The Mechanics of
Tractor - Implement Performance

Theory and Worked Examples

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CHAPTER 3

TRACTOR PERFORMANCE ON FIRM SURFACE

CONTENTS

Note: The Title Page, Preface, Table of Contents, Index, Appendices and details of the Farmland tractor can be found with Chapter 1.

CHAPTER 3

TRACTOR PERFORMANCE ON A FIRM SURFACE

3.1 INTRODUCTION

We begin the study of tractor performance in detail by considering the performance of a conventional two-wheel drive tractor when operating on a firm surface.

As shown in Chapter 2 the ideal performance of a tractor reflects the performance of the engine and the transmission.

(i) The travel speed depends directly on the engine speed, inversely on the transmission ratio and ,when speed losses are considered, on the wheelslip.

(ii) The drawbar pull depends directly on the engine torque, on the transmission ratio and, when force losses are considered, on the rolling resistance.

(iii) The drawbar power directly on the engine power and the losses through the transmission and at the wheel / ground surface as in (i) and (ii) above.

The actual performance of tractors has traditionally been determined by measurement during practical / experimental tests of their engines and the complete tractor operating under controlled and repeatable conditions as discussed in Section 1.4.2 (b) above.

In Chapter 3 we consider a conventional rear wheel drive tractor driven by a diesel engine through a transmission with discrete gears. The tractor was set up with tyres (size and weight) and other conditions as recommended by the manufacturer. It was then operated to explore the two variables that are open to choice by the operator, viz, governor setting and gear selected.

The testing is done:

(i) with the engine driving a rotary dynamometer or brake. Here the speed of the engine varies with the torque load on it for various settings of the governor as determined by the operator. The fuel consumption and efficiency of the engine are also measures of its performance.

(ii) with the tractor being operated on a firm surface. Here the travel speed varies as the drawbar load is varied. The transmission ratio (the gear), as selected by the operator, influences the performance because it determines the condition under which the draught load is matched to the output of the engine. The efficiency of the transmission which is high and nearly constant is not a significant variable.

The example given is for the hypothetical 'Farmland' tractor based on a selection of results from an Australian Tractor Test Report No 78 (Brown and Baillie, 1973). Other data which are used in this book, have been extracted and are presented in Table 1, Appendix II.

The performance of the tractor is presented in graphical form. A detailed discussion of this technique is presented in Vasey and Baillie (1969).

The following discussion is generally applicable to tractors with governed diesel engines (since these are now most commonly used) although most of the principles would apply to the performance of tractors with other forms of engine. Also, while the discussion is given mainly in terms of a four-wheel tractor, the same principles would generally apply to a two-wheel tractor (Pudjiono and Macmillan, 1995).

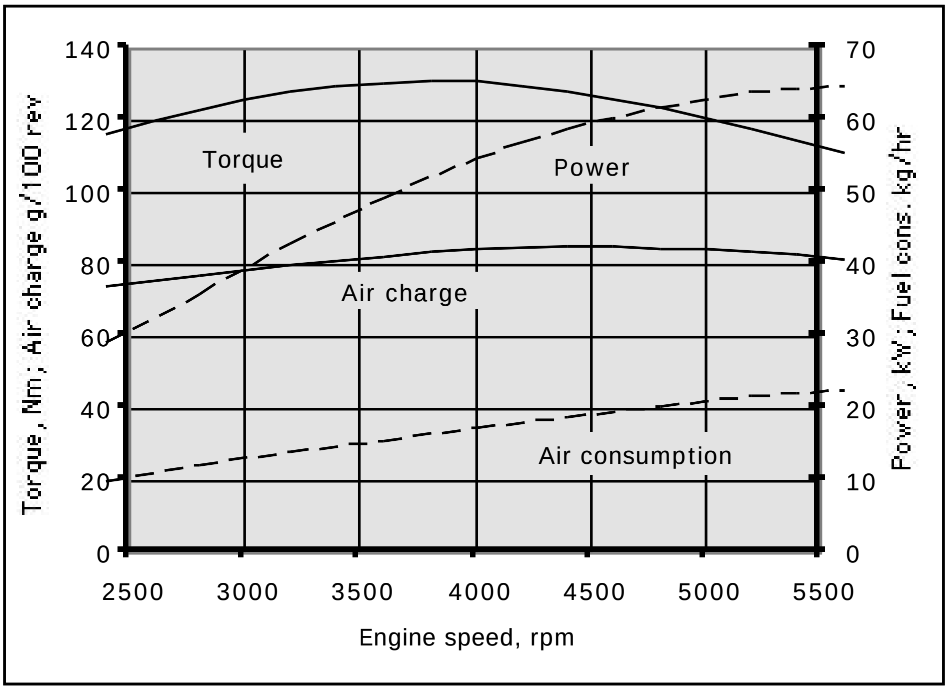

Figure 3.1: Variation in air charge and torque also air consumption rate and power with engine speed. Reproduced from data in Goulburn and Brown (1993) with permission by Mechanical Engineering Publications / Professional Engineering Publishing Ltd.

