Static Force Analysis for Skid Loader – Virtual Work

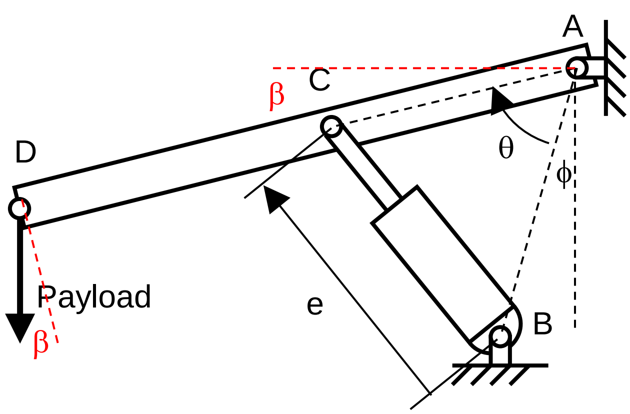
A trunnion mount hydraulic cylinder actuates the arm of a skid steer loader as shown below. At this position, e = 40 inches, $\theta = 61.131°$, $\dot{e} = -12$ ips, $\dot{\theta} = -0.3625$ rad/s.

Determine the force on the hydraulic cylinder required to lower an 800 lbf payload attached to point D by a cable. The payload moves with constant velocity at the position shown. You may neglect the effects of friction. The weight of the arm and cylinder are small compared to the payload. Show your work.

from Newtonian solution
$F_C = 2261.9$ lbf

$F_{CYLINDER}$ 2261.7 lbf up/left

$\theta + \phi = 77.131°$
$\beta = 90° - \theta - \phi = 12.869°$



Not to scale
AB = 36 inches
AC = 42 inches
AD = 96 inches
$\phi = 16°$

$V_D = AD\ \dot{\theta} = 34.8$ ips

power
$\overline{F}_C \circ \overline{V}_C + \overline{P} \circ \overline{V}_D = 0$

β

$-F_C\,(\dot{e}) + P\,(\cos\beta)\,V_D = 0$

What corresponding hydraulic pressure would be required for a cylinder with a 3 inch DIA bore?

$P_{CYLINDER}$ 320 psi $A = \pi D^2 / 4 = 7.069\ in^2$

Is this value reasonable? Why?

OK, industrial hydraulics often go to 3000 psi

If you include friction between the piston and cylinder wall, will it increase or decrease your computation for pressure.

increase decrease Why? pressure pushes up
friction force will be up opposing piston motion

What value would you use for the coefficient of friction between the piston and cylinder wall?

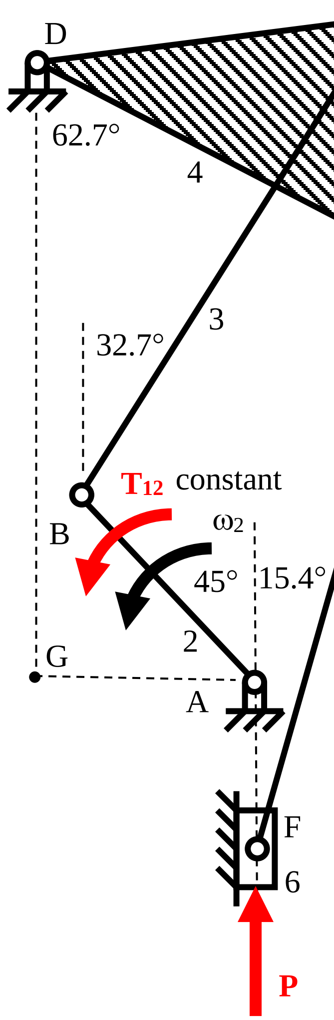
μ 0.1 lubricated Why?

Should your analysis be different if the cylinder were retracting at constant velocity instead of the payload moving at constant velocity?

yes no Why? constant $\dot{e}$ means $\dot{\theta}$ will not be constant means velocity of the payload will not be constant, therefore must account for acceleration of payload mass

Static Force Analysis for Sewing Machine – Virtual Work

Determine crank torque T_{12} required to maintain this sewing machine linkage in static equilibrium as shown below for applied load P = 10 N. Assume that friction and the weight of the links are negligible.



