(a) Binary links: 1, 4, 7, 8
Ternary links: 2, 3, 5, 6
Quaternary links : None
Degrees of freedom:

$$DoF = 3(n_L - 1) - 2n'_J - n''_J$$
$$= 3(8-1) - 2(10)$$
$$= 1$$

b i) $\frac{\cancel{m}N_c}{\cancel{2}} + \frac{\cancel{m}N_B}{\cancel{2}} = \frac{\cancel{m}N_{D_{outer}}}{\cancel{2}} + \frac{\cancel{m}N_A}{\cancel{2}}$

$$N_C = N_{D_{outer}} + N_A - N_B$$
$$= 64 + 36 - 60$$
$$= 40$$

ii) $N_J + N_H = N_K + N_L$
$$N_L = N_J + N_H - N_K$$
$$= 54 + 24 - 40$$
$$= 38$$

1biii) $n_A = n_B$

$$\frac{n_c}{n_B} = \left(-\frac{N_B}{N_C}\right)$$

$$n_c = \left(-\frac{60}{40}\right)(-100) \quad \because \; n_B = n_A$$

$$= 150 \text{ rpm CCW} = n_J = n_{arm-1}$$

iv) $$\frac{n_D}{n_A} = \left(-\frac{36}{64}\right)$$

$$n_D = \left(-\frac{36}{64}\right)(-100)$$

$$= 56.25$$

$$= 56.25 \text{ rpm CW}$$

v) $n_G = n_{arm-2}$

$$\frac{n_G - n_{arm-1}}{n_D - n_{arm-1}} = \left(\frac{N_{D_{inner}}}{N_E}\right)\left(\frac{N_F}{N_G}\right)$$

$$\frac{n_G - 150}{56.25 - 150} = \frac{58}{18}\left(\frac{26}{66}\right)$$

$$n_G = \frac{12275}{396}$$

$$\approx 31 \text{ rpm CCW}$$

1b vi) $$\frac{n_L - n_{arm-2}}{n_J - n_{arm-2}} = \left(-\frac{N_J}{N_H}\right)\left(-\frac{N_K}{N_L}\right)$$

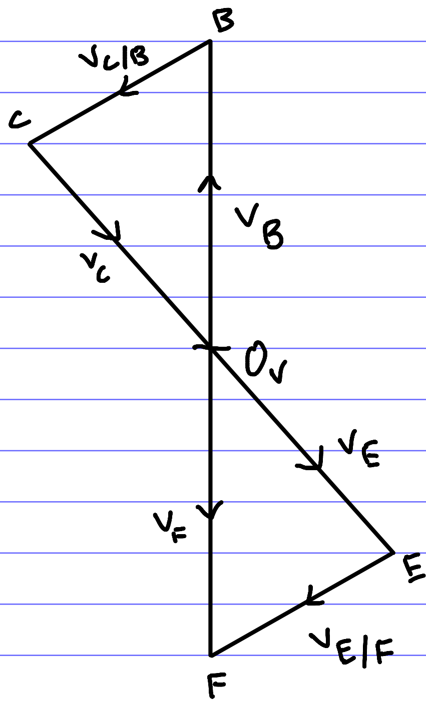
$$n_L - \frac{12275}{396} = \left(-\frac{54}{24}\right)\left(-\frac{40}{38}\right)\left(150 - \frac{12275}{396}\right)$$

$$n_L = 312.8455609$$

$$\approx 313 \text{ rpm CCW}$$

$$\therefore\ n_m = n_L = 313 \text{ rpm CCW}$$

2a i)



$v_B = r\omega$

$= 30\ (2)$

$= 60\ mms^{-1}$

$\overset{\times\checkmark}{v_C} = \overset{\checkmark\checkmark}{v_B} + \overset{\times\checkmark}{v_{C/B}}$

