ORDRE DES INGÉNIEURS DU QUÉBEC

May 2015 SESSION

Open-book examination
Calculators : only authorized models
Duration : 3 hours

14-AE-A6
POWER UNITS FOR AGRICULTURAL, BIOSYSTEMS, AND FOOD INDUSTRIES

Version: May 2015[1]

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Question #1 (20 points)

A six-cylinder diesel engine in a tractor is built as follows: 130.2mm (5.13in) bore diameter, a 127.0 mm (5in.) stroke, and a clearance volume of 0.119L (7.26in^3) in each cylinder. Assume n=1.3.

a) Calculate the total engine displacement. (4 points)

b) Calculate the compression ratio. (4 points)

c) Calculate the theoretical cycle efficiency. (6 points)

d) Why did Diesel design his cycle with constant pressure between points 2 and 3 (on the theoretical diesel cycle) instead of using constant volume, as in the Otto cycle? Give one raison. Briefly explain your answer. (6 points)

Question #2 (20 points)

A diesel naturally aspired engine (intake manifold at an atmospheric pressure equal to 101.3 kPa and at an air temperature of 25°C) produces a power of 90 kW. The engine has a Specific Fuel Consumption (SFC) of 3.1 kW.h/L. It is possible to install a turbocharger on the same engine. The compressor raised the air pressure and temperature in the intake manifold at 180 kPa and at 130°C, respectively.

a) Calculate the diesel engine power with the turbocharger installed on it. The Air/Fuel ratio (A/F) is constant. What is the percentage (%) of the power raised with the turbocharger? (7 points)

b) What is the percentage (%) of the power raised with the same turbocharger plus an intercooler installed on the same diesel engine? The intercooler cools down the compressed air at 70°C. (7 points)

c) Calculate the fuel consumption per hour (L/h) : (1) when the engine is naturally aspired and (2) when the engine has a turbo plus an intercooler. Assume that the SFC is constant. (6 points)

Question #3 (20 points)

A tractor power train is illustrated below. The two rear drive wheels have a radius of 0.9m and at maximum power there is a 15% slip (assume that the travel reduction is equal to the slip). Each gear reduction ratio between the engine and the rear axle shaft ($N_{engine}/N_{rear\ shaft}$) are shown for the first 12 gear ratios:

N1 = 240:1 N2 = 210:1 N3 = 180:1 N4 = 150:1

N5 = 130:1 N6 = 115:1 N7 = 100:1 N8 = 85:1

N9 = 70:1 N10 = 55:1 N11 = 40:1 N12 = 25:1

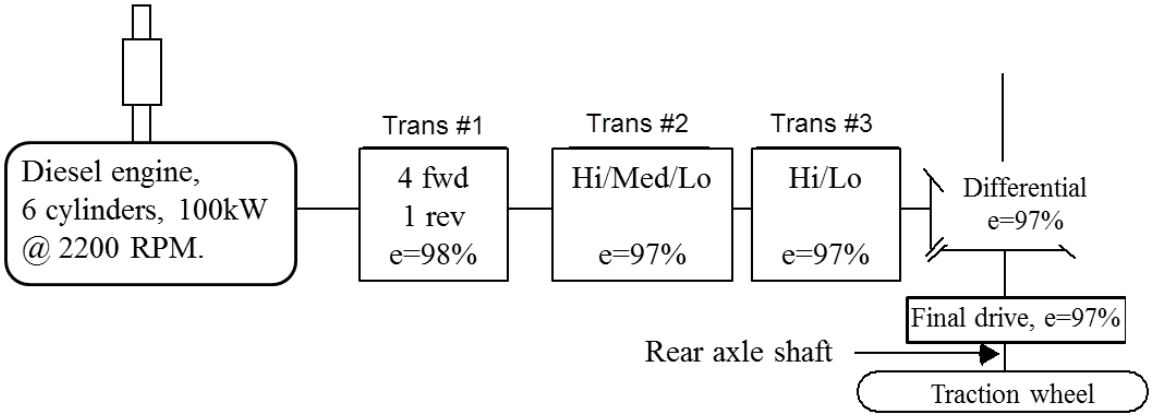


Figure 1. The tractor power train.