AB	= 1.60 cm
BC	= 3.57 cm
DC	= 2.24 cm
CE	= 1.60 cm
DE	= 2.74 cm
EF	= 3.81 cm
AG	= 1.42 cm
DG	= 3.81 cm
DCE	= 90°
CDE	= 35.7°

from velocity solution

$\omega_2 = +8\pi$ rad/sec

$\overline{V}_F = 64.71$ cps down

actual power, no friction, no springs

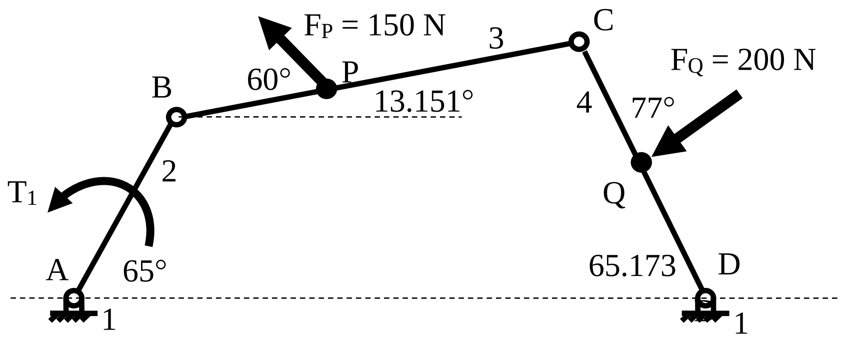
$$T_{12} \circ \omega_2 + \overline{V}_F \circ \overline{P} = 0$$

assume T_{12} is CCW

$$(+T_{12}) (+8\pi \text{ rad/sec}) + (-64.72 \text{ cm/sec}) (+10 \text{ N}) = 0$$

$T_{12} = + 25.75$ N.cm

Static Force Analysis for Four Bar – Virtual Work



AB = 30 cm
BC = 60 cm
CD = 45 cm
AD = 90 cm
BP = 23 cm
DQ = 24 cm

$$\begin{bmatrix} -r_3\sin\theta_3 & r_4\sin\theta_4 \\ r_3\cos\theta_3 & -r_4\cos\theta_4 \end{bmatrix}\begin{Bmatrix}\dot\theta_3\\ \dot\theta_4\end{Bmatrix} = \begin{Bmatrix} r_2\dot\theta_2\sin\theta_2 \\ -r_2\dot\theta_2\cos\theta_2\end{Bmatrix}$$

Assume $\dot\theta_2 = +1$ rad/sec virtual velocity

$$\begin{bmatrix} -13.651 & 40.841 \\ 58.426 & -18.895 \end{bmatrix}\begin{Bmatrix}\dot\theta_3\\ \dot\theta_4\end{Bmatrix} = \begin{Bmatrix} 27.189 \\ -12.678\end{Bmatrix} \qquad \begin{Bmatrix}\dot\theta_3\\ \dot\theta_4\end{Bmatrix} = \begin{Bmatrix} -0.390 \\ 0.535\end{Bmatrix}\text{rad/sec}$$

$$\vec V_P = j\, r_2\dot\theta_2 e^{j\theta 2} + j\,(BP)\dot\theta_3 e^{j\theta 3} = -r_2\dot\theta_2\sin\theta_2 + j\, r_2\dot\theta_2\cos\theta_2 - (BP)\dot\theta_3\sin\theta_3 + j\,(BP)\dot\theta_3\cos\theta_3$$

$$\vec V_P = -25.148 + j\,3.944\ \text{cm/sec}$$

$$\vec V_Q = j\,(DQ)\dot\theta_4 e^{j\theta 4} = (DQ)\dot\theta_4\sin\theta_4 + j\,(DQ)\dot\theta_4\cos\theta_4 = -11.653 - j\,5.391\ \text{cm/sec}$$

