Sample Questions Agricultural and Biological Professional Engineering Examination

V. Machines

V.A. Hydraulic power component performance (e.g., pumps, motors, conduit, pipe size, valves, cylinders, logic controls)

A fluid power hydraulic system is being designed to move a cylinder at constant speed. The maximum operating pressure of the system is 1,200 psi and the maximum operating load on the cylinder is 14,500 lb, requiring a rod diameter of 1.75 in. When the cylinder is being extended against the resistive load, the maximum pressures in the cap and rod ends of the cylinder are 1,080 and 65 psi, respectively. Selecting from standard cylinder bore diameters, the required cylinder bore diameter in inches is:

(A) 6
(B) 5
(C) 4
(D) 3.25

Correct answer (B)

Reference: *Engineering Principles of Agricultural Machines* by Srivastava, Goering, and Rohrbach, p. 97.

The area at the rod end of the cylinder with a rod diameter of 1.75 in:

$$A_{\text{rod end}} = A_{\text{cap}} - A_{\text{rod}}$$

$$A_{\text{rod}} = \frac{\pi}{4} d_r^{\,2} = \frac{\pi}{4}(1.75\,\text{in})^2 = 2.405\,\text{in}^2$$

Using a force balance on the cylinder:

$$P_{\text{cap}} A_{\text{cap}} - F_{\text{load}} - P_{\text{rod}} A_{\text{rod end}} = 0$$

Working through the algebra: $P_{\text{cap}} A_{\text{cap}} - F_{\text{load}} - P_{\text{rod}} (A_{\text{cap}} - A_{\text{rod}}) = 0$

$$(P_{\text{cap}} - P_{\text{rod}})A_{\text{cap}} = F_{\text{load}} - P_{\text{rod}} A_{\text{rod}} \quad \text{so} \quad A_{\text{cap}} = \frac{F_{\text{load}} - P_{\text{rod}} A_{\text{rod}}}{(P_{\text{cap}} - P_{\text{rod}})} = \frac{\pi}{4} B^2$$

$$B = \sqrt{\left(\frac{4}{\pi}\right)\frac{F_{\text{load}} - P_{\text{rod}} A_{\text{rod}}}{(P_{\text{cap}} - P_{\text{rod}})}} = \sqrt{\left(\frac{4}{\pi}\right)\frac{14{,}500\,\text{lb} - (65\,\text{psi})(2.405\,\text{in}^2)}{(1080\,\text{psi} - 65\,\text{psi})}} = 4.242\,\text{in}$$

As this is the minimum diameter, the next larger bore diameter, 5 in. (answer B), must be selected.

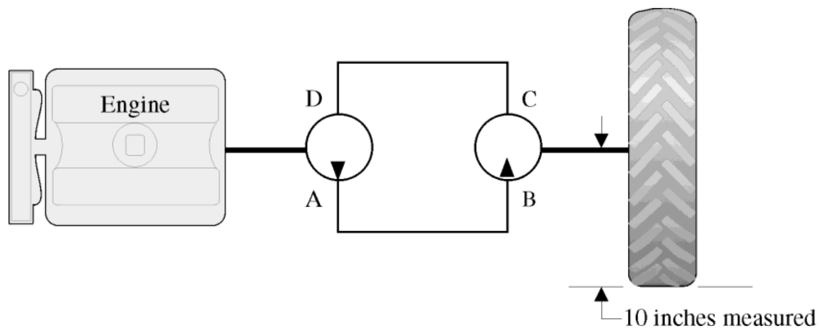
V.A. Hydraulic power component performance (e.g., pumps, motors, conduit, pipe size, valves, cylinders, logic controls)

Using the information in the table below including the desired condition of pressure and flow, the maximum tractive force (lb) that can be expected while the vehicle is operating at normal speed with a hydraulic motor having a displacement of 4.0 in^3/rev, a torque efficiency of 85%, and with the tire on the right, is most nearly:

Desired Condition of Pressure and Flow*					
Condition at Desired Output	Q_A (gal/min)	P_A (lb/in^2)	P_B (lb/in^2)	P_C (lb/in^2)	P_D (lb/in^2)
1	20	3,000	2,800	300	100

* Reference: Goering, C.E., and Hansen, 2004. Engine and Tractor Power, 4th ed.

