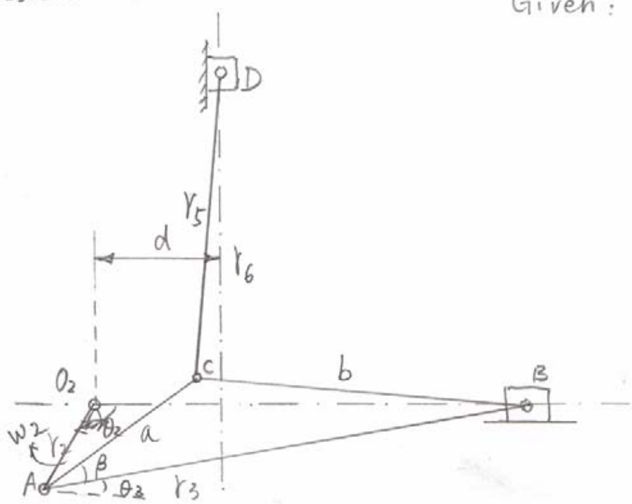
These are solutions to Problem Set 5.

Assignment #5.

Problem 1.



Given: $\omega_2 = 42\ rad/s$ cw, $\alpha_2 = 0$. $\theta_2 = -120°$.

$R_{AO_2} = r_2 = 2 in$, $R_{BA} = r_3 = 10 in$.

$R_{CA} = a = 4 in$. $R_{CB} = b = 7 in$

$R_{BO_2} = r_1$. $d = 3 in$.

$R_{DC} = r_5 = 8 in$

Note: $\theta_3 = 10°$. $\beta = 34°$. $\theta_5 = 83°$.

The Velocity results are obtained by previous assignment solution.

$\dot{\theta}_3 = -4.26\ rad/s$. $\dot{r}_1 = -65.3\ m/s$.

$\dot{\theta}_5 = 7.67\ rad/s$, $V_D = 22.25\ m/s$.

First Loop closure:

$$\vec{R}_{AO_2} + \vec{R}_{BA} - \vec{R}_{BO_2} = \vec{0}$$

$$\downarrow$$

$$\left.\begin{aligned} r_2\cos\theta_2 + r_3\cos\theta_3 - r_1\cos\theta_1 = 0 \\ r_2\sin\theta_2 + r_3\sin\theta_3 - r_1\sin\theta_1 = 0 \end{aligned}\right\}$$

$\downarrow$ Differentiate with time, $\theta_1 = 0$ also.

$$\left.\begin{aligned} -r_2\sin\theta_2\cdot\dot{\theta}_2 - r_3\sin\theta_3\cdot\dot{\theta}_3 - \dot{r}_1 = 0 \\ r_2\cos\theta_2\cdot\dot{\theta}_2 + r_3\cos\theta_3\cdot\dot{\theta}_3 = 0 \end{aligned}\right\}$$

$$\downarrow d/dt$$

$$\left.\begin{aligned} -r_2\cos\theta_2\cdot\dot{\theta}_2^2 - r_2\sin\theta_2\cdot\ddot{\theta}_2 - r_3\cos\theta_3\cdot\dot{\theta}_3^2 - r_3\sin\theta_3\cdot\ddot{\theta}_3 - \ddot{r}_1 = 0 \\ -r_2\sin\theta_2\cdot\dot{\theta}_2^2 + r_2\cos\theta_2\cdot\ddot{\theta}_2 - r_3\sin\theta_3\cdot\dot{\theta}_3^2 + r_3\cos\theta_3\cdot\ddot{\theta}_3 = 0 \end{aligned}\right\}$$

$\downarrow$ in matix form.

$$\begin{bmatrix} -1 & -r_3\sin\theta_3 \\ 0 & r_3\cos\theta_3 \end{bmatrix} \begin{bmatrix} \ddot{r}_1 \\ \ddot{\theta}_3 \end{bmatrix} = \begin{bmatrix} r_2\cos\theta_2\cdot\dot{\theta}_2^2 + r_2\sin\theta_2\ddot{\theta}_2 + r_3\cos\theta_3\dot{\theta}_3^2 \\ r_2\sin\theta_2\dot{\theta}_2^2 - r_2\cos\theta_2\ddot{\theta}_2 + r_3\sin\theta_3\dot{\theta}_3^2 \end{bmatrix}$$

Invert coefficient Matrix.

