NAME: SOLUTION

PROBLEM 1: Draw the S-V-A-J diagrams for a cam with the following characteristics.

REGION
- I a. Rise ¾ in. with constant acceleration in 90°.
- II b. Rise ¾ in. with constant deceleration in 90°.
- III c. Dwell 30°.
- IV d. Fall ¾ in with constant acceleration in 60°.
- V e. Fall ¾ in with constant deceleration in 60°.
- VI f. Dwell 30°.

REGION I: $\beta_I = \frac{\pi}{2}$, $\theta_I = \theta$

BOUNDARY CONDITIONS

$S(0) = 0$ $\qquad v(0) = 0$

$S(\frac{\pi}{2}) = 0.75\text{in}$

THE PROBLEM STATEMENT FOR THIS REGION RESTRICTS THE ACCELERATION TO BE CONSTANT, THUS RESTRICTING THE FORM OF THE FUNCTION TO

$$S = C_0 + C_1\cdot\left(\frac{\theta_I}{\beta_I}\right) + C_2\cdot\left(\frac{\theta_I}{\beta_I}\right)^2 = C_0 + C_1\cdot\frac{2}{\pi}\cdot\theta_I + C_2\cdot\frac{4}{\pi^2}\cdot\theta_I^2$$

IMPOSING THE BOUNDARY CONDITION $S(0)=0$

$$S(0) = 0_{in} = C_0 + C_1\cdot\frac{2}{\pi}\cdot(0) + C_2\left(\frac{4}{\pi^2}\right)(0)^2 \Rightarrow \underline{C_0 = 0}$$

$$S(\theta) = C_1\cdot\frac{2}{\pi}\cdot\theta_I + C_2\cdot\frac{4}{\pi^2}\cdot\theta_I^2$$

$$v(\theta) = C_1\cdot\frac{2}{\pi} + C_2\cdot\frac{8}{\pi^2}\cdot\theta_I$$

IMPOSING THE BOUNDARY CONDITION

$$v(0) = 0\,\tfrac{in}{rad} = C_1\cdot\frac{2}{\pi} + C_2\cdot\frac{8}{\pi^2}\cdot(0) \Rightarrow \underline{C_1 = 0}$$

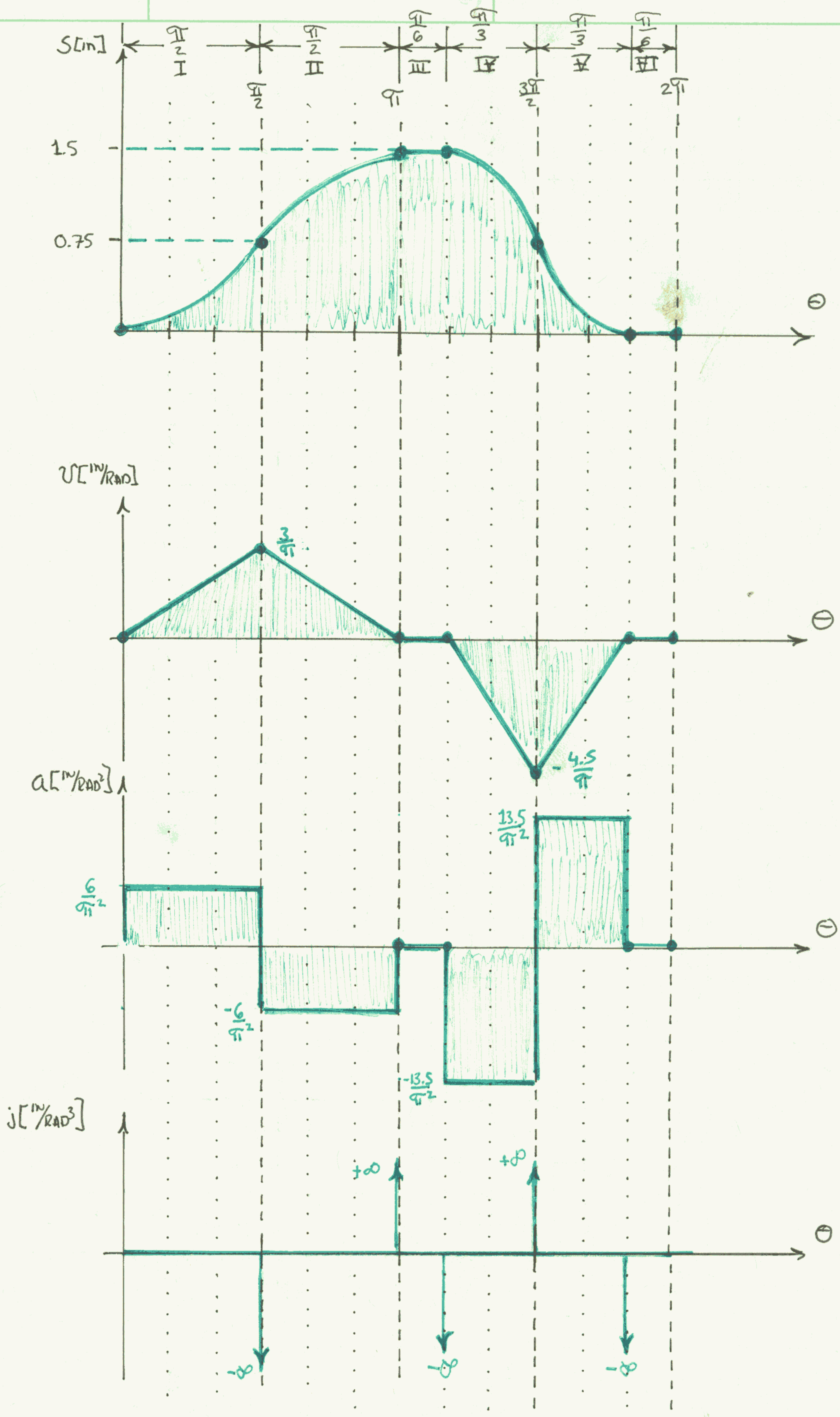
$$S(\theta) = C_2\cdot\frac{4}{\pi^2}\cdot\theta_I^2$$

$$v(\theta) = C_2\cdot\frac{8}{\pi^2}\cdot\theta_I$$

IMPOSING THE FINAL BOUNDARY CONDITION, $S(\frac{\pi}{2}) = 0.75\text{in}$

$$S\left(\frac{\pi}{2}\right) = 0.75\text{in} = C_2\cdot\frac{4}{\pi^2}\cdot\frac{\pi^2}{4} \Rightarrow \underline{C_2 = 0.75\text{in}}$$