(A) 70
(B) 130
(C) 160
(D) 270



Correct answer (B)
Reference: Goering, C.E., and Hansen. 2004. Engine and Tractor Power, 4th ed. ASAE p. 391-392
Solution:
F_t = traction force
r = wheel radius = 10 in
T = motor output torque
e_{tm} = motor torque efficiency = 0.85
D_m = motor displacement = 4.0 in^3/rev
ΔP_m = pressure drop across the motor = P_B - P_C

$$T = r \cdot F_t \quad \text{so:} \quad F_t = \frac{T}{r}$$

$$e_{tm} = \frac{T \cdot 2\pi \frac{\text{rad}}{\text{rev}}}{\Delta P_m \cdot D_m} \quad \text{so:} \quad T = \frac{\Delta P_m \cdot D_m \cdot e_{tm}}{2\pi \frac{\text{rad}}{\text{rev}}} = \frac{(P_B - P_C) \cdot D_m \cdot e_{tm}}{2\pi \frac{\text{rad}}{\text{rev}}}$$

$$T = \frac{(2800-300)\frac{lb}{in^2}\cdot\left(4.0\frac{in^3}{rev}\right)\cdot 0.85}{2\pi\frac{rad}{rev}} = 1352.8\ in\cdot lb$$

$$F_t = \frac{T}{r} = \frac{1352.8\ in\cdot lb}{10\ in} = 135.3\ lb$$

V.B. Hydraulic circuit analysis (e.g., heat generation, pressure drop, constant pressure, constant flow, load sensing, unloading, sequencing)

A hydraulic cylinder with a bore diameter of 4.0 in. and a rod diameter of 2.0 in. has a 24 in. long stroke. The minimum flow rate in gallons per minute from the pump that will allow the cylinder to be cycled (extended and then retracted) continuously at a rate of 5 cycles in 4 minutes is most nearly:

(A) 3.3

(B) 2.9

(C) 1.6

(D) 0.4

Correct answer (B)

Reference: *Engineering Principles of Agricultural Machines* by Srivastava, Goering, and Rohrbach, pp. 96-107.

Volume of fluid pump must deliver to cap end of cylinder to extend cylinder:

$$V_{ext.} = \frac{\pi}{4}B^2L = \frac{\pi}{4}(4.0\ in)^2\,24\,in = 301.6\frac{in^3}{extension}$$

Volume of fluid pump must deliver to rod end of cylinder to retract cylinder:

$$V_{retr.} = \frac{\pi}{4}\left(B^2 - d_r^{\ 2}\right)L = \frac{\pi}{4}\left[(4.0\ in)^2 - (2.0\ in)^2\right]24\,in = 226.2\frac{in^3}{retraction}$$

Total volume of fluid pump must deliver to circuit to cycle the cylinder:

$$V_{cycle} = V_{ext.} + V_{retr.} = 301.6\frac{in^3}{extension} + 226.2\frac{in^3}{retraction} = 527.8\frac{in^3}{cycle}$$

Required minimum pump flow rate:

$$Q_{pump} = \frac{5\,cycles}{4\,min}V_{cycle} = \frac{5\,cycles}{4\,min}\left(527.8\frac{in^3}{cycle}\right)\frac{1\,gal}{231\,in^3} = 2.86\frac{gal}{min}$$

V.F. Machine and component power requirements (e.g., electrical, hydraulic, mechanical, pneumatic)

A sprayer manufacturer wants to produce a small sprayer for acreages. The sprayer will have a 200 L tank with recirculation nozzles inside the tank using some of the flow to keep the spray solution in the tank well mixed. The maximum flow rate is to be 76 L/min and the maximum pressure at the pump is to be 410 kPa. If the overall mechanical efficiency of the pump is expected to be 60%, the input power required to operate the pump will be most nearly:

(A) 0.3 kW

(B) 0.5 kW

(C) 0.9 kW

(D) 9.0 kW

Correct answer (C)

Reference: *Engineering Principles of Agricultural Machines* by Srivastava, Goering, and Rohrbach, pp. 284-289.

Equation 7.1, p. 288:

$$Pwr = \frac{Q \cdot P}{\left(60{,}000 \frac{L \cdot kPa}{min \cdot kW}\right) \eta_m}$$

Pwr = input power to the pump, kW

Q = flow rate from the pump, 76 L/min

P = pressure at the pump, 410 kPa

η_m = overall mechanical efficiency of the pump, decimal = 0.60

$$Pwr = \frac{\left(76 \frac{L}{min}\right) \cdot (410\ kPa)}{\left(60{,}000 \frac{L \cdot kPa}{min \cdot kW}\right) \cdot (0.60)} = 0.866\ kW$$

