2024

ADAMS PROJECT

PHASE I

DYNAMICS SPRING 1403

PREPARED BY:

ASRA MEHROLHASSANI SID: 810800024

THE CURRENT DOCUMENT IS A REPORT OF THE FIRST PHASE OF THE ADAMS PROJECT

Table of Contents

Adams Project: Phase I

Introduction

The current document is a report of the first phase of the Adams Project, prepared for the class Dynamics- ME 8106-116-0.

This report aims to present a solution to the problem assigned to group 9.

Knowledge of ‘**Plane Kinematics of Particles**” is required for understanding this document.

For further insights, the reader can study chapters 5/1 to 5/6 of “Engineering Mechanics: Dynamics” written by J. L. Meriam, L. G. Kraige, and J. Bolton.

Problem 9

Problem description

In the engine system shown, l = 160 mm and b = 60 mm. Knowing that the crank AB rotates with a constant velocity of 1000 rpm clockwise, determine the velocity of the piston P and the angular velocity of the connecting rod when (a) $\theta = 0°$, (b) $\theta = 90°$.

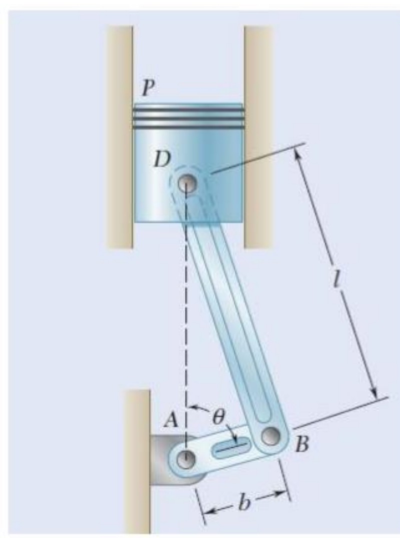


Figure 1.Engine System

Given

$\boldsymbol{l = 160\ (mm)}$

$\boldsymbol{b = 60\ (mm)}$

$\boldsymbol{\omega_{B/A} = 1000\ (rpm)\ CW.}$ ( )

Required

$\boldsymbol{Vp}$, Velocity of the piston P , $\omega_{D/B}$ @ $\theta = 0°$

$\boldsymbol{Vp}$, Velocity of the piston P, $\omega_{D/B}$ @ $\theta = 90°$

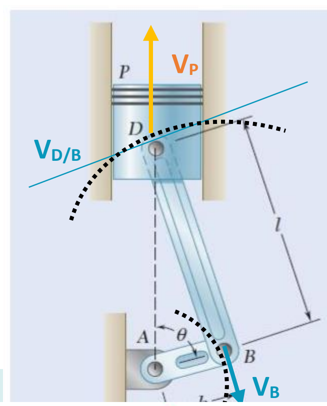
Solution

Knowledge of '**Plane Kinematics of Particles**" is required for understanding this section.

For further insights, the reader can study chapters 5/1 to 5/6 of "Engineering Mechanics: Dynamics" written by J. L. Meriam, L. G. Kraige, and J. Bolton.

Solution: Relative Velocity

Motion Analysis (Velocity)



Since D and B are on the same rigid body:

$\mathbf{V_P = V_D = V_B + V_{D/B}}$

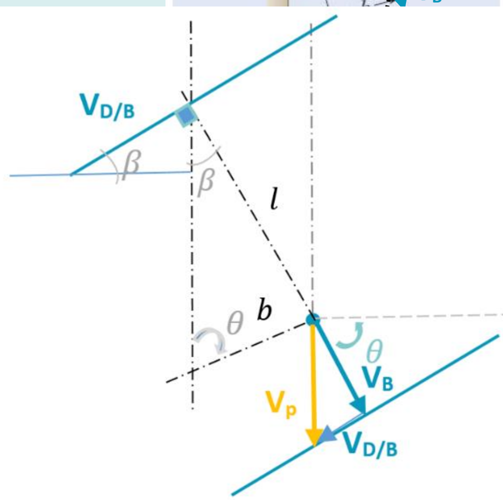
Since D and B are on the same rigid body:

$\mathbf{V_B = V_A + V_{B/A}}$

Since point A is stationary, $V_A = 0$ and thus:

$\mathbf{V_B = V_{B/A}}$

$V_B = V_{B/A} = AB.\ \omega_{B/A} = b.\omega_{B/A}$, (Fixed-axis rotation)



Geometry of the problem

Due to the geometry of the problem (figure 3.),

$V_{D/B}$ makes an angle equal to β with the horizontal line.

