Chapter 3

Linkages with Rolling and Sliding Contacts and Joints on moving Sliders

KUAS ME, C. F. Chang 1

Velocity Relationship Between Coincident Points

(ref p. 105, Eq. 3.25)

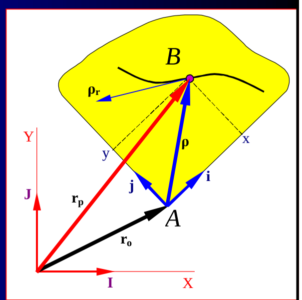
General velocity relationship between any two points A and B :

$$\boxed{\mathbf{v}_B = \mathbf{v}_A + \boldsymbol{\omega}\times\boldsymbol{\rho} + \dot{\boldsymbol{\rho}}_r}$$

P相對於動座標系之速度

動座標系旋轉所造成之速度, ⊥ρ

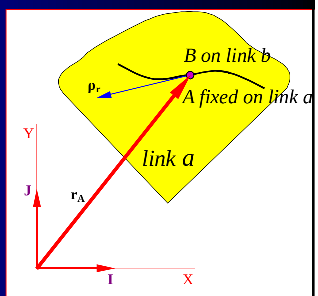
動座標系平移所造成之速度



If points A and B are coincident but belong to different bodies, we have ρ=0 and thus

$$\boxed{\mathbf{v}_B = \mathbf{v}_A + \dot{\boldsymbol{\rho}}_r = \mathbf{v}_A + \mathbf{v}_{B/A}}$$

$v_{B/A}$ must be tangent to the path that point *B* traces on link *a*



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Acceleration Relationship Between Coincident Points
(ref p. 105, Eq. 3.26)

General velocity relationship between any two points A and B :

$$\mathbf{a}_B = \mathbf{a}_A + \boldsymbol{\omega}\times(\boldsymbol{\omega}\times\boldsymbol{\rho}) + \dot{\boldsymbol{\omega}}\times\boldsymbol{\rho} + 2\boldsymbol{\omega}\times\dot{\boldsymbol{\rho}}_r + \ddot{\boldsymbol{\rho}}_r$$

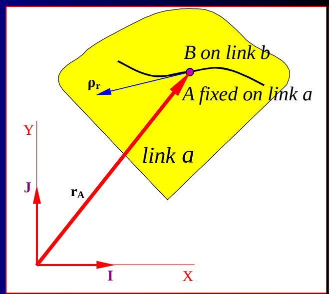
P在動座標系上運動之相對加速度

動座標系旋轉所造成之科氏速度

動座標系旋轉所造成之切線加速度

動座標系旋轉所造成之法向加速度

動座標系平移所造成之加速度



If points A and B are coincident but belong to different bodies, we have ρ=0 and thus

$$\mathbf{a}_B = \mathbf{a}_A + \ddot{\boldsymbol{\rho}}_r + 2\boldsymbol{\omega}\times\dot{\boldsymbol{\rho}}_r = \mathbf{a}_A + \mathbf{a}_{B/A} + \mathbf{a}^c_{B/A}$$

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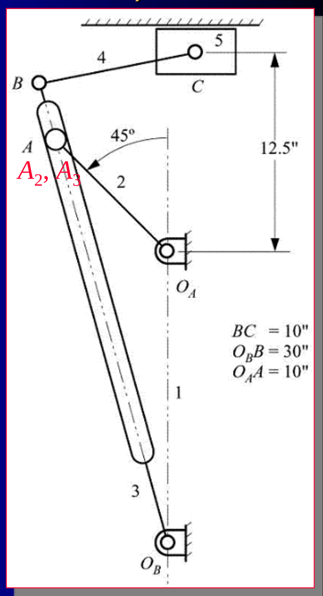
Example 3.1 Velocity and Acceleration Analysis of a Quick-Return Mechanism (pp. 107-111)

- Given:
  - Link 2 is driven with a *constant angular velocity* of 10 rpm CCW
- Find:
  - The sliding velocity of the slider,
  - The angular accelerations of links 3 and 4
  - The acceleration of slider for the quick-return mechanism
- Analysis of the problem :

$$\mathbf{v}_{A_3} = \mathbf{v}_{A_2} + \mathbf{v}_{A_3/A_2}$$

$$\mathbf{v}_B : \mathbf{v}_{A_3} = O_B B : O_B A_3$$

$$\mathbf{v}_C = \mathbf{v}_B + \mathbf{v}_{C/B}$$



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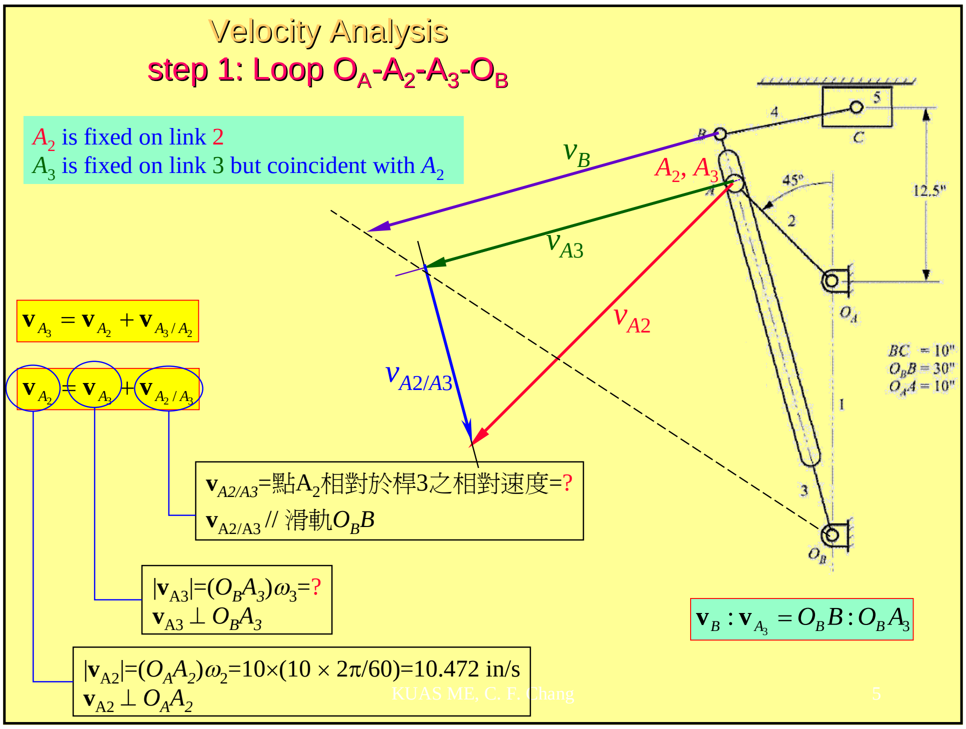
Velocity Analysis
step 1: Loop O_A-A_2-A_3-O_B
A_2 is fixed on link 2
A_3 is fixed on link 3 but coincident with A_2
v_B
A_2, A_3
v_{A3}
v_{A2}
$v_{A2/A3}$
$\mathbf{v}_{A_3} = \mathbf{v}_{A_2} + \mathbf{v}_{A_3/A_2}$
$\mathbf{v}_{A_2} = \mathbf{v}_{A_3} + \mathbf{v}_{A_2/A_3}$
$\mathbf{v}_{A2/A3}$=點A_2相對於桿3之相對速度=?
$\mathbf{v}_{A2/A3}$ // 滑軌O_BB
$|\mathbf{v}_{A3}|=(O_BA_3)\omega_3$=?
$\mathbf{v}_{A3} \perp O_BA_3$
$|\mathbf{v}_{A2}|=(O_AA_2)\omega_2=10\times(10 \times 2\pi/60)=10.472$ in/s
$\mathbf{v}_{A2} \perp O_AA_2$
$\mathbf{v}_B : \mathbf{v}_{A_3} = O_BB : O_BA_3$
45°
12.5"
BC = 10"
O_BB = 30"
O_AA = 10"
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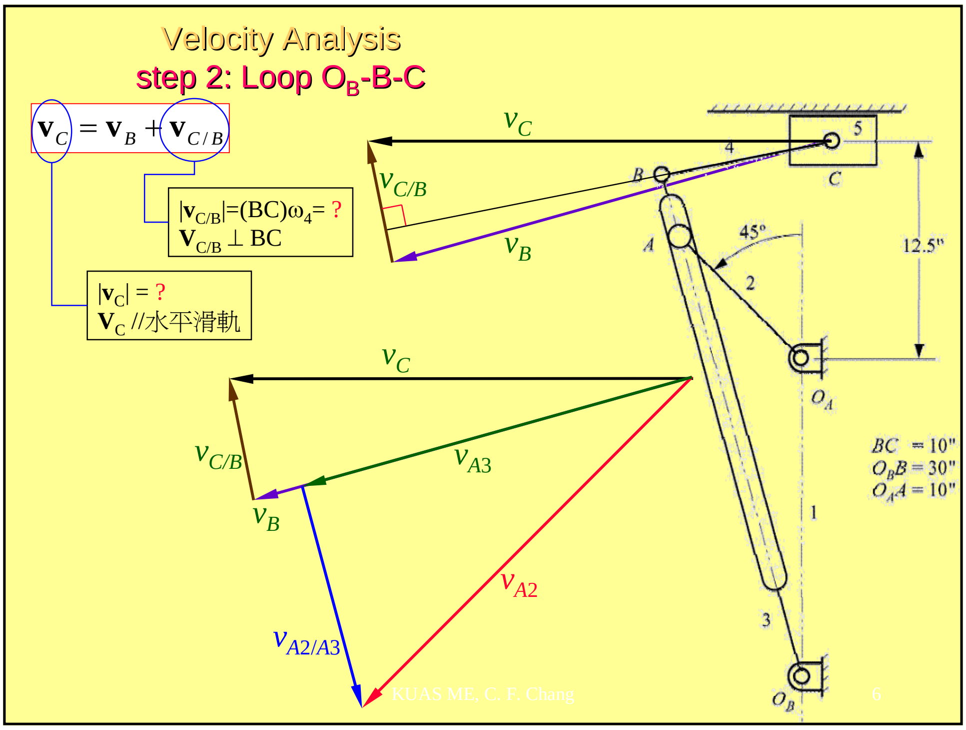
Velocity Analysis
step 2: Loop O_B-B-C
$\mathbf{v}_C = \mathbf{v}_B + \mathbf{v}_{C/B}$
$|\mathbf{v}_{C/B}|=(BC)\omega_4$= ?
$\mathbf{V}_{C/B} \perp$ BC
$|\mathbf{v}_C|$ = ?
$\mathbf{V}_C$ //水平滑軌
v_C
$v_{C/B}$
v_B
v_{A3}
v_{A2}
$v_{A2/A3}$
45°
12.5"
BC = 10"
O_BB = 30"
O_AA = 10"
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Velocity Analysis
step 3: Calculate the Result