a) Calculate the engine output torque (Te) when the third (3^{th}) gear ratio N3 is selected. (4 points)

b) Calculate the rear wheel traction force for the condition defined in a). (3 points)

c) Calculate the actual tractor speed when the sixth (6^{th}) gear ratio N6 is selected. (3 points)

d) Calculate the drawbar power (kW) for the condition defined in c). Assume that the overall wheel rolling resistance is equal to 5kN. Is the engine powerful enough? (4 points)

e) Find the gear ratio for the transmission #2 when the fifth (5^{th}) gear ratio N5 is selected. The other gear ratios in the power train are as fallow : (3 points)

Trans. #1→ 3:1 Trans. #3 → 2.5:1

Differential → 3.4:1 Final drive → 5:1

f) Calculate the power that is transmitted to each rear axle shaft at the engine rated speed of 2200 rotation per minute (rpm). (3 points)

Question #4 (20 points)

A two wheel drive tractor has a total weight of 70kN and is to be used to pull a towed plow on a firm soil (the plow is pulled parallel to the ground). Here are the geometric characteristics of the tractor:

Wheelbase (WB): 2 550 mm

Distance from rear axle centerline to center of gravity (Xcg): 760 mm

The drawbar height (Zr): 460 mm

Distance from drawbar force (hitch point) to the rear axle centerline: 915 mm

Drive wheel overall diameter: 1 830 mm

To solve the next questions, you can either use the appropriate equation and/or the Zoz chart found in the appendix. In the last case, you can draw directly on the Zoz chart provided in the appendix and you must explain your approach.

a) Find the optimal drawbar pull force to achieve the best traction efficiency (TE) as possible. (6 points)

b) Calculate the required rear axle power (P_A) to pull out the plow at an actual travel speed of 5.5 km/h. For this case, assume a drawbar pull force equal to 22kN. (5 points)

c) Calculate the front and rear wheel reactions on the soil while the tractor is pulling the plow with a drawbar pull of 22kN. (5 points)

d) Calculate the tractor travel speed without load (no slip). (4 points)

Question #5 (20 points)

The hydraulic cylinder speed and travel are controlled by the hydraulic oil circuit shown on figure 2. The hydraulic axial piston pump (pressure compensated) has a power (or overall) efficiency (e_{pp}) of 90%. See figure 3 for the delivery-pressure diagram of the pump. The double-acting hydraulic cylinder has a 30 inches travel displacement (stroke), a 4 inches bore diameter and a 1.25 inch piston rod diameter. The hydraulic cylinder has an extension push of 12,570 pounds.

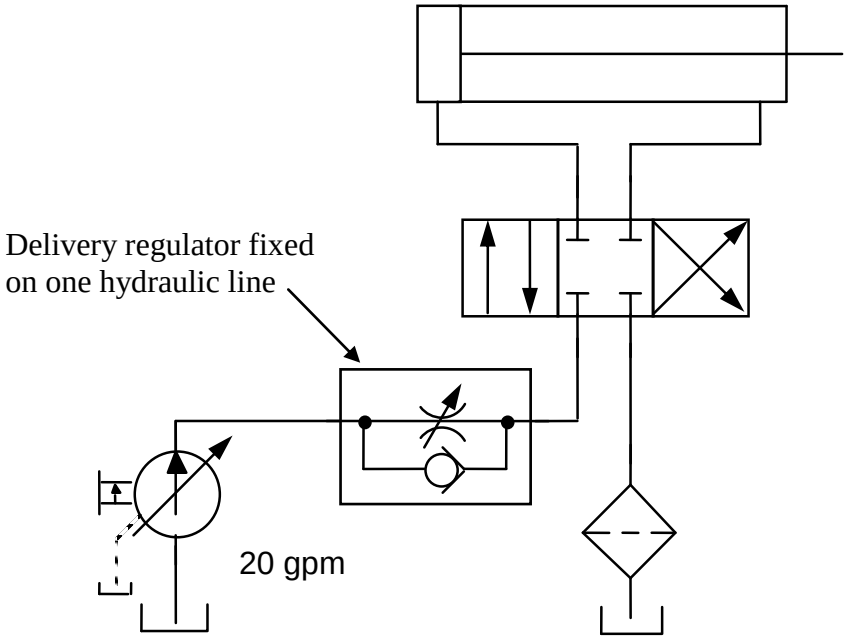


Figure 2. Hydraulic system.

