

ORDRE DES INGÉNIEURS DU QUÉBEC

NOVEMBER 2014 SESSION

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

14-AE-A6

POWER UNITS FOR AGRICULTURAL, BIOSYSTEMS, AND FOOD INDUSTRIES

Version: November 2014¹

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Question #1 (20 points)

A six-cylinder diesel engine in a tractor is built as follow: 130.2mm (5.13in) bore diameter, a 127.0 mm (5in.) stroke, and a clearance volume of 0.119L (7.26in³) 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 reason. Briefly explain your answer. (6 points)

Question #2 (20 points)

A diesel naturally aspirated engine (intake manifold at atmospheric pressure) 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 at 180 kPa and then the air temperature raised at 130°C. When the engine is naturally aspirated, the intake manifold pressure is equal to 101.3 kPa at an air temperature of 25°C.

- 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) with the turbo plus the intercooler on the engine. 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 ($N_{\text{engine}}/N_{\text{rear shaft}}$) are shown for the first 12 gear ratios:

$$N1 = 240:1 \quad N2 = 210:1 \quad N3 = 180:1 \quad N4 = 150:1$$

$$N5 = 130:1 \quad N6 = 115:1 \quad N7 = 100:1 \quad N8 = 85:1$$

$$N9 = 70:1 \quad N10 = 55:1 \quad N11 = 40:1 \quad N12 = 25:1$$

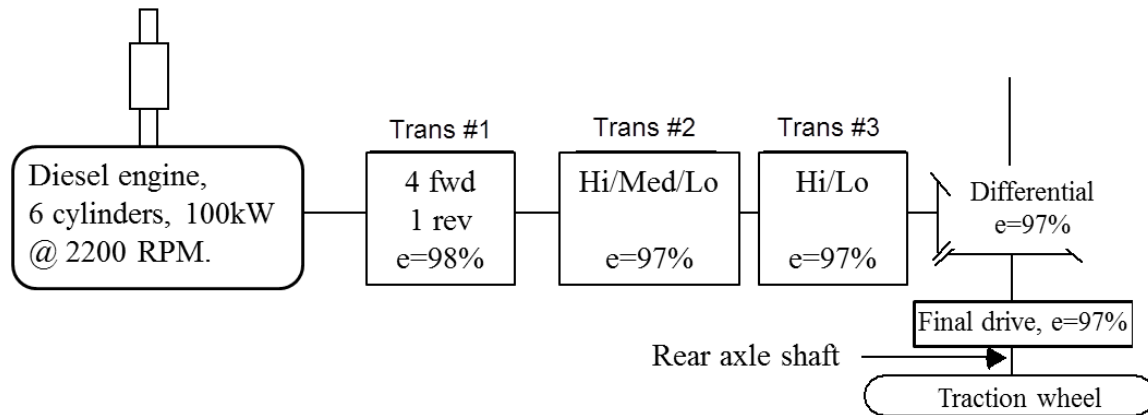


Figure 1. The tractor power train.

- Calculate the engine output torque (T_e) when the third (3^{th}) gear ratio is selected. (4 points)
- Calculate the rear wheel traction force for the condition defined in a). (3 points)
- Calculate the actual tractor speed when the sixth (6^{th}) gear ratio is selected. (3 points)
- 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)
- Find the gear ratio for the transmission #2 when the fifth (5^{th}) gear ratio is selected. The other gear ratios in the power train are as follow : (3 points)

$$\text{Trans. \#1} \rightarrow 3:1$$

$$\text{Trans. \#3} \rightarrow 2.5:1$$

$$\text{Differential} \rightarrow 3.4:1$$

$$\text{Final drive} \rightarrow 5:1$$

- 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): 2550 mm

Distance from rear axle centerline to center of gravity (X_{cg}): 760 mm

The drawbar height (Z_r): 460 mm

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

Drive wheel overall diameter: 1830 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.

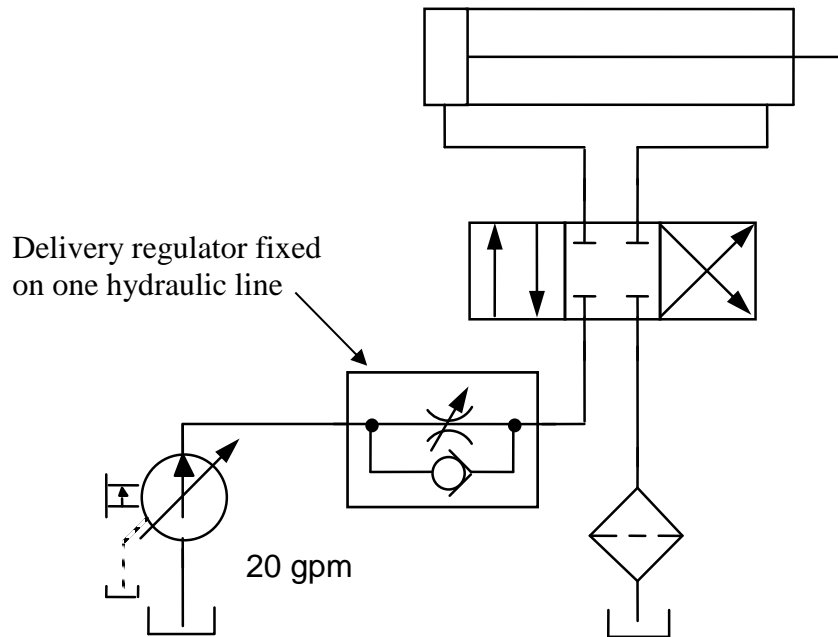


Figure 2. Hydraulic system.