$\mathbf{v}_{A_3} = \mathbf{v}_{A_2} + \mathbf{v}_{A_3/A_2}$

$\mathbf{v}_C = \mathbf{v}_B + \mathbf{v}_{C/B}$

$|\mathbf{v}_{A2}|=(O_A A_2)\omega_2=10\times(10\times 2\pi/60)=10.472$ in/s
$\mathbf{v}_{A2} \perp O_A A_2$

$|\mathbf{v}_{A3/A2}|=?$
$\mathbf{v}_{A3/A2} \,//\, O_B B$

$|\mathbf{v}_{A3}|= (O_B A_3)\omega_3=?$
$\mathbf{v}_{A3} \perp O_B A_3$

$\omega_3=|\mathbf{v}_{A3}|/(O_B A_3) =0.344$ *rad/s, CCW* ←*ANS*

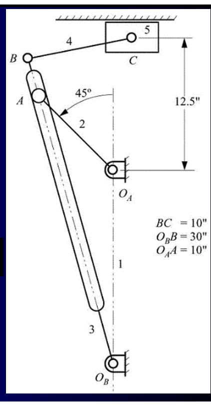
$\mathbf{v}_B : \mathbf{v}_{A_3} = O_B B : O_B A_3$

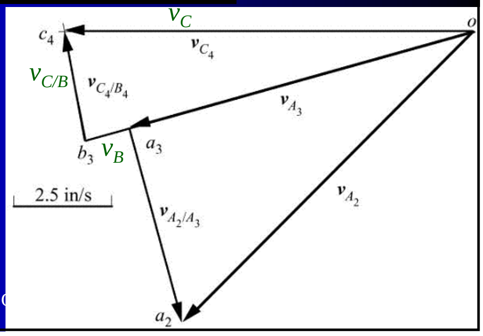
$|\mathbf{v}_{C/B}|=(BC)\omega_4= ?$
$\mathbf{v}_{C/B} \perp BC$

$\omega_4=|\mathbf{v}_{C/B}|/(BC) =0.608$ *rad/s, CCW* ←*ANS*

$|\mathbf{v}_C|= ?$
$\mathbf{v}_C$ // fixed slot

Measuring the lengths on the velocity polygon gives
$|\mathbf{v}_{A3}|=(oa_3)S_v=9.07$ *in/s*
$|\mathbf{v}_{A3/A2}|=(a_2a_3)S_v=5.09$ *in/s*
$|\mathbf{v}_{C/B}| =(b_3c_4)S_v=2.823$ *in/s*
$|\mathbf{v}_C| =(oc_4)S_v=11.06$ *in/s* ←*ANS*





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Acceleration Analysis
step 1: Loop O_A-A_2-A_3-O_B

$\mathbf{a}_{A_2} = \mathbf{a}_{A_3} + \mathbf{a}_{A_2/A_3} + \mathbf{a}^c_{A_2/A_3}$

$\mathbf{a}^n_{A_2} + \mathbf{a}^t_{A_2} = \mathbf{a}^n_{A_3} + \mathbf{a}^t_{A_3} + \mathbf{a}_{A_2/A_3} + 2\omega_3 \times \mathbf{v}_{A_2/A_3}$

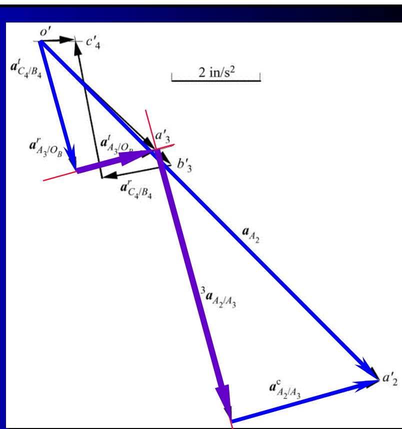
$|\mathbf{a}^n_{A3}|= (O_B A_3)(\omega_3)^2 = (26.37)(0.344)^2= 3.12$ *in/s²*
$\mathbf{a}^n_{A3}//O_B A_3$ and point to O_B

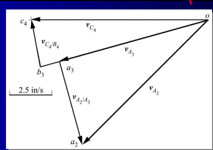
$|\mathbf{a}^t_{A3}|= (O_B A_3)\alpha_3=?$
$\mathbf{a}^t_{A3} \perp O_B A_3$

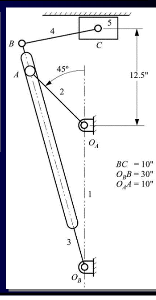
$|\mathbf{a}_{A2/A3}|= ?$
$\mathbf{a}_{A2/A3}$ //moving slot $O_B B$