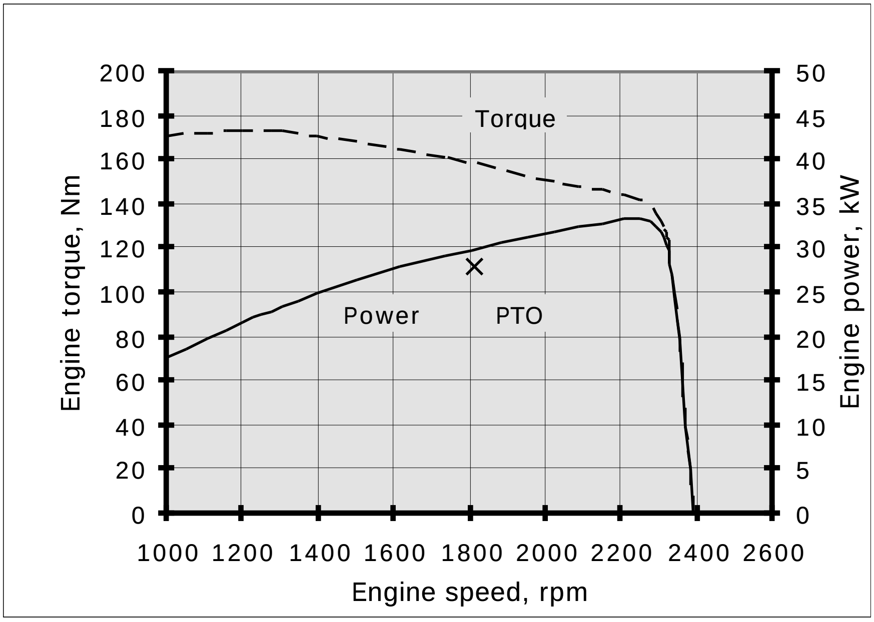

Figure 3.2: Variation of engine torque and power with speed for the Farmland tractor engine at maximum governor setting; data from Figure 2.2.

3.2 ENGINE PERFORMANCE

3.2.1 General

The detailed operation and performance of the diesel engine is presented in many text books, hence the discussion here will be limited to its input and output performance characteristics.

(a) Output

This is transmitted from the crankshaft in a rotational form, hence it is measured in terms of:
(i) torque - rotational effort, Nm
(ii) speed - rotational motion, rad/sec or rpm

The output will be represented by the way in which the torque developed by the engine (equals torque load applied to the engine) varies with its (rotational) speed.

(b) Input

This is in the form of:
(i) air drawn into the engine acting as a pump (air charge)
(ii) fuel metered into the air:
  * already in the cylinders for diesel engine
  * by the carburetor during its passage to cylinders for a spark ignition engine

The maximum output of the engine is effectively determined by the maximum input, the limiting factor being the quantity of air (charge) drawn into the cylinder on each stroke (Goulburn and Brown, 1993). This in turn will depend on:
(i) the size of the cylinders
(ii) the restriction offered by the air passages, valves, etc
(iii) the time available for the air to be drawn in

For a given engine:
(i) at high speed, the time available for the air to enter the cylinders is so short that the air charge is reduced;
(ii) at low speed, the time available for the air to enter the cylinders is longer but heating of the air in the cylinder reduces the charge

Hence, for a given engine, there is an optimum speed at which most air is drawn in; at both higher and lower speeds, less air enters (Figure 3.1).

Because the output (torque) from the engine depends on input (air), the maximum output (torque) coincides approximately with maximum air charge. Strictly, this statement is only true for a fixed air / fuel ratio, as determined by the amount of fuel which can be effectively burnt in the air available. More fuel will give slightly greater output torque, but most of the extra fuel will be wasted and will appear as black, un-burnt carbon in the exhaust gas.

3.2.2 Output

(a) Torque - speed

The torque output represents the magnitude of the rotational effort developed by the engine against a torque load applied to it. The torque-speed graph for an un-governed engine shows a very wide range of speed as the torque load is varied; see Figure 3.1.

In operation the load on a tractor and hence the torque on the engine varies widely and in an unpredictable way, which would cause the tractor to slow down and speed up according to the load. This would be unsuitable, particularly for many PTO driven machines such as cereal harvesters or forage mowers where a constant PTO speed is needed.

To overcome this problem and to reduce the speed variation with load, the engine is fitted with a governor. This is a device which:
(i) can be set by the operator to give different engine speeds
(ii) automatically increases the fuel to the engine as the load on it increases, to keep its speed approximately constant

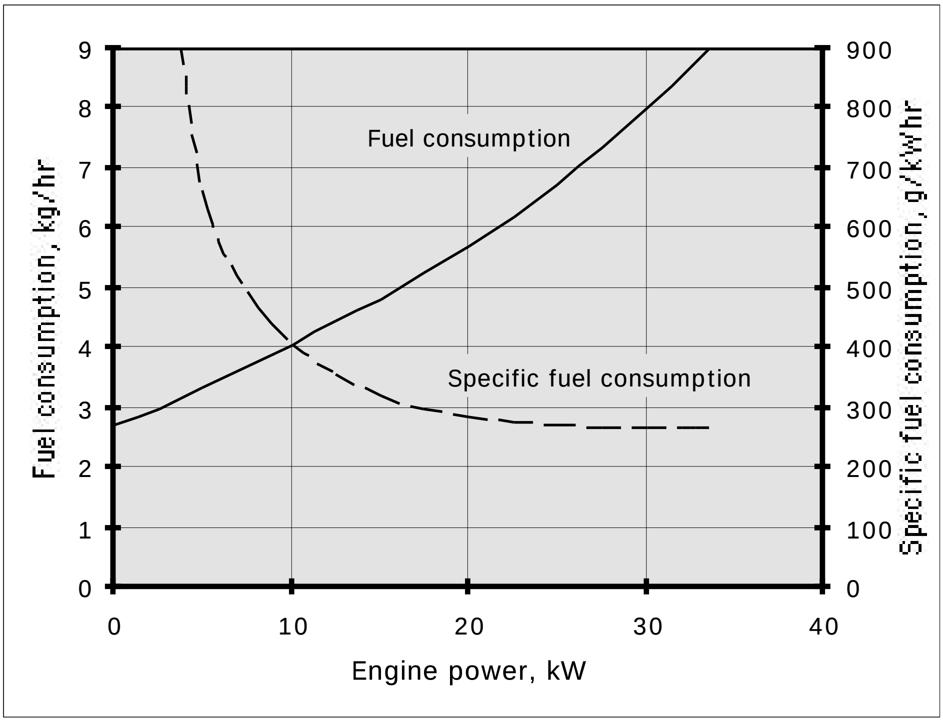

Figure 3.3 Variation of fuel consumption and specific fuel consumption with engine power for the Farmland tractor engine at maximum governor setting.

