ME 470 Final Project: Detailed Drawing with Kinematic and Dynamic Analysis

4 bar linkage

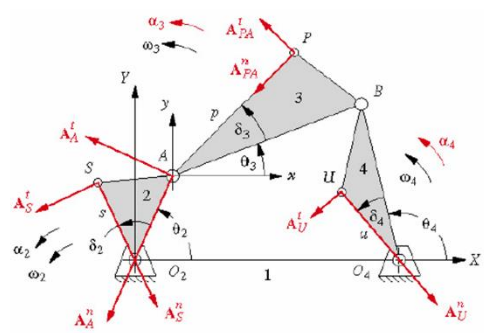
a, b, c, d, ω_2, α_2	Choose Values

Ideally you will determine the following values at all possible values of θ_2 so that you can visualize where the forces will be the highest.

$K_1 = \frac{d}{a}$ $K_2 = \frac{d}{c}$ $K_3 = \frac{a^2 - b^2 + c^2 + d^2}{2ac}$ $K_4 = \frac{d}{b}$ $K_5 = \frac{c^2 - d^2 - a^2 - b^2}{2ab}$	$A = cos\theta_2 - K_1 - K_2 cos\theta_2 + K_3$ $B = -2\sin\theta_2$ $C = K_1 - (K_2 + 1)cos\theta_2 + K_3$ $D = cos\theta_2 - K_1 + K_4 cos\theta_2 + K_5$ $E = -2\sin\theta_2$ $F = K_1 + (K_4 - 1)cos\theta_2 + K_5$	$\theta_{4_{1,2}} = 2\tan^{-1}\left(\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}\right)$ $\theta_{3_{1,2}} = 2\tan^{-1}\left(\frac{-E \pm \sqrt{E^2 - 4DF}}{2D}\right)$
μ	$\mu = \theta_4 - \theta_3$	

Velocity

ω_3	$\omega_3 = \frac{a\omega_2}{b}\frac{\sin(\theta_4 - \theta_2)}{\sin(\theta_3 - \theta_4)}$
ω_4	$\omega_4 = \frac{a\omega_2}{c}\frac{\sin(\theta_2 - \theta_3)}{\sin(\theta_4 - \theta_3)}$