$S(\theta) = 0.75\text{in}\cdot\frac{4}{\pi^2}\cdot\theta_I^2 = \frac{3.0}{\pi^2}\frac{in}{rad^2}\theta_I^2$:	$S(0) = 0$	$S(\frac{\pi}{2}) = 0.75\text{in}$
$v(\theta_I) = \frac{6.0}{\pi^2}\frac{in}{rad^2}\cdot\theta_I$:	$v(0) = 0$	$v(\frac{\pi}{2}) = \frac{3.0}{\pi}\frac{in}{rad}$
$a(\theta_I) = \frac{6.0}{\pi^2}\frac{in}{rad^2}$		



S[in]
π/2
I
π/2
II
π/6
III
π/3
IV
π/3
V
π/6
VI
π/2
π
3π/2
2π
1.5
0.75
θ
v[in/rad]
3/π
-4.5/π
a[in/rad²]
6/π²
-6/π²
13.5/π²
-13.5/π²
j[in/rad³]
+∞
-∞

REGION II: $\beta_{II} = \frac{\pi}{2}$, $\theta_{II} = \theta - \beta_I$

BOUNDARY CONDITIONS -

$S(0) = 0.75\text{in}$ $\quad v(0) = \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}}$

$S(\frac{\pi}{2}) = 1.5\text{in}$ $\quad v(\frac{\pi}{2}) = 0$

THE PROBLEM STATEMENT FOR THIS REGION RESTRICTS THE DECELERATION TO BE CONSTANT, THUS RESTRICTING THE FUNCTION TO THE FORM

$$S(\theta_{II}) = C_0 + C_1\left(\frac{\theta_{II}}{\beta_{II}}\right) + C_2\left(\frac{\theta_{II}}{\beta_{II}}\right)^2 = C_0 + C_1\cdot\frac{2}{\pi}\cdot\theta_{II} + C_2\cdot\frac{4}{\beta^2}\cdot\theta_{II}^2$$

IMPOSING THE BOUNDARY CONDITION $S(0) = 0.75\text{in}$

$$S(0) = 0.75\text{in} = C_0 + C_1\cdot\frac{2}{\pi}\cdot 0 + C_2\cdot\frac{4}{\pi^2}\cdot(0)^2 \Rightarrow \underline{\underline{C_0 = 0.75\text{in}}}$$

$$S(\theta_{II}) = 0.75\text{in} + C_1\cdot\frac{2}{\pi}\cdot\theta_{II} + C_2\cdot\frac{4}{\pi^2}\cdot\theta_{II}^2$$

$$v(\theta_{II}) = C_1\cdot\frac{2}{\pi} + C_2\cdot\frac{8}{\pi^2}\cdot\theta_{II}$$

IMPOSING THE BOUNDARY CONDITION $v(0) = \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}}$

$$v(0) = \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}} = C_1\cdot\frac{2}{\pi}\cdot\frac{1}{\text{rad}} + C_2\cdot\frac{8}{\pi^2}\frac{1}{\text{rad}^2}\cdot(0) \Rightarrow \underline{\underline{C_1 = 1.5\text{ in}}}$$

$$S(\theta_{II}) = 0.75\text{in} + \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}}\cdot\theta_{II} + C_2\cdot\frac{4}{\pi^2}\cdot\theta_{II}^2$$

$$v(\theta_{II}) = \frac{3.0}{\pi}\frac{\text{in}}{\text{RAD}} + C_2\frac{8}{\pi^2}\cdot\theta_{II}$$

IMPOSING THE BOUNDARY CONDITIONS $S(\frac{\pi}{2}) = 1.5\text{in}$

$$S(\tfrac{\pi}{2}) = 1.5\text{in} = 0.75\text{in} + \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}}\cdot\left(\frac{\pi}{2}\right) + C_2\cdot\left(\frac{4}{\pi^2}\right)\cdot\left(\frac{\pi^2}{4}\right) \Rightarrow \underline{\underline{C_2 = -0.75\text{in}}}$$

$$\boxed{\begin{array}{lll} S(\theta_{II}) = 0.75\text{in} + \frac{3.0}{\pi}\cdot\frac{\text{in}}{\text{rad}}\cdot\theta_{II} - \frac{3.0}{\pi^2}\frac{\text{in}}{\text{rad}^2}\theta_{II}^2 & S(0) = 0.75\text{in} & S(\frac{\pi}{2}) = 1.5\text{in} \\ v(\theta_{II}) = \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}} - \frac{6.0}{\pi^2}\cdot\frac{\text{in}}{\text{rad}^2}\cdot\theta_{II} & v(0) = \frac{3.0}{\pi}\frac{\text{in}}{\text{rad}} = 0.9549\frac{\text{in}}{\text{rad}} & v(\frac{\pi}{2}) = 0\frac{\text{in}}{\text{rad}} \\ a(\theta_{II}) = -\frac{6.0}{\pi^2}\cdot\frac{\text{in}}{\text{rad}^2} & & \end{array}}$$

NOTE THAT EVEN THOUGH THE BOUNDARY CONDITION $v(\frac{\pi}{2}) = 0$ WAS NEVER IMPOSED, IT IS STILL SATISFIED. THE REQUIREMENT OF CONSTANT DECELERATION DOES NOT ALLOW THIS BOUNDARY CONDITION TO BE CONSIDERED.