For any given governor setting, there are two ranges in which the engine can operate (Figure 3.2).

(i) In the "governed range(s)", where the engine runs under control of the governor. As the torque load varies, so fuel is varied to keep the speed approximately constant as shown by the near vertical line. Only the maximum governor setting is shown in Figure 3.2; lines for other governor settings are shown in Figure 3.4.

(ii) In the ‘full-fuel range’, where the governor is not controlling the fuel supply. The fuel system supplies a fixed maximum quantity of fuel per stroke (as set by the manufacturer); the speed varies widely (from 2250 to 1000 rpm) as shown by the dotted line in Figure 3.2.

The governed range is where the tractor is normally operated; the load and, as shown later, particularly the gear ratio are chosen to cause the engine to operate in this range. Thus the speed range is determined by the setting of the governor by the operator; within that range, the speed is automatically set by the governor.

Maximum torque for a diesel engine is reached at quite a low speed. The increase in torque as the engine slows down in the full fuel range (sometimes called "torque back-up") is a reserve of effort; it indicates the ability of the engine to increase its torque output, above that at maximum power, prior to stalling (stopping). This feature appears in the drawbar characteristics of the tractor as discussed in Section 3.3.1 and following.

(b) Power - speed

While the torque represents a fundamental performance parameter for the engine, the operator is usually more interested in the rate at which that torque effort will do work, ie, the power of the engine.

From Equation 2.3

Engine power(1), $Q_e = 2\pi \,.\,$ Engine torque T_e . Engine speed N_e

For each point on and under the torque - speed curve, there is a corresponding point on and under the power - speed curve (Fig. 3.2). As the load on the engine is increased, the condition where the governor first provides the maximum fuel rate, gives maximum power for that governor setting. At higher torques and lower speeds in the full fuel range the power is less.

The output from the PTO also reflects that of the engine. However Figure 3.2 shows only one value of the power output from the PTO when it is operating at the (arbitrarily) defined `standard PTO speed´ of 540 rpm. At this speed the engine in the Farmland tractor is rotating at 1810 rpm. From this it will be seen that greater (or lesser) maximum power can be taken from the PTO but they will be at a speed greater (or less) than 540 rpm.

(c) Summary

As we increase the torque load on the engine:
(i) in the governed ranges, the torque and power increase and the speed decreases slightly until the power reaches a maximum
(ii) in the full-fuel range, any further increase in the torque load causes:
    * a small increase in the torque
    * a large decrease in the speed
    * a resultant decrease in the power
(iii) at maximum torque the engine will stall.

Varying the governor setting:
(i) varies the governed range of speed in which the engine runs
(ii) varies the maximum power developed by the engine
(iii) does not vary the maximum torque developed by the engine

The governed ranges are of most interest to the operator because it is in these that the engine operates most of the time.

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(1) Engine power is often termed `brake´ power (measured by a `brake´ or dynamometer) or `shaft´ power (available at the output `shaft´).