$$\rightarrow \begin{bmatrix} \ddot{r}_1 \\ \ddot{\theta}_3 \end{bmatrix} = \begin{bmatrix} -1 & \frac{\sin\theta_3}{\cos\theta_3} \\ 0 & \frac{-1}{r_3\cos\theta_3} \end{bmatrix} \begin{bmatrix} r_2\cos\theta_2\,\dot{\theta}_2^2 + r_2\sin\theta_2\,\ddot{\theta}_2 + r_3\cos\theta_3\,\dot{\theta}_3^2 \\ r_2\sin\theta_2\,\dot{\theta}_2^2 - r_2\cos\theta_2\cdot\ddot{\theta}_2 + r_3\sin\theta_3\,\dot{\theta}_3^2 \end{bmatrix}$$

$$\ddot{\theta}_2 = 0 \;\; \rightarrow \;\; \left.\begin{aligned} \ddot{r}_1 &= 2118 \text{ in}/s^2 \\ \ddot{\theta}_3 &= -307 \text{ rad}/s^2 \end{aligned}\right\} \rightarrow \left\{\begin{aligned} A_B &= 2118 \text{ in}/s^2 \rightarrow \\ \alpha_3 &= -307 \text{ rad}/s^2 \text{ cw} \end{aligned}\right.$$

Second Loop closure:

$$\vec{R}_{AO_2} + \vec{R}_{CA} + \vec{R}_{D6C} - \underbrace{\vec{R}_{D6O_2}}_{\vec{R}^x_{D6O_2} + \vec{R}^y_{D6O_2}} = \vec{0} \quad \rightarrow \left\{\begin{aligned} r_6 &= R^y_{D6O_2} \\ d &= R^x_{D6O_2} \end{aligned}\right.$$

$$\downarrow$$

$$\left.\begin{aligned} r_2\cos\theta_2 + a\cos(\theta_3+\beta) + r_5\cos\theta_5 - d &= 0 \\ r_2\sin\theta_2 + a\sin(\theta_3+\beta) + r_5\sin\theta_5 - r_6 &= 0 \end{aligned}\right\}$$

$\downarrow \; d/dt$. Note: β is a constant.

$$\left.\begin{aligned} -r_2\sin\theta_2\cdot\dot{\theta}_2 - a\sin(\theta_3+\beta)\cdot\dot{\theta}_3 - r_5\sin\theta_5\cdot\dot{\theta}_5 &= 0 \\ r_2\cos\theta_2\cdot\dot{\theta}_2 + a\cos(\theta_3+\beta)\cdot\dot{\theta}_3 + r_5\cos\theta_5\,\dot{\theta}_5 - \dot{r}_6 &= 0 \end{aligned}\right\}$$

$$\downarrow \; d/dt$$

$$\left.\begin{aligned} -r_2\cos\theta_2\,\dot{\theta}_2^2 - r\sin\theta_2\cdot\ddot{\theta}_2 - a\cos(\theta_3+\beta)\,\dot{\theta}_3^2 - a\sin(\theta_3+\beta)\cdot\ddot{\theta}_3 - r_5\cos\theta_5\cdot\dot{\theta}_5^2 - r_5\sin\theta_5\,\ddot{\theta}_5 &= 0 \\ -r_2\sin\theta_2\,\dot{\theta}_2^2 + r_2\cos\theta_2\cdot\ddot{\theta}_2 - a\sin(\theta_3+\beta)\,\dot{\theta}_3^2 + a\cos(\theta_3+\beta)\cdot\ddot{\theta}_3 - r_5\sin\theta_5\,\dot{\theta}_5^2 + r_5\cos\theta_5\,\ddot{\theta}_5 - \ddot{r}_6 &= 0 \end{aligned}\right\}$$

$\downarrow$ in Matrix form.

$$\begin{bmatrix} r_5\sin\theta_5 & 0 \\ r_5\cos\theta_5 & -1 \end{bmatrix} \begin{bmatrix} \ddot{\theta}_5 \\ \ddot{r}_6 \end{bmatrix} = \begin{bmatrix} -r_2\cos\theta_2\dot{\theta}_2^2 - r_2\sin\theta_2\cdot\ddot{\theta}_2 - a\cos(\theta+\beta)\,\dot{\theta}_3^2 - a\sin(\theta_3+\beta)\,\ddot{\theta}_3 - r_5\cos\theta_5\cdot\dot{\theta}_5^2 \\ r_2\sin\theta_2\,\dot{\theta}_2^2 - r_2\cos\theta_2\,\ddot{\theta}_2 + a\sin(\theta_3+\beta)\,\dot{\theta}_3^2 - a\cos(\theta_3+\beta)\cdot\ddot{\theta}_3 + r_5\sin\theta_5\,\dot{\theta}_5^2 \end{bmatrix}$$

invert coefficient matrix. $\longrightarrow$

$\ddot{\theta}_2 = 0$

$$\begin{bmatrix} \ddot{\theta}_5 \\ \ddot{r}_6 \end{bmatrix} = \begin{bmatrix} \frac{1}{r_5 \sin\theta_5} & 0 \\ \frac{\cos\theta_5}{\sin\theta_5} & -1 \end{bmatrix} \begin{bmatrix} -r_2\cos\theta_2 \cdot \dot{\theta}_2^2 - a\cos(\theta+\beta)\dot{\theta}_3^2 - a\sin(\theta+\beta)\ddot{\theta}_3 - r_5\cos\theta_5 \cdot \dot{\theta}_5^2 \\ r_2\sin\theta_2 \dot{\theta}_2^2 + a\sin(\theta+\beta)\dot{\theta}_3^2 - a\cos(\theta+\beta)\ddot{\theta}_3 + r_5\sin\theta_5 \dot{\theta}_5^2 \end{bmatrix}$$