REGION III $\beta_{III} = \pi/6$, $\theta_{III} = \theta - \beta_I - \beta_{II}$

$$\boxed{\begin{array}{l} S(\theta_{III}) = 1.5\text{in} \\ v(\theta_{III}) = 0\,\text{in}/\text{rad} \\ a(\theta_{III}) = 0\,\text{in}/\text{rad}^2 \\ j(\theta_{III}) = 0\,\text{in}/\text{rad}^3 \end{array}}$$

REGION IV $\beta_{IV} = \pi/3$, $\theta_{IV} = \theta - \beta_I - \beta_{II} - \beta_{III}$

BOUNDARY CONDITIONS

$S(0) = 1.5\text{in}$ $\quad v(0) = 0$

$S(\pi/3) = 0.75\text{in}$

THE PROBLEM STATEMENT FOR THIS REGION RESTRICTS THE ACCELERATION TO BE CONSTANT, THUS RESTRICTING THE FUNCTION TO THE FORM

$$S(\theta_{IV}) = C_0 + C_1\left(\frac{\theta_{IV}}{\beta_{IV}}\right) + C_2\left(\frac{\theta_{IV}}{\beta_{IV}}\right)^2 = C_0 + C_1 \cdot \frac{3}{\pi} \cdot \theta_{IV} + C_2 \cdot \frac{9}{\pi^2} \cdot \theta_{IV}^2$$

IMPOSING THE BOUNDARY CONDITION $S(0) = 1.5\text{in}$

$$S(0) = 1.5\text{in} = C_0 + C_1 \cdot \frac{3}{\pi}(0) + C_2 \cdot \frac{9}{\pi^2}(0)^2 \Rightarrow \underline{\underline{C_0 = 1.5\text{in}}}$$

$$S(\theta_{IV}) = 1.5\text{in} + C_1 \cdot \frac{3}{\pi}\theta_{IV} + C_2 \cdot \frac{9}{\pi^2} \cdot \theta_{IV}^2$$

$$v(\theta_{IV}) = C_1 \cdot \frac{3}{\pi} + C_2 \cdot \frac{18}{\pi^2}\theta_{IV}$$

IMPOSING THE BOUNDARY CONDITION $v(0) = 0$

$$v(0) = 0\,\frac{\text{in}}{\text{rad}} = C_1 \cdot \frac{3}{\pi} \cdot \frac{1}{\text{rad}} + C_2 \cdot \frac{18}{\pi^2}(0) \Rightarrow \underline{\underline{C_1 = 0}}$$

$$S(\theta_{IV}) = 1.5\text{in} + C_2 \cdot \frac{9}{\pi^2} \cdot \theta_{IV}^2$$

$$v(\theta_{IV}) = C_2 \cdot \frac{18}{\pi^2} \cdot \theta_{IV}^2$$

IMPOSING THE BOUNDARY CONDITION $S(\frac{\pi}{3}) = 0.75\text{in}$

$$S(\tfrac{\pi}{3}) = 0.75\text{in} = 1.5\text{in} + C_2 \cdot \frac{9}{\pi^2} \cdot \frac{1}{\text{rad}^2} \cdot \left(\frac{\pi^2}{9}\text{rad}^2\right) \Rightarrow \underline{\underline{C_2 = -0.75\text{in}}}$$

$$\boxed{\begin{array}{lll} S(\theta_{IV}) = 1.5\text{in} - \frac{6.75}{\pi^2}\frac{\text{in}}{\text{rad}^2} \cdot \theta_{IV}^2 & S(0) = 1.5\text{in} & S(\frac{\pi}{3}) = 0.75\text{in} \\ v(\theta_{IV}) = -\frac{13.5}{\pi^2}\frac{\text{in}}{\text{rad}^2} \cdot \theta_{IV} & v(0) = 0\frac{\text{in}}{\text{rad}} & v(\frac{\pi}{3}) = -\frac{4.5}{\pi}\frac{\text{in}}{\text{rad}} \\ a(\theta_{IV}) = -\frac{13.5}{\pi}\frac{\text{in}}{\text{rad}^2} & & \end{array}}$$

REGION V $\beta_V = \pi/3$, $\Theta_V = \Theta - \beta_I - \beta_2 - \beta_{III} - \beta_{IV}$

BOUNDARY CONDITIONS

$S(0) = 0.75\text{in}$ $\quad v(0) = -\frac{4.5}{\pi}\ \frac{\text{in}}{\text{rad}}$

$S(\pi/3) = 0$ $\quad v(\pi/3) = 0$

THE PROBLEM STATEMENT FOR THIS REGION RESTRICTS THE DECELERATION TO BE CONSTANT, THUS RESTRICTING THE FUNCTION TO THE FORM

$$S(\Theta_V) = C_0 + C_1\cdot\left(\frac{\Theta_V}{\beta_V}\right) + C_2\cdot\left(\frac{\Theta_V}{\beta_V}\right)^2 = C_0 + C_1\cdot\frac{3}{\pi}\cdot\Theta_V + C_2\cdot\frac{9}{\pi^2}\cdot\Theta_V^2$$

IMPOSING THE BOUNDARY CONDITION $S(0) = 0.75\text{in}$

$$S(0) = 0.75\text{in} = C_0 + C_1\cdot\frac{3}{\pi}(0) + C_2\cdot\frac{9}{\pi^2}\cdot(0)^2 \Rightarrow \underline{\underline{C_0 = 0.75\text{in}}}$$

$$S(\Theta_V) = 0.75\text{in} + C_1\cdot\frac{3}{\pi}\Theta_V + C_2\cdot\frac{9}{\pi^2}\Theta_V^2$$

$$v(\Theta_V) = C_1\cdot\frac{3}{\pi} + C_2\cdot\frac{18}{\pi^2}\cdot\Theta_V$$

IMPOSING THE BOUNDARY CONDITION $v(0) = -\frac{4.5}{\pi^2}\cdot\frac{\text{in}}{\text{rad}}$

$$v(0) = -\frac{4.5}{\pi}\cdot\frac{\text{in}}{\text{rad}} = C_1\cdot\frac{3}{\pi}\cdot\frac{1}{\text{rad}} + C_2\cdot\frac{18}{\pi^2}\cdot(0)^2 \Rightarrow \underline{\underline{C_1 = -1.5\text{ in}}}$$

$$S(\Theta_V) = 0.75\text{in} - \frac{4.5}{\pi}\cdot\Theta_V + C_2\cdot\frac{9}{\pi^2}\cdot\Theta_V^2$$