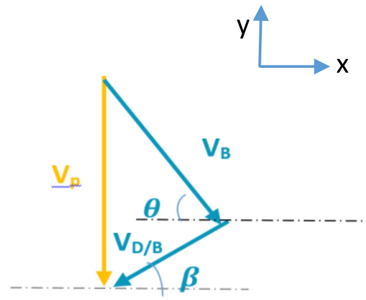
To determine the value of β, **Law of Sines** is applied and thus:

$$\frac{b}{\sin(\beta)} = \frac{l}{sine(\theta)}, \ b = \frac{sin(\beta).l}{sin(\theta)}$$

Figure 4. The Geometry of the Problem

Figure 3. Geometry of the problem

Notice how the piston (figure 1.) can only move either upwards or downwards. (Vertically)



In “Motion Analysis” section we obtained the relations below:

$\mathbf{V_P = V_D = V_B + V_{D/B}, V_B = V_{B//A}}$

Due to the geometry presented in figure 4 (which is obtained from the above relations) we can derive the below relations:

Figure 5. Velocity Vectors

Horizontal direction (x-axis):

$V_B \,.\, \mathrm{Cos}(\theta) - V_{D/B} \,.\, \mathrm{Cos}(\beta) = 0$

Vertical direction (y-axis):

$V_B \,.\, \mathrm{Sin}(\theta) + V_{D/B} \,.\, \mathrm{Sin}(\beta) = V_P$

Calculations

Part a) Determine V_p and $\omega_{D/B}$ when $\theta = 0$

The geometry of the problem is presented in figure 5.
As it is clear, V_B and $V_{D/B}$ are horizontal vectors and since V_D is vertical ,V_D must be zero.

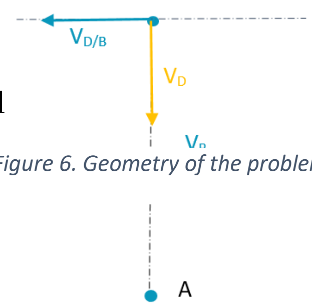


Figure 6. Geometry of the problem

$\mathbf{V_P = V_D = V_B + V_{D/B}}$

In other words:

$V_B \,.\, \mathrm{Sin}(\theta) + V_{D/B} \,.\, \mathrm{Sin}(\beta) = V_P,\ \theta = 0 \ and \ \beta = 0$

And thus:

$V_{piston} = 0$ (mm/s) , the angular velocity of the connected rod

Notice how since Vp is vertical and has no horizontal coordinates, $V_{D/B}$ and V_B must cancel each other out. To determine $\omega_{D/B}$ we’ll use the relation below:

$V_{Dx} = V_{Bx} + V_{D/Bx}\,,\ -V_{Bx} = V_{D/Bx}$

$V_{Bx} = V_B = b.\omega_{B/A}$ (Fixed axis rotation)

$\omega_{B/A}$ = 1000 (rpm) $\frac{2\pi}{60}$ = 104.7 (rad/s)

V_B = $V_{D/B}$ = $l.\omega_{D/B}$ and thus $\omega_{D/B}$ = V_B / l

Substituting the values into the relation:

$\omega_{D/B}$ =($b.\omega_{B/A}$)/l = 39.3 (rad/s) **CCW** , the angular velocity of the

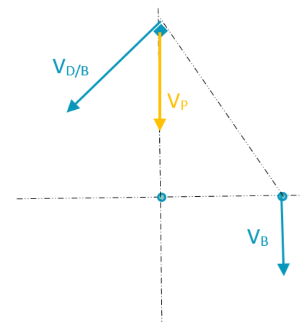


Figure 7.Geometry of the problem

Part b) Determine V_p and $\omega_{D/B}$ when θ = 90:
The geometry of the problem is presented in figure 6.
As it is clear, V_p and V_B are vertical vectors and since V_D has a projection on the horizontal direction (x-axis)$V_{D/B}$ must be zero.

V_P =V_D = V_B + $V_{D/B}$

In other words:

$V_{D/B}$ = V_P - V_B

And thus:

$V_{D/B}$ = 0 and also:

$\omega_{D/B}$ =$V_{D/B}$ /l = 0 rad/s , the angular velocity of the connected rod

Since **$V_{D/B}$** = 0, we can conclude that **V_P = V_B + $V_{D/B}$ = V_B**

V_B = $b.\omega_{B/A}$ (Fixed axis rotation)

V_P = V_B = $b.\omega_{B/A}$ = 6.282 (m/s)

V_P = 6282 (mm/s) ↓ , the angular velocity of the connected rod

Adams Project: Phase ll

The current project is modeled and simulated in Adams View 2018 software. In the coming sections we will discuss the modeling and simulation phase of studding the provided Engine System.

Modeling

Settings

The provided Engine System (figure. 8) is modeled in a space with no gravity and the unit system is set to MMKS(mm, Kg, N, s, deg). Few settings are mentioned below:

Gravity: No Gravity
Units: MMKS(mm, Kg, N, s, deg)
Working Grid:

	x	y
Size	500 mm	600 mm
Spacing	10 mm	10 mm

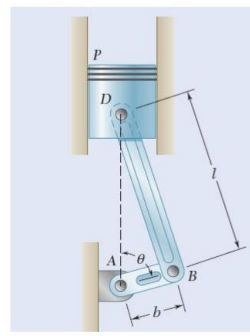
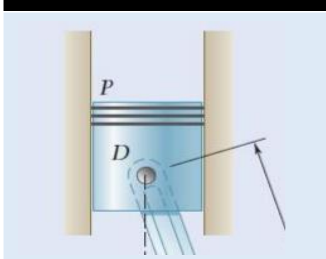
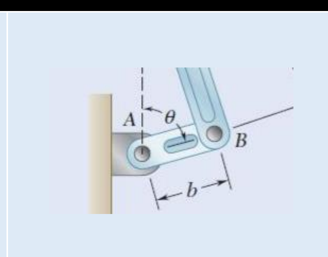
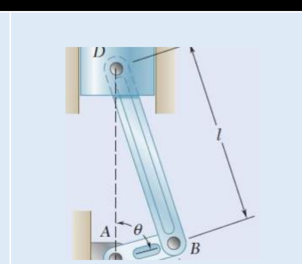
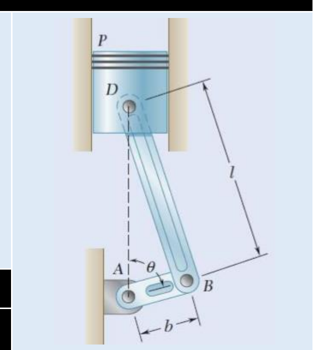
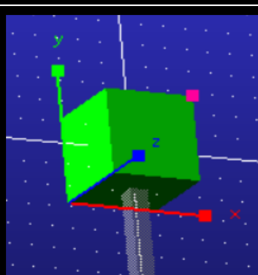
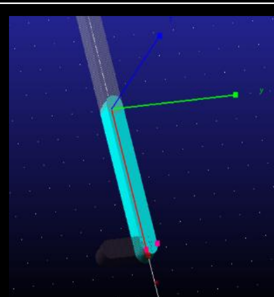
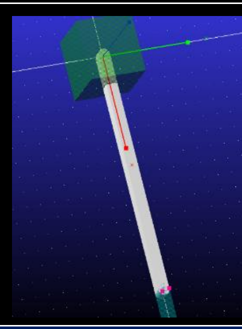
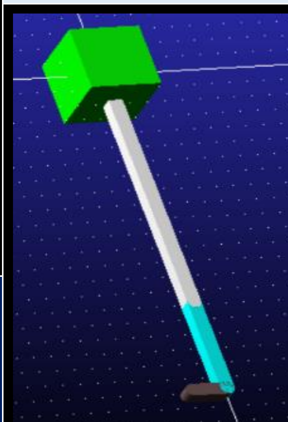


Figure 8. Engine System

Body

Piston	Crank AB	Crank BD	Engine System
			
Model			
			
Length: 40 mm **Height: 40 mm** **Depth: 40 mm**	Length: 60 mm Width: 8 mm Depth: 8 mm	Length: 160 mm Width: 8 mm Depth: 8 mm	

Since the model is simulated with no gravity, specifying mass for the elements is not necessary.

Note l: One could simply model the walls and add them around the piston, however by modeling extra elements we would be increasing the error of the simulation.

Note ll: For each element**, the z parameter of the center of mass must be zero**, otherwise simulation will face error.

Connections

	Pin A	Crank AB	Crank BD	Piston	Ground
Pin A	-	-	-	-	Fixed Joint
Crank AB	Revolute Joint	-	Revolute Joint	-	-
Crank BD	-	Revolute Joint	-	Revolute Joint	-
Piston	-	-	Revolute Joint	-	Translational Joint

A Fixed Joint is set between Pin A and the Ground since Pin A is fixed relative to the ground and has no motion. Revolute Joints are created when one element has a rotational motion with respect to the other element and due to the provided problem, Crank AB relative to Pin A, Crank BD relative to Crank AB and Piston relative to crank BD, all have rotational motion. According to the problem (figure 8.), the Piston experiences a downward translational motion relative to the Ground and therefore to model the connection, a translational Joint is used.

Motions

As mentioned in the problem's description, the angular velocity of crank AB is 1000 round per minutes and it is constant throughout the motion.

ω_{AB} =1000 rpm = 6000 deg/s (CW)

Rotational Joint Motion is set for the Revolute Joint between pin A and the Crank AB and then modified to match the value -6000 deg/s (The angular velocity is negative since the motion is clock wise) as shown in figure 9.

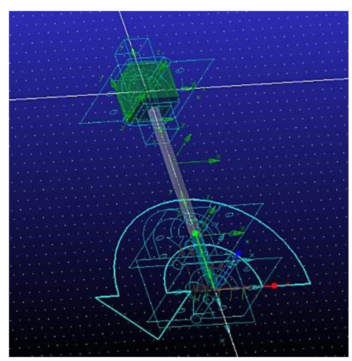


Figure 9. Rotational Joint Motion

Forces

Due to the problem's description, there is no force exerted on the system (not even gravity).

Measures

To measure the angle θ provided in the problem's description, an angle measure is created from the "Design Exploration" section.

The angle is defined between the line AD (the line connecting the piston’s center of mass and the Point D) and crank AB.