$$\therefore \left.\begin{aligned} \ddot{\theta}_5 &= 315.8 \text{ rad/s}^2 \\ \ddot{r}_6 &= 1962 \text{ in/s}^2 \end{aligned}\right\} \rightarrow \left\{\begin{aligned} \alpha_5 &= 315.8 \text{ rad/s}^2 \text{ ccw} \\ A_D &= 1962 \text{ in/s}^2 \uparrow \end{aligned}\right.$$

Vector equation for point C: $\vec{R}_{AO_2} + \vec{R}_{CA} - \vec{R}_{CO_2} = \vec{0}$

$\downarrow$

$$\left.\begin{aligned} r_2\cos\theta_2 + a\cos(\theta_3+\beta) - x_c &= 0 \\ r_2\sin\theta_2 + a\sin(\theta_3+\beta) - y_c &= 0 \end{aligned}\right\}$$

$\downarrow d/dt$

$$\left.\begin{aligned} -r_2\sin\theta_2 \cdot \dot{\theta}_2 - a\sin(\theta_3+\beta)\dot{\theta}_3 - \dot{x}_c &= 0 \\ r_2\cos\theta_2 \cdot \dot{\theta}_2 + a\cos(\theta_3+\beta)\dot{\theta}_3 - \dot{y}_c &= 0 \end{aligned}\right\}$$

$\downarrow d/dt$

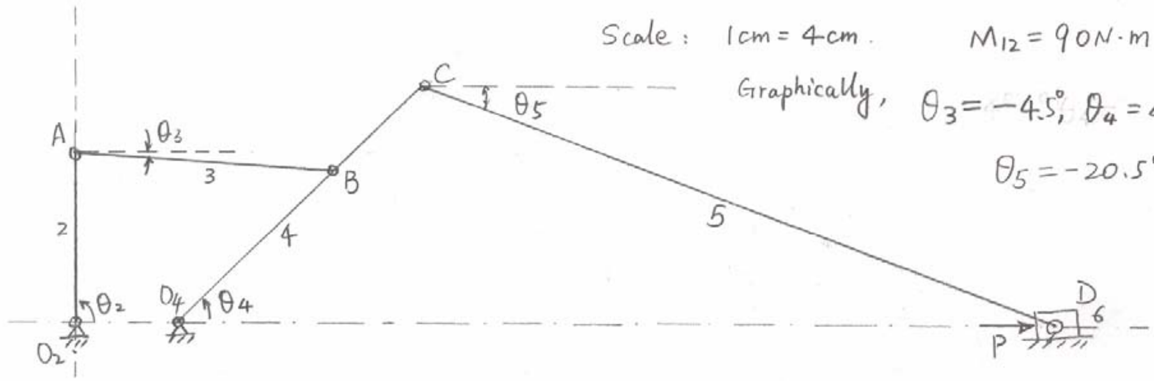
$$\left.\begin{aligned} -r_2\cos\theta_2 \cdot \dot{\theta}_2^2 - r_2\sin\theta_2 \ddot{\theta}_2 - a\cos(\theta_3+\beta)\dot{\theta}_3^2 - a\sin(\theta_3+\beta)\ddot{\theta}_3 - \ddot{x}_c &= 0 \\ -r_2\sin\theta_2 \cdot \dot{\theta}_2^2 + r_2\cos\theta_2 \ddot{\theta}_2 - a\sin(\theta_3+\beta)\dot{\theta}_3^2 + a\cos(\theta_3+\beta)\ddot{\theta}_3 - \ddot{y}_c &= 0. \end{aligned}\right\}$$

$\downarrow$

$$\left.\begin{aligned} \ddot{x}_c &= 2565 \text{ in/s}^2 \\ \ddot{y}_c &= 2121 \text{ in/s}^2 \end{aligned}\right\} \rightarrow A_c = 3328 \text{ in/s}^2 \nearrow$$

Problem 2. (Figure 14.6. Page 465 in book J. J. Uicker, et. al.)

Given: $R_{AO_2} = 100\,mm$. $R_{BA} = 150\,mm$. $R_{BO_4} = 125\,mm$.
$R_{CO_4} = 200\,mm$, $R_{CD} = 400\,mm$. $R_{O_2O_4} = 60\,mm$.
Scale: 1cm = 4cm. $M_{12} = 90\,N\cdot m$ ccw.
Graphically, $\theta_3 = -45°$, $\theta_4 = 45°$
$\theta_5 = -20.5°$.



