results. We have taken 200 data points as size within the interval 0 to 2*pi.

The obtained plots for the displacement, velocity and acceleration are given below:

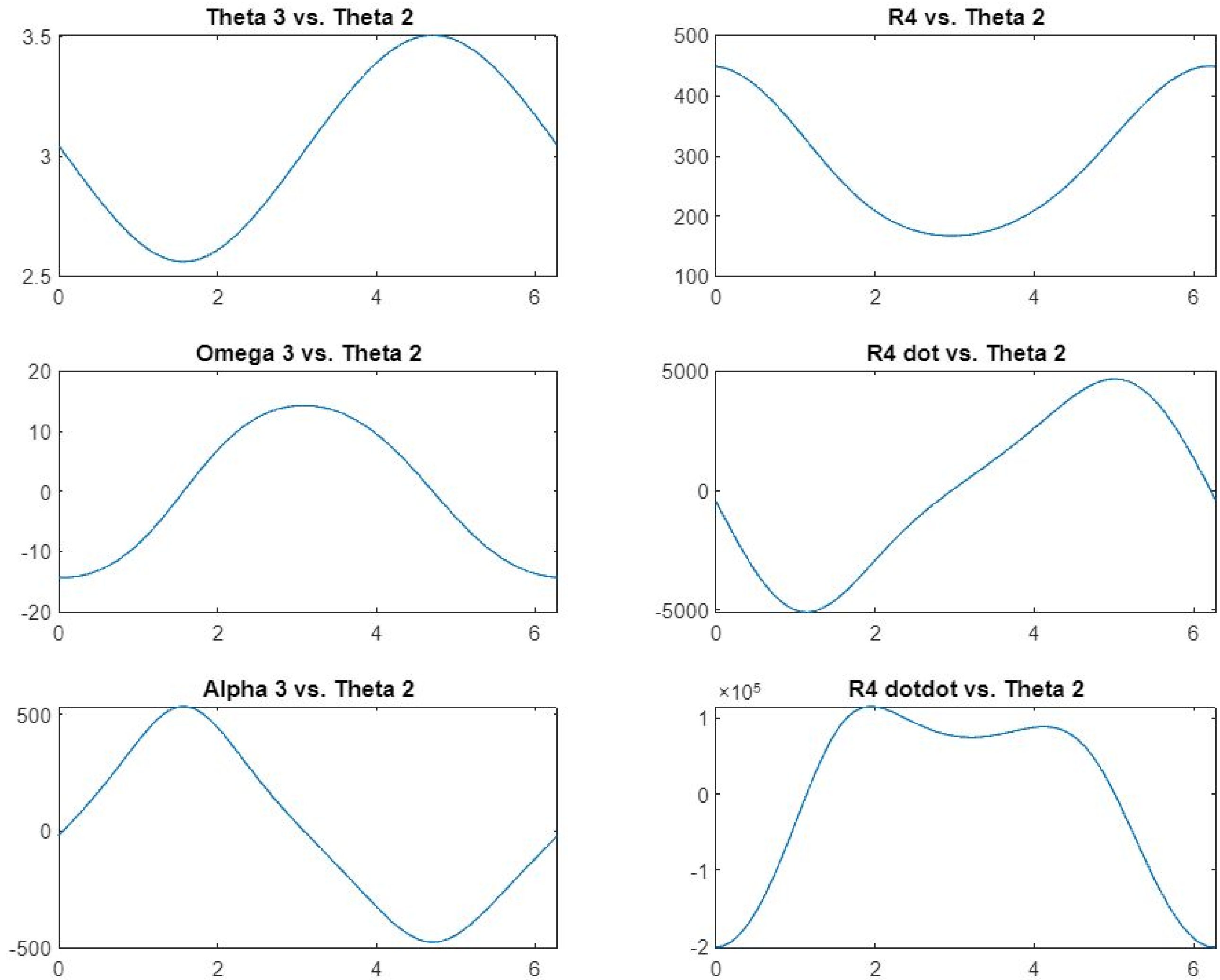

Figure 19: Variation of various parameters during one complete cycle for revolution of crank

where, theta 3, omega 3 and alpha 3 are the angular displacement, angular velocity and angular acceleration respectively for link 3.

Also, R4, R4 dot and R4 dotdot are the linear displacement, linear velocity and linear acceleration of the Slider D respectively.

To perform the comparative analysis, we have run the matlab code to obtain 4 values by keeping the “size” variable as 4 which provides values at 4 points(four positions of crank) viz. 0° , 90°, 270° and 360° respectively.