$v_{C/B} = 27\ mms^{-1}$

$\omega_3 = \frac{27}{44.70}$

$= \frac{90}{149}$

$\approx 0.604\ rads^{-1}$

$v_C = 54\ mms^{-1}$

$\omega_4 = \frac{54}{45}$

$= 1.2\ rads^{-1}$

2ai) $V_E = V_F + V_{E/F}$

$V_{E/F} = 35\,mms^{-1}$

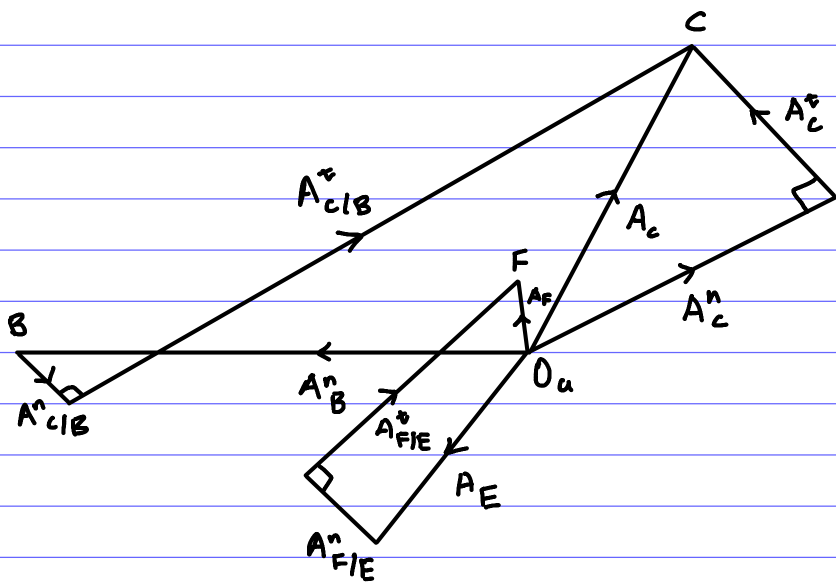
$\omega_5 = \frac{35}{42.3}$

$= \frac{350}{423}$

$\approx 0.827\,rads^{-1}$

$V_F = 72\,mms^{-1}$

2aii)



✓✓ ×✓ ✓✓ ✓✓ ×✓

2aii) $A_C^n + A_C^t = A_B^n + A_{C/B}^n + A_{C/B}^t$

$\omega_4^2 CD = 64.8$ $\quad \omega_2^2 AB = 120$ $\quad \omega_3^2 BC = 16.31$

$A_F = A_E + A_{F/E}^n + A_{F/E}^t$

$\omega_5^2 EF = 28.93$

$A_{CB}^t = 143 \times 1.2 = 171.6\,mms^{-2}$

$\alpha_3 = \dfrac{A_{CB}^t}{BC} = 3.84\,rads^{-2}$

$A_C^t = 31 \times 1.2 = 37.2\,mms^{-2}$

$\alpha_4 = \dfrac{A_C^t}{CD} = 0.83\,rads^{-1}$

$A_{F/E}^t = 71 \times 1.2 = 85.2\,mms^{-2}$

$\alpha_5 = \dfrac{A_{F/E}^t}{EF} = 2.01\,rads^{-1}$

$A_F = 15 \times 1.2 = 18\,mms^{-2}$

2bi) Crank rocker → shortest link next to fixed link

O_2A must be L_{min}.

$$L_{max} + O_2A \leq L_a + L_b$$

$$O_2A \leq 98 + 58 - 100$$

$$0 \leq O_2A \leq 56$$

ii) Non-Grashof linkage: $L_{max} + L_{min} > L_a + L_B$

① If O_6D is L_{max}:

$$O_6D + 33 > 42 + 58$$

$$O_6D > 67$$

For 4-bar linkage:

$$L_{max} \leq L_{min} + L_a + L_b$$

$$O_6D \leq 33 + 42 + 58$$

$$O_6D \leq 133$$

$$67 < O_6D \leq 133$$

② If O_6D is L_{min}:

$$58 + O_6D > 42 + 33$$

$$O_6D > 17$$

$$17 < O_6D \leq 133$$

③ If O_6D is L_a or L_b:

$$58 + 33 > O_6D + 42$$

$$O_6D < 49$$

$$0 < O_6D < 49$$

$\therefore \; 0 < O_6D < 49$

3a) $\omega = 2\ rads^{-1}$

$30° < \theta < 130°$ (cycloidal motion rise):

$$s = L\left(\frac{\theta - \theta_i}{\beta} - \frac{1}{2\pi}\sin\frac{2\pi(\theta - \theta_i)}{\beta}\right)$$

$$= 40\left(\frac{\theta - 30}{100} - \frac{1}{2\pi}\sin 360\left(\frac{\theta - 30}{100}\right)\right)$$

$$s(\theta = 90°) = 40\left(\frac{90 - 30}{100} - \frac{1}{2\pi}\sin 360\left(\frac{90 - 30}{100}\right)\right)$$

$$= 27.74\ mm$$

b) $180° < \theta < 360°$ (simple harmonic motion return):

$$s = \frac{L}{2}\left(1 - \cos\left(\frac{\pi\theta}{\beta}\right)\right)$$

$$= \frac{40}{2}\left(1 - \cos\left(\frac{\pi\theta}{\cancel{\pi}}\right)\right)$$