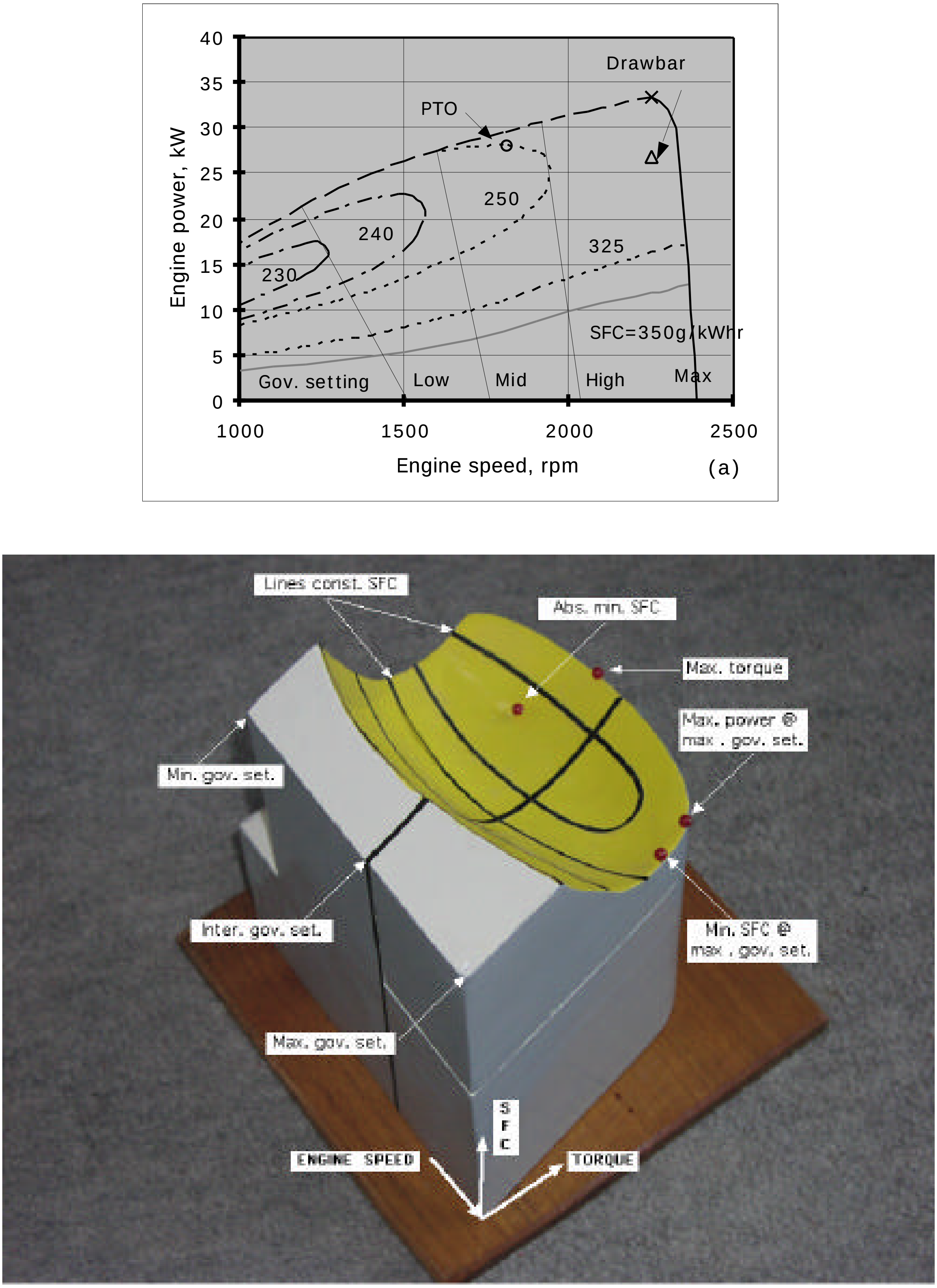

Figure 3.4: (a) Specific fuel consumption plotted on an engine <u>power</u> / engine speed base for the Farmland tractor engine at various governor settings.
(b) Model showing specific fuel consumption plotted on an engine <u>torque</u> / engine speed base for the International 434 tractor engine at various governor settings.

3.2.3 Input

(a) Fuel consumption

The other factor of interest in engine performance is the input as represented by the fuel consumption (strictly fuel consumption rate) and how this varies with the output as represented by the power in the governed range.

$$\text{Fuel consumption (FC)} = \frac{\text{Fuel used F}}{\text{Time taken t}} \qquad (3.1)$$

It is quoted in kg/hr or L/hr and is usually plotted against power.

As seen in Figure 3.3 the fuel consumption (above that required to keep the engine running at zero power) is approximately proportional to power. The graph shown applies to maximum governor setting; lower governor settings would give similar, but slightly lower fuel consumption - power graphs.

(b) Specific fuel consumption rate

The fuel consumption is a suitable parameter for representing the input performance of one engine but does not allow a comparison of engines of different size. To do that, it is convenient to calculate the fuel consumption (rate) per kW of power developed by the engine. Hence we define:

$$\text{Specific fuel consumption (SFC)} = \frac{\text{Fuel consumption FC}}{\text{Engine power } Q_e} \quad \text{g/kWhr} \qquad (3.2)$$

Specific fuel consumption (sometimes termed fuel economy) is also usually plotted against engine power as also shown in Figure 3.3; low values signify good economy, ie, low rate of fuel consumption per unit power developed.

Figure 3.3 gives the specific fuel consumption at maximum governor setting; lower governor settings would give similar, but usually slightly lower, specific fuel consumption - power graphs.

At each point on and under the power-speed graph, we can calculate a specific fuel consumption; if this is plotted perpendicular to the page we obtain a surface representing the three important aspects of the engine performance on one graph, viz, speed, power and specific fuel consumption. Lines of equal specific fuel consumption are shown as contours on Figure 3.4 (a). A model of the specific fuel consumption, here plotted on a torque - speed base, is shown (for a different tractor) in Figure 3.4(b).

The specific fuel consumption is generally lowest at 80 - 90% of maximum power at any governor setting. Hence, leaving aside other considerations discussed later, it would be desirable, from an economic point of view, to load the engine so that its operating point was in this region. The absolute lowest specific fuel consumption usually occurs at an intermediate governor setting.

Problem 3.1

An engine rotates at 2100 rpm and develops a torque of 79 Nm; it uses 1.17 kg of fuel in 15 min.
Calculate the power it develops, its fuel consumption and specific fuel consumption.
Answer:

$$Q = 2\pi NT = \frac{2\pi \times 2100 \times 79}{60} = 17.4 \text{ kW}$$

$$FC = \frac{F}{t} = \frac{1.17}{0.25} = 4.68 \text{ kg/hr}$$

$$SFC = \frac{FC}{Q} = \frac{4.68}{17.4} = 269 \text{ g/kWhr}$$

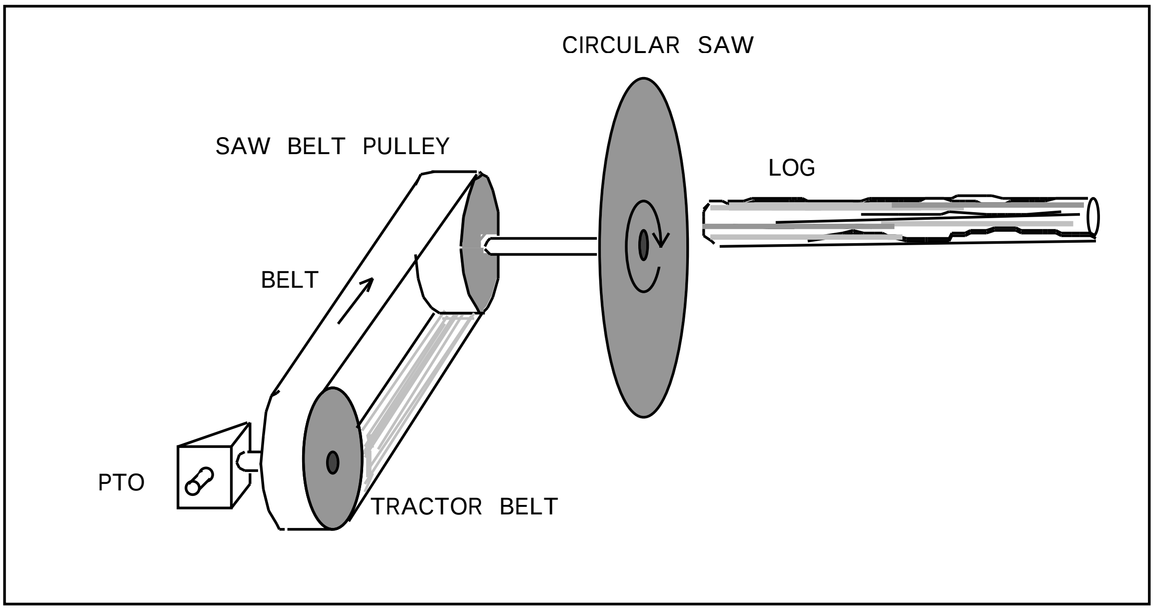

Figure 3.5 Schematic of wood saw driven from PTO of Farmland tractor; refer Problem 3.4

Problem 3.2

Using data for the Farmland tractor engine from Figures 3.2, 3.3 and 3.4(a):

(i) What is the maximum power available at 2000 rpm? Answer: 31.5 kW
(ii) What is the power available at maximum torque? Answer: 22.5 kW
(iii) What are the FC and SFC at 25kW and maximum governor setting? Answer: 6.8 kg/hr; 270 g/kWhr
(iv) What are the SFC and FC at 15kW and 1500 rpm?
Answers: SFC = 245 g/kWhr (interpolated between contours)
FC = 245 x 15 = 3.7 kg/hr
(v) What is the best SFC for a no-load speed of 2040 rpm? Answer: 250 g/kWhr
(vi) What is the FC and SFC when the PTO is operating at 540rpm and maximum power?
Answers: SFC = 250 g/kWhr; FC = 250 x 28 =7 kg/hr

Problem 3.3

Using data for the Farmland tractor engine from Figure 3.2

(i) What is the speed of the PTO when the engine is rotating at its maximum speed and power?
Answer: PTO speed $= 540 \frac{2250}{1810} = 670$ rpm
(ii) Estimate the maximum power available at the PTO for maximum engine speed.
Answer: 31.5 kW
(iii) At what speed should the engine rotate to give a PTO speed of 600 rpm?
Answer: PTO speed $= 1810 \frac{600}{540} = 2010$ rpm
(iv) Estimate the efficiency of the PTO.
Answer: PTO efficiency $= \frac{28}{30} \quad 100 = 93\%$

Problem 3.4

A circular saw 1.05 m in diameter is to be driven from the PTO of the Farmland tractor as shown schematically in Figure 3.5. The linear speed of the cutting tip of the saw is to be approximately 50 m/s. The pulley on the PTO gear box and that on the saw shaft are both 230 mm diameter. The belt pulley runs at 1300rpm when the engine speed is 2250 rpm.

(i) What engine speed should be used?
Answer:

For the saw, $V = 50 = \pi D N$, $N = \frac{50 \text{ x } 60}{3.14 \text{ x } 1.05} = 910$ rpm

For this saw speed, engine speed, $N_e = \frac{910}{1300} \quad 2250 = 1575$ rpm

(ii) Using Figure 3.4 (a), estimate the maximum power available at the saw. Answer: 25 kW

(iii) If the saw absorbs 20 kW for 30% of the time and 7.5 kW for the remainder, estimate the average fuel consumption?

Answer: At 20 kW, SFC = 240 g/kWhr; FC = 240 x 20 = 4.8 kg/hr
At 7.5 kW, SFC = 325 g/kWhr; FC = 335 x 7.5 = 2.5 kg/hr

Average FC = 0.3 x 4.8 + 0.7 x 2.5 = 3.2 kg/hr

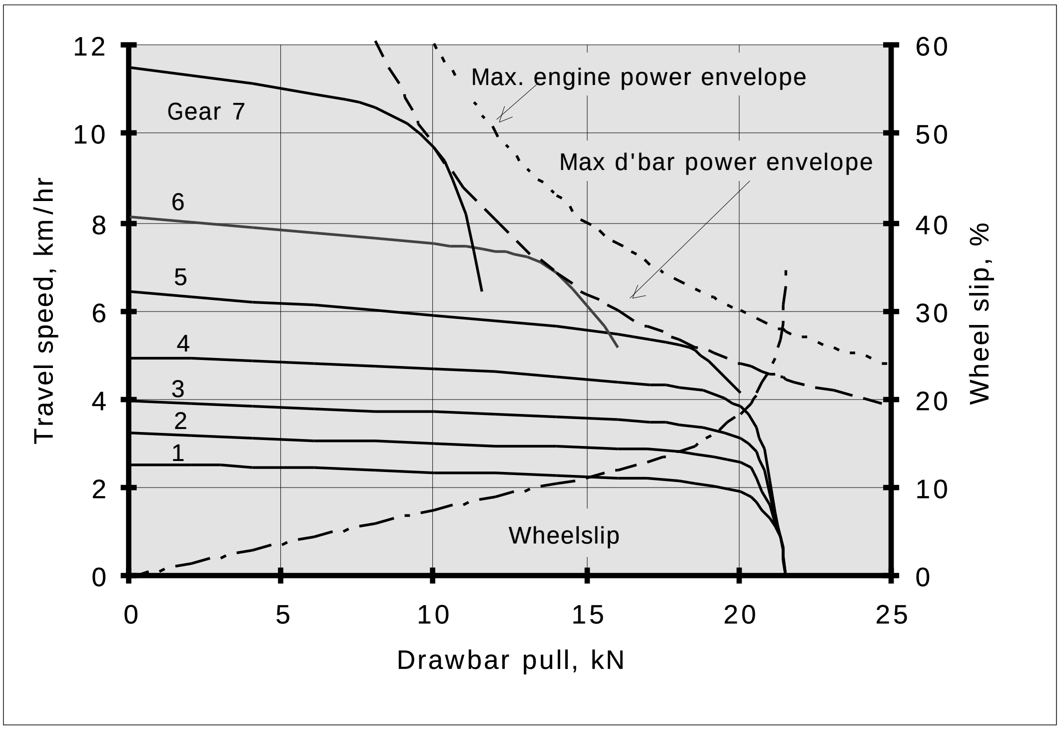

Figure 3.6 Travel speed and wheelslip versus drawbar pull for the Farmland tractor at maximum governor setting in various gears