$|\mathbf{a}^c_{A2/A3}|=2\omega_3(\mathbf{v}_{A2/A3})=2(5.09)(0.344)=3.5$ *in/s²*
$\mathbf{a}_{cor}$ =rotate $\mathbf{v}_{A2/A3}$ by 90° according to ω_3

$|\mathbf{a}^n_{A2}|= (O_A A_2)(\omega_2)^2= 10.97$ *in/s²*
$\mathbf{a}^n_{A2}//O_A A_2$ and point to O_A







Then, Determine $\mathbf{a}_B$ =4.12 *in/s²* by using acceleration image theorem

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Acceleration Analysis

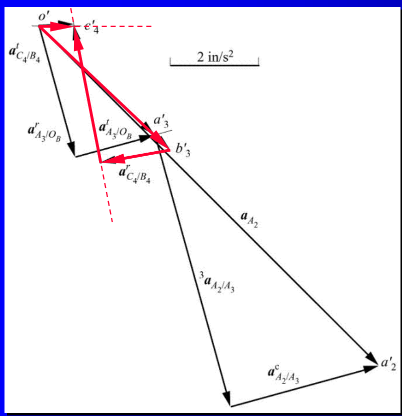
step 2: Loop O_B-B-C (a_B is known)

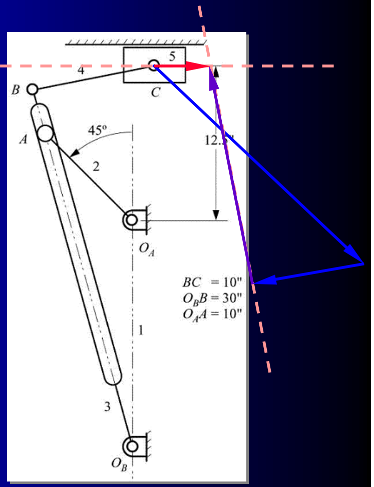
$\mathbf{a}_C = \mathbf{a}_B + \mathbf{a}_{C/B} \rightarrow \mathbf{a}_C = \mathbf{a}_B + (\mathbf{a}^n_{C/B} + \mathbf{a}^t_{C/B})$

$|\mathbf{a}^n_{C/B}| = (BC)(\omega_4)^2 = (5)(0.608)^2 = 1.85\, in/s^2$, // BC

$|\mathbf{a}^t_{C/B}| = (BC)(\alpha_3) = ?\ in/s^2$, $\perp BC$

$\mathbf{a}_C = ?\ in/s^2$, // horizontal fixed slot





By measurement in figure, we get

$a_C = 0.7986\ in/s^2$, *to the right* ← *ANS*

$\alpha_3 = |a^t_{C/B}|/(BC) = 0.071\, in/s^2$

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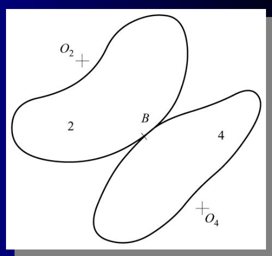
Basic Relationships for Rolling Contact



$\mathbf{v}_{B_4} = \mathbf{v}_{B_2}$ ($\because$ pure rolling)

$\mathbf{v}_{B_2/B_4} = 0$

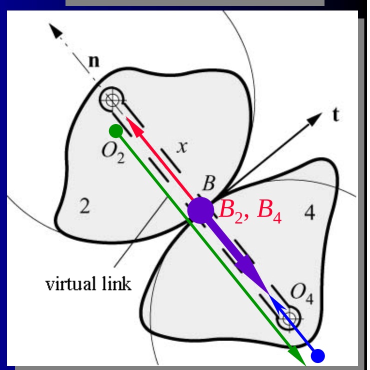
$\mathbf{a}_{B_2/B_4} = \mathbf{a}^n_{B_2/O_2} + \mathbf{a}^n_{O_2/O_4} + \mathbf{a}^n_{O_4/B_4}$

$|\mathbf{a}^n_{B2/O2}| = (B_2O_2)(\omega_2)^2 = |\mathbf{v}_{B2/O2}|^2/(B_2O_2)$
B_2 to O_2

$|\mathbf{a}^n_{O2/O4}| = (O_2O_4)(\omega_x)^2 = |\mathbf{v}_{O2/O4}|^2/(O_2O_4)$
O_2 to O_4

$|\mathbf{a}^n_{O4/B4}| = (O_4B_4)(\omega_4)^2 = |\mathbf{v}_{O4/B4}|^2/(O_4B_4)$
O_4 to B_4

$\therefore \mathbf{a}_{B2/B4}$ // C-C (O_2O_4)



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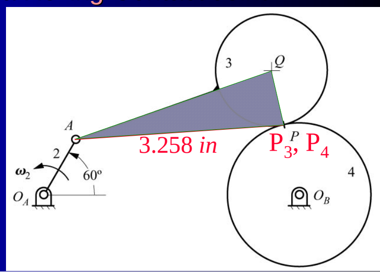
Example 3.2 Analysis of Linage with a Rolling Contact Joint

Givien: ω_2=10 rad/s, α_2 = 0

Find: the angular acceleration, α_4 , of gear 4

$\mathbf{v}_{P4} = \mathbf{v}_{P3} = \mathbf{v}_A + \mathbf{v}_{P_3/A}$ Note: A, Q, and P_3, are on the same link 3

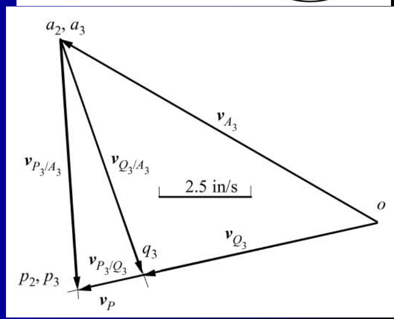


$|\mathbf{v}_A|$= $(O_AA)\omega_2$= (1 in)(10 rad/s) =10 *in/s*
$\mathbf{v}_A \perp O_AA$

$|\mathbf{v}_{P3/A}|=(AP_3)\omega_3$=?
$\mathbf{v}_{P3/A} \perp AP_3$

$|\mathbf{v}_{P4}|$= $(O_BP_4)\omega_4$=?
$\mathbf{v}_{P4} \perp O_BP_4$

AO_A	= 1.0 in
AQ	= 3.250 in
PQ	= 0.875 in
O_BP	= 1.125 in
O_AO_B	= 4.0 in
ω_2	= 10 rpm *CCW*



Choosing S_v=2.5 to draw the velocity polygon yields

$|\mathbf{v}_{P/A}|$ =(ap)S_v=6.85 *in/s*
$|\mathbf{v}_P|$ =(op)S_v=38.32 *in/s*

$\omega_3=|\mathbf{v}_{P/A}|/(AP_3)$ =6.85/3.258=2.10 *rad/s, CW*
$\omega_4=|\mathbf{v}_P|/(O_BP_4)$ =38.32/1.125=7.39 *rad/s, CCW*

※Triangle apq in velocity polygon can be determined by using velocity image theorem
➔$v_{Q/OB}=v_Q - v_{OB}=v_Q$ - 0=6.54

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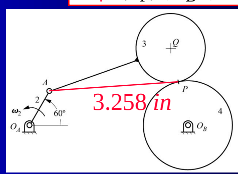
Example 3.2 : Acceleration Analysis

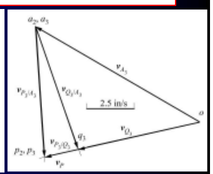
$\omega_3=|\mathbf{v}_{P/A}|/(AP)$ =2.10 *rad/s, CW*
ω_4= $|\mathbf{v}_P|/(O_BP)$ =7.39 *rad/s, CCW*

$$\mathbf{a}_{P_4} = \mathbf{a}_{P_3} + \mathbf{a}_{P_4/P_3} = (\mathbf{a}_A + \mathbf{a}_{P_3/A}) + \mathbf{a}_{P_4/P_3}$$