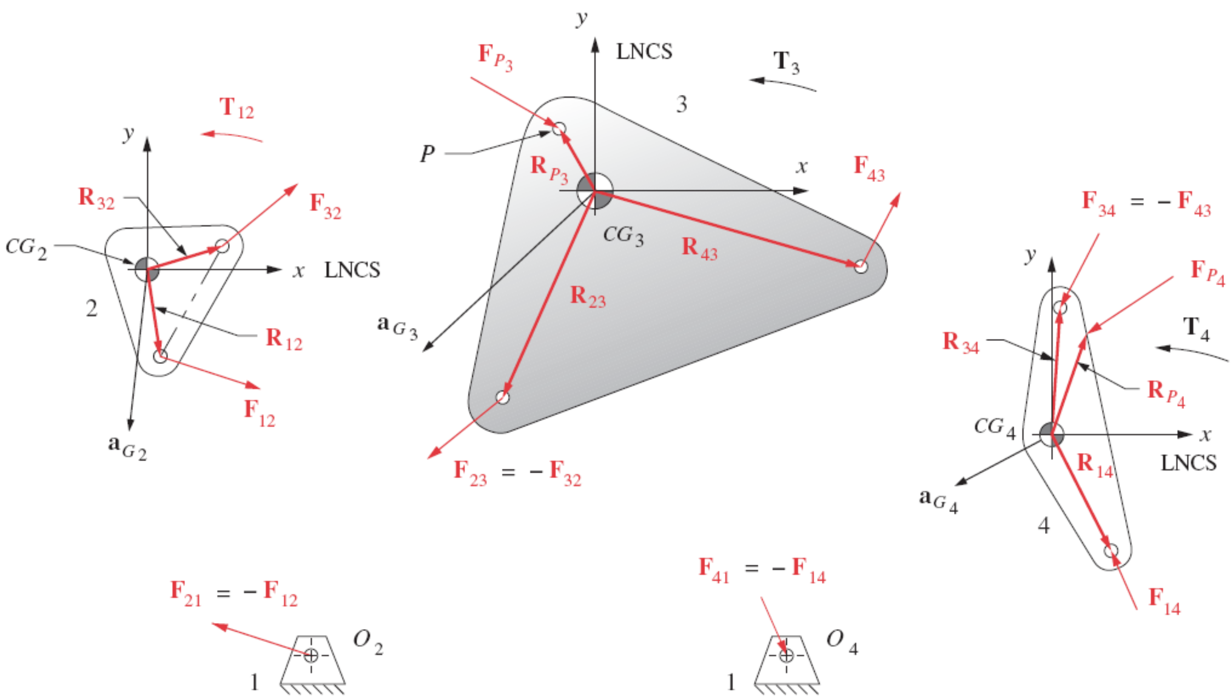
Acceleration

	$A = c\sin\theta_4 \qquad B = b\sin\theta_3$ $C = a\alpha_2\sin\theta_2 + a\omega_2^2\cos\theta_2 + b\omega_3^2\cos\theta_3 - c\omega_4^2\cos\theta_4$ $D = c\cos\theta_4 \qquad E = b\cos\theta_3$ $F = a\alpha_2\cos\theta_2 - a\omega_2^2\sin\theta_2 - b\omega_3^2\sin\theta_3 + c\omega_4^2\sin\theta_4$
α_3 α_4	$\alpha_3 = \frac{CD - AF}{AE - BD} \qquad \alpha_4 = \frac{CE - BF}{AE - BD}$
	Determine the location of the center of mass for link 2, link 3, link 4: s, p, u, δ_2, δ_3, δ_4
A_{G2} A_{G3} A_{G4}	$A_{G2} = A_S = -[s\alpha_2\sin(\theta_2 + \delta_2) + s\omega_2^2\cos(\theta_2 + \delta_2)] + j[s\alpha_2\cos(\theta_2 + \delta_2) - s\omega_2^2\sin(\theta_2 + \delta_2)]$ $A_{G3} = A_P = A_A + A_{PA} = -[a\alpha_2\sin\theta_2 + a\omega_2^2\cos\theta_2] + j[a\alpha_2\cos\theta_2 - a\omega_2^2\sin\theta_2] + -[p\alpha_3\sin(\theta_3 + \delta_3) + p\omega_3^2\cos(\theta_3 + \delta_3)] + j[p\alpha_3\cos(\theta_3 + \delta_3) - p\omega_3^2\sin(\theta_3 + \delta_3)]$ $A_{G4} = A_U = -[u\alpha_4\sin(\theta_4 + \delta_4) + u\omega_4^2\cos(\theta_4 + \delta_4)] + j[u\alpha_4\cos(\theta_4 + \delta_4) - u\omega_4^2\sin(\theta_4 + \delta_4)]$

	Determine mass of link 2, link 3, and link 4: m_2, m_3, m_4 in slugs, blobs, or kg Determine mass moment of inertia of link 2, link 3, link 4: I_{G2}, I_{G3}, I_{G4} Bar Link: $I_G = \frac{1}{12} mass(width^2 + length^2)$ Circle Link: $I_G = \frac{1}{2} mass(radius^2)$ Utilizing the value of θ_3, θ_4, μ, ω_3, ω_4, α_3, α_4, a_{G2}, a_{G3}, a_{G4}, s, p, u, δ_2, δ_3, δ_4 m_2, m_3, m_4, I_{G2}, I_{G3}, I_{G4} Determine R_{12x}, R_{12y}, R_{32x}, R_{32y}, R_{23}, R_{23y} R_{43x}, R_{43y}, R_{14x}, R_{14y}, R_{34x}, R_{34y} position vectors. Estimate position and magnitude of any externally applied forces and torques. Determine F_{12x}, F_{12y}, F_{32x}, F_{32y}, F_{43x}, F_{43y}, F_{14x}, F_{14y}, T_{12} based on any given input values.

R-values

Link 2	Link 3	Link 4
$R_{12x} = s\cos(\theta_2 + \delta_2 + 180°)$	$R_{23x} = p\cos(\theta_3 + \delta_3 + 180°)$	$R_{14x} = u\cos(\theta_4 + \delta_4 + 180°)$
$R_{12y} = s\sin(\theta_2 + \delta_2 + 180°)$	$R_{23y} = p\sin(\theta_3 + \delta_3 + 180°)$	$R_{14y} = u\sin(\theta_4 + \delta_4 + 180°)$
$R_{32x} = a\cos(\theta_2) + R_{12x}$	$R_{43x} = b\cos(\theta_3) + R_{23x}$	$R_{34x} = c\cos(\theta_4) + R_{14x}$
$R_{32y} = a\sin(\theta_2) + R_{12y}$	$R_{43y} = b\sin(\theta_3) + R_{23y}$	$R_{34y} = c\sin(\theta_4) + R_{14y}$



$$
\begin{bmatrix}
1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
-R_{12_y} & R_{12_x} & -R_{32_y} & R_{32_x} & 0 & 0 & 0 & 0 & 1 \\
0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & R_{23_y} & -R_{23_x} & -R_{43_y} & R_{43_x} & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & -1 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & R_{34_y} & -R_{34_x} & -R_{14_y} & R_{14_x} & 0
\end{bmatrix}
\begin{bmatrix}
F_{12_x} \\ F_{12_y} \\ F_{32_x} \\ F_{32_y} \\ F_{43_x} \\ F_{43_y} \\ F_{14_x} \\ F_{14_y} \\ T_{12}
\end{bmatrix}
=
\begin{bmatrix}
m_2 a_{G_{2x}} \\
m_2 a_{G_{2y}} \\
I_{G_2}\alpha_2 \\
m_3 a_{G_{3x}} - F_{P_{3x}} \\
m_3 a_{G_{3y}} - F_{P_{3y}} \\
I_{G_3}\alpha_3 - (R_{P_{3x}} F_{P_{3y}} - R_{P_{3y}} F_{P_{3x}}) - T_3 \\
m_4 a_{G_{4x}} - F_{P_{4x}} \\
m_4 a_{G_{4y}} - F_{P_{4y}} \\
I_{G_4}\alpha_4 - (R_{P_{4x}} F_{P_{4y}} - R_{P_{4y}} F_{P_{4x}}) - T_4
\end{bmatrix}
$$