$$v(\Theta_V) = -\frac{4.5}{\pi} + C_2\cdot\frac{18}{\pi^2}\cdot\Theta_V$$

IMPOSING THE BOUNDARY CONDITION $S(\pi/3) = 0$

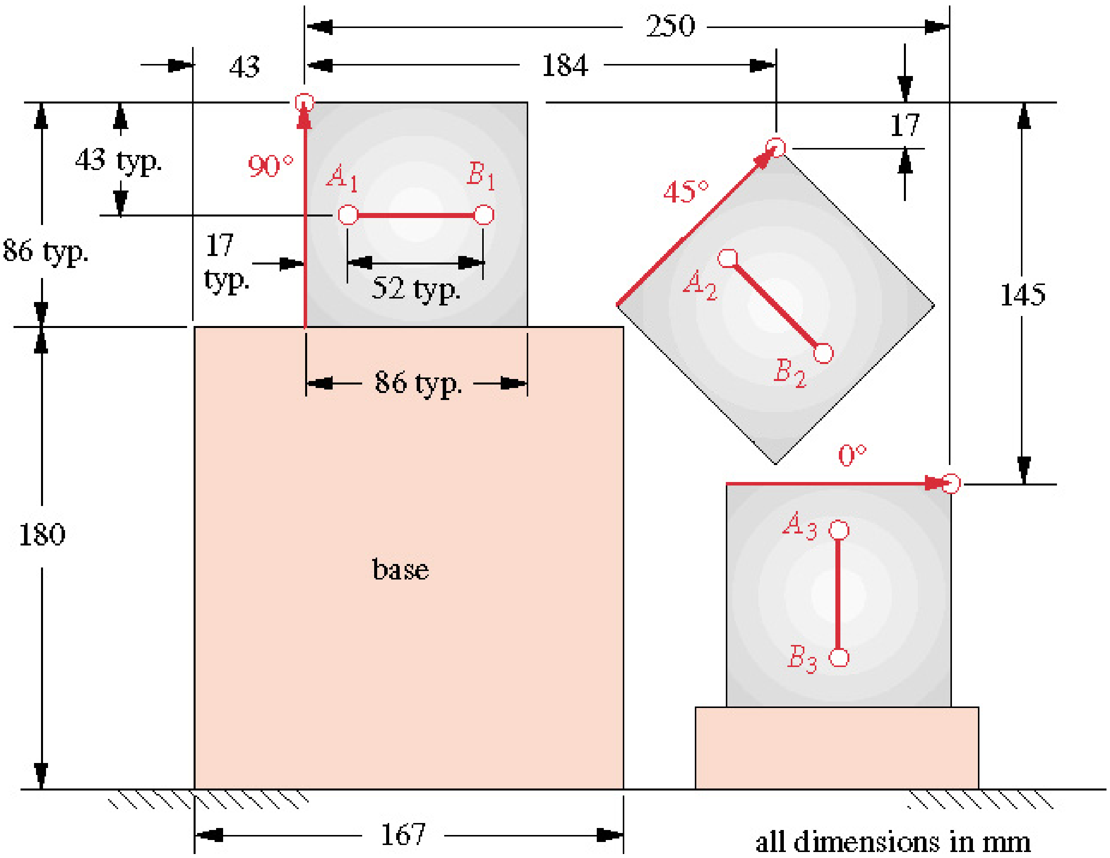
$$S\left(\frac{\pi}{3}\right) = 0\text{ in} = 0.75\text{in} - \frac{4.5}{\pi}\cdot\left(\frac{\pi}{3}\right) + C_2\cdot\frac{9}{\pi^2}\cdot\left(\frac{\pi}{3}\right)^2 \Rightarrow \underline{\underline{C_2 = 0.75\text{in}}}$$

$$\boxed{\begin{array}{lll} S(\Theta_V) = 0.75\text{in} - \frac{4.5}{\pi}\cdot\Theta_V + \frac{6.75}{\pi^2}\cdot\Theta_V^2 & S(0) = 0.75\text{in} & S\left(\frac{\pi}{3}\right) = 0\text{in} \\ v(\Theta_V) = -\frac{4.5}{\pi}\frac{\text{in}}{\text{rad}} + \frac{13.5}{\pi^2}\frac{\text{in}}{\text{rad}^2}\cdot\Theta_V & v(0) = -\frac{4.5}{\pi}\frac{\text{in}}{\text{rad}} & v\left(\frac{\pi}{3}\right) = 0\frac{\text{in}}{\text{rad}} \\ a(\Theta_V) = \frac{13.5}{\pi^2}\frac{\text{in}}{\text{rad}^2} & = -1.4324\frac{\text{in}}{\text{rad}} & \end{array}}$$

REGION VI $\beta_{VI} = \pi/6$, $\Theta_{VI} = \Theta - \beta_I - \beta_{II} - \beta_{III} - \beta_{IV} - \beta_V$