Final Model

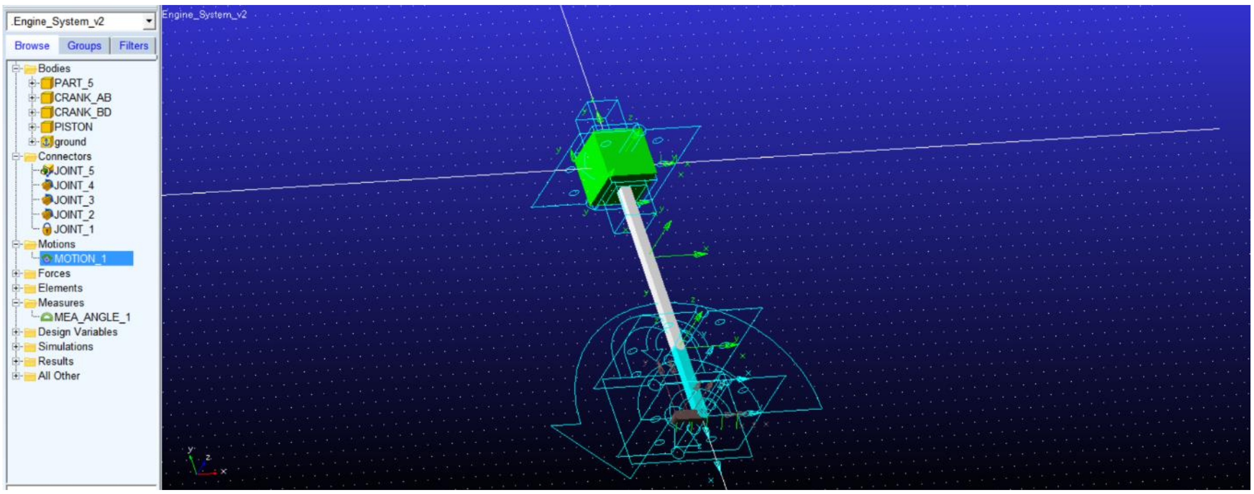
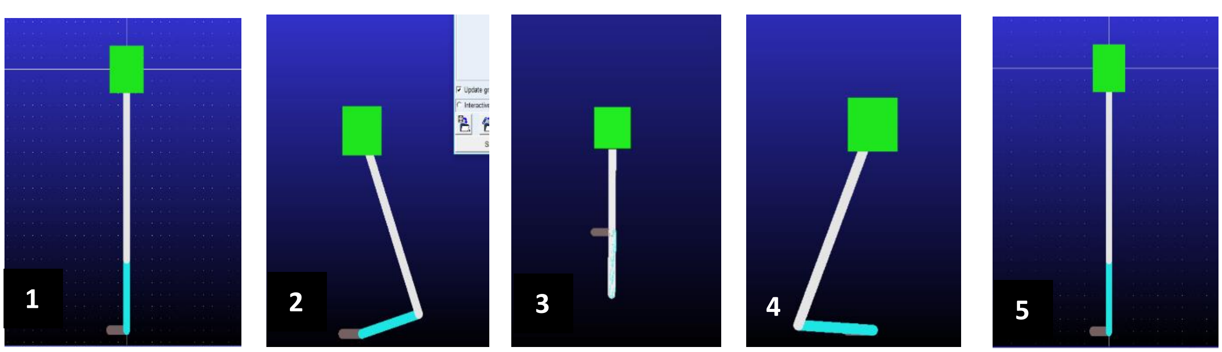


Figure 10. Final Model

Simulation

In this section, the post processor is used to analyze the dynamics of the modeled Engine System. This section is divided into two main subsections: Animation and Plots and Interpretation. In the Plots and Interpretation subsection, we have used the postprocessor to obtain the values required in Phase I of the project plus plotting the piston’s displacement, velocity, acceleration and the crank AB’s angular velocity with respect to time.

Animation



Plots and Interpretation

Piston Velocity at $\theta = 0$ and $\theta = 90$

As represented by the plot given by the postprocessor, It can be seen that the values obtained in Phase l are valid:

V_p = 0 mm/s at θ = 0
V_p = 6282 mm/s at θ = 90

Due to figure 11, it is clear that at θ = 0, the piston's velocity is zero (in all directions). The green line denotes where the piston's velocity is -6282 mm/s and as shown, θ at this instant (t = 0.015 s) is equal to 90 degrees and thus the values derived in Phase l are valid. The blue line represents the angle θ with respect to time, notice how to plot θ, we need to create an Angle Measure (from Design Exploration).

