The University of Jordan

School of Engineering

Department of Mechatronics

Mechanics of Machines

(0944331)

Course project

Radial engine

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Introduction

History

The concept of the radial engine dates to the late 19th century when inventors and engineers began experimenting with different engine configurations. One of the earliest successful radial engines was built by French engineer Leon Levavasseur in 1908.

The 1920s and 1930s saw the golden age of aviation, and radial engines became the Dominant powerplants for many aircrafts, the engine powered a wide range of Aircrafts, from small biplanes to large bombers.

Figure 1 radial engine used in WW2 for aircraft FW-190

The development of the first practical radial engine is credited to the French engineer Léon Levavasseur. In 1908, Levavasseur designed and built the Antoinette 8V, a pioneering aircraft engine that featured a radial arrangement of cylinders. The Antoinette 8V was a water-cooled engine with eight cylinders arranged in a circular fashion around the crankshaft. This design provided a compact and efficient powerplant for early aircraft.

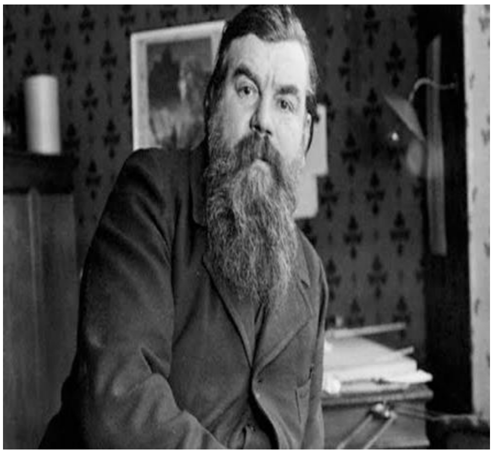


Figure 2 Leon Levavasseur

The engine was improved by George Mead and CharlesLawrence,These engineers and their respective companies made significant advancements in radial engine technology, enhancing performance, reliability, and efficiency.

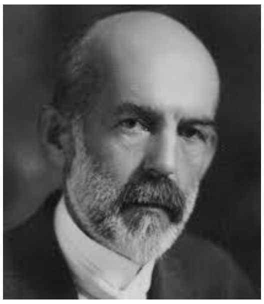


Figure 4 George Mead

Figure 3 Charles Lawrence

Their work contributed to the widespread adoption of radial engines during the golden age of aviation, and aircraft industry in WW2.