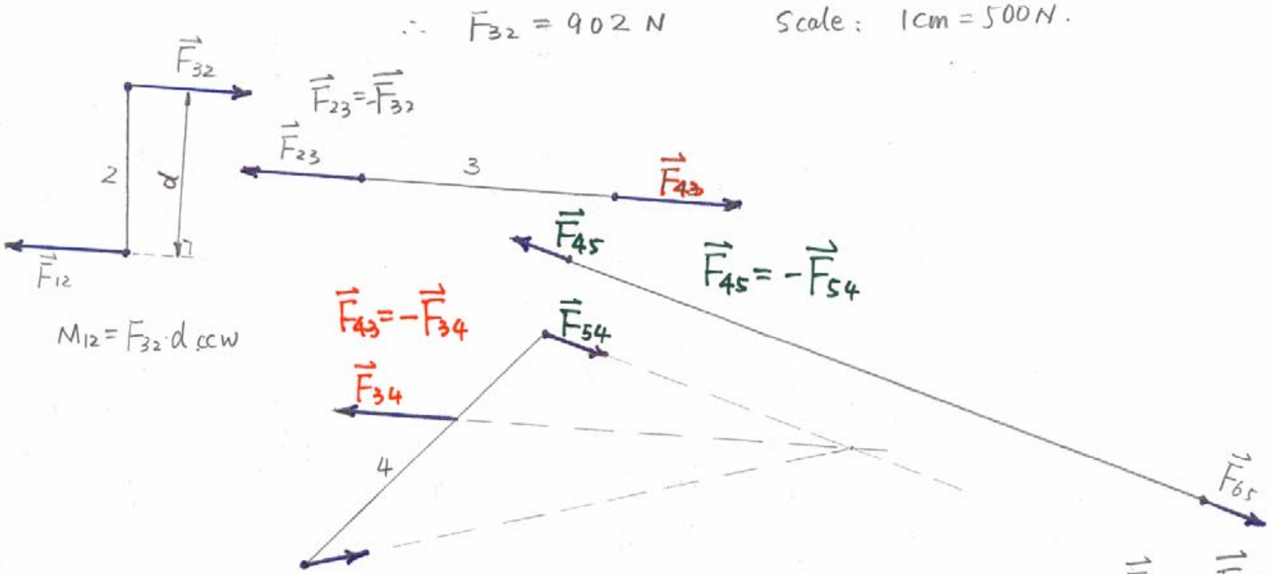
Kinematic Analysis: $\vec{R}_{AO_2} = R_{AO_2}(\cos\theta_2\,\hat{i} + \sin\theta_2\,\hat{j}) = 100\,\hat{j}$.

$\vec{R}_{BA} = R_{BA}(\cos\theta_3\,\hat{i} + \sin\theta_3\,\hat{j}) = 149.6\,\hat{i} - 10.5\,\hat{j}$. $\vec{R}_{CO_4} = 141.4\,\hat{i} + 141.4\,\hat{j}$

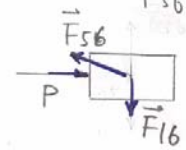
$\vec{R}_{DC} = 374.7\,\hat{i} - 141.2\,\hat{j}$, $\vec{R}_{BO_4} = 88.3\,\hat{i} + 88.3\,\hat{j}$

Force Analysis: $M_{12} = 90\,N\text{-}m$. $\vec{M}_{12} = -\vec{R}_{AO_2} \times \vec{F}_{32}$.

$\therefore F_{32} = 902\,N$ Scale: 1cm = 500N.



$\vec{F}_{56} = -\vec{F}_{65}$

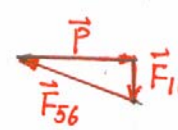


(No friction)

(Scale: 1cm=250N)

$\vec{F}_{14} = 475N \nearrow$

$\vec{F}_{54} = 462.5N \searrow$



$\vec{P} = 435N \rightarrow$

Analytically, starting with body 2,

$$\vec{F}_{12} = -\vec{F}_{32}.$$

$$\Sigma \vec{M}_{O_2} = \vec{M}_{12} + \vec{R}_{AO_2} \times \vec{F}_{32} = \vec{0} \longrightarrow \quad \vec{M}_{12} = -\vec{R}_{AO_2} \times \vec{F}_{32}$$

$$90\,\hat{k}\ (N\cdot m) = 90000\,\hat{k}\ (N\cdot mm) = \vec{M}_{12} = -100\hat{j} \times (F_{32}\cos\theta_3\,\hat{i} - F_{32}\cdot\sin\theta_3\,\hat{j})$$

$$= 100\,F_{32}\cos\theta_3\,\hat{k}$$

$$\therefore\ F_{32} = 902\ N. \qquad \vec{F}_{32} = 899\,\hat{i} - 70.8\,\hat{j}.\ (N)$$