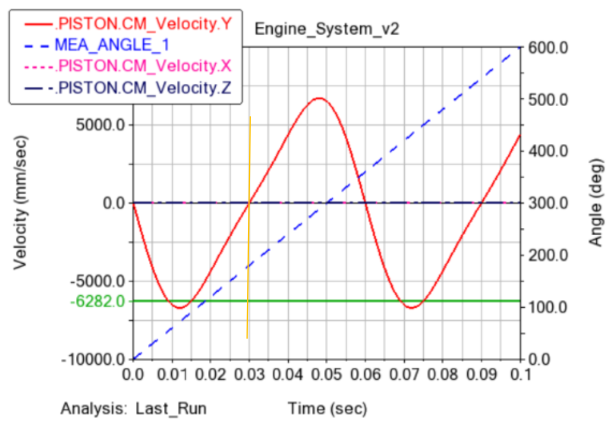


Figure 11. The graph above represents the piston's velocity (-y direction) along with the angle ϑ with respect to time. The green line denotes the value of -6282 (mm/s) for the piston's velocity, the corresponding angles (on the blue line) to this value is 55.2 +/- 4deg and 90 deg.

Notice how the Piston has no velocity in x and z direction as the piston's motion is vertically restricted. (Refer to Connections under the Modeling subsection.)

From the plot in figure 11, it can easily be perceived that the piston experiences the downward velocity 6282 mm/s **twice** as θ reaches 0 for the second time (one revolution). By the help of the postprocessor's Plot Tracking tool ( ), the estimated value for θ when velocity hits -6282 (mm/s) for the first time, is roughly **55.2 +/-4 deg**. The +/-4 deg represents the lack of precision by 4 degrees.

It can be seen from the graph that the magnitude of the Piston's velocity (V_P) increases from θ=0 and experiences its peak at $\theta = 70$ +/- 5 deg with the value 6716 +/- 30 (mm/s) where the magnitude of V_P starts decreasing until it hits its minimum, zero at θ=180 deg (the yellow line in figure 11. intersects with V_P at V_p = 0 (mm/s) and with θ at θ = 180.) From θ = 180 onwards the motion's direction is upwards and the magnitude of V_p increases until it hits the peak at θ = 283.3 +/- 5deg, where V_p starts to decrease until it reaches zero at θ = 360. (Vividly this motion is periodic, unlike the model provided by the problem where theta cannot exceed after 180 degrees.)

Crank BD Angular Velocity at $\theta = 0$ and $\theta = 90$

As represented by the plot given by the postprocessor, It can be seen that the values obtained in Phase l are valid:

ω_{BD} = 0 rad/s at θ = 90
ω_{BD} = 39.3 rad/s or 2250 deg/s at θ = 0 (CCW)

Figure 12 shows that at θ = 90, the crank BD's angular velocity (ω_{BD}) is zero. The green line denotes ω_{BD} is 2250 deg/s (maximum) and as shown, θ at this instant (t = 0.015) is equal to 0 degrees and thus the values derived in Phase l are valid. The blue line represents the angle θ with respect to time, notice how to plot θ, we need to create an Angle Measure (from Design Exploration).

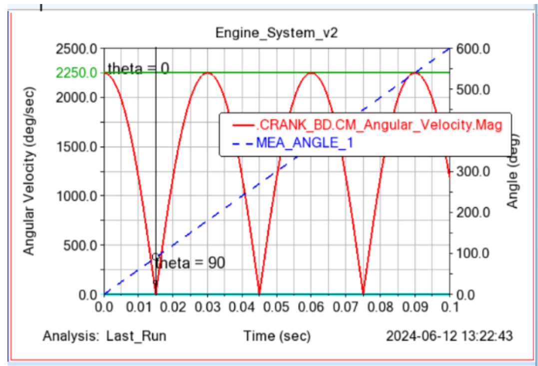


Figure 12. The graph above represents the crank BD's angular velocity along with the angle ϑ with respect to time. The green line denotes the value of 2250 (deg/s) for the crank BD's angular velocity, the corresponding angle (on the blue line) to this value is zero.

Piston Displacement, Velocity and Acceleration with Respect to Time

The graph presented in figure 13, plots the Piston's velocity with respect to time (-y direction: red). As expected, -x and -z parameters of displacement are zero. The **maximum distance reached from y = 0, is 120 mm** which occurs at θ = 180 deg.

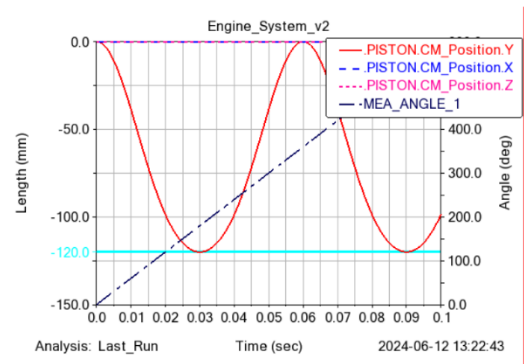


Figure 13. Piston's displacement with respect to time.

We can simply derive the above result by noticing the geometry of the problem (Figure 8.) at θ = 180 Where crank AB is behind Crank BD and Point B is below Point A therefor the current position of the Piston with respect to Point A would be 160 – 60 = 100 mm. Initially at θ = 0, the piston is 160 + 60 = 220 mm above Pin A and therefore the maximum distance from the P at θ = 0 is 120 mm.

Notice how in the postprocessor the origin of motion for the Piston is Point P at θ = 0 and thus as represented by the Cyan line in figure 13. , this value is negative since the Piston is below the origin at this instant.