3.3 TRACTOR DRAWBAR PERFORMANCE

3.3.1 Output

(a) Travel speed - drawbar pull

The mechanism of the tractor (the transmission and wheels) converts the rotary motion of the engine to linear motion of the drawbar. As shown in Section 2.2.1 above, the tractor operates:

(i) with an ideal travel speed:

$$V_o = \pi \ D \frac{N_e}{q}$$

This neglects loss in travel speed due to slip of the driving wheels.

(ii) with an ideal drawbar pull:

$$P = \frac{2 \ q \ T_e}{D}$$

This neglects loss in drawbar pull due to rolling resistance of the wheels.

Thus for the tractor in:
(i) higher gears (smaller values of q, smaller speed reductions, smaller torque multiplications) will give higher travel speeds and lower maximum drawbar pulls
(ii) lower gears (larger values of q, larger speed reductions, larger torque multiplications) will give lower travel speeds and higher maximum drawbar pulls

The actual travel speed - drawbar pull graphs for the Farmland tractor when tested on a test track at maximum governed speed are shown in Figure 3.6. Consideration of the above equations and Figure 3.2 will show that:
(i) travel speed at zero drawbar pull is determined by gear ratio, q
(ii) travel speed decreases as drawbar pull is increased because of decreasing engine speed and increasing wheelslip

Comparison of these with the ideal graphs in Figure 2.2(c) shows that they are similar in form but the:
(i) actual travel speeds are less than the ideal, particularly at higher drawbar pulls
(ii) actual drawbar pulls are less than the ideal

Increasing the drawbar pull of the tractor in the three highest gears will eventually bring the engine to its maximum torque condition at which forward motion will cease; the engine will stall.

In the four lowest gears, the torque multiplication (q) is so great that, instead of stalling the engine as in the higher gears, the engine can make the wheels slip completely and hence the drawbar pull is effectively limited by wheelslip. In these gears, the engine does not reach full power; all such gears have the same maximum pull (Figure. 3.6).

Plotting the maximum engine power envelope from Section 2.2.4 and a maximum drawbar power envelope on these axes shows how the actual performance falls short of the maximum, particularly at large drawbar pulls.

The above graphs are shown for maximum governor settings: lower settings will give lower travel speeds but approximately the same maximum drawbar pull in any gear corresponding to maximum torque, which is independent of the governor setting.

Note the small, 'triangular' shaped areas between the performance lines for the gears and the maximum drawbar power envelope. These are areas in which the engine could operate the tractor but which are unavailable because of the discrete values of the gear ratios. More gears would reduce the size of these; in the limit a continuously variable transmission (as in a hydrostatic drive) would allow the tractor to operate at all points on or under the maximum drawbar power envelope.

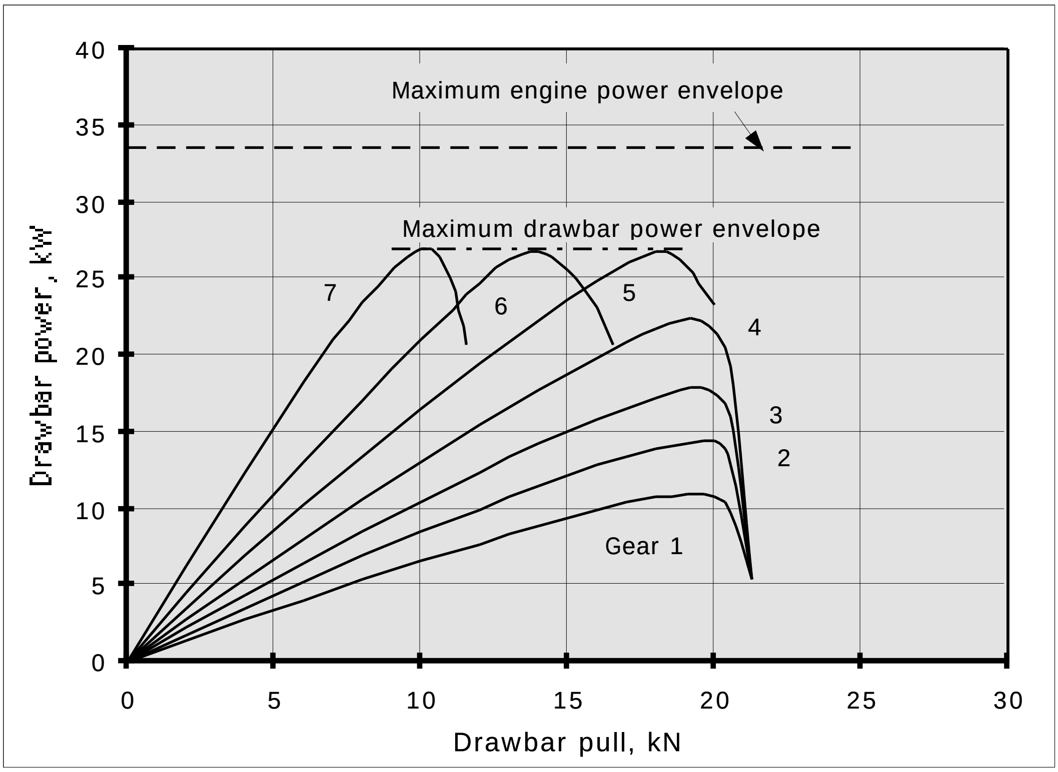

Figure 3.7 Drawbar power versus drawbar pull for the Farmland tractor at maximum governor setting in various gears.