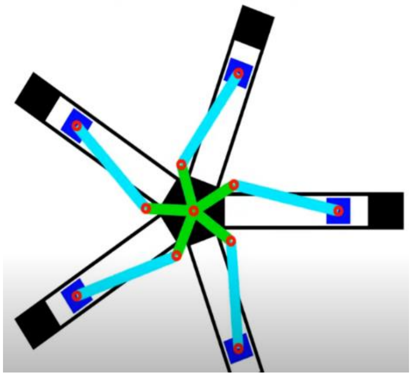


Figure 5 parallel motion

Calculations

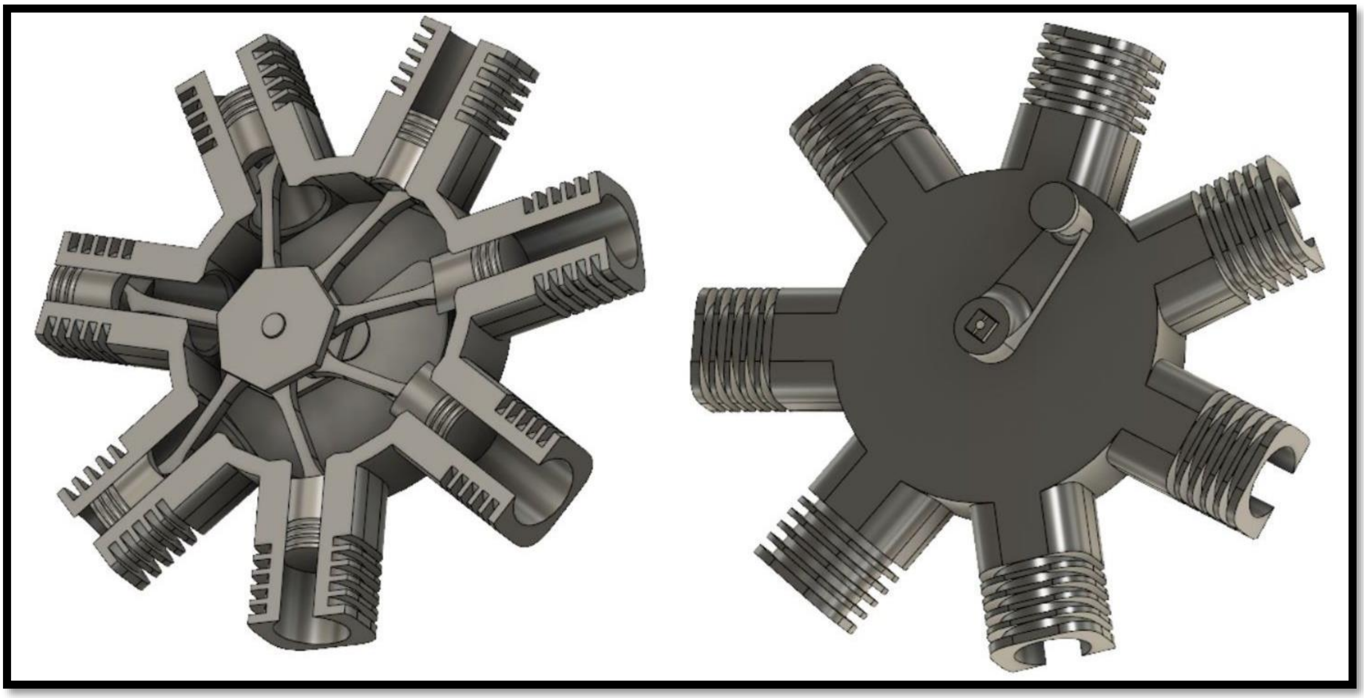


Figure 8: Radial engine design

Position Analysis

From the loop

$\overrightarrow{R_2}$ - $\overrightarrow{R_3}$ - $\overrightarrow{R_4}$ $-$ $\overrightarrow{R_1}$ $= 0$

$ae^{j\theta 2}$ - $be^{j\theta 3}$ $-$ $ce^{j\theta 4}$ $-$ $de^{j\theta 1}$ $= 0$

C= 0 (there is no offset)

So, we have:

$a\cos\theta_2$ - $b\cos\theta_3 - d\cos\theta_1 = 0$ -- (1)

$a\sin\theta_2$ - $b\sin\theta_3 - d\sin\theta_1 = 0$ -- (2)

Velocity Analysis

$ae^{j\theta 2} - \; be^{j\theta 3} \; - de^{j\theta 1} = 0$

Derive the equation.

$aj\omega_2 e^{j\theta 2} + bj\omega_3 e^{j\theta 3} - cj\omega_4 e^{j\theta 4} - \dot{d}j - fj\omega_1 e^{j\theta 1} = 0$

So, we have:

$a\,\omega_2 \cos\theta_2 - b\,\omega_3 \cos\theta_3 \; - d' = 0$ ---(3)

$-a\,\omega_2 \sin\theta_2 \; + b\,\omega_3 \sin\theta_3 - \; d' \; = 0$---(4)

Acceleration Analysis

$aj\omega_2 e^{j\theta 2} - bj\omega_3 e^{j\theta 3} - d'' = 0$

Derive the equation.