V.G. Machines for materials handling/conveyance

Barley is to be conveyed from a dump pit to a holding bin using a screw conveyor inclined at approximately 40° from horizontal. Based on the operational data tabulated below for the inclined conveyor for moving barley, the screw speed setting (rpm) that will maximize grain flow rate with minimal expended energy is most nearly:

Select operational parameters for conveying barley (41.6 lb_m/bu) through a 40° inclined screw conveyor

Screw speed (rpm)	Flight fill (%)	Grain flow rate (lb_m/min)	Thrust on screw (lb_f)	Required power (hp)	Specific energy (*X* 10^{-5} kWh/lb_m)
80	74	215	143	0.58	3.32
155	70	395	138	0.90	2.83
200	67	480	130	0.98	2.52

265	61	580	112	1.05	2.25
380	51	705	88	1.25	2.20
520	42	800	78	1.60	2.49
675	36	880	76	2.10	2.97
740	32	910	75	2.25	3.07

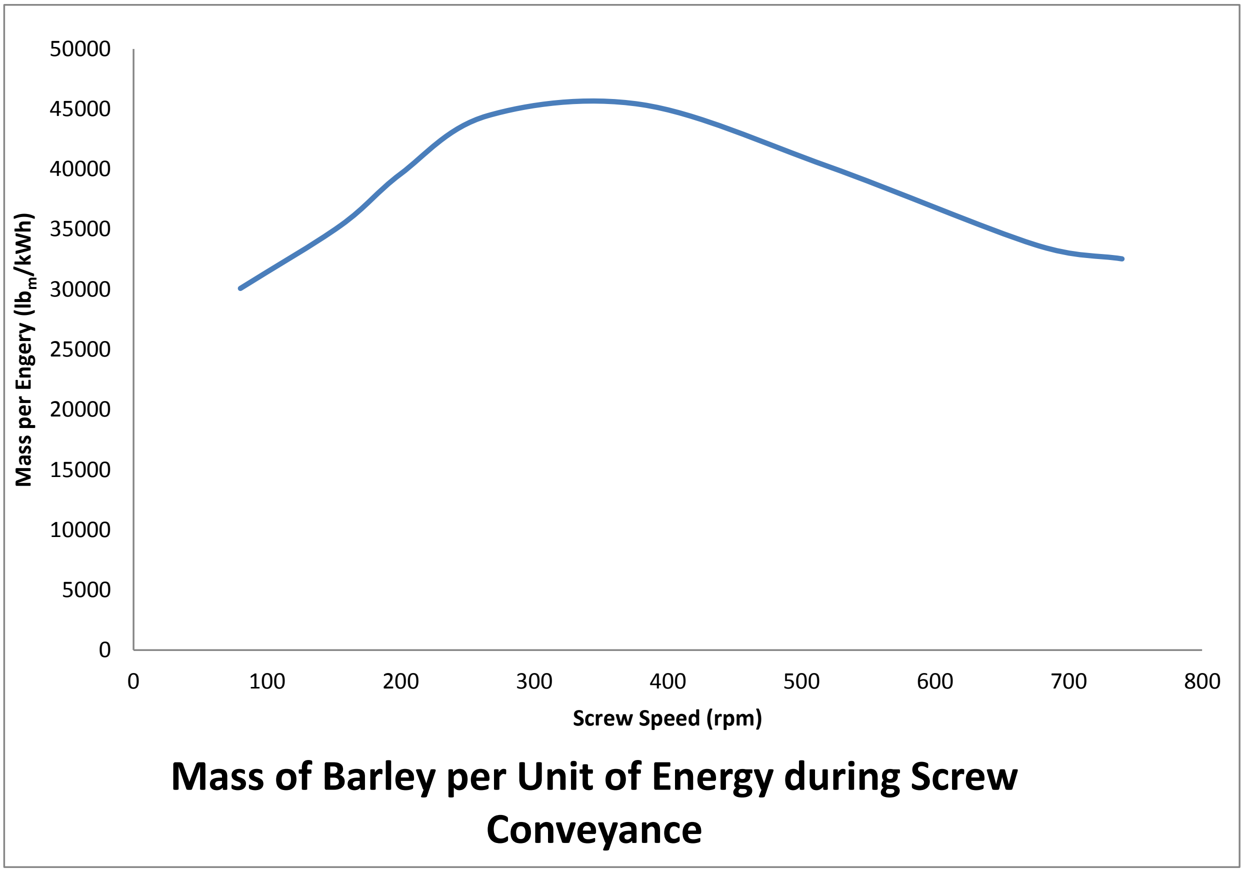
Source: Regan, WM and SM Henderson. 1959. Performance characteristics of inclined screw conveyors. Agric. Engr. 40(8):450-452.