ω_2=const

$$(\mathbf{a}^n_P + \mathbf{a}^t_P) = (\mathbf{a}^n_A + \cancel{\mathbf{a}^t_A}) + (\mathbf{a}^n_{P_3/A} + \mathbf{a}^t_{P_3/A}) + \mathbf{a}^n_{P_4/P_3}$$





$|\mathbf{a}^n_A|$= $(O_AA)(\omega_2)^2$= 1(10)^2 =100 *in/s^2*, //O_AA

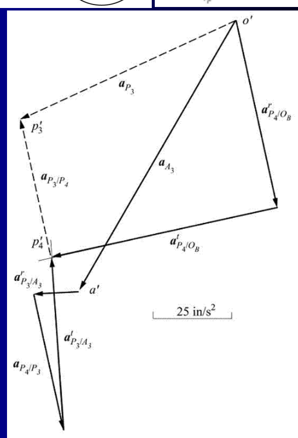
$|\mathbf{a}^n_{P/3A}|$= $(AP)(\omega_3)^2$= (3.258)(2.1)^2 =45.4 *in/s^2*, //*AP*
$|\mathbf{a}^t_{P3/A}|$= $(AP)(\alpha_3)$= (3.258) α_3 =? *in/s^2*, ⊥ *AP*

$|\mathbf{a}^n_{P4}|$= $(O_BP)(\omega_4)^2$= (1.125)(7.39)^2 =61.4 *in/s^2*, //O_BP
$|\mathbf{a}^t_{P4}|$= $(O_BP)(\alpha_4)$= (4.0) α_4 =? *in/s^2*, ⊥ O_BP

$$\mathbf{a}_{P_4/P_3} = \mathbf{a}^n_{P_4/O_B} + \mathbf{a}^n_{O_B/Q} + \mathbf{a}^n_{Q/P_3}$$

$|\mathbf{a}_{P4/P3}|$= 44.36 *in/s^2*, //Q to O_B (*see next page*)

Choosing S_a=25 to drawing the acceleration polygon gives



$|\mathbf{a}^t_P|$ =(*op*)S_a=(1.816)(50)=90.8 *in/s^2* =74.25 *in/s^2*

$\alpha_4=|\mathbf{a}^t_P|/(O_BP)$ =74.25/1.125=66.0 *rad/s^2* ←*ANS*

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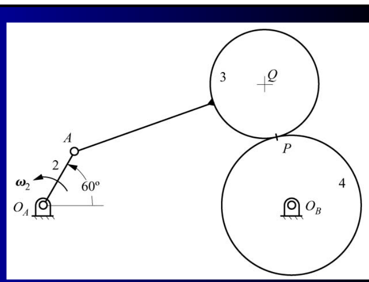
Remark on $\mathbf{a}_{P4/P3}$

計算加速度時, 由於製圖之誤差以及計算方法的不同, 可能出現不同之結果, 例如:



$$\mathbf{a}_{P_4/P_3} = \mathbf{a}^n_{P_4/O_B} + \mathbf{a}^n_{O_B/Q} + \mathbf{a}^n_{Q/P_3}$$

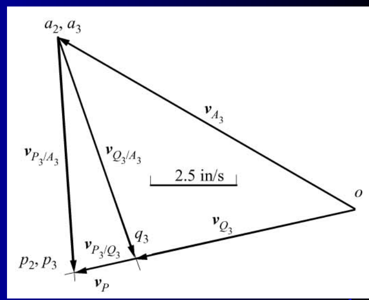
$$\left|\mathbf{a}^n_{P_4/O_B}\right| = \overline{O_B P_4}\omega_4^2 = 1.125\times 7.39^2 = 61.438$$

$$\left|\mathbf{a}^n_{P_4/O_B}\right| = \frac{\left|v_{P_4/O_B}\right|^2}{\overline{O_B P_4}} = \frac{8.32^2}{1.125} = 61.531$$

$$\left|\mathbf{a}^n_{O_B/Q}\right| = \frac{\left|v_{O_B/Q}\right|^2}{\overline{QO_B}} = \frac{\left|v_{Q/O_B}\right|^2}{\overline{QO_B}} = \frac{6.54^2}{2} = 21.386$$

$$\left|\mathbf{a}^n_{Q/P_3}\right| = \overline{P_3 Q}\omega_3^2 = 0.875\times 2.1^2 = 3.859$$

$$\left|\mathbf{a}^n_{Q/P_3}\right| = \frac{\left|v_{Q/P_3}\right|^2}{\overline{QP_3}} = \frac{1.92^2}{0.875} = 4.213$$



$\therefore |\mathbf{a}_{P4/P3}|$=61.531-21.386+4.213= 44.36 *in/s²*, //QO_B

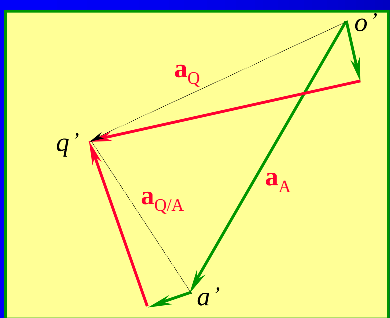
Another Method: Using a Virtual Linkage

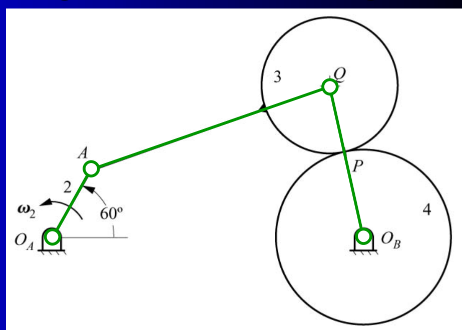
Determine $\mathbf{a}_Q$ by solving

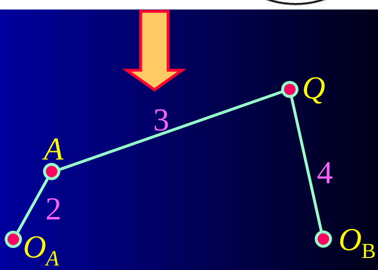
$$(\mathbf{a}^n_Q + \mathbf{a}^t_Q) = (\mathbf{a}^n_A) + (\mathbf{a}^n_{Q/A} + \mathbf{a}^t_{Q/A})$$

$|a^t_Q| = (O_B Q)\,\alpha_4$

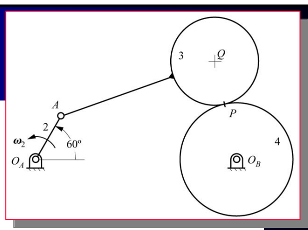
$\alpha_4 = |a^t_Q|/(O_B Q)$=66 *rad/s²* ← *ANS*