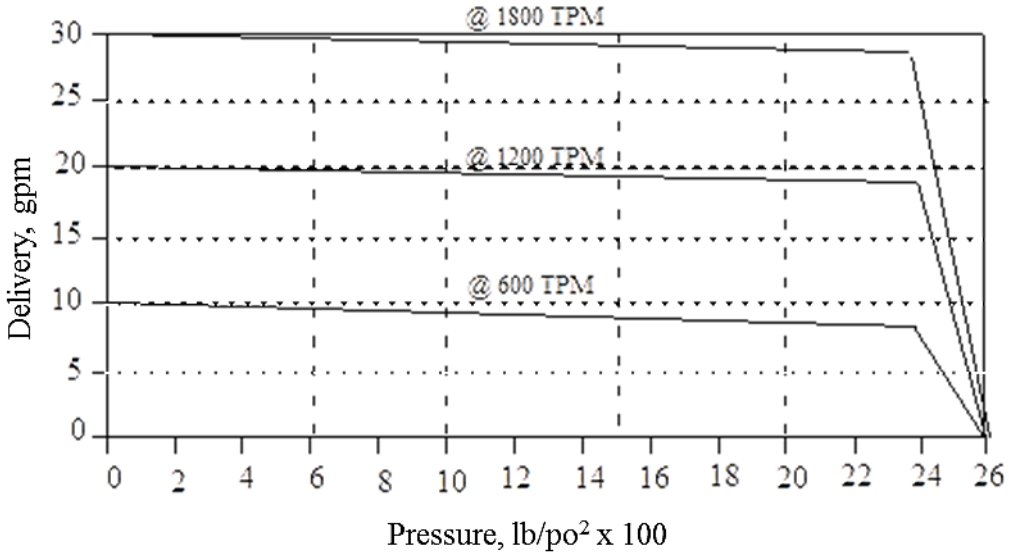


Figure 3. Delivery-pressure diagram of the variable displacement axial piston pump.

a) Find the pump output pressure when the pump delivery is set at 10 gallon per minute (gpm) and the pump operation speed is set at 1200 rotation per minute (rpm). (3 points)

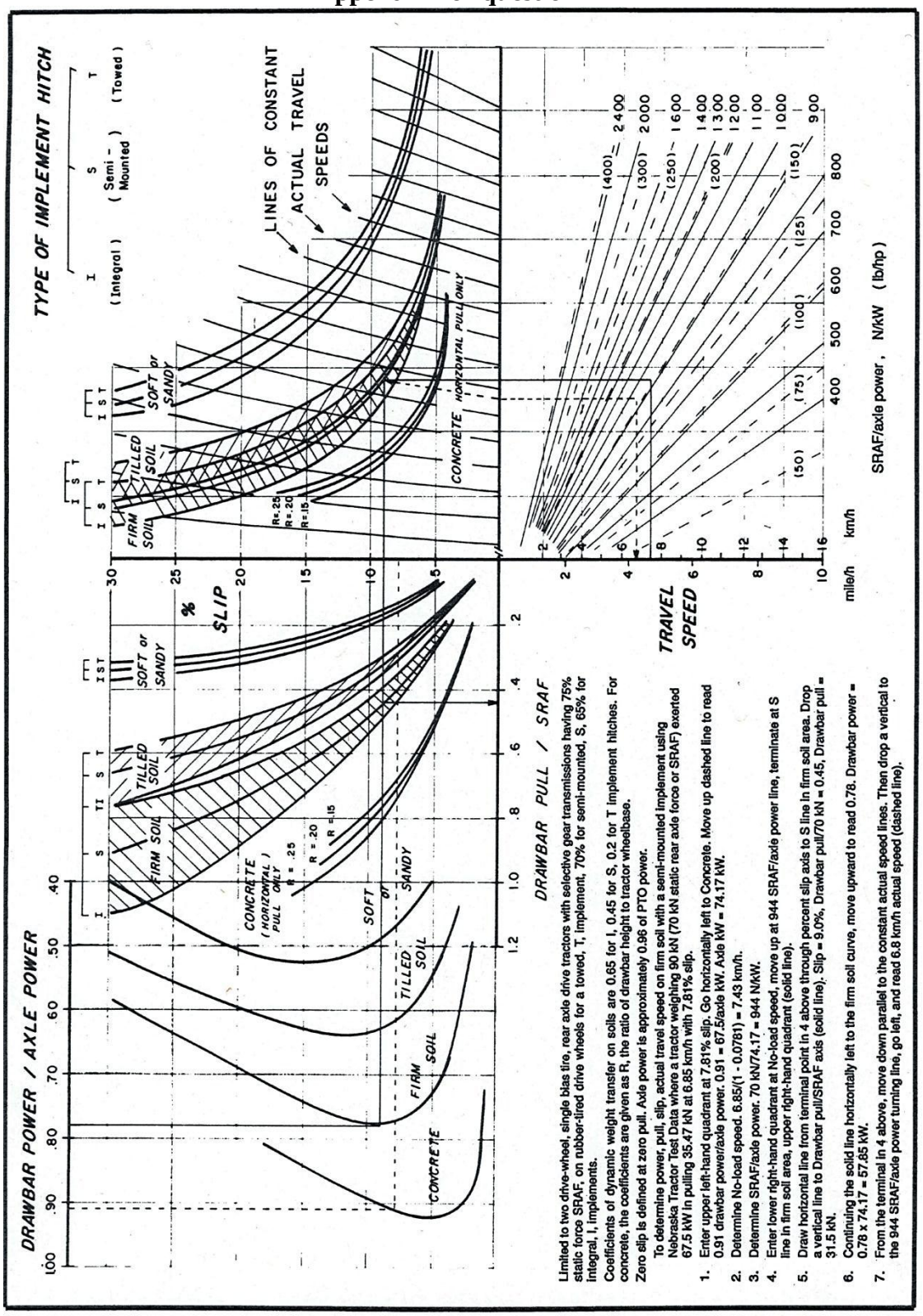
b) Calculate the hydraulic cylinder mechanical power. Assume that the hydraulic cylinder has an overall efficiency of 98%. (5 points)