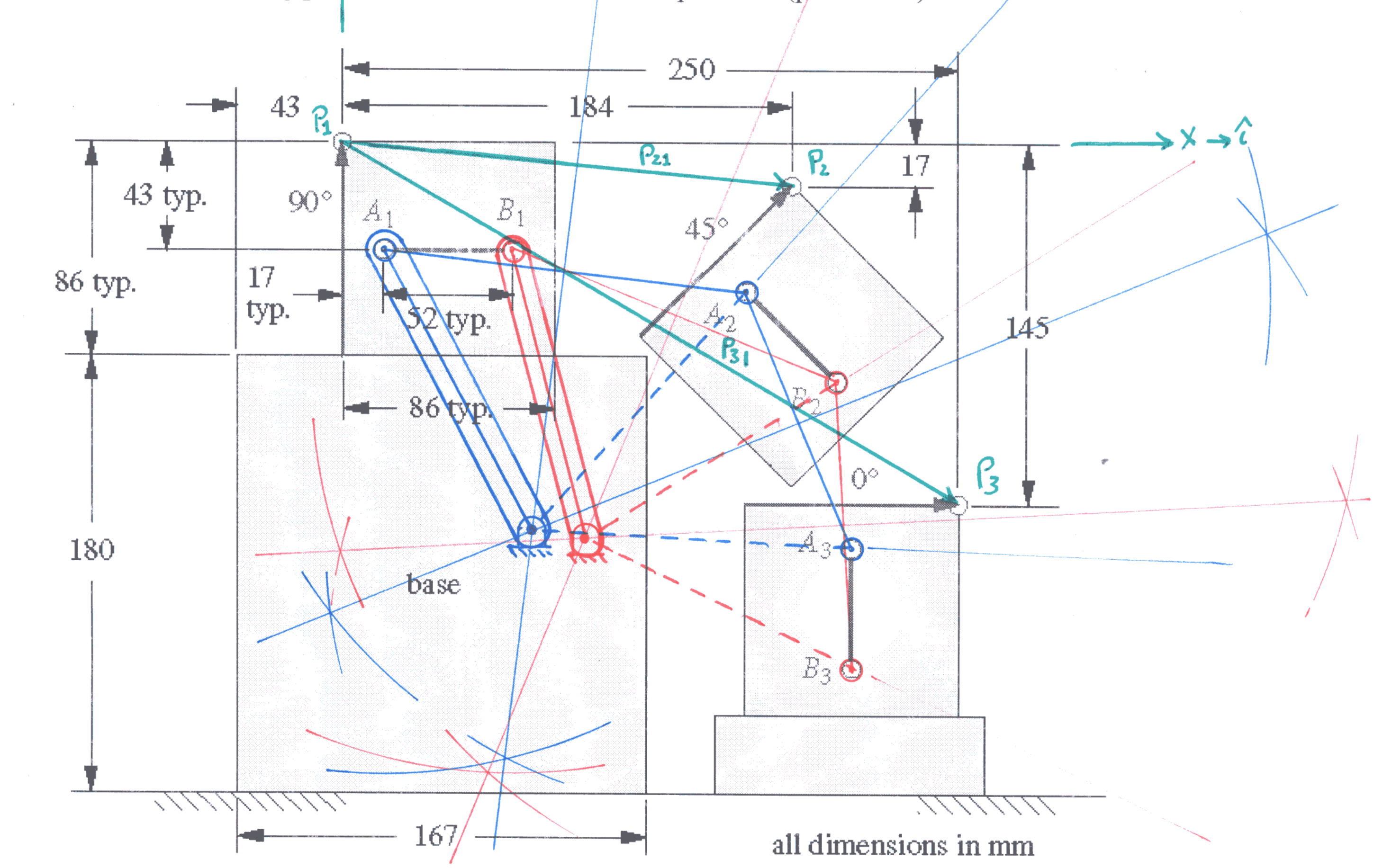
$$\boxed{\begin{array}{l} S(\Theta_{VI}) = 0\text{ in} \\ v(\Theta_{VI}) = 0\text{ in/rad} \\ a(\Theta_{VI}) = 0\text{ in/rad}^2 \end{array}}$$

PROBLEM 2: An automate packaging facility has a station that requires a box to be carries from the upright position on top of a pedestal (position 1), through an intermediate position (position 2), to a resting position on its side on a lower pedestal (position 3).



2a. Design a four bar linkage that will carry the package through the prescribed motion. Print a copy of your programs results and insert it after this page.

PROBLEM 2: An automate packaging facility has a station that requires a box to be carries from the upright position on top of a pedestal (position 1), through an intermediate position (position 2), to a resting position on its side on a lower pedestal (position 3).



2a. Design a four bar linkage that will carry the package through the prescribed motion. Print a copy of your programs results and insert it after this page.

$P_{21} = \sqrt{(184mm)^2 + (17mm)^2} = 184.78mm$

$P_{31} = \sqrt{(250mm)^2 + (145mm)^2} = 289.01mm$

$\delta_2 = \tan^{-1}\left(\frac{-17}{184}\right) = 354.7°$

$\delta_3 = \tan^{-1}\left(\frac{-145}{250}\right) = 329.9°$

$\alpha_2 = 45° - 90° = -45° = 315°$

$\alpha_3 = 0° - 90° = -90° = 270°$

CHOICES:

$\beta_2 = 290°$

$\beta_3 = 240°$

$\gamma_2 = 288°$

$\gamma_3 = 230°$

THREE POSITION ANALYTICAL MOTION SYNTHESIS

$$\vec{W}_2+\vec{Z}_2=\vec{W}_1+\vec{Z}_1+\vec{P}_{21};\quad \vec{W}_3+\vec{Z}_3=\vec{W}_1+\vec{Z}_1+\vec{P}_{31}$$

$$\left|\vec{W}_1\right|=\left|\vec{W}_2\right|=\left|\vec{W}_3\right|=w;\quad \left|\vec{Z}_1\right|=\left|\vec{Z}_2\right|=\left|\vec{Z}_3\right|=z$$

$$\vec{W}_1=w\cdot\left[\cos(\theta)\hat{i}+\sin(\theta)\hat{j}\right]$$

$$\vec{W}_2=w\cdot\left[\cos(\theta+\beta_2)\hat{i}+\sin(\theta+\beta_2)\hat{j}\right]$$

$$\vec{W}_3=w\cdot\left[\cos(\theta+\beta_3)\hat{i}+\sin(\theta+\beta_3)\hat{j}\right]$$

$$\vec{Z}_1=z\cdot\left[\cos(\phi)\hat{i}+\sin(\phi)\hat{j}\right]$$

$$\vec{Z}_2=z\cdot\left[\cos(\phi+\alpha_2)\hat{i}+\sin(\phi+\alpha_2)\hat{j}\right]$$

$$\vec{Z}_3=z\cdot\left[\cos(\phi+\alpha_3)\hat{i}+\sin(\phi+\alpha_3)\hat{j}\right]$$

$$\vec{P}_{21}=p_{21}\cdot\left[\cos(\delta_2)\hat{i}+\sin(\delta_2)\hat{j}\right]$$

$$\vec{P}_{31}=p_{31}\cdot\left[\cos(\delta_3)\hat{i}+\sin(\delta_3)\hat{j}\right]$$

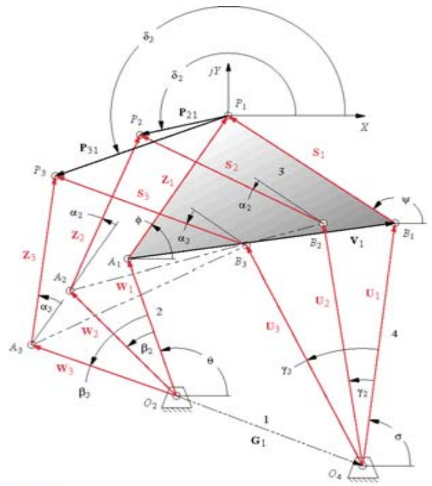


FIGURE 5-4
Three-position analytical synthesis

$$\vec{U}_2+\vec{S}_2=\vec{U}_1+\vec{S}_1+\vec{P}_{21};\quad \vec{U}_3+\vec{S}_3=\vec{U}_1+\vec{S}_1+\vec{P}_{31}$$