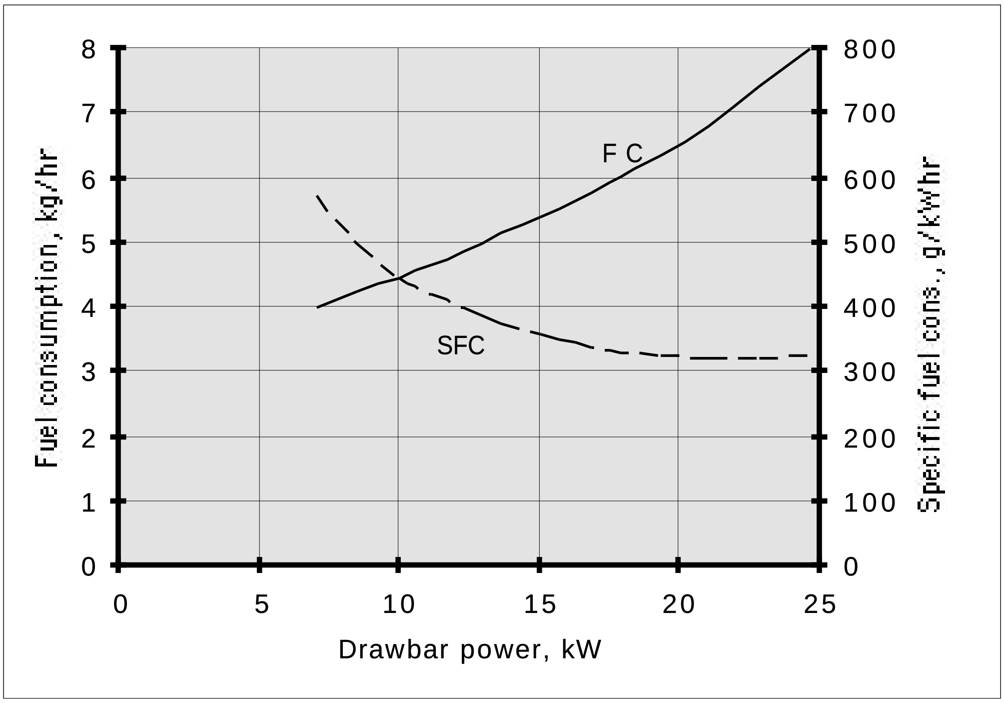

Figure 3.8: Drawbar fuel consumption and specific fuel consumption versus drawbar power for the Farmland tractor in 6th gear at maximum governor setting

(b) Drawbar power - drawbar pull

Given the drawbar pull - travel speed characteristics of the tractor shown above, the drawbar power - drawbar pull characteristic will be determined from Equation 2.4:

$$\text{Drawbar power Q} = \text{Drawbar pull P} \bullet \text{Travel speed V}$$

It is usual to plot drawbar power against drawbar pull as shown in Figure. 3.7.

Consideration of the above equation and Figure 3.6 will show that:
(i) at zero drawbar pull, the drawbar power will be zero
(ii) the maximum drawbar power (shown with 'x' for the three higher gears) will correspond to maximum engine power
(iii) for the lower gears, in which wheelslip is limiting, drawbar power will not reach the value corresponding to maximum engine power

We can also identify the ideal power `envelope´ from Section 2.2.4 which the drawbar power curves approach in the higher gears. In the lower gears, where drawbar pull is limited by wheelslip, they fall far short; the difference represents mainly the power losses because of wheelslip and, to a lesser extent, rolling resistance. This matter is discussed further in Section 5.4.2.

3.3.2 Input

(a) Fuel consumption - drawbar power

The fuel consumption characteristics of the tractor shown in Figure 3.8 for 6th gear and for the maximum governor setting will reflect the fuel consumption characteristics of the engine. Again the fuel consumption (rate) (above that required to keep the tractor moving with no drawbar pull) is approximately proportional to the drawbar power being developed.

(b) Specific fuel consumption - drawbar power

The specific fuel consumption (rate) for the tractor is defined as:

$$\text{SFC} = \frac{\text{Fuel consumption FC (tractor)}}{\text{Drawbar power Q}}$$

The graph of specific fuel consumption versus drawbar power at maximum governor setting is also shown in Figure. 3.8.

For a given engine power the tractor SFC will be higher than for the engine alone since the drawbar power will be less than the engine power due to power loss in the transmission and wheels.

Conditions of efficient fuel use (good economy, low SFC) by the tractor will correspond to governor setting (hence engine speed), gear selected (hence travel speed) and drawbar pull (determined by the load) that will bring the engine to work in an area of low engine SFC as shown in Figure 3.4.

3.3.3 Other measures of tractor performance

(a) Wheelslip - drawbar pull

Wheelslip (usually abbreviated slip) represents a loss of forward motion by the tractor and an associated loss of power as discussed in Section 2.3 above. It arises because the force at the wheel / surface causes a loss of motion, ie, the tractor does not move forward an amount equal to the amount that the wheel rotates. (See also the more detailed discussion in Section 4.1 below).

The definition of slip given in Section 2.3.1 is equivalent to:

$$\text{Slip } i = \frac{m_o - m}{mo}$$

where: m = distance traveled for given number of revolutions with drawbar pull
m_o = distance traveled for given number of revolutions with zero drawbar pull

Because it is closely related to the wheel / surface reaction (parallel to the surface), which depends on the drawbar pull, it is usual to plot slip against this variable, as also shown in Fig. 3.6. Slip does not depend to a significant extent on speed, hence a single slip - drawbar pull graph is shown for all gears (travel speeds).