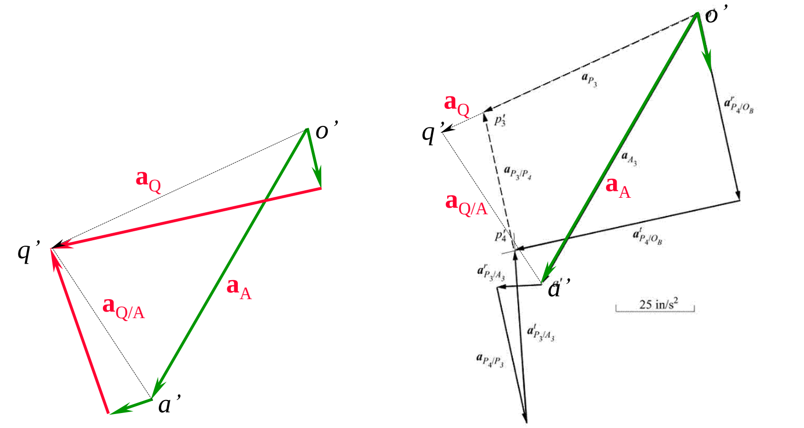


Comparing the Results



$\Delta a'p_3'q'$ is similar to that of APQ;

that is, satisfying the acceleration image theorem



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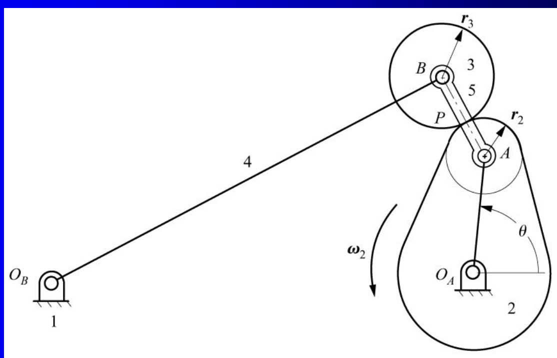
Example 3.3 Analysis of a Geared Linkage—Rolling Contact (pp. 119-120)

- Given:
  - Cam 2 is rotated CCW with *constant angular velocity* of 1000 rpm
  - O_AO_B=4.0, O_BB=4.25, r_2=0.5, r_3=2.5, O_AA=1.153, AB=0.901 (unit: in)
- Find:
  - The angular velocity and
  - The angular acceleration of the arm (link4)



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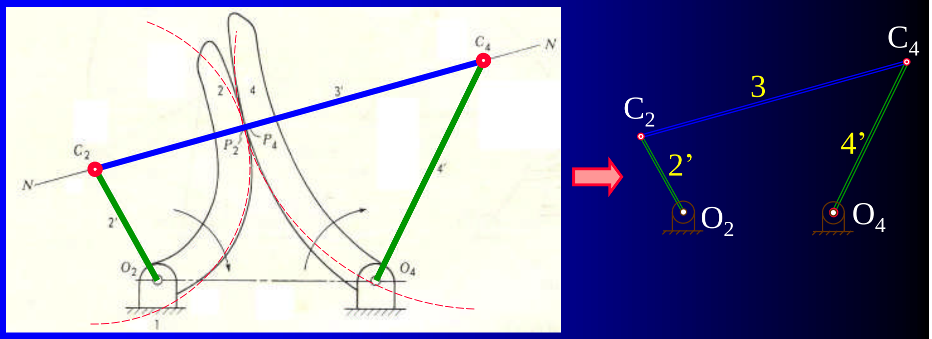
Equivalent Linkages

- When motion analysis is to be made for a direct-contact mechanism, the problem can be simplified by replacing the mechanism by an equivalent four-bar linkage.
- An equivalent four-bar linkage is one whose driving link and driven link have angular velocities and accelerations which are identical at the instant to those of the original linkage.



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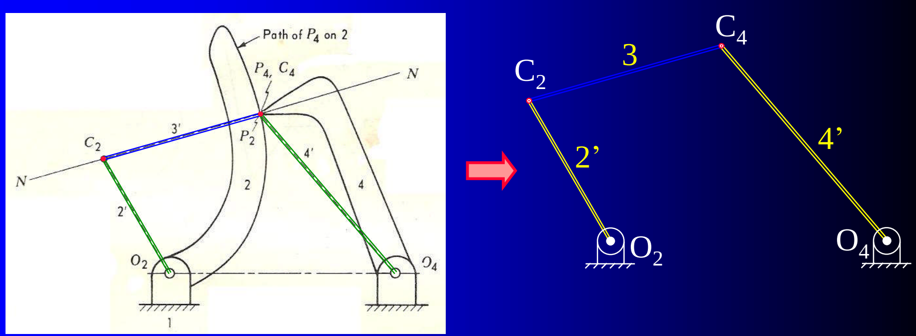
Examples for Determining Equivalent Linkages (cont.)