$$\left|\vec{U}_1\right|=\left|\vec{U}_2\right|=\left|\vec{U}_3\right|=u;\quad \left|\vec{S}_1\right|=\left|\vec{S}_2\right|=\left|\vec{S}_3\right|=s$$

$$\vec{U}_1=u\cdot\left[\cos(\sigma)\hat{i}+\sin(\sigma)\hat{j}\right]$$

$$\vec{U}_2=u\cdot\left[\cos(\sigma+\gamma_2)\hat{i}+\sin(\sigma+\gamma_2)\hat{j}\right]$$

$$\vec{U}_3=u\cdot\left[\cos(\sigma+\gamma_3)\hat{i}+\sin(\sigma+\gamma_3)\hat{j}\right]$$

$$\vec{S}_1=s\cdot\left[\cos(\psi)\hat{i}+\sin(\psi)\hat{j}\right]$$

$$\vec{S}_2=s\cdot\left[\cos(\psi+\alpha_2)\hat{i}+\sin(\psi+\alpha_2)\hat{j}\right]$$

$$\vec{S}_3=s\cdot\left[\cos(\psi+\alpha_3)\hat{i}+\sin(\psi+\alpha_3)\hat{j}\right]$$

$$\vec{P}_{21}=p_{21}\cdot\left[\cos(\delta_2)\hat{i}+\sin(\delta_2)\hat{j}\right]$$

$$\vec{P}_{31}=p_{31}\cdot\left[\cos(\delta_3)\hat{i}+\sin(\delta_3)\hat{j}\right]$$

FIRST DYAD

GIVEN:		CHOSEN:		FIND:	
P12	184.78	β2	290.00	w	135.97
P13	289.01	β3	240.00	θ	121.14
δ2	354.70			z	38.05
δ3	329.90			ϕ	99.47
α2	315.00			W1x	-70.31
α3	270.00			W1y	116.38
				Z1x	-6.26
				Z1y	37.53

	x-coord	y-coord.
O2	76.57	-153.90
A1	6.26	-37.53
A2	161.8795	-48.0299
A3	212.5098	-151.2
P1	0.00	0.00
P2	183.99	-17.07
P3	250.04	-144.94

$$\begin{bmatrix} -0.6580 & 0.9397 & -0.2929 & 0.7071 \\ -0.9397 & -0.6580 & -0.7071 & -0.2929 \\ -1.5000 & 0.8660 & -1.0000 & 1.0000 \\ -0.8660 & -1.5000 & -1.0000 & -1.0000 \end{bmatrix} \begin{Bmatrix} \text{W1x} \\ \text{W1y} \\ \text{Z1x} \\ \text{Z1y} \end{Bmatrix} = \begin{Bmatrix} 183.9900 \\ -17.0682 \\ 250.0374 \\ -144.9416 \end{Bmatrix}$$

$$\begin{bmatrix} \cos\beta_2-1 & -\sin\beta_2 & \cos\alpha_2-1 & -\sin\alpha_2 \\ \sin\beta_2 & \cos\beta_2-1 & \sin\alpha_2 & \cos\alpha_2-1 \\ \cos\beta_3-1 & -\sin\beta_3 & \cos\alpha_3-1 & -\sin\alpha_3 \\ \sin\beta_3 & \cos\beta_3-1 & \sin\alpha_3 & \cos\alpha_3-1 \end{bmatrix} \cdot \begin{Bmatrix} W_{1x} \\ W_{1y} \\ Z_{1x} \\ Z_{1y} \end{Bmatrix} = \begin{Bmatrix} p_{21}\cdot\cos\delta_2 \\ p_{21}\cdot\sin\delta_2 \\ p_{31}\cdot\cos\delta_3 \\ p_{31}\cdot\sin\delta_3 \end{Bmatrix}$$

SECOND DYAD

GIVEN:		CHOSEN:		FIND:	
P12	184.78	γ2	288.00	u	127.11
P13	289.01	γ3	230.00	σ	104.19
δ2	354.70			s	77.59
δ3	329.90			ψ	152.85
α2	315.00			U1x	-31.16
α3	270.00			U1y	123.23
				S1x	-69.04
				S1y	35.40

	x-coord	y-coord.
O4	100.20	-158.64
B1	69.04	-35.40
B2	207.77	-90.92
B3	214.63	-213.98
P1	0.00	0.00
P2	183.99	-17.07
P3	250.04	-144.94

$$\begin{bmatrix} -0.6910 & 0.9511 & -0.2929 & 0.7071 \\ -0.9511 & -0.6910 & -0.7071 & -0.2929 \\ -1.6428 & 0.7660 & -1.0000 & 1.0000 \\ -0.7660 & -1.6428 & -1.0000 & -1.0000 \end{bmatrix} \begin{Bmatrix} \text{U1x} \\ \text{U1y} \\ \text{S1x} \\ \text{S1y} \end{Bmatrix} = \begin{Bmatrix} 183.9900 \\ -17.0682 \\ 250.0374 \\ -144.9416 \end{Bmatrix}$$

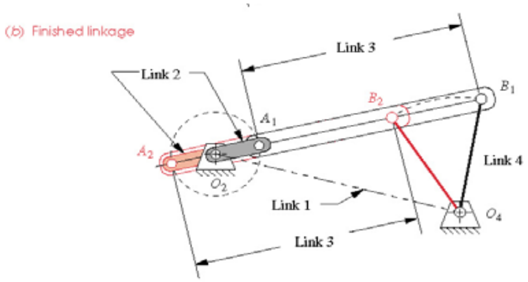
$$\begin{bmatrix} \cos\gamma_2-1 & -\sin\gamma_2 & \cos\alpha_2-1 & -\sin\alpha_2 \\ \sin\gamma_2 & \cos\gamma_2-1 & \sin\alpha_2 & \cos\alpha_2-1 \\ \cos\gamma_3-1 & -\sin\gamma_3 & \cos\alpha_3-1 & -\sin\alpha_3 \\ \sin\gamma_3 & \cos\gamma_3-1 & \sin\alpha_3 & \cos\alpha_3-1 \end{bmatrix} \cdot \begin{Bmatrix} U_{1x} \\ U_{1y} \\ S_{1x} \\ S_{1y} \end{Bmatrix} = \begin{Bmatrix} p_{21}\cdot\cos\delta_2 \\ p_{21}\cdot\sin\delta_2 \\ p_{31}\cdot\cos\delta_3 \\ p_{31}\cdot\sin\delta_3 \end{Bmatrix}$$