$\vec F_P$ = 150 N @ 133.151° = - 102.589 + j 109.433 N

$\vec F_Q$ = 200 N @ 217.827° = - 157.973 - j 122.656 N

$$\vec T_{12}\circ\vec{\dot\theta}_2 + \vec F_P\circ\vec V_P + \vec F_Q\circ\vec V_Q = 0$$

$T_{12}\dot\theta_2$ + (2579.91 + 431.60) N.cm/sec + (1840.86 + 661.24) N.cm/sec = 0

T_{12} = -5513.6 N.cm

from Newtonian matrix solution T_{12} = -5514.89 N.cm

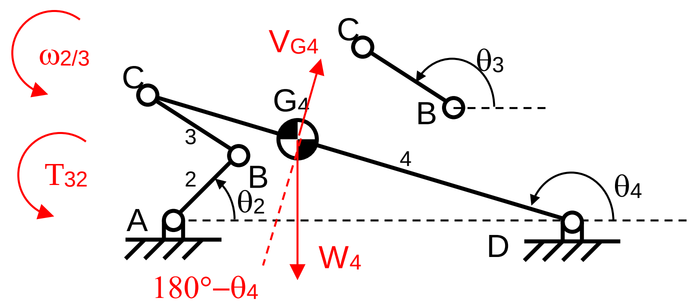
Static Force Analysis for Pushups – Virtual Work

A person doing pushups can be modeled as a four bar linkage. The ground is the base link, the forearms are link 2, the upper arms are link 3, and the torso and legs are link 4 as shown below. The wrists are revolute O_2, the elbows are revolute A, the shoulders are revolute B, and the toes are revolute O_4. Mass of the torso/legs is 180 lbm and the mass center is located at G_4. Assume that all muscular effort is provided by the triceps as torque T_{32} across the elbows.

For an initial estimate, use the additional assumptions:

a) ω_4 is constant at this position
b) Weight of the arms is negligible compared to weight of the torso/legs.
c) Friction is negligible at A, B, C and D.
d) No muscular torque is generated at A, C and D.

AD = 52 inch	$\theta_2 = 45°$
AB = 12 in	$\theta_3 = 149.14°$
BC = 14 in	$\theta_4 = 164.24°$
CD = 57.7 in	$\omega_2 = 0.5$ rad/sec
$DG_4 = 39$ in	$\omega_3 = -1.435$ rad/sec
	$\omega_4 = -0.387$ rad/sec



Determine angular velocity across the elbows $\omega_{2/3}$ for the position and velocity provided above.

$\omega_{2/3} = \omega_2 - \omega_3 = +1.935$ rad/sec

Determine elbow torque T_{32} for the position and velocity provided above.

$V_{G4} = DG_4\ \omega_4 = 15.093$ ips UP, $A_{G4}^T = DG_4\ \alpha_4 = 0$, $A_{G4}^N = DG_4\ \omega_4^2 = 5.84$ ips^2 = 0.015 G negligible

$\overline{W}_4 \circ \overline{V}_{G4} + \overline{T}_{32} \circ \overline{\omega}_{2/3} = 0$ $\quad$ $-W_4 \cos(180°-\theta_4)\ V_{G4} + T_{32}\ \omega_{2/3} = 0$ $\quad$ $T_{32} = +1351.2$ in.lbf

Do the magnitude and direction for your answer seem reasonable? Why?

from Newtonian solution $\quad$ $T_{32} = 1351.2$ in.lbf CCW

Rate the last four assumptions and state your reasoning.

b) constant ω_4 1=poor 2=acceptable for an approximation 3=very good

c) weight of arms is negligible 1=poor 2=acceptable for an approximation 3=very good

d) friction is negligible 1=poor 2=acceptable for an approximation 3=very good

e) no muscle force at A, C, D 1=poor 2=acceptable for an approximation 3=very good

Determine ω_4 of the torso/legs when the forearm is aligned with the upper arms ($\theta_2 = \theta_3$). $\omega_4 = 0$