The plot provided in figure 14. , plots the Piston's Velocity with respect to time. Notice how the -z and the -x parameters are zero throughout the motion. For further insight, "Piston's velocity at θ = 0 and θ = 90" under the subsection Plots and Interpretation, can be studied.

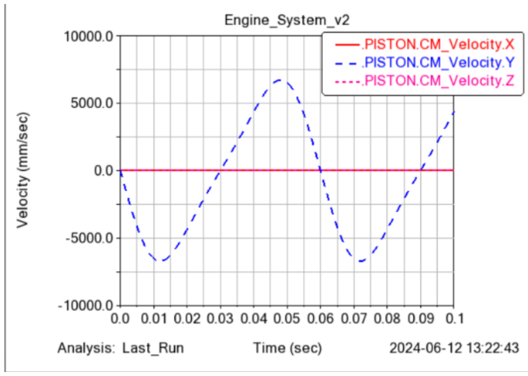


Figure 14.Piston's velocity with respect to time

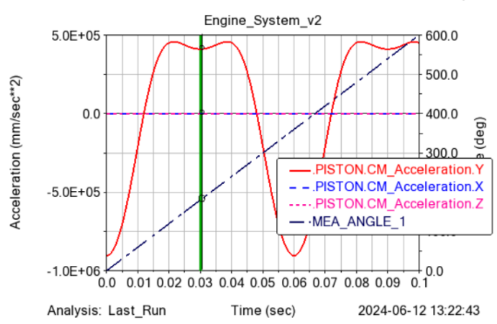


Figure 15. Piston's acceleration with respect to time

Figure 15. plots the Piston's acceleration with respect to time. The green vertical line denotes the instant 0.03 where θ = 180 deg. Notice how the velocity of the Piston is expected to increase when acceleration is positive. When acceleration reaches zero for the first time, θ *is* 70 +/- 5 deg which is the minimum of the Piston's velocity graph. (Discussed in previous sections.)

Crank AB's Angular Velocity

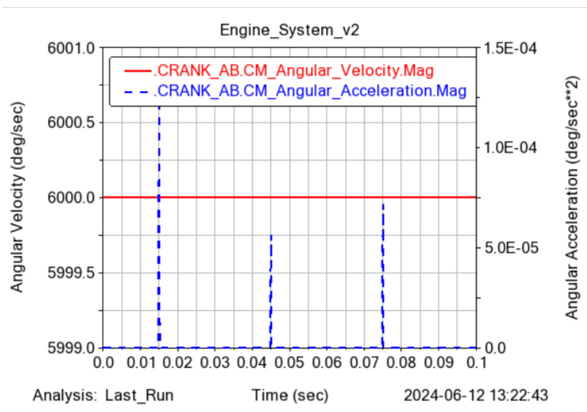


Figure 16. Angular velocity and angular acceleration of crank AB

As stated in the problem description, the angular velocity of the crank AB is a constant and the value is 1000 rpm or in other words 6000 deg/s. (Figure 16). One might question the validity of the crank AB's angular acceleration graph since the angular velocity is constant and the angular acceleration is expected to remain zero. Since the postprocessor uses a finite number of steps (states) to simulate the model, and acceleration is achieved by taking derivative from finite number of values, the resultant graph might plot unnecessary high values (noise). (Notice how a small difference divided by a rather small number can result in a large number.)

Figure 17 shows the torque exerted on the joint between Pin A and Crank AB with respect to time.

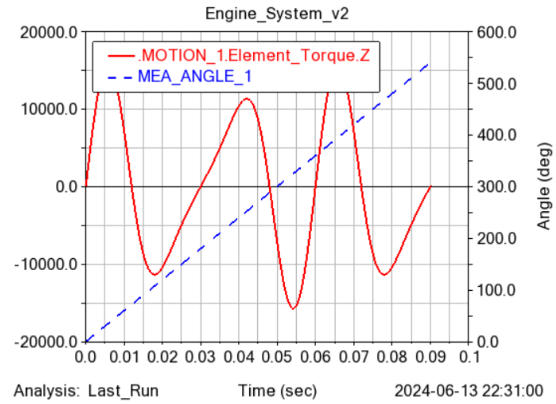


Figure 17. the torque exerted on the joint between Pin A and Crank AB

Further Study

Matlab

In this section we have simulated the results from the Adams Project via Matlab.