$$\vec{F}_{23} = -\vec{F}_{32} = -899\,\hat{i} + 70.8\,\hat{j} \quad (N)$$

→ Link 3: $\vec{F}_{23} + \vec{F}_{43} = 0 \ \rightarrow\ \vec{F}_{43} = -\vec{F}_{23} = 899\,\hat{i} - 70.8\,\hat{j} \quad (N)$

$$\vec{F}_{34} = -\vec{F}_{43} = -899\,\hat{i} + 70.8\,\hat{j} \quad (N)$$

→ Free body diagram of link 4:

$$\vec{0} = \vec{M}_{O_4} = \vec{R}_{BO_4} \times \vec{F}_{34} + \vec{R}_{CO_4} \times \vec{F}_{54}$$

$$= (88.3\,\hat{i} + 88.3\,\hat{j}) \times (-899\,\hat{i} + 70.8\,\hat{j}) + (141.4\,\hat{i} + 141.4\,\hat{j}) \times (F_{54}\cos\theta_5\,\hat{i} + F_{54}\sin\theta_5\,\hat{j})$$

$$= 85633\,\hat{k} + F_{54}\,(-182\,\hat{k})$$

$$F_{54} = 470.5\ N \quad \rightarrow\ \vec{F}_{54} = 440.7\,\hat{i} - 164.8\,\hat{j} \quad (N)$$

$$\vec{F}_{14} + \vec{F}_{54} + \vec{F}_{34} = 0 \ \Rightarrow\ \vec{F}_{14} = -\vec{F}_{54} - \vec{F}_{34} = 458.3\,\hat{i} + 94\,\hat{j} \quad (N)$$

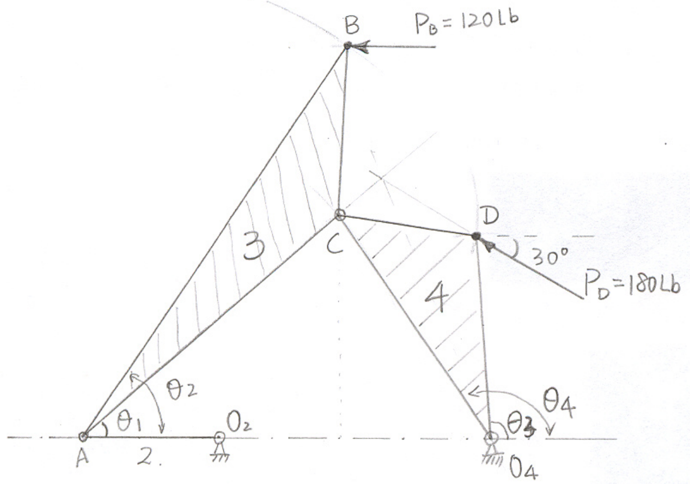
$$\vec{F}_{45} = -\vec{F}_{54} = -440.7\,\hat{i} + 164.8\,\hat{j} \quad (N)$$

→ Link 5: $\vec{F}_{65} = -\vec{F}_{45} = 440.7\,\hat{i} - 164.8\,\hat{j}.\qquad \vec{F}_{56} = -\vec{F}_{65}$

→ Link 6: (No friction) $\left.\begin{array}{l} \vec{P} + \vec{F}_{56}^{\,x} = 0 \\ \vec{F}_{16} + \vec{F}_{56}^{\,y} = 0 \end{array}\right\} \longrightarrow \begin{array}{l} \vec{P} = 440.7\,\hat{i} \\ \vec{F}_{16} = -164.8\,\hat{j}. \end{array}$

Problem 1:

(1) Method of superposition: (Linear System).



Given:

$R_{O_4O_2} = R_{CO_4} = 8 in$, $R_{AO_2} = 4 in$.

$R_{CA} = 10 in$. $R_{BA} = 14 in$,

$R_{DO_4} = 6 in$, $R_{DC} = 4 in$,

$R_{BC} = 5 in$,

$P_B = 120 Lb$, $P_D = 180 Lb. \angle 120°$.

Kinematic Analysis: $\theta_1 = 41.41°$. $\theta_2 = 55.98°$. $\theta_3 = 95.27°$. $\theta_4 = 124.23°$.

Therefore, $\vec{R}_{AO_2} = -4\vec{i}$, $\vec{R}_{CA} = 7.5\vec{i} + 6.61\vec{j}$ $\vec{R}_{BA} = 7.83\vec{i} + 11.6\vec{j}$

$\vec{R}_{CO_4} = -4.5\vec{i} + 6.61\vec{j}$. $\vec{R}_{DO_4} = -0.55\vec{i} + 5.98\vec{j}$.