Slip is an important dependent variable in showing the `state´ of the traction process and will be used in Chapter 4 to define the drawbar pull for one optimum condition, that is, maximum drawbar power.

(b) Tractive efficiency

Tractive efficiency was defined in Section 2.4.1 as:

$$\eta_t = \frac{\text{Drawbar power } Q_d}{\text{Wheel power } Q_w}$$

If we assume power losses in the transmission from engine to the wheels of, say 10%, we can write:

$$\eta_t = \frac{Q_d}{0.9 \times Qe}$$

Thus for the higher gears, for which we know both maximum engine power and maximum drawbar power (under the same conditions), we can calculate tractive efficiency as shown in Problems 3.5 and 3.9 below.

(c) Tractive coefficient

Tractive coefficient was defined in Section 2.4.2 as:

$$\text{Tractive coefficient } \psi = \frac{\text{Drawbar pull } P}{\text{Weight on driving wheels } W}$$

The tractive coefficient can be used to estimate the maximum drawbar pull for the tractor with other weights on the wheels or for other tractors with similar tyres, etc; see Problem 3.10 below.

Problem 3.5

A tractor was tested on a firm surface and gave the following data.

Rear wheel weight Wr = 3900 kg Engine power $Q_e = 62.1$ kW
Drawbar pull P = 26.2 kN Fuel consumed F = 176 g
Distance, no-load $m_o = 55.8$ m Time t = 25.8 s
Distance, load m = 46.2 m

Determine the wheelslip, travel speed, drawbar power, tractive efficiency, fuel consumption and specific fuel consumption.

Answers:

$$\text{Wheelslip, } i = \frac{(m_o - m)}{m_o} = \frac{(55.8 - 46.2)}{55.8} = 17\%$$

$$\text{Travel speed, } V = \frac{m}{t} = \frac{46.2}{25.8} = 1.79 \text{ m/s}$$

Drawbar power, $Q_d = PV = 26.2 \times 1.79 = 47$ kW

Assuming transmission efficiency $\eta_r = 0.9$

Wheel power, $Q_w = 0.9 \times 62.1 = 55.9$ kW

$$\text{Tractive efficiency, } \eta_t = \frac{Q_d}{Q_w} = \frac{46.9}{55.9} = 84\ \%$$

$$\text{Fuel consumption rate, FC} = \frac{F}{t} = \frac{176}{25.8} = 6.8 \text{ g/sec} = 24.5 \text{ kg/hr}$$

$$\text{Specific fuel consumption, SFC} = \frac{FC}{Q_d} = \frac{6.8 \times 3600}{47.2} = 520 \text{ g/kWhr}$$

Problem 3.6

For the Farmland tractor operating in 5th gear at maximum governor setting, use data from Figures 3.6 and 3.7 to determine:
(i) the travel speed, drawbar power and the wheel slip if the drawbar pull is 10kN?
Answers: 6 km/hr, 17 kW, 7.5 %
(ii) what is the maximum drawbar pull in the governed range and the wheelslip under these conditions?
Answers: 18 kN, 15 %

Problem 3.7

For the Farmland tractor operating at maximum governor setting with a drawbar pull of 15 kN use data from Figure 3.6 and 3.7 to determine, for gears 1, 3 and 5, at what speeds it will travel, what drawbar powers will be developed and what will be the wheelslip?
Answers: Gear 1, 2.3 km/hr, 9 kW, 11 %; gear 3, 3.6 km/hr, 15 kW,11 %; gear 5, 5.7 km/hr, 23 kW, 11 %.

Problem 3.8

For the Farmland tractor operating at maximum governor setting, and developing 20 kW at the drawbar, use data from Figure 3.6 and 3.7 to determine, for gears 4, 5 and 6, what drawbar pulls it will develop, at what speeds it will travel and what will be the wheel slips?
Answers: Gear 4, 16.5 kN, 3.5 km/hr,12 %; gear 5, 12.5 kN, 5.9 km/hr, 9%; gear 6, 9.5 kN, 7.6 km/hr, 7 %

Problem 3.9

For the Farmland tractor operating in 6th gear at maximum governor setting, use data from Figure 3.6 and 3.7 to determine:
(i) what are the maximum drawbar power and the corresponding engine power?
Answers: 26.2 kW, 33.5 kW.
(ii) an estimate of the tractive efficiency:
Answers:

$$\text{Tractive efficiency } \eta_t = \frac{\text{Drawbar power Qd}}{0.90 \text{ x Engine power } Q_e} = \frac{26.2}{0.9 \text{ x } 33.5} = 87\ \%$$

Problem 3.10

For the Farmland tractor use data from Figure 3.6 and 3.7 to determine:

(i) What are the maximum drawbar pull and the maximum tractive coefficient if the weight on the rear wheels is 2570kg.
Answer: 21.5 kN

$$\text{Tractive coefficient } = \frac{\text{Maximum drawbar pull Pmax}}{\text{Weight on driving wheels W}} = \frac{21.5 \text{ x } 1000}{2570 \text{ x } 9.8} = 0.85 \text{ at 100\% wheelslip}$$

(ii) What weight would have to be added to the rear wheels of the tractor for it to have a maximum pull of 24kN?
Answer: Assuming the same tractive coefficient at 100 % wheelslip:

$$\text{Weight on rear wheels W} = \frac{\text{Maximum drawbar pull, } P_{max}}{\text{Maximum tractive coefficient, } \psi_{max}}$$

$$= \frac{24}{0.85} = 28.2 \text{ kN} = 2880 \text{ kg}$$

Weight to be added = 2880 - 2570 = 310 kg

Note: A large increase in the weight on the rear wheels will give a proportional increase in the drawbar pull but may overload the transmission components and / or cause the tractor to tip over rearwards.

3.4 REFERENCES

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