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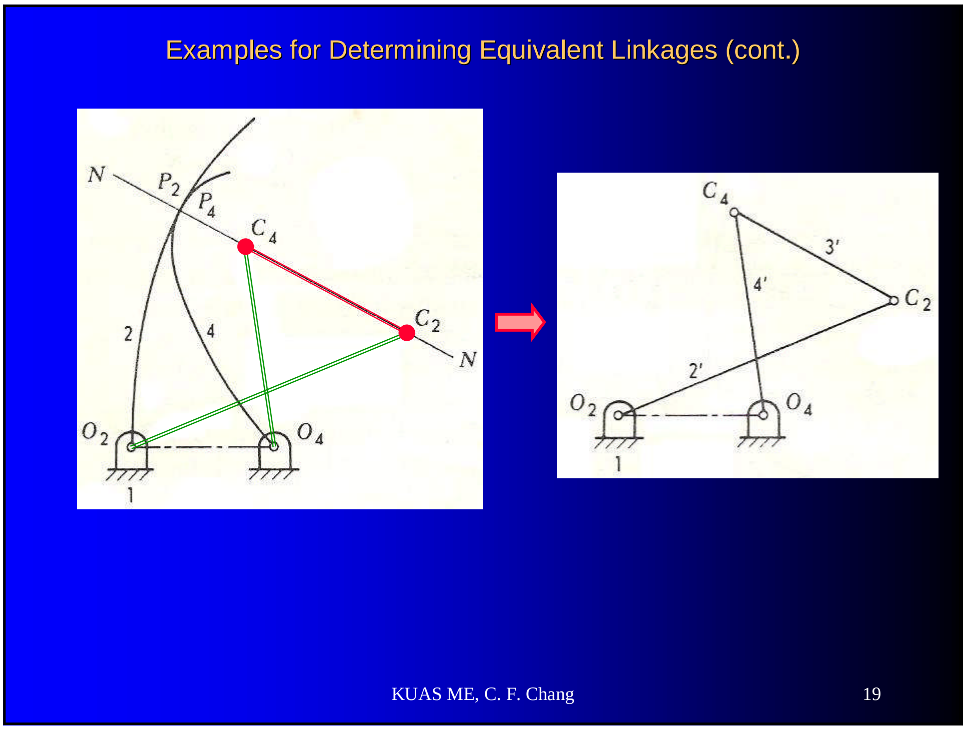
Examples for Determining Equivalent Linkages (cont.)
N
P2
P4
C4
C2
N
2
4
O2
O4
1
3'
4'
2'
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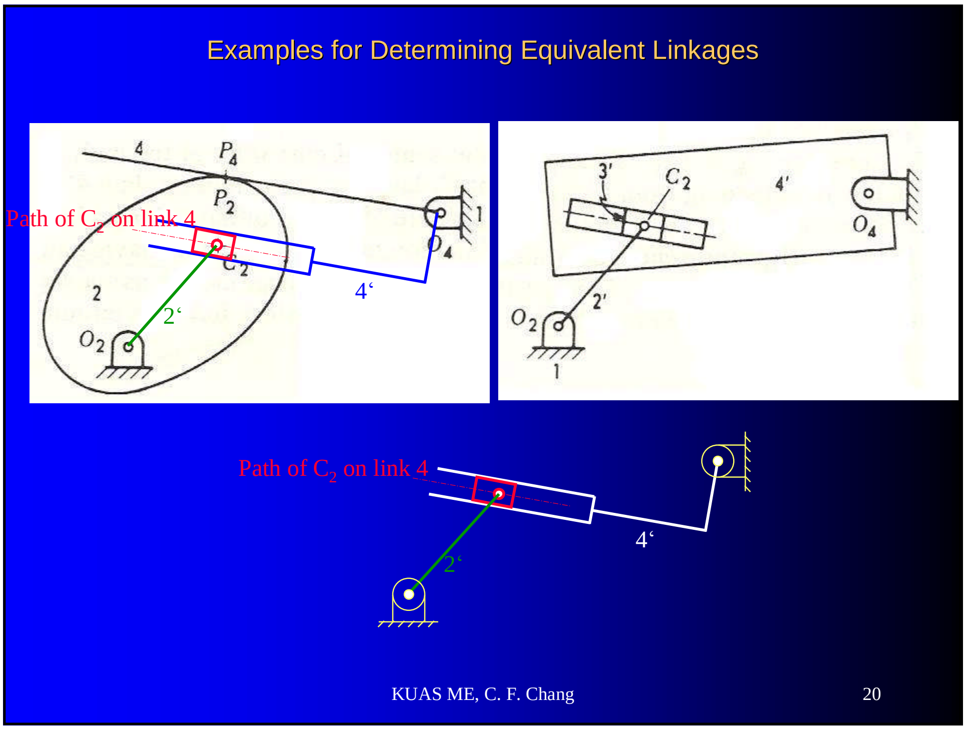
Examples for Determining Equivalent Linkages
4
P4
P2
Path of C2 on link 4
C2
4'
2
2'
O2
O4
1
3'
C2
4'
O4
2'
O2
1
Path of C2 on link 4
4'
2'
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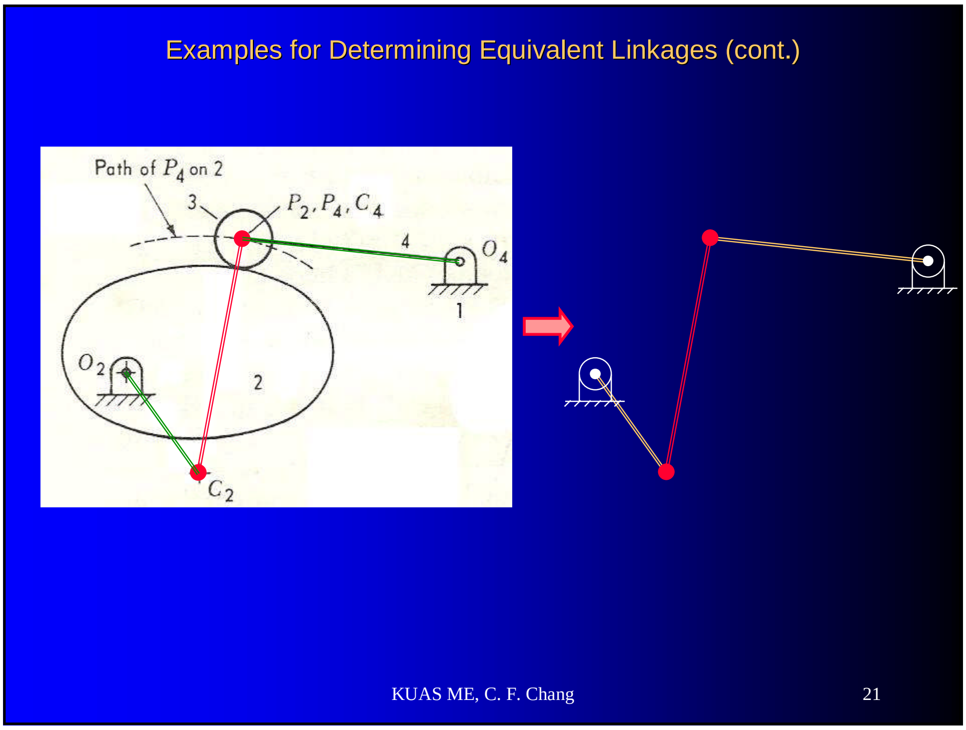
Examples for Determining Equivalent Linkages (cont.)
Path of P_4 on 2
3
P_2, P_4, C_4
4
O_4
1
O_2
2
C_2
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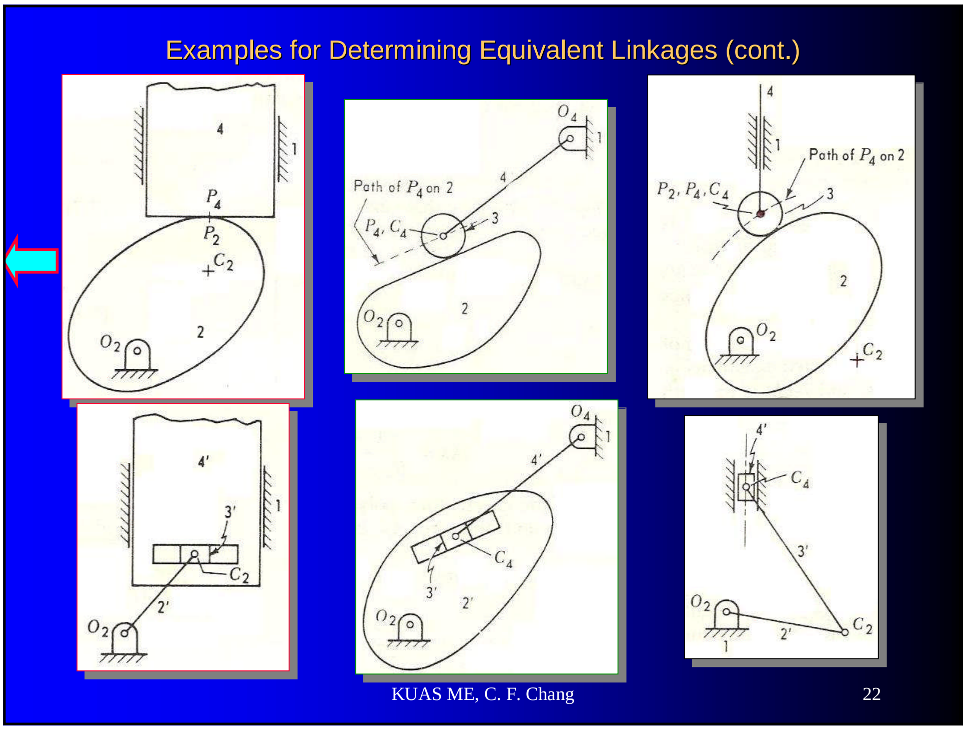
Examples for Determining Equivalent Linkages (cont.)
Path of P_4 on 2
P_4, C_4
P_2, P_4, C_4
O_4
O_2
C_2
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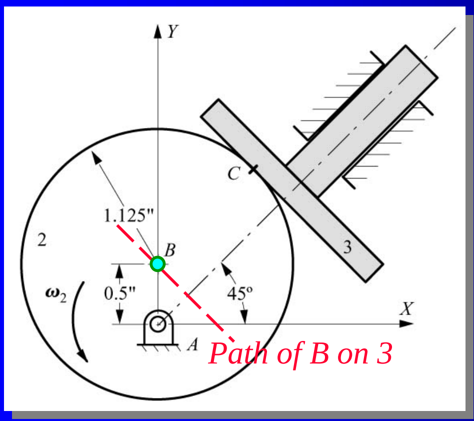
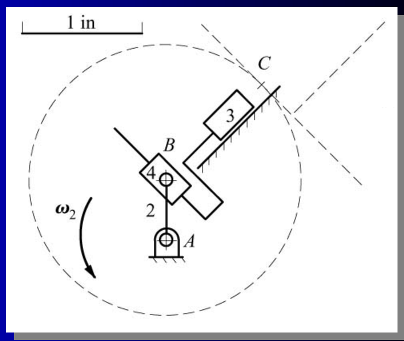
Motion Analysis Using the concept of Equivalent Linkage
Ex 3.4 & Ex 3.5 (pp. 122-128)

- Find the velocity and acceleration of the cam follower (link 3) if the cam is rotating at a constant angular velocity of 100 rad/s CCW
- Find the sliding velocity at the point of contact, C.