$$= 20(1 - \cos\theta)$$

$$\dot{s} = 20\dot{\theta}\sin\theta$$

$$\dot{s}(\theta = 200°) = 20\dot{\theta}\sin(\theta_e - \theta)$$

$$= 20(2)\sin(360 - 200°)$$

$$= 13.68\ mms^{-1}$$

3c) $\ddot{s} = 20\ddot{\theta}\sin\theta + 20\dot{\theta}^2\cos\theta$

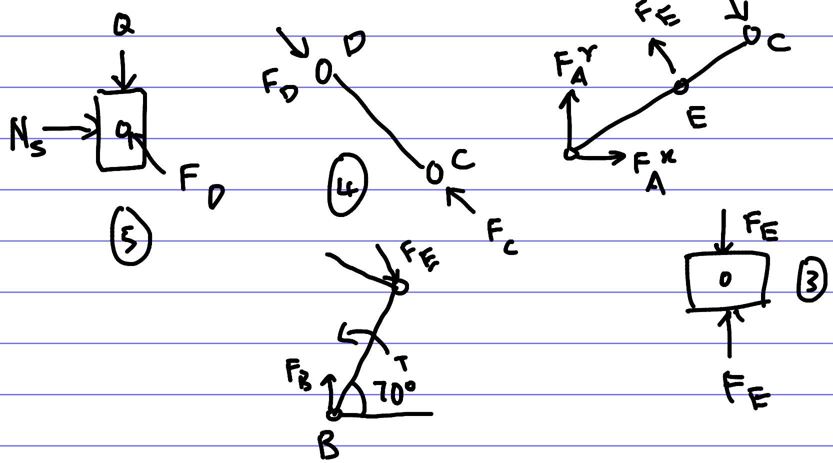
$= 20\omega^2\cos\theta \quad \because \ddot{\theta} = 0, \ \dot{\theta} = \omega$

$\ddot{s}(\theta = 330^\circ) = 20(2)^2\cos(\theta_e - \theta)$

$= 20(4)\cos(360 - 330)$

$= 69.28 \text{ mms}^{-2}$

4i) Two-force members: CD



For link 5:

$\Sigma F_y = 0$:

$F_D^Y = Q$

$F_D^Y = 20N$

$F_D\cos30^\circ = 20$

$F_D = 23.09401077$

$\approx 23.09N$

$F_C = F_D$

$\approx 23.09N$

4ii) For link 2:

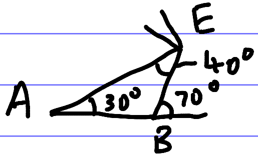
$$\sum M = 0$$

$$F_E(105) = F_c(200)$$

$$F_E = \frac{23.09(200)}{105}$$

$$= 43.98859194$$

$$\approx 43.99N$$



For link 1:

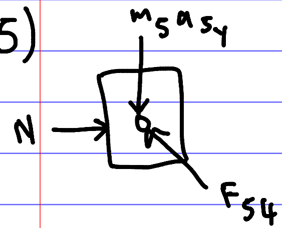
$$\sum M = 0$$

$$F_E \cos 40^\circ (56) = T$$

$$T = 1887.044119$$

$$\approx 1887.04N$$

5)



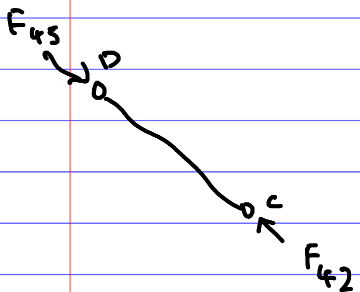
$\sum F_y = 0:$

$m_5 a_{5y} - F_{54} \cos 30^\circ = 0$

$$F_{54} = \frac{m_5 a_{5y}}{\cos 30^\circ}$$

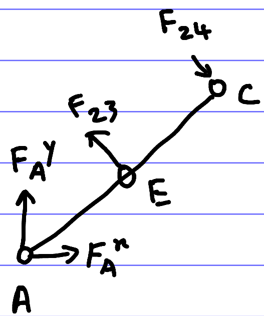
$\sum F_x = 0:$

$N = F_{54} \sin 30^\circ$



$\sum F = 0:$

$F_{43} = F_{45}$



$\sum F_y = 0:$

$F_A^Y + F_{23} \cos 30^\circ - F_{24} \cos 30^\circ = 0$

$F_A^Y = F_{24} \cos 30^\circ - F_{23} \cos 30^\circ$

$\sum F_x = 0:$

$F_A^x - F_{23} \sin 30^\circ + F_{24} \sin 30^\circ = 0$

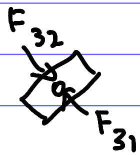
$F_A^x = F_{23} \sin 30^\circ - F_{24} \sin 30^\circ$

$\sum M = 0:$

$F_{24} AC = F_{23} \times AE$

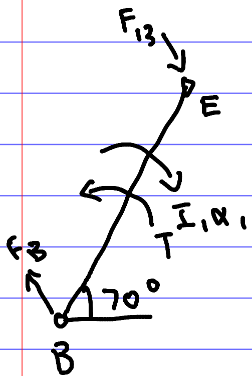
$$F_{23} = \frac{0.46 F_{24}}{0.24} = 1.1917 F_{24}$$

5)



$$\sum F = 0$$

$$F_{32} = F_{31}$$



$\sum M = 0$:

$$T - I_1\alpha_1 - F_{13}\cos 40°(BE) = 0$$

$$T = 0.1F_3 + I_1\alpha_1$$

$$\sum F = 0$$

$$F_B = F_{13}$$