A) 80
B) 380
C) 740
D) any setting between 80 and 740 as flow rate/energy value is constant

Solution
Correct answer (B)
Reference: FE Reference Handbook, ver 9.2, NCEES, 2014
Grain flow rate (lb_m/min) divided by required power (hp) results in a grain mass per energy value (lb_m/hp·min). Conversion of hp·min to hph and then to kWh follows:

$$X\ \frac{lb_m}{hp \cdot min} \times \frac{60\ min}{hr} \times \frac{hph}{0.7457\ kWh} = X'\frac{lb_m}{kWh}$$

Plotting of mass per energy values at the given screw speed values results in figure as shown below where maximum mass per unit of energy is most nearly at 380 rpm.
Additionally, the reciprocal of the values on the curve would be those of specific energy (kWh/lb_m) such as those shown in last column of table. Inspection of the values in the last column of the given table finds the minimum energy per unit mass value (2.20×10^{-5} kWh/lb_m) to be at a screw speed of 380 rpm.



V.H. Machines for offroad/field use (e.g., harvesters, planters, sprayers, heavy equipment, tillage equipment)

An 8-shank chisel plow with 10-cm twisted shovels is pulled through a field at a typical speed of 8 km/h in medium-textured soil. Assuming a draft of 24.7 kN and a depth of 20 cm the drawbar power in kW to pull the implement is most nearly:

(A) 25
(B) 35
(C) 45
(D) 55

Correct answer (D)

Reference: ASABE Standard EP 496.3 Agricultural machinery management

Section 4.1.1.3, $P_{db} = Ds/3.6$

P_{db} = drawbar power

D = draft = 24.7 kN

S = travel speed = 8 km/h

$$P_{db} = \frac{(24.7\ kN) \cdot \left(8\frac{km}{h}\right)}{\left(\frac{3600\ s}{h}\right) \cdot \left(\frac{km}{1000\ m}\right) \cdot \frac{kN \cdot m}{s \cdot kW}} = 54.89\ kW$$

V.J. Mechanical power transmission (e.g.,chains, belts, clutches, gears, shafts, CVT, pulleys, U-joints)

The power to be transmitted to a component on a peanut digger with a two-sheave open belt drive is 7.0 kW. The service factor for the component is 1.3. The belt velocity is 11 m/s. The slack-side tension for the drive is 150 N. The tight-side tension (in N) on the drive is most nearly:

(A) 635

(B) 785

(C) 830

(D) 975

Correct answer (D)

Reference: *Engineering Principles of Agricultural Machines* by Srivastava, Goering, and Rohrbach, pp. 64-65.

Calculating the design power: $$P_d = P(S.F.) = (7.0\ kW)(1.3)\left(\frac{1000W}{kW}\right) = 9{,}100W$$

Formula for belt power: $$P = (T_1 - T_2)v$$

Solving for the belt tight-side tension: $$T_1 = \frac{P}{v} + T_2 = \left(\frac{9100\,W}{11 m/s}\right)\left(\frac{N \cdot m}{s \cdot W}\right) + 150\,N = 977.3\,N$$

V.L. Machine stability analysis (e.g., stationary, in-motion or moving)

Consider a tractor having a 270-cm wheel base and static (no load) front and rear axle weights of 25 kN and 50 kN, respectively. This tractor has a hitch point 60 cm behind the rear axle and 50 cm above ground level. How much load, in kN, will be on the front axle if there is a rearward horizontal load on the hitch of 35 kN?

(A) 16

(B) 18

(C) 20

(D) 22

Correct answer (B)

Reference: Goering, C.E., and Hansen. 2004. Engine and Tractor Power, 4th ed. ASAE, p. 419-420, Equation 16.3

W_f = front axle weight of static tractor = 25 kN
W_r = rear axle weight of static tractor = 50 kN

W = total tractor weight = $W_f + W_r$ = 25 kN + 50 kN = 75 kN
R_f = load on front axle
X_{cg} = horizontal distance from rear axle centerline forward to tractor center of gravity
F_{db} = rearward horizontal load on drawbar = 35 kN
Z_r = distance from rear wheel contact point with the ground to the line of action of the drawbar pull. In this case the drawbar pull is horizontal, so Z_r is equal to the height of the drawbar = 50 cm.
WB = tractor wheel base = 270 cm

From no-load condition: $X_{cg} = \left(\frac{W_f}{Wr}\right) WB = \left(\frac{25\ kN}{75\ kN}\right) 270\ cm = 90\ cm$
From loaded condition (sum moments around rear axle contact point):