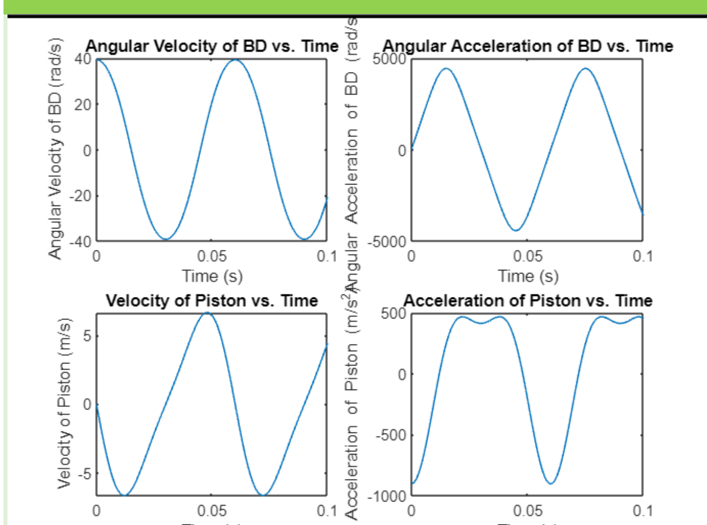
Notice how since the angular velocity is constant, $\theta = \omega * t$. Our code is based in the relations derived in Phase l.

<u>Note how the units are in meters, not mm.</u>

```
% Given data
l = 160 / 1000; % Length of BD (meters)
b = 60 / 1000;  % Crank length (meters)
n = l / b;      % Ratio of connecting rod to crank


% Angular velocity of crank AB (constant)
N = 1000; % RPM
w = 2 * pi * N / 60; % Angular velocity in radians per second


% Time vector (from 0 to 2 seconds, for example)
t = linspace(0, 0.1, 100); % Adjust the time range as needed


% Angular position (theta) as a function of time
theta = w * t;


% Angular velocity of BD (connecting rod) in terms of time
wBD = w * cos(theta) ./ sqrt(n^2 - sin(theta).^2);


% Angular acceleration of BD in terms of time
alphaBD = w^2 * (n^2 - 1) * sin(theta) ./ ((n^2 - sin(theta).^2).^(3/2));


% Plot results
subplot(2,2,1);
plot(t, wBD);
xlabel('Time (s)');
ylabel('Angular Velocity of BD (rad/s)');
title('Angular Velocity of BD vs. Time');


subplot(2,2,2);
```

```
plot(t, alphaBD);
xlabel('Time (s)');
ylabel('Angular Acceleration of BD (rad/s^2)');
title('Angular Acceleration of BD vs. Time');


% Velocity of piston P (in terms of time)
Vp = -1 * b * w * (sin(theta) + sin(2 * theta) / (2 * n));


% Acceleration of piston P (in terms of time)
ap = -1 * b * w^2 * (cos(theta) + cos(2 * theta) / n);


subplot(2,2,3);
plot(t, Vp);
xlabel('Time (s)');
ylabel('Velocity of Piston (m/s)');
title('Velocity of Piston vs. Time');


subplot(2,2,4);
plot(t, ap);
xlabel('Time (s)');
ylabel('Acceleration of Piston (m/s^2)');
title('Acceleration of Piston vs. Time');
```

Output:



As shown above, the results match the one's obtained from ADAMS postprocessor.

Deriving the values for Phase I

```
%theta = 0
% Velocity of piston P (in terms of time)
Vp_theta0 = -1 * b * w * (sin(0) + sin(2 * 0) / (2 * n))




% Velocity of piston P (in terms of time)
Vp_theta90 = -1 * b * w * (sin(pi/2) + sin(2 * pi/2) / (2 * n))




% Angular velocity of BD (connecting rod) in terms of time
wBD_theta0 = w * cos(0) ./ sqrt(n^2 - sin(0).^2)


% Angular velocity of BD (connecting rod) in terms of time
wBD_theta90 = round(w * cos(pi/2) ./ sqrt(n^2 - sin(pi/2).^2))
```

Output:

```
Vp_theta0 = 0
Vp_theta90 = -6.2832
wBD_theta0 = 39.2699
wBD_theta90 = 0
```

Applications in Real life

The assigned problem to group 9 was analyzed in previous sections. In this section the application of the mechanism is introduced.

Components of An Engine System

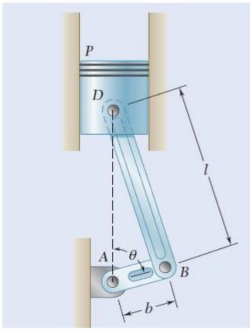


Figure 18. The provided Engine System

1. **Piston**: The piston is a cylindrical component that moves up and down inside a cylinder. It is usually **made of aluminum alloy** and fits within the cylinder bore.During the engine cycle, the piston undergoes reciprocating motion (upward and downward movement).

2. **Crankshaft**: The crankshaft is a rotating shaft that converts the reciprocating motion of the piston into rotational motion.It is typically made of forged steel and has several crankpins (offset sections) along its length. The crankshaft is connected to the piston via a connecting rod. **Crank AB**

3. **Connecting Rod**: The connecting rod (also known as the conrod) links the piston to the crankshaft. It has one end attached to the piston pin (wrist pin) and the other end to the crankpin on the crankshaft. As the piston moves up and down, the connecting rod transfers this motion to the crankshaft. **Link BD**

Working Principle: When fuel ignites in the cylinder, it creates pressure that pushes the piston downward (power stroke).The connecting rod transmits this linear motion to the crankshaft. The crankshaft rotates, converting the linear motion into rotational motion.The rotational energy from the crankshaft drives the vehicle's wheels or powers other machinery.