Section 3.2: Comparison of Kinematic Parameters

Section 3.2.1: Displacement Analysis

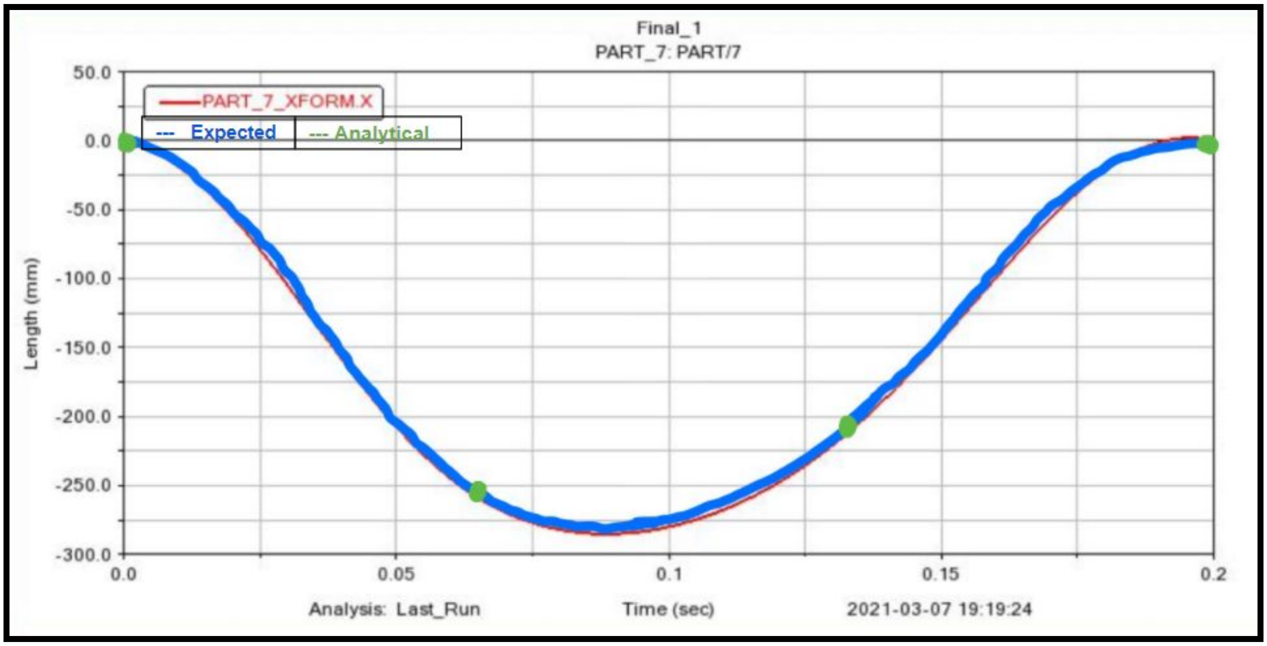

Figure 20: X-Direction Displacement of Output (Slider D)

Section 3.2.2: Velocity Analysis

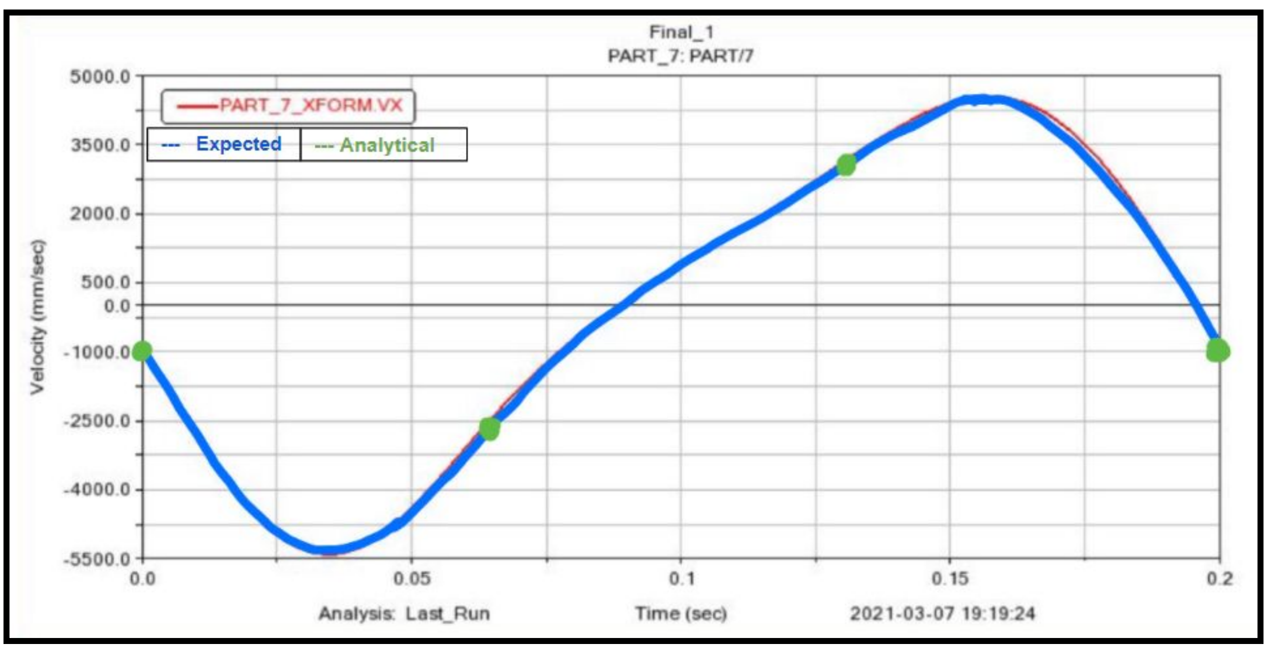

Figure 21: X-Direction Velocity of Output (Slider D)