Force Analysis:

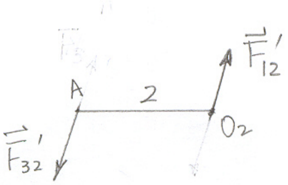
→ Starting with body 3 with $P_B = 120 lb \angle 180°$. (only)

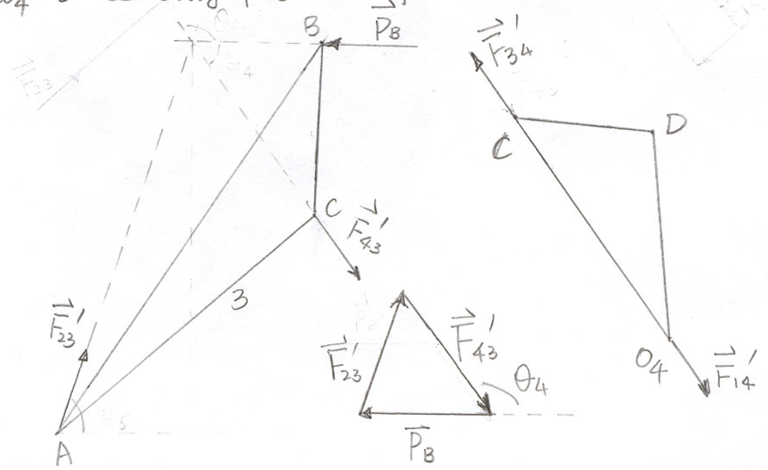
[Note: The other Force $\vec{F}_D$ is neglected in this part.]

As shown below, we have the forces: $\vec{P}_B + \vec{F}_{23}' + \vec{F}_{43}' = 0$

$\vec{F}_{43}'$ is along with R_{CO_4} since Body 4 is two-force member.

→ For P_B.





For P_B, we have $\vec{P}_B + \vec{F}_{23}' + \vec{F}_{43}' = 0$,

Also consider the moment balance with respect to point A:

$$\Sigma \vec{M}_A' = \vec{R}_{BA} \times \vec{P}_B + \vec{R}_{CA} \times \vec{F}_{43}' = 0$$

Here

$$\vec{R}_{BA} \times \vec{P}_B = (7.83\vec{i} + 11.6\vec{j}) \times (-120\vec{i}) = 1392\,\vec{k} \text{ lb}\cdot\text{in. ccw}$$

$$\vec{R}_{CA} \times \vec{F}_{43}' = (7.5\vec{i} + 6.61\vec{j}) \times (F_{43}\cos\theta_4\,\vec{i} + F_{43}\sin\theta_4\,\vec{j})$$

$$= (7.5\vec{i} + 6.61\vec{j}) \times (-0.5625 F_{43}\vec{i} + 0.827 F_{43}\vec{j})$$

$$= 9.92 F_{43}\,\vec{k} = -1392\,\vec{k} \text{ lb}\cdot\text{in}$$

$\therefore F_{43}' = -140.31$ lb. $\vec{F}_{43}' = 78.9\vec{i} - 116.04\vec{j}$. lb

$\vec{F}_{34}' = -78.9\vec{i} + 116.04\vec{j}$ lb $\quad \vec{F}_{14}' = -\vec{F}_{34}' = 78.9\vec{i} - 116.04\vec{j}$. lb

By using $\vec{P}_B + \vec{F}_{23}' + \vec{F}_{43}' = 0$,

$$\begin{cases} -120 + F_{23x}' + 78.9 = 0 \\ 0 + F_{23y}' + (-116.04) = 0 \end{cases} \quad \therefore \vec{F}_{23}' = 41.1\vec{i} + 116.04\vec{j} \text{ (lb)}$$

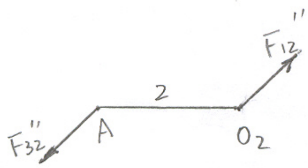
Therefore, $\vec{F}_{32}' = -\vec{F}_{23}' = -41.1\vec{i} - 116.04\vec{j}$ lb

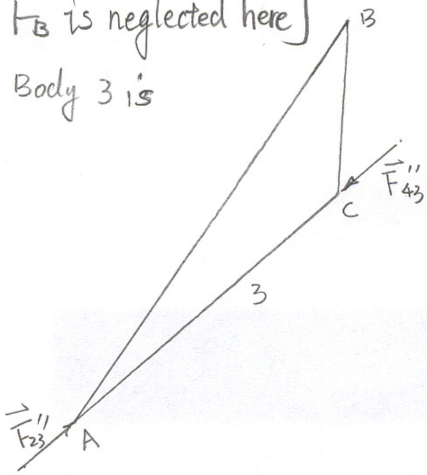
$$\vec{M}_{12}' = -\vec{R}_{AO_2} \times \vec{F}_{32}' = -(-4\vec{i}) \times (-41.1\vec{i} - 116.04\vec{j}) = -464.16\,\vec{k} \text{ lbin}$$