$(a\omega_2{}^2 e^{j\theta 2} + aj\alpha_2 e^{j\theta 2}) - (b\omega_3{}^2 e^{j\theta 3} + bj\alpha_3 e^{j\theta 3}) - (c\omega_4{}^2 e^{j\theta 4} + cj\alpha_4 e^{j\theta 4}) - (d'') = 0$

So, we have:

$-a\;\alpha_2 \sin\theta_2 - a\;\omega_2{}^2 \cos\theta_2 + b\;\alpha_3 \sin\theta_3 + b\;\omega_3{}^2 \cos\theta_3$ – d''=0 -- (5)

$a\;\alpha_2 \cos\theta_2 - a\;\omega_2{}^2 \sin\theta_2 \; - b\;\alpha_3 \cos\theta_3 + b\;\omega_3{}^2 \sin\theta_3$ – d''=0 -- (6)

Jerk Analysis

$$(a\omega_2{}^2 e^{j\theta 2} + aj\alpha_2\ e^{j\theta 2}) + (b\omega_3{}^2 e^{j\theta 3} + bj\alpha_3 e^{j\theta 3}) - (d\omega_1{}^2 e^{j\theta 1} + dj\alpha_1 e^{j\theta 1}) = 0$$

So, we have:

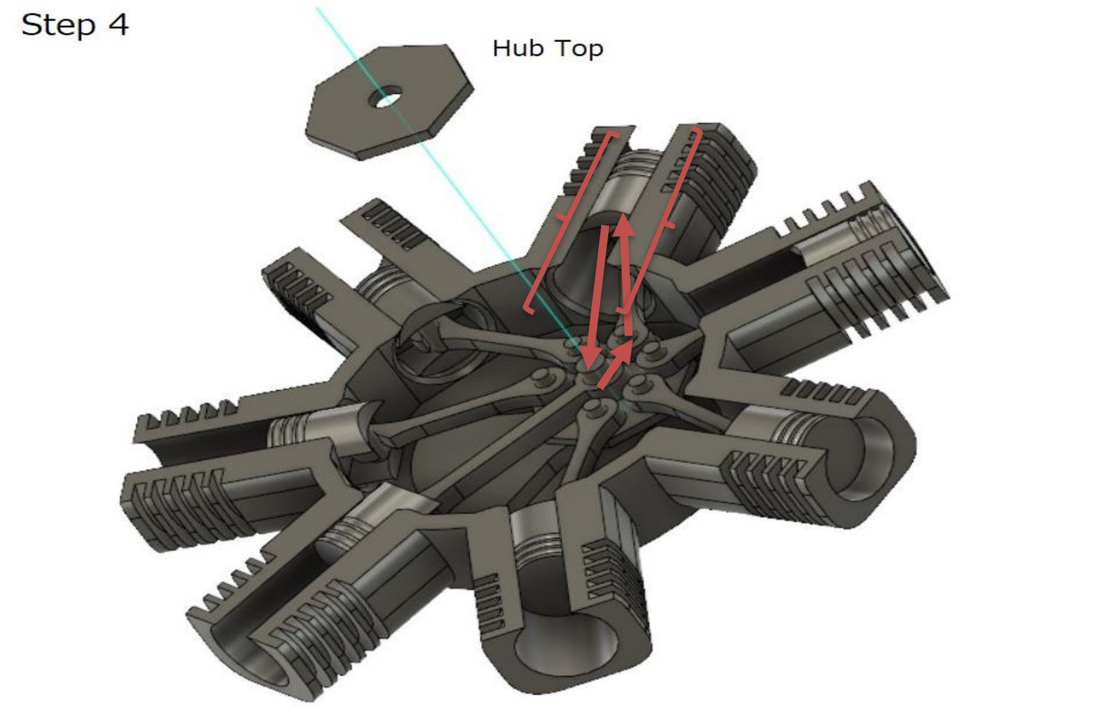
$$a\,\omega_2{}^3 \sin\theta_2 - 3\,a\,\alpha_2\,\omega_2 \cos\theta_2\ - a\,\varphi_2\ \sin\theta_2 + b\,\omega_3{}^3 \sin\theta_3 - 3\,b\,\alpha_3\,\omega_3 \cos\theta_3\ - b\,\varphi_3\ \sin\theta_3 - \dddot{d} = 0$$