Section 3.2.3: Acceleration Analysis

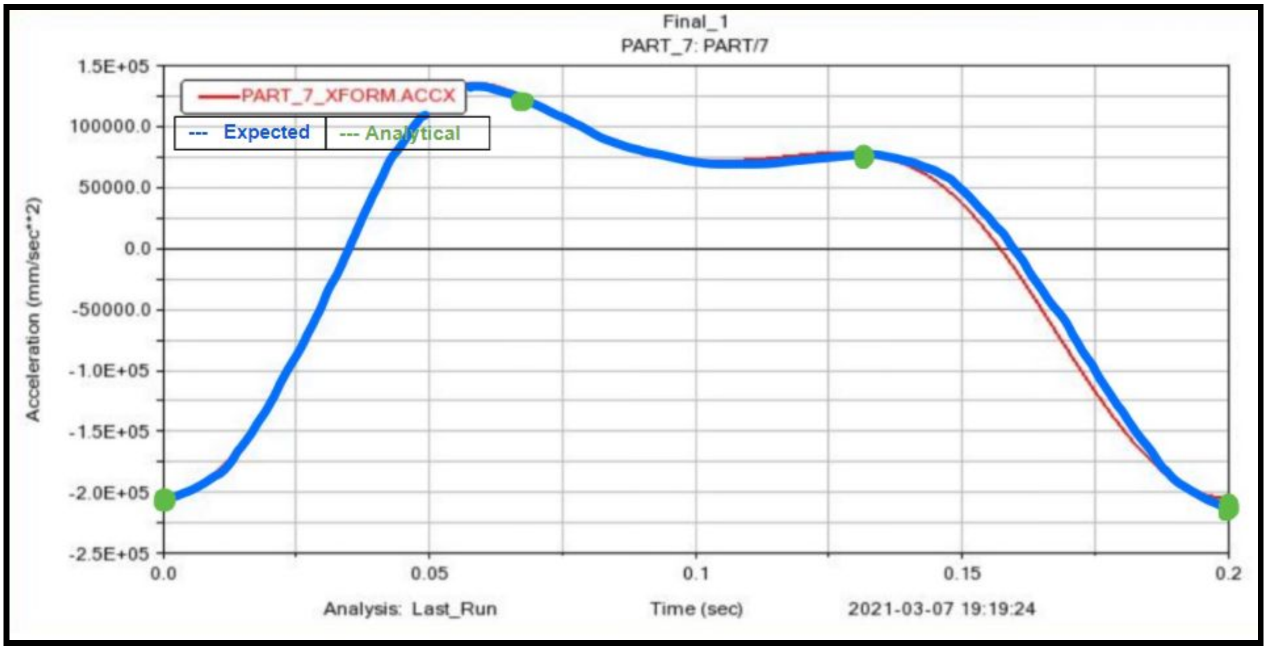

Figure 22: X-Direction Acceleration of Output (Slider D)

Section 3.2.4: Comments

- The analytically obtained results exactly match the simulated results with 99% accuracy. This is because in analytical calculation displacement, velocity, acceleration of fixed link is taken as zero. Similar constraints are put in the ADAMS model to simulate motion and plot displacement, velocity, acceleration of components. Hence these results match quite well as presented in the above sections.
- With the above said statement but the shapes of the curve match with the result which is intuitive.
- Also, inertia affects material response to motion has considerable effect on resultant displacement, velocity and acceleration profile which can be observed in the comparison section mentioned above.

Section 4: Reference

1. https://mm-nitk.vlabs.ac.in/exp29/index.html
2. https://www.semanticscholar.org/paper/Fig.2.1.-Reciprocating-steam-engine-2.-STRUCTURAL/8c0c1dd9450fe0d943461a3fff18cfe2f78da4ba
3. “Theory of Machines “by Shigley
4. https://www.researchgate.net/figure/Fig-10-The-effects-of-crank-speed-sieve-angle-and-feeding-rate-on-the-machine_fig3_332061350
5. https://www.wartsila.com/encyclopedia/term/diesel-engine#:~:text=The%20medium%20speed%20four%2Dstroke,%2C%20compression%2C%20power%20and%20exhaust.