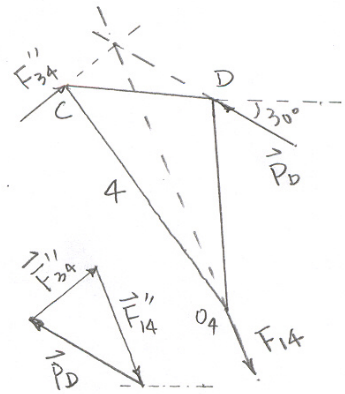
Also, $\vec{F}_{12}' = 41.1\vec{i} + 116.04\vec{j}$ lb

→ For P_D: [The other force $\vec{F}_B$ is neglected here]

Note, $\vec{F}''_{34}$ along $\vec{R}_{AC}$ since Body 3 is two-force member.







Analysis Solution:

For P_D, we have $\vec{P}_D + \vec{F}''_{34} + \vec{F}'_{14} = 0$,

Also considering the moment balance about Point O_4

$$\Sigma \vec{M}''_{O_4} = \vec{R}_{DO_4} \times \vec{P}_D + \vec{R}_{CO_4} \times \vec{F}''_{34} = 0$$

Thus,

$$\vec{R}_{DO_4} \times \vec{P}_D = (-0.55\vec{i} + 5.98\vec{j}) \times (-180 \cdot \cos 30° \vec{i} + 180 \sin 30° \vec{j}) = 882.7\vec{K} \text{ lb·in. (CCW)}$$

$$\vec{R}_{CO_4} \times \vec{F}''_{34} = (-4.5\vec{i} + 6.61\vec{j}) \times (F''_{34} \cos\theta_1 \vec{i} + F''_{34} \sin\theta_1 \vec{j}) = -7.93 F''_{34} \vec{K} = -882.7\vec{K}$$

$$\therefore F''_{34} = 111.25 \text{ lb.} \qquad \vec{F}''_{34} = 83.44\vec{i} + 73.59\vec{j} \text{ lb}$$

$$\therefore \vec{F}''_{14} = -\vec{P}_D - \vec{F}''_{34} = 72.44\vec{i} - 163.59\vec{j} \text{ lb}$$

From {Body 3, Body 2},

$$\vec{F}''_{43} = -\vec{F}''_{34} = -83.44\vec{i} - 73.59\vec{j} \text{ lb}$$

$$\vec{F}''_{23} = -\vec{F}''_{43}, \Rightarrow \vec{F}''_{32} = -\vec{F}''_{23} = -83.44\vec{i} - 73.59\vec{j} \text{ lb}$$

$$\therefore \vec{M}''_{12} = -\vec{R}_{AO_2} \times \vec{F}''_{32} = (-4\vec{i}) \times (-83.44\vec{i} - 73.59\vec{j}) = -294.36\vec{K} \text{ lb.in}$$

$$\vec{F}''_{12} = -\vec{F}''_{23} = 83.44\vec{i} + 73.59\vec{j} \text{ lb}$$

Consequently, the results of Superposition of both forces, $\vec{F}_B$ and $\vec{F}_D$, can be obtained:

- The moment on crank 2:

$$\vec{M}_{12} = \vec{M}_{12}' + \vec{M}_{12}'' = -464.16\vec{k} - 294.36\vec{k}$$

$$= -758.52\vec{k} \text{ lb}\cdot\text{in}$$

- The constraint forces:

$$\vec{F}_{12} = \vec{F}_{12}' + \vec{F}_{12}'' = (41.1\vec{i} + 116.04\vec{j}) + (83.44\vec{i} + 73.59\vec{j})$$

$$= 124.54\vec{i} + 189.63\vec{j} \text{ lb}$$

$$\vec{F}_{32} = \vec{F}_{32}' + \vec{F}_{32}'' = -124.54\vec{i} - 189.63\vec{j} \text{ lb}$$

Note, $\vec{F}_{23} = -\vec{F}_{32}$.

$$\vec{F}_{43} = \vec{F}_{43}' + \vec{F}_{43}'' = 78.9\vec{i} - 116.04\vec{j} - 83.4\vec{i} - 73.59\vec{j}$$