2c. Design a drive mechanism that can be used to make sure the linkage that you designed will cycle 10 times per minute. Print a copy of your program that performs this design and insert it into the exam after this page.

$$10 \frac{\text{cycles}}{\text{min}} \cdot \frac{2\pi \text{ rad}}{\text{cycle}} \cdot \frac{\text{min}}{60 \text{ s}} = 1.0472 \, {}^{1}/_{s}$$

NON-QUICK-RETURN (From Three Position Results)

	X-pos	Y-pos	mag	angle	i	j
O4	**76.57**	**-153.90**	**171.90**	**-63.5**	**0.4454**	**-0.8953**
3P-A1	**6.26**	**-37.53**	**38.05**	**-80.5**	**0.1645**	**-0.9864**
3P-A2	**161.88**	**-48.03**	**168.85**	**-16.5**	**0.9587**	**-0.2844**
3P-A3	**212.51**	**-151.20**	**260.81**	**-35.4**	**0.8148**	**-0.5797**
Factors						
P	0.5	**% dist up Link 4**				
K	-2.5	**Length of Link 3+Link 2 to B1B2**				
Link 1	**354.88**					
Link 2	**58.88**					
Link 3	**353.25**					
Link 4	**67.98**	**Grashof**				



(b) Finished linkage

$\dot{\theta}_2 =$	1.0470 1/s
$\ddot{\theta}_2 =$	0.0000 1/s^2
ω3-1	0.1745 1/s
ω3-i	-0.0074 1/s
ω3-2	-0.1745 1/s
ω4-1	0.0000 1/s
ω4-i	0.9019 1/s
ω4-2	0.0000 1/s
α3-1	0.2637 1/s^2
α3-i	0.0261 1/s^2
α3-2	0.3692 1/s^2
α4-1	-1.5822 1/s^2
α4-i	0.0545 1/s^2
α4-2	2.2151 1/s^2

	x comp	y comp	mag	angle	i	j
rO4	**76.57**	**-153.90**	**171.90**	**-63.5**	**0.4454**	**-0.8953**
rO43P-A1	-70.31	116.38	135.97	121.1	-0.5171	0.8559
rO43P-A2	85.31	105.87	135.97	51.1	0.6274	0.7787
rO43P-A3	135.94	2.70	135.97	1.1	0.9998	0.0199
rB1	**41.41**	**-95.72**	**104.29**	**-66.6**	**0.3971**	**-0.9178**
rO4B1	-35.16	58.19	67.98	121.1	-0.5171	0.8559
rB2	**144.54**	**-152.55**	**210.15**	**-46.5**	**0.6878**	**-0.7259**
rO4B2	67.97	1.35	67.98	1.1	0.9998	0.0199
intermediate **rBi**	**119.22**	**-100.97**	**156.23**	**-40.3**	**0.7631**	**-0.6463**
rO4Bi	42.65	52.94	67.98	51.1	0.6274	0.7787
rB1B2	103.13	-56.84	117.75	-28.9	0.8758	-0.4827
rO2	**-216.40**	**46.38**	**221.31**	**167.9**	**-0.9778**	**0.2095**
rB102	-257.81	142.09	294.38	151.1	-0.8758	0.4827
rBiO2	-335.62	147.34	366.54	156.3	-0.9156	0.4020
rA1	**-267.96**	**74.79**	**278.20**	**164.4**	**-0.9632**	**0.2688**
rO2A1	-51.56	28.42	58.88	151.1	-0.8758	0.4827
rA2	**-164.84**	**17.96**	**165.81**	**173.8**	**-0.9941**	**0.1083**
rO2A2	51.56	-28.42	58.88	-28.9	0.8758	-0.4827
rAi	**-177.56**	**90.62**	**199.35**	**153.0**	**-0.8907**	**0.4546**
rO2Ai	38.84	44.25	58.88	48.7	0.6597	0.7515 negatives t
rB1A1	-309.38	170.51	353.25	151.1	-0.8758	0.4827
rBiAi	-296.78	191.59	353.25	147.2	-0.8401	0.5424
rB2A2	-309.38	170.51	353.25	151.1	-0.8758	0.4827
rO4O2	-292.97	200.28	354.88	145.6	-0.8255	0.5644

Kinematics

	x comp	y comp	mag	angle	i	j
r1	292.97	-200.28	354.88	-34.4	0.8255	-0.5644
r4-1	-35.16	58.19	67.98	121.1	-0.5171	0.8559
r4-i	42.65	52.94	67.98	51.1	0.6274	0.7787
r4-2	67.97	1.35	67.98	1.1	0.9998	0.0199
r2-1	-51.56	28.42	58.88	151.1	-0.8758	0.4827
r2-i	38.84	44.25	58.88	48.7	0.6597	0.7515
r2-2	51.56	-28.42	58.88	-28.9	0.8758	-0.4827
r3-1	309.38	-170.51	353.25	-28.9	0.8758	-0.4827
r3-i	296.78	-191.59	353.25	-32.8	0.8401	-0.5424
r3-2	309.38	-170.51	353.25	-28.9	0.8758	-0.4827
vA-1	-29.75	-53.99	61.64	-118.9	-0.4827	-0.8758
vA-i	-46.33	40.67	61.64	138.7	-0.7515	0.6597
vA-2	29.75	53.99	61.64	61.1	0.4827	0.8758
vB-1	0.00	0.00	0.00	-148.9	-0.8559	-0.5171
vB-i	-47.74	38.47	61.31	141.1	-0.7787	0.6274
vB-2	0.00	0.00	0.00	-88.9	0.0199	-0.9998
aA-1	56.52	-31.15	64.54	-28.9	0.8758	-0.4827
aA-i	-42.58	-48.50	64.54	-131.3	-0.6597	-0.7515
aA-2	-56.52	31.15	64.54	151.1	-0.8758	0.4827
aB-1	92.07	55.62	107.57	31.1	0.8559	0.5171
aB-i	-37.58	-40.73	55.42	-132.7	-0.6781	-0.7350
aB-2	-2.99	150.56	150.59	91.1	-0.0199	0.9998

2c. Determine the following kinematic parameters for the four bar linkage that you designed.

i. Angular velocities and accelerations for the drive, coupler, and rocker links in all three positions
ii. The position, velocity, and acceleration of the designated corner of the box in all three positions.
iii. The position, velocity, and acceleration of the joints between the drive and coupler, and the coupler and rocker in all three positions.