- - - - - - - - -(7)

$$-a\,\omega_2{}^3 \cos\theta_2 - 3\,a\,\alpha_2\,\omega_2\ \sin\theta_2\ + a\,\varphi_2\ \cos\theta_2 - b\,\omega_3{}^3 \cos\theta_3 - 3\,b\,\alpha_3\,\omega_3\ \sin\theta_3\ + b\,\varphi_3\ \cos\theta_3 - \dddot{d} = 0$$

- - - - - - - - -(8)

Force Analysis

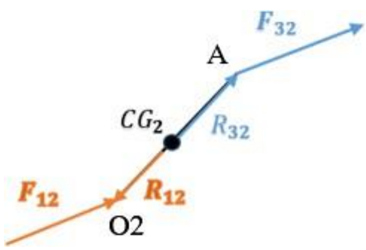


- For link 2:

$$\sum F_x = ma_x \rightarrow\ F_{12x} + F_{32x} = m_2 a_{G2x}$$

$$\sum F_y = ma_y \rightarrow F_{12y} + F_{32y} = m_2 a_{G2y}$$

$$\sum T = I_G \alpha \rightarrow T_{12} + (R_{12x}F_{12y} - R_{12y}F_{12x}) + (R_{32x}F_{32y} - R_{32y}F_{32x}) = I_{G2}\alpha_2$$

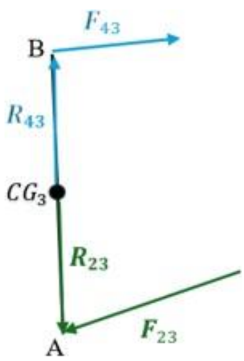


- For link 3:

$$\sum F_x = ma_x \rightarrow\ F_{43x} - F_{23x} = m_3 a_{G3x}$$

$$\sum F_y = ma_y \rightarrow F_{43y} - F_{23y} = m_3 a_{G3y}$$

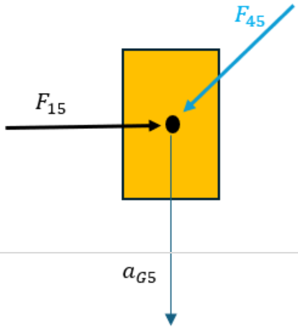
$$\sum T = I_G \alpha \rightarrow (R_{43x}F_{43y} - R_{43y}F_{43x}) + (R_{23x}F_{23y} - R_{23y}F_{23x}) = I_{G3}\alpha_3$$



- For link 4 :

$$\sum F_x = ma_x \rightarrow \quad F_{34x} + F_{14x} = m_4 a_{G4x}$$

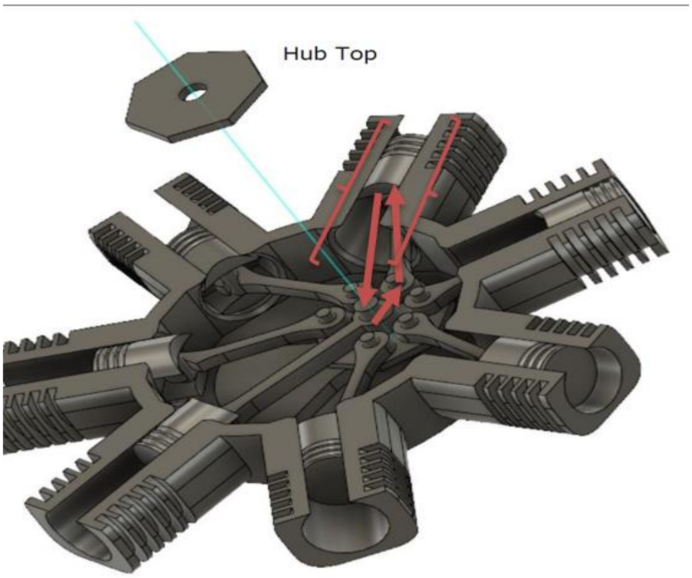
$$\sum F_y = ma_y \rightarrow F_{34y} + F_{14y} = m_4 a_{G4y}$$



$$\sum T = I_G \alpha \rightarrow (R_{34x}F_{45y} - R_{34y}F_{34x})$$

$$+ (R_{14x}F_{14y} - R_{14y}F_{14x}) = I_{G5}$$

Using MATLAB



➔ Loop:

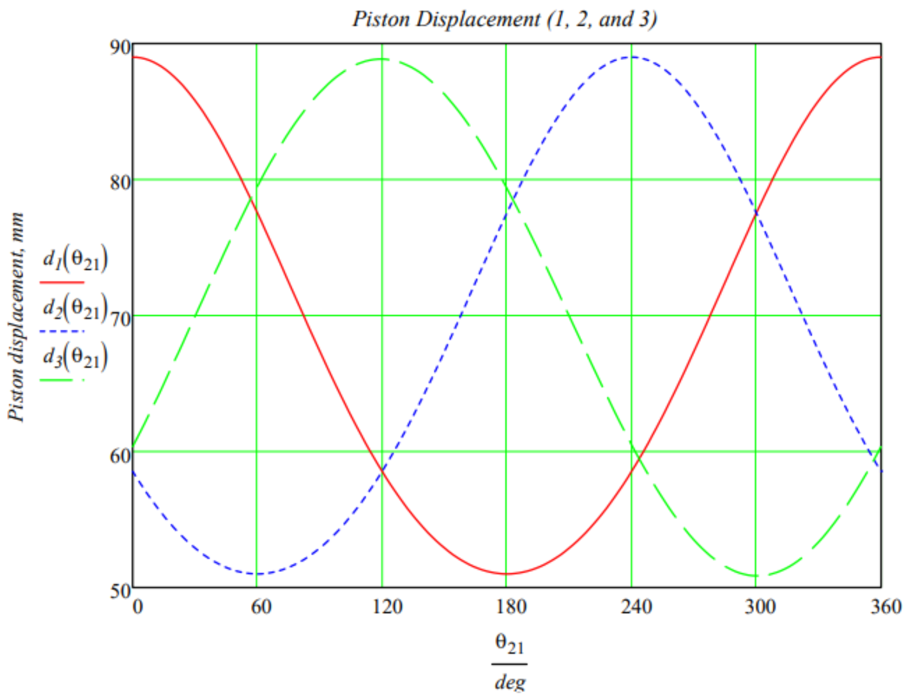
When: a=10mm, b= 36mm cm, c=0 cm, d= variable

And $\theta_1 = 90$, $\theta_3 = 60$, $\theta_2 = [0\text{-}360]$,

<u>Position:</u>

$a\cos\theta_2 - b\cos\theta_3 - \mathrm{d}\cos\theta_1 = 0$ --------------------------------------- (1)

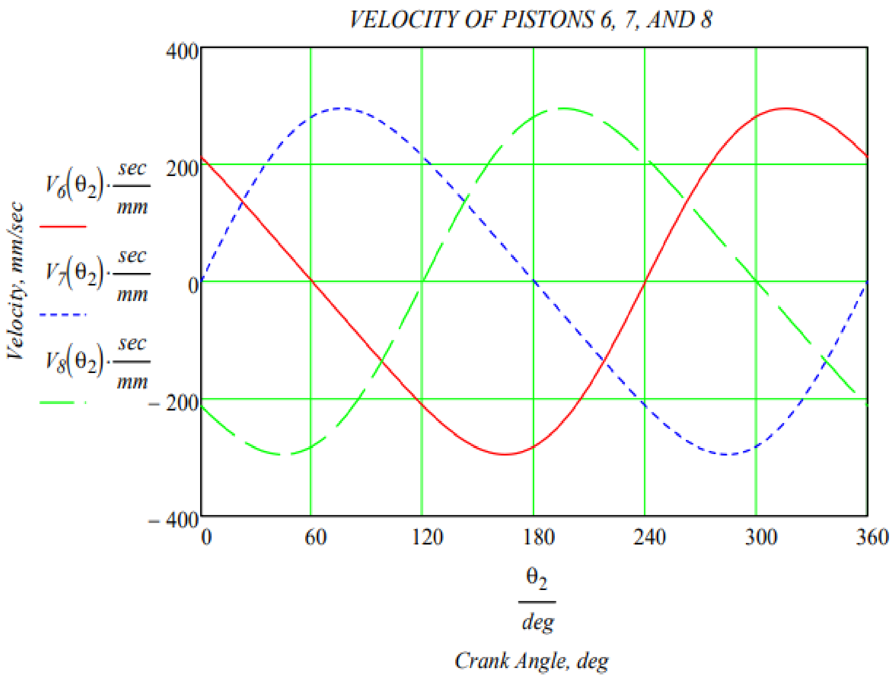
$a\sin\theta_2 - b\sin\theta_3 - \mathrm{d}\sin\theta_1 = 0$ ---(2)