c) Calculate the maximum pump volumetric displacement (po^3). (5 points)

d) Calculate the hydraulic system power (overall) efficiency (%). (5 points)

e) Is the delivery regulator schematic diagram (placed on one line between the pump and the closed-center directional control valve) correctly design? Briefly explain your answer. (2 points)

Appendix[2] for question #4



Limited to two drive-wheel, single bias tire, rear axle drive tractors with selective gear transmissions having 75% static force SRAF, on rubber-tired drive wheels for a towed, T, implement, 70% for semi-mounted, S, 65% for integral, I, implements.

Coefficients of dynamic weight transfer on soils are 0.65 for I, 0.45 for S, 0.2 for T implement hitches. For concrete, the coefficients are given as R, the ratio of drawbar height to tractor wheelbase.

Zero slip is defined at zero pull. Axle power is approximately 0.96 of PTO power.

To determine power, pull, slip, actual travel speed on firm soil with a semi-mounted implement using Nebraska Tractor Test Data where a tractor weighing 90 kN (70 kN static rear axle force or SRAF) exerted 67.5 kW in pulling 35.47 kN at 6.85 km/h with 7.81% slip.

1. Enter upper left-hand quadrant at 7.81% slip. Go horizontally left to Concrete. Move up dashed line to read 0.91 drawbar power/axle power. 0.91 = 67.5/axle kW. Axle kW = 74.17 kW.
2. Determine No-load speed. 6.85/(1 - 0.0781) = 7.43 km/h.
3. Determine SRAF/axle power. 70 kN/74.17 = 944 N/kW.
4. Enter lower right-hand quadrant at No-load speed, move up at 944 SRAF/axle power line, terminate at S line in firm soil area, upper right-hand quadrant (solid line).
5. Draw horizontal line from terminal point in 4 above through percent slip axis to S line in firm soil area. Drop a vertical line to Drawbar pull/SRAF axis (solid line). Slip = 9.0%, Drawbar pull/70 kN = 0.45, Drawbar pull = 31.5 kN.
6. Continuing the solid line horizontally left to the firm soil curve, move upward to read 0.78. Drawbar power = 0.78 x 74.17 = 57.85 kW.
7. From the terminal in 4 above, move down parallel to the constant actual speed lines. Then drop a vertical to the 944 SRAF/axle power turning line, go left, and read 6.8 km/h actual speed (dashed line).

[2] Engine and tractor power. 4th Edition. Chapter 16, figure 16.9, p.429.