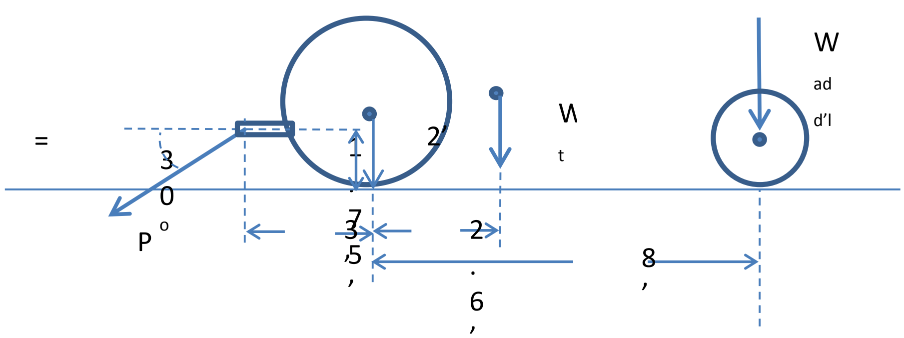
$$R_f \cdot WB + F_{db} \cdot Z_r - W \cdot X_{cg} = 0$$

$$R_f = \frac{W \cdot X_{cg} - F_{db} \cdot Z_r}{WB} = \frac{(75\ kN) \cdot (90\ cm) - (35\ kN) \cdot (50\ cm)}{270\ cm} = 18.52\ kN$$

V.L. Machine stability analysis (e.g., stationary, in-motion or moving)

A tractor with a wheel base of 8 feet and rear tire radius of 2 feet is pulling a load of 8,300 pounds acting at a downward 30 degree angle from horizontal. The load hitch point is 3 feet behind the rear axle and 1.75 feet above the ground surface. The total tractor weight is 9,000 pounds with the center of mass acting at a point 2.6 feet in front of the rear axle. The minimum amount of additional weight (lb) that must act upon the front axle in order to maintain static equilibrium is most nearly:

(A) 0 (already in static equilibrium)
(B) 200
(C) 430
(D) 680



Correct answer (B)
Reference: **Goering, C.E., and Hansen. 2004. Engine and Tractor Power, 4th ed. ASAE**

Solution:
Sum moments about the point where the rear wheel contacts the ground (directly under the rear axle centerline):
$\Sigma M = 0 = P \cdot \cos\theta \cdot y_{db} + P \cdot \sin\theta \cdot x_{db} - W_t \cdot x_{cg} - W_{add'l} \cdot x_{WB}$

$$W_{addl} = \frac{P \cdot \cos\theta \cdot y_{db} + P \cdot \sin\theta \cdot x_{db} - W_t \cdot x_{cg}}{x_{WB}}$$

$$W_{addl} = \frac{8{,}300\text{lb} \cdot \cos 30° \cdot 1.75\text{ft} + 8{,}300\text{lb} \cdot \sin 30° \cdot 3\text{ft} - 9{,}000\text{lb} \cdot 2.6\text{ft}}{8\text{ft}} = 203.6\text{lb}$$

V.M. Structural analysis of machine components (e.g., power transmission systems and drive trains, frames)

If a $^{3}/_{4}$-inch diameter, grade 8 bolt is used as a hitch pin in double shear, what is the maximum permissible horizontal load in pounds? Assume maximum shear stress theory and a tensile strength of 120,000 psi.

(A) 26,500
(B) 35,000
(C) 53,000
(D) 106,000

Correct answer (C)

Reference: *Machine Design for Mobile and Industrial Equipment or FE Reference Handbook version 9.0 page 227*

Load strength is 120,000 psi (tensile); assuming max shear stress theory, proof shear strength would be 60,000 psi (τ_y = 60,000 psi). Since the bolt is in double shear, the correct area to be used is twice the cross-sectional area of the bolt.
τ = shear strength = 60,000 psi
F = maximum load
A = shear area
d = bolt diameter = 0.75 in

$$\tau = F/A$$

$$A = 2 \cdot \frac{\pi}{4} \cdot d^2 = \frac{\pi}{2} \cdot d^2$$

$$\tau = \frac{F}{\frac{\pi}{2} \cdot d^2} = \frac{2 \cdot F}{\pi \cdot d^2}$$

$$F = \frac{\tau \cdot \pi \cdot d^2}{2} = \frac{\left(60{,}000 \frac{lb}{in^2}\right) \cdot \pi \cdot (0.75\ in)^2}{2} = 53{,}014\ lb$$