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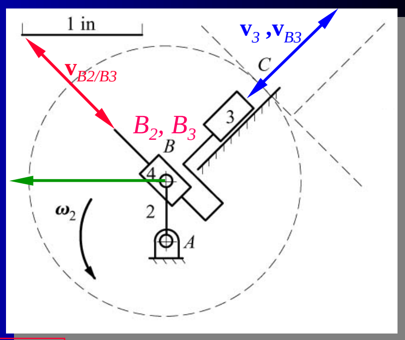
Ex 3.4 & Ex 3.5 Velocity Analysis

- Define:
  - B_2 on link 2
  - B_3 on link 3
  - B_2 and B_3 are coincident with joint B
- Ans:
  - v_{B3}=0.7x50=35 in/s = the velocity of link 3

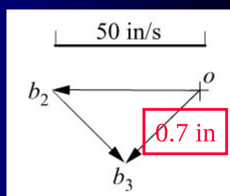


$\mathbf{v}_{B_2} = \mathbf{v}_{B_3} + \mathbf{v}_{B_2/B_3}$

$\mathbf{v}_{B2/B3}$=點B_2相對於桿3之相對速度=?
$\mathbf{v}_{B2/B3}$ // moving slide

$|\mathbf{v}_{B3}|$=?
$\mathbf{v}_{B3}$ //fixed slide

$|\mathbf{v}_{B2}|=(AB_2)\omega_2=0.5\times100=50$ in/s
$\mathbf{v}_{B2} \perp AB_2$



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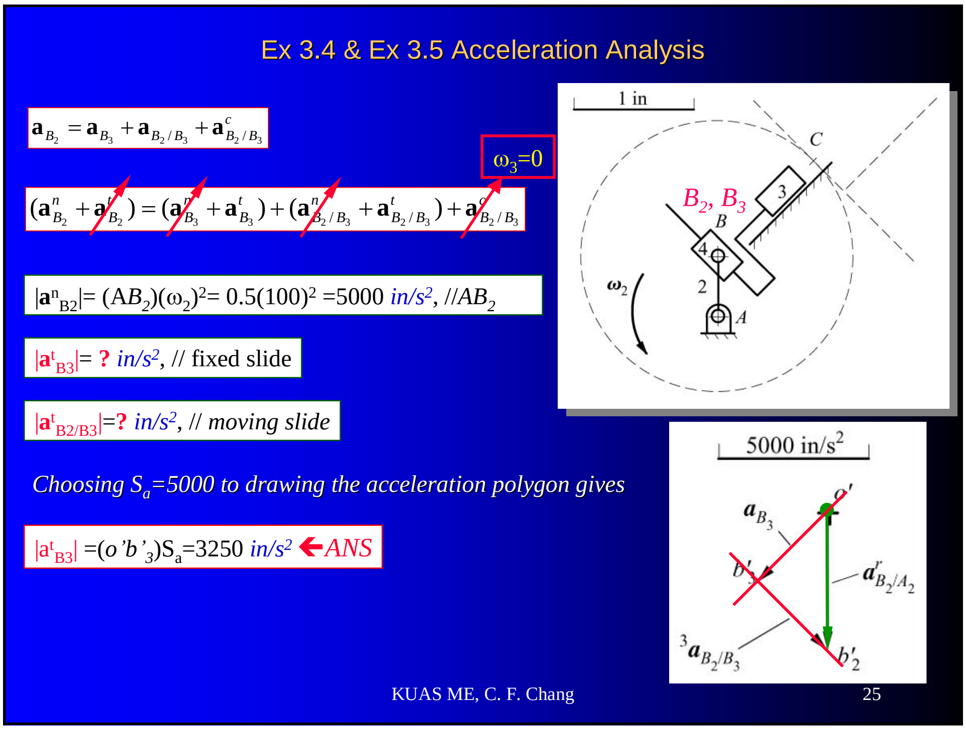
Ex 3.4 & Ex 3.5 Acceleration Analysis
$\mathbf{a}_{B_2} = \mathbf{a}_{B_3} + \mathbf{a}_{B_2/B_3} + \mathbf{a}^c_{B_2/B_3}$
$\omega_3=0$
$(\mathbf{a}^n_{B_2} + \mathbf{a}^t_{B_2}) = (\mathbf{a}^n_{B_3} + \mathbf{a}^t_{B_3}) + (\mathbf{a}^n_{B_2/B_3} + \mathbf{a}^t_{B_2/B_3}) + \mathbf{a}^c_{B_2/B_3}$
$|\mathbf{a}^n_{B2}|= (AB_2)(\omega_2)^2= 0.5(100)^2 =5000$ in/s², //AB₂
$|\mathbf{a}^t_{B3}|=$? in/s², // fixed slide
$|\mathbf{a}^t_{B2/B3}|=$? in/s², // moving slide
Choosing S_a=5000 to drawing the acceleration polygon gives
$|\mathbf{a}^t_{B3}| =(o'b'_3)S_a$=3250 in/s² ANS
1 in
C
B₂, B₃
B
3
4
2
A
ω₂
5000 in/s²
o'
b'₃
b'₂
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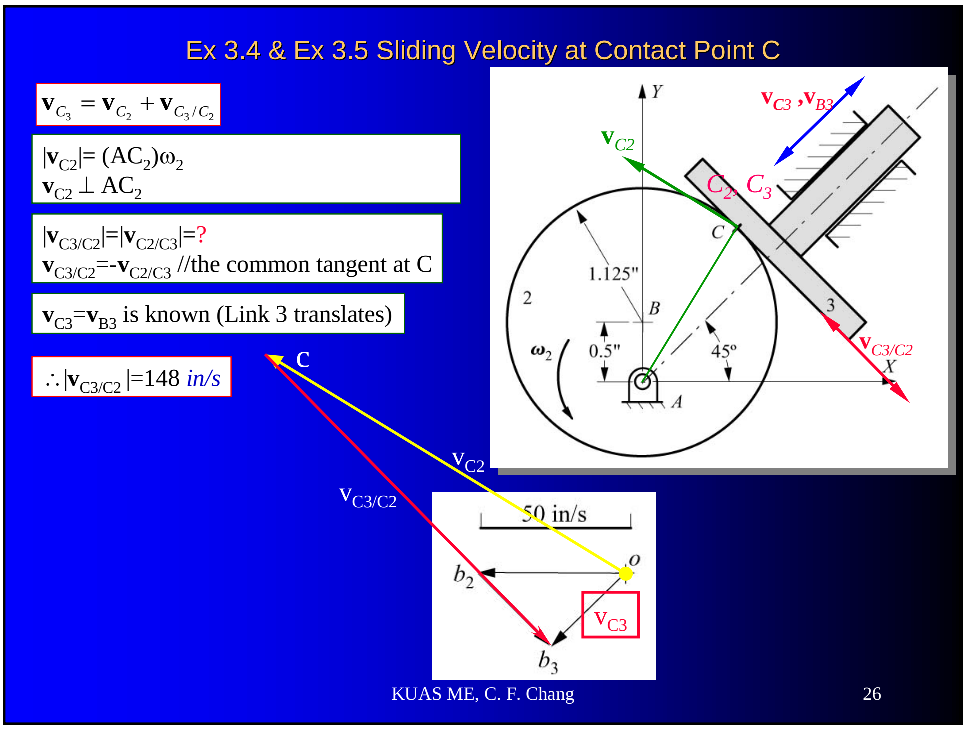
Ex 3.4 & Ex 3.5 Sliding Velocity at Contact Point C
$\mathbf{v}_{C_3} = \mathbf{v}_{C_2} + \mathbf{v}_{C_3/C_2}$
$|\mathbf{v}_{C2}|= (AC_2)\omega_2$
$\mathbf{v}_{C2} \perp AC_2$
$|\mathbf{v}_{C3/C2}|=|\mathbf{v}_{C2/C3}|=$?
$\mathbf{v}_{C3/C2}=-\mathbf{v}_{C2/C3}$ //the common tangent at C
$\mathbf{v}_{C3}=\mathbf{v}_{B3}$ is known (Link 3 translates)
$\therefore |\mathbf{v}_{C3/C2}|$=148 in/s
C
v_{C2}
$v_{C3/C2}$
50 in/s
o
b_2
b_3
v_{C3}
Y
v_{C3} ,v_{B3}
v_{C2}
C₂, C₃
C
1.125"
B
2
3
0.5"
45°
ω₂
A
$v_{C3/C2}$
X
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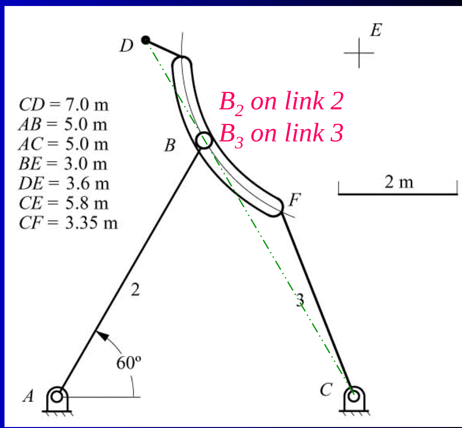
Ex 3.7 (pp. 132-136)