Four Stroke Cycle Engine

In four-stroke cycle engine, the cycle of operation is completed in four strokes of the piston or two revolutions of the crankshaft. Each stroke consists of 1800 of crankshaft rotation and hence a cycle consists of 720 of crankshaft rotation. The series of operation of an ideal four-stroke engine are as follows:

1. **Intake Stroke**: The process begins with the intake stroke. The intake valve opens, allowing a mixture of air and fuel to enter the cylinder. The piston moves downward to create space for the incoming mixture.

2. **Compression Stroke**: The intake valve closes, and the piston starts moving upward (compression stroke).The mixture is compressed within the cylinder. The pressure and

temperature increase significantly.

3. **Power Stroke**: At the top of the compression stroke (TDC), the spark plug ignites the compressed mixture.The rapid combustion generates high pressure. The pressure pushes the piston downward (power stroke).The connecting rod transfers this linear motion to the crankshaft.

4. **Exhaust Stroke**:After the power stroke, the exhaust valve opens. The piston moves upward again (exhaust stroke).The exhaust gases are expelled from the cylinder.

5. **Crankshaft Rotation**: As the piston moves up and down, the crankshaft rotates. The crankshaft converts the reciprocating motion into rotational motion. This rotation drives the vehicle's wheels or powers other machinery.

6. **Angular Position (θ)**: The crankshaft angle (θ) determines the position of the piston and connecting rod.

7. **Efficiency and Optimization**: Factors like combustion efficiency, friction, and heat losses impact overall performance. Real-world engines deviate from idealized models due to practical limitations.

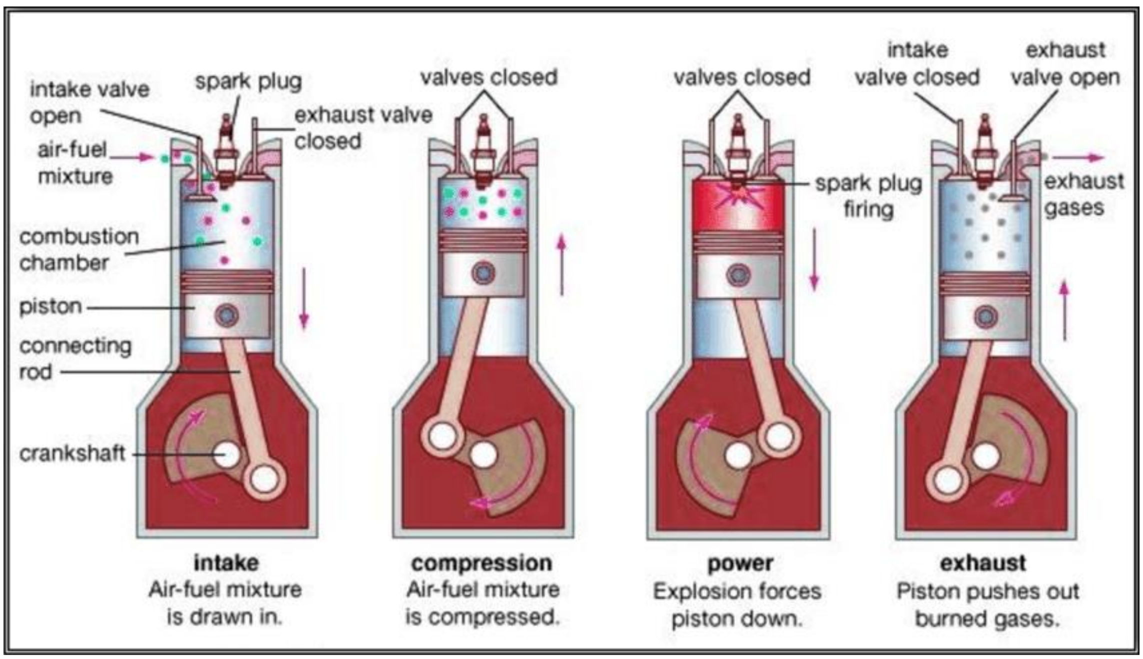


Figure 19. Four stroke cycle engine

Two stroke cycle engine

In two stroke engines the cycle is completed in two strokes of piston i.e. one revolution of the crankshaft as against two revolutions of four stroke cycle engine. The two-stroke cycle eliminates the separate induction and exhaust strokes.

1. Compression stroke: The piston travels up the cylinder, so compressing the trapped charge. If the fuel is not pre-mixed, the fuel is injected towards the end of the compression stroke; ignition should again occur before TDC. Simultaneously under side of the piston is drawing in a charge through a spring-loaded non-return inlet valve.

2. Power stroke: The burning mixture raises the temperature and pressure in the cylinder, and forces the piston down. The downward motion of the piston also compresses the charge in the crankcase. As the piston approaches the end of its stroke the exhaust port is uncovered and blow down occurs. When the piston is at BDC the transfer port is also uncovered, and the compressed charge in the crankcase expands into the cylinder. Some of the remaining exhaust