Print the results of the program that you used to calculate these values and insert it after this page.

KINEMATIC ANALYSIS - CRITICAL POSITIONS

	x-coord	y-coord.	mag	angle	i	j
O2	76.57	-153.90	171.90	-63.5	0.4454	-0.8953
A1	6.26	-37.53	38.05	-80.5	0.1645	-0.9864
A2	161.88	-48.03	168.85	-16.5	0.9587	-0.2844
A3	212.51	-151.20	260.81	-35.4	0.8148	-0.5797
P1	0.00	0.00	0.00	0.0	1.0000	0.0000
P2	183.99	-17.07	184.78	-5.3	0.9957	-0.0924
P3	250.04	-144.94	289.01	-30.1	0.8652	-0.5015

KINEMATIC ANALYSIS - CRITICAL POSITIONS

	x-coord	y-coord.	mag	angle	i	j
O4	100.20	-158.64	187.63	-57.7	0.5340	-0.8455
B1	69.04	-35.40	77.59	-27.1	0.8898	-0.4563
B2	207.77	-90.92	226.80	-23.6	0.9161	-0.4009
B3	214.63	-213.98	303.08	-44.9	0.7082	-0.7060
P1	0.00	0.00	0.00	#DIV/0!	#DIV/0!	#DIV/0!
P2	183.99	-17.07	184.78	-5.3	0.9957	-0.0924
P3	250.04	-144.94	289.01	-30.1	0.8652	-0.5015

ω2-1	0.0000	1/s
ω2-2	0.9019	1/s
ω2-3	0.0000	1/s
α2-1	-1.5822	1/s^2
α2-2	0.0545	1/s^2
α2-3	2.2151	1/s^2
ω3-1	0.0000	1/s
ω3-2	0.6555	1/s
ω3-3	0.0000	1/s
ω4-1	0.0000	1/s
ω4-2	0.9949	1/s
ω4-3	0.0000	1/s
α3-1	-1.0217	1/s^2
α3-2	-0.1965	1/s^2
α3-3	2.4552	1/s^2
α4-1	-1.5118	1/s^2
α4-2	-0.0467	1/s^2
α4-3	2.6770	1/s^2

	x comp	y comp	mag	angle	i	j
r1	23.63	-4.73	24.10	-11.3	0.9805	-0.1965
r4-1	-31.16	123.23	127.11	104.2	-0.2451	0.9695
r4-2	107.57	67.72	127.11	32.2	0.8463	0.5327
r4-3	114.43	-55.34	127.11	-25.8	0.9002	-0.4354
r2-1	-70.31	116.38	135.97	121.1	-0.5171	0.8559
r2-2	85.31	105.87	135.97	51.1	0.6274	0.7787
r2-3	135.94	2.70	135.97	1.1	0.9998	0.0199
r3-1	62.78	2.12	62.82	1.9	0.9994	0.0338
r3-2	45.89	-42.89	62.82	-43.1	0.7306	-0.6828
r3-3	2.12	-62.78	62.82	-88.1	0.0338	-0.9994
rAP-1	-6.26	37.53	38.05	99.5	-0.1645	0.9864
rAP-2	22.11	30.96	38.05	54.5	0.5812	0.8138
rAP-3	37.53	6.26	38.05	9.5	0.9864	0.1645
vA-1	0.00	0.00	0.00	-148.9	-0.8559	-0.5171
vA-2	-95.49	76.94	122.63	141.1	-0.7787	0.6274
vA-3	0.00	0.00	0.00	-88.9	0.0199	-0.9998
vB-1	0.00	0.00	0.00	-165.8	-0.9695	-0.2451
vB-2	-67.37	107.02	126.46	122.2	-0.5327	0.8463
vB-3	0.00	0.00	0.00	-115.8	-0.4354	-0.9002
vP-1	0.00	0.00	0.00	-152.1	-0.8840	-0.4675
vP-2	-115.78	91.43	147.53	141.7	-0.7848	0.6198
vP-3	0.00	0.00	0.00	-86.9	0.0542	-0.9985
aA-1	184.13	111.25	215.13	31.1	0.8559	0.5171
aA-2	-75.17	-81.47	110.85	-132.7	-0.6781	-0.7350
aA-3	-5.99	301.13	301.19	91.1	-0.0199	0.9998
aB-1	186.30	47.11	192.17	14.2	0.9695	0.2451
aB-2	-103.31	-72.05	125.96	-145.1	-0.8202	-0.5720
aB-3	148.15	306.34	340.28	64.2	0.4354	0.9002
aP-1	222.48	117.64	251.66	27.9	0.8840	0.4675
aP-2	-78.58	-99.11	126.49	-128.4	-0.6213	-0.7836
aP-3	-21.35	393.26	393.84	93.1	-0.0542	0.9985

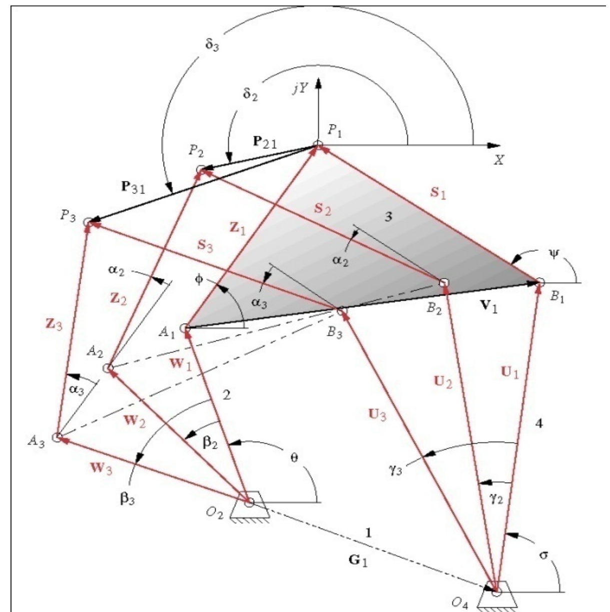


FIGURE 5-4

Three-position analytical synthesis