MATLAB code

```
close all
clear all
clc

%% SET UP

r2 = 10;
r3 = 36;

% Set up for animation
figure
axis (gca, 'equal');
axis ([-400 600 -400 400])

zz(3,:) = [0, 0];

% Angles
th2 = deg2rad (0:20:720);

% Angluar speed
om2 = 1;

%% LOOP

% i is the time to run the animation for
for i = 1:500


    th1 = om2*(i/10);
    aph = asin((r2*sin(th1))/(r3));

    % Distance between Slider and stationary point
    r1 = ((r2*cos(th1)) + (r3*cos(aph)));

    % Positions of links and joints
    zz(1,:) = [r1, 0];
    zz(2,:) = [r2*cos(th1), r2*sin(th1)];

    % Plot the results
    plot (zz(:,1), zz(:,2), 'o-')
    title ('Slider Crank Mechanism')
    axis ([-400 600 -400 400])
    pause (0.01)

end
```

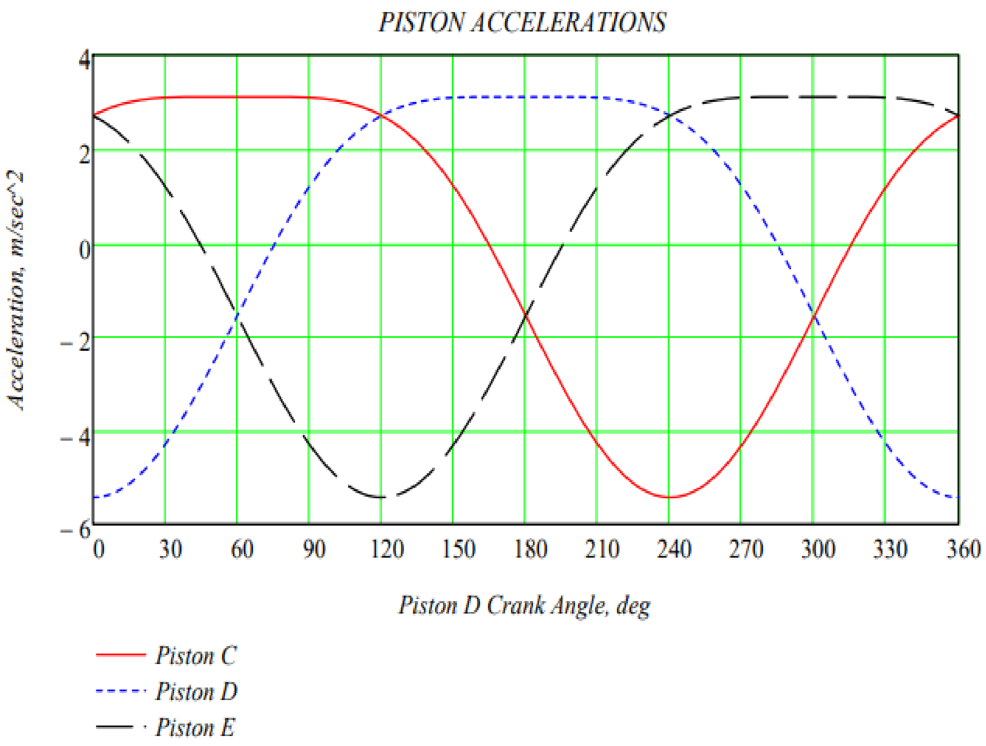
Velocity:



Matlab Code

```
wab=6.28 r2=10 ;r3=36;
theta=0:0.1:2*pi;
phi = asin((r*sin(theta))/r3);
wbc= (wab*r2*sin(theta))./(r3*sin(phi));
v=wab*r2.*cos(theta)+wbc*r3.*cos(phi);
plot(theta,v)
```

Acceleration:



MATLAB code

```
% Crank-Slider Mechanism Acceleration Calculation

% Input parameters
theta = linspace(0, 2*pi, 100); % Crank angle in radians
r =10 ; % Crank length (meters)
l = 36; % Connecting rod length (meters)
omega = 2*pi; % Angular velocity of the crank (rad/s)

% Calculate position coordinates
x = r * cos(theta) + sqrt(l^2 - r^2 * sin(theta).^2);

% Calculate velocity components
v_x = -r * omega * sin(theta);
v_y = r * omega * cos(theta);

% Calculate acceleration components
a_x = -r * omega^2 * cos(theta);
a_y = -r * omega^2 * sin(theta);
```

```
% Total acceleration magnitude
a_total = sqrt(a_x.^2 + a_y.^2);

% Plotting
figure;

subplot(3, 1, 1);
plot(theta, x);
title('Position');

subplot(3, 1, 2);
plot(theta, v_x, theta, v_y);
legend('v_x', 'v_y');
title('Velocity');

subplot(3, 1, 3);
plot(theta, a_x, theta, a_y, theta, a_total);
legend('a_x', 'a_y', 'a_{total}');
title('Acceleration');

% Display maximum acceleration
max_acceleration = max(a_total);
fprintf('Maximum acceleration: %.2f m/s^2\n', max_acceleration);
```

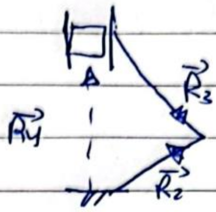
Using Analytical method:

$a = 10mm$ $\omega_2 = 6.28$ rad/s ccw

$b = 36mm$ $\theta_1 = 90$

$c = 0$

for $\theta_2 = 60$



solution:

position →

$$-a\cos\theta_2 - b\cos\theta_3 - d\cos\theta_1 = 0 \rightarrow$$
$$-a\sin\theta_2 - b\sin\theta_3 - d\sin\theta_1 = 0$$

$$10\cos(60) - 36\cos(\theta_3) - d\cos(90) = 0 \rightarrow$$
$$10\sin(60) - 36\sin(\theta_3) - d = 0$$

$\boxed{\theta_3 = -82^\circ}$, $\boxed{d = 44.3\ mm}$

Velocity →

$$-a\omega_2\sin\theta_2 + b\omega_3\sin\theta_3 - \dot{d} = 0$$
$$a\omega_2\cos\theta_2 - b\omega_3\cos\theta_3 - \dot{d} = 0$$

$$(-10)(6.28)(\sin(60)) + (36)(\omega_3)\sin(-82) - \dot{d} = 0 \rightarrow \text{using calculator}$$
$$(10)(6.28)(\cos(60)) - (36)(\omega_3)\cos(-82) - \dot{d} = 0$$

$\boxed{\omega_3 = 2.799\ rad/s}$

$\boxed{\dot{d} = -45.427}$

acceleration → constant ω_2 so $\alpha_2 = 0$

$$(-\alpha_2)(a)(\sin\theta_2) - (a)(\omega_2)^2\cos\theta_2 - b\alpha_3\sin\theta_3 - b\omega_3^2\cos\theta_3 - \ddot{d} = 0$$
$$(\alpha_2)(a)(\cos\theta_2) - (a)(\omega_2)^2\sin\theta_2 + b\alpha_3\cos\theta_3 - b\omega_3^2\sin\theta_3 - \ddot{d} = 0$$

using calculator → $\boxed{\alpha_3 = 6.625\ rad/s^2}$ $\boxed{\ddot{d} = 29.1\ mm/s^2}$

References

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