- Given: ω_2=2 rad/s CCW, α_2=3 rad/s² CCW
- Find:
  - ω_3, α_3=3, $\mathbf{v}_D$=3, and $\mathbf{a}_D$
  - The center of curvature of the path that B_3 traces on link 2

$$\mathbf{v}_{B_2}=\mathbf{v}_{B_3}+\mathbf{v}_{B_2/B_3}$$

$$\mathbf{a}_{B_2}=\mathbf{a}_{B_3}+\mathbf{a}_{B_2/B_3}+\mathbf{a}^c_{B_2/B_3}$$

$$\mathbf{a}_{B_2}=\mathbf{a}_{B_3}+\mathbf{a}_{B_2/B_3}+2\boldsymbol{\omega}_3\times\mathbf{v}_{B_2/B_3}$$



Ex 3.7 : Velocity Analysis

$$\mathbf{v}_{B_2}=\mathbf{v}_{B_3}+\mathbf{v}_{B_2/B_3}$$

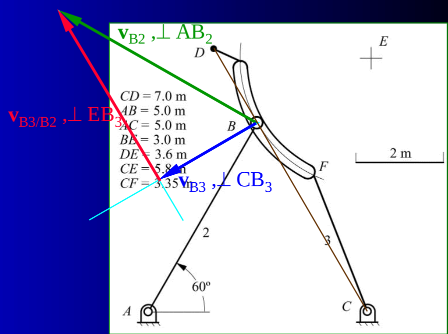
$|\mathbf{v}_{B2}|=(AB_2)\omega_2=(5)(2)=10$ m/s, $\perp AB_2$

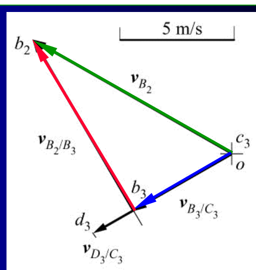
$|\mathbf{v}_{B3}|=(CB_3)\omega_3$=? $\perp CB_3$

$|\mathbf{v}_{B2/B3}|=|\mathbf{v}_{C2/C3}|$=?, tangent to the slot

From the velocity polygon, we get
$|\mathbf{v}_{B3/B2}|$=8.7 *m/s*
$|\mathbf{v}_D|$=7 *m/s* ← *ANS*

$\therefore\ \omega_3=|\mathbf{v}_{B3}|/(CB_3)=5/5=1$ rad/s ← *ANS*





Ex 3.7 : Acceleration Analysis

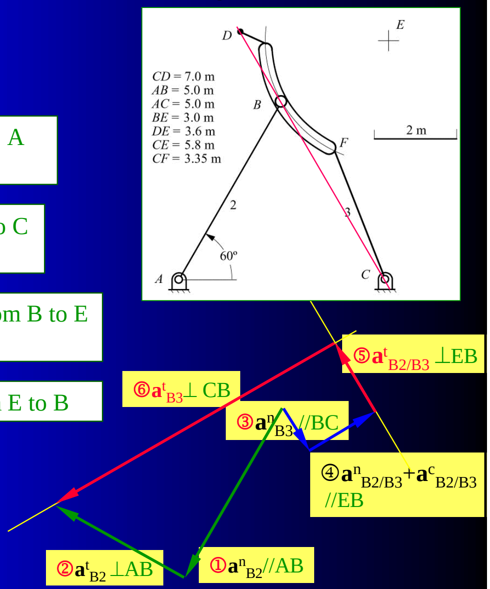
$$\mathbf{a}_{B_2} = \mathbf{a}_{B_3} + \mathbf{a}_{B_2/B_3} + \mathbf{a}^c_{B_2/B_3}$$

$|\mathbf{a}^n_{B2}|=(AB_2)(\omega_2)^2=(5)2^2=20$ m/s^2, from B_2 to A
$|\mathbf{a}^t_{B2}|=(AB_2)\alpha_2=(5)(3)=15$ m/s^2, $\perp AB_2$

$|\mathbf{a}^n_{B3}|=(CB_3)(\omega_3)^2=(5)(1)=5$ m/s^2?, from B_3 to C
$|\mathbf{a}^t_{B3}|=(CB_3)\alpha_3=?$, $\perp CB_3$

$|\mathbf{a}^n_{B2/B3}|=|\mathbf{v}_{B2/B3}|^2/(EB)=8.7^2/3=25.23$ m/s^2, from B to E
$|\mathbf{a}^t_{B2/B3}|=?$, $\perp EB_3$

$|\mathbf{a}^c_{B2/B3}|=2\omega_3 v_{B2/B3}=2(1)(8.7)=17.4$ m/s^2, from E to B



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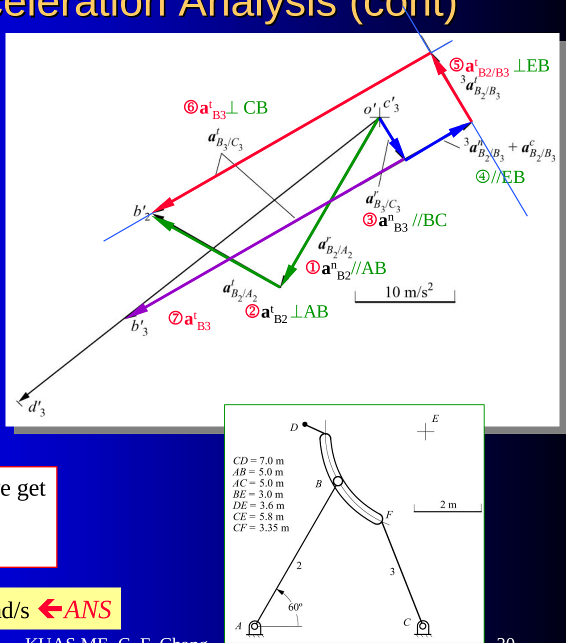
Ex 3.7 : Acceleration Analysis (cont)

$$\mathbf{a}_{B_2} = \mathbf{a}_{B_3} + \mathbf{a}_{B_2/B_3} + \mathbf{a}^c_{B_2/B_3}$$

b'_3 can be determined from
$\mathbf{a}_{B3}=\mathbf{a}^n_{B3}+\mathbf{a}^t_{B3}$

Then, d'_3 is determined by using the concept of acceleration image
c'-b'-d' is similar to C-B-D



From the acceleration polygon, we get
$|\mathbf{a}^t_{B3}|=32.2$ m/s^2
$|\mathbf{a}_D|=45.9$ m/s^2 ← *ANS*

$\therefore\ \alpha_3=|\mathbf{a}^t_{B3}|/(CB_3)=32.2/5=11.2$ rad/s ← *ANS*

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