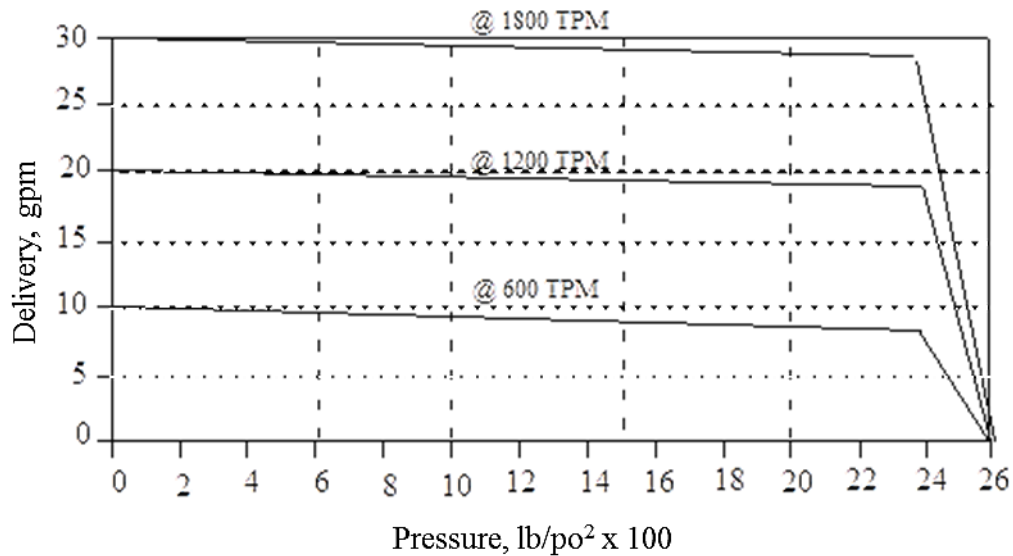
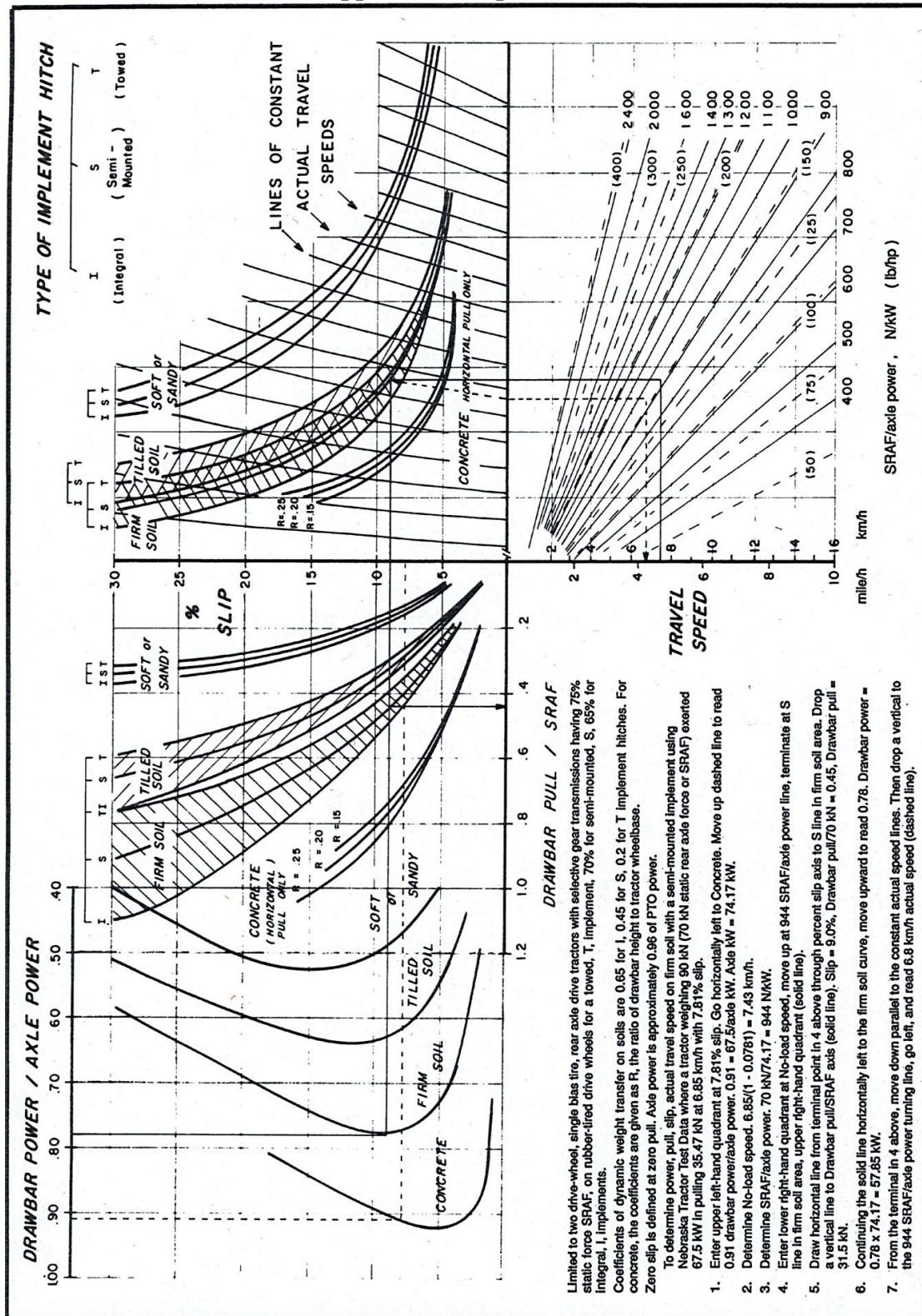


Figure 3. Delivery-pressure diagram of the variable displacement axial piston pump.

- 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 (in^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)

Appendix² for question #4



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