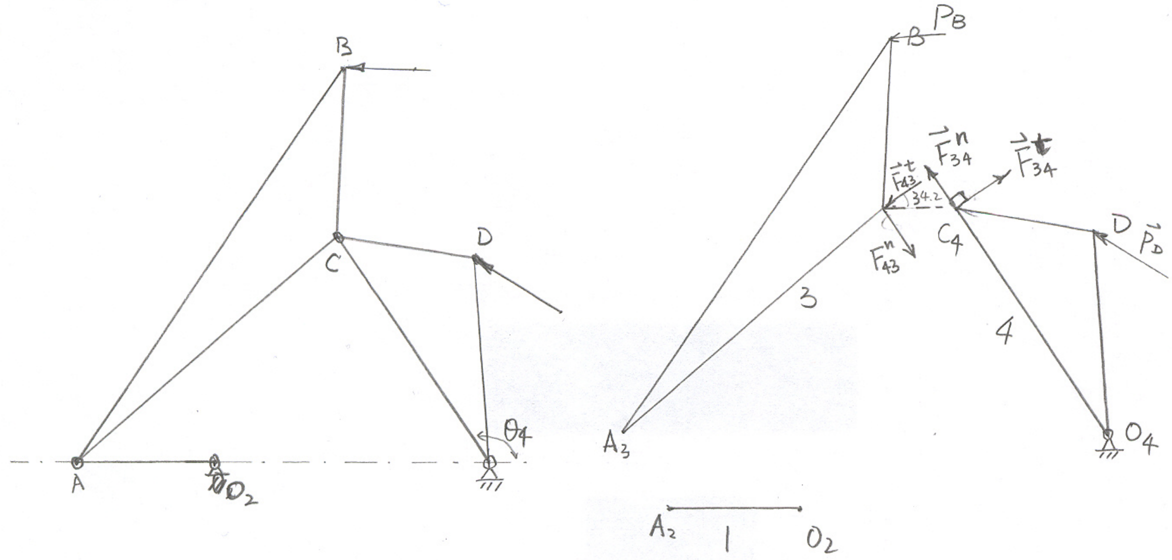
$$= -4.5\vec{i} - 189.63\vec{j} \text{ lb}$$

$$\vec{F}_{34} = -\vec{F}_{43} = 4.5\vec{i} + 189.63\vec{j} \text{ N.}$$

$$\vec{F}_{14} = \vec{F}_{14}' + \vec{F}_{14}'' = 78.9\vec{i} - 116.04\vec{j} + 72.44\vec{i} - 163.59\vec{j}$$

$$= 151.4\vec{i} - 296.9\vec{j} \text{ lb}$$

(ii) Method II:



Decompose the system into parts, and first consider Body 4,

$$\Sigma M_{O4} = \vec{R}_{DO_4} \times \vec{P}_D + \vec{R}_{C_4O_4} \times \vec{F}_{34}^t$$

$$= (-0.55\vec{i} + 5.97\vec{j}) \times (-156\vec{i} + 90\vec{j}) + \vec{R}_{CO_4} \times \vec{F}_{34}^t$$

$\therefore$ $F_{34}^t = 110.3$ lb $\angle 34.23$. or $\vec{F}_{34}^t = 91\vec{i} + 62\vec{j}$ lb.

$\vec{F}_{43}^t = -91\vec{i} - 62\vec{j}$ lb.

Now consider body 3, the moment with respect to A:

$$\Sigma M_A = 0 = \vec{R}_{BA} \times \vec{P}_B + \vec{R}_{CA} \times \vec{F}_{43}^t + \vec{R}_{CA} \times \vec{F}_{43}^n$$

Hence, $\vec{R}_{BA} \times \vec{P}_B = 1392\vec{k}$ lb·in.

$\vec{R}_{CA} \times \vec{F}_{43}^t = (7.5\vec{i} + 6.6\vec{j}) \times (-91.2\vec{i} - 62\vec{j}) = 136.9\ \vec{k}$ lb·in.

$\therefore$ $F_{43}^n (7.5\vec{i} + 6.6\vec{j}) \times [\cos(-55.8)\vec{i} + \sin(-55.8)\vec{j}] = 9.91\, F_{43}^n = 1392 + 136.9$

$\therefore$ $\vec{F}_{43}^n = 154.2 \angle -55.8°$. or $\vec{F}_{43}^n = 86.7\vec{i} - 127.6\vec{j}$ lb.

$\therefore$ $\vec{F}_{43} = \vec{F}_{43}^n + \vec{F}_{43}^t = -4.3\vec{i} - 189.6\vec{j}$. lb

Thus $\vec{F}_{34} = -\vec{F}_{43} = 4.3\vec{i} + 189.6\vec{j}$. lb.

Now, from the force balance:

Body 4:

$$\vec{F}_{14} = -\vec{P}_D - \vec{F}_{34} = 152\vec{i} - 279\vec{j} \text{ lb}$$

Body 3:

$$\vec{F}_{23} = -\vec{P}_B - \vec{F}_{43} = 120\vec{i} + 4.3\vec{i} + 189.6\vec{j}$$

$$= 124.3\vec{i} + 189.6\vec{j} \text{ lb}$$

Body 2:

$$\therefore \vec{F}_{32} = -124.3\vec{i} - 189.6\vec{j} \text{ lb}$$

$$\vec{M}_{12} = -\vec{R}_{AO_2} \times \vec{F}_{32} = -(4.0\vec{i}) \times (-124.3\vec{i} - 189.6\vec{j})$$

$$= -758.4\vec{k} \text{ lb}\cdot\text{in. cw.}$$