DECEMBER 2014
www.craneworld.com
A KHL Group publication

INTERNATIONAL cranes AND SPECIALIZED TRANSPORT

Site report: India

The Knowledge

WC&TS review

TopLift result

Wind energy

Heavy lifting

SC&RA OFFICIAL MAGAZINE

THE MAGAZINE FOR EQUIPMENT USERS AND BUYERS

A case study

In his regular feature, MARCO VAN DAAL presents a case study on pull force

To find out if a prime mover is suitable for a particular project some basic calculations need to be performed. These are rather difficult if you are not familiar with them; however, you only have to make these calculations once in the life time of the prime mover.

Given is the following engine info:

- Mack prime mover (engine type E7-400), see Figure 1 for the actual transport
- Energy output = 318 kW (426 HP)
- RPM at energy output = 1,800 per min
- Max torque = 1,560 N*m 1,149 lb*ft
- RPM at max torque = 1,200 per min
- Max RPM = 2,100 per min
- Min RPM = 475 per min

As this prime mover is used for pulling a load, what we are interested in is the torque as this determines if the prime mover (in the appropriate gear) is strong enough to get the transporter rolling. In this case the maximum torque is 1,560 N*m (1,149 lb*ft) and this is delivered (to the drive shaft and eventually to the tyres) at 1,200 revolutions per minute (RPM). This does not mean that the prime mover should increase RPM to 1,200 per min to get rolling. It means that the RPM should be gradually increased until the combination starts moving, usually at a lower than max RPM. If the combination does not move at 1,200 RPM, however, there is no need or use to further increase the RPM as the maximum torque has already been reached, the prime mover is too weak to pull this load.

The maximum speed is achieved at 1,800 per min but that becomes only important once the prime mover is already rolling and speed becomes more important than torque.

The first five gears (total 18 gears) of this truck's main gearbox have gear ratios of:

- 1st gear = 16.42
- 2nd gear = 8.78
- 3rd gear = 6.28
- 4th gear = 4.52
- 5th gear = 3.22

The higher the gear ratio, the more pulling power (torque) the truck can deliver. This truck can generate 500 % more torque in 1st gear than in 5th gear, it is really designed to get a heavy load moving.

In addition, this truck is equipped with a secondary gearbox, also called an auxiliary gearbox or transfer case. This is a gearbox installed in line with the main gearbox that multiplies engine output before it is delivered to the drive axles and tyres.

The gear ratios of the transfer case are:

- 1st gear = 2.37
- 2nd gear = 1.24
- 3rd gear = 1.00
- 4th gear = 0.81

The first two gears of this transfer case enhance the truck's power; the 3rd gear (with ratio 1.00) adds nothing to the original gearbox ratios and makes the truck perform as if the transfer case was not present. The 4th gear would actually hurt the truck in pulling performance but enhances it in speed; this gear would only be used once the truck is already moving at considerable speed.

The last gear is found in the differential, it has a ratio of 8.27. All gears together are assumed to have a 90 % efficiency, 10 % is lost in internal friction and generation of heat that is transferred to the oil in the various gear boxes.

The truck has 12.00R24 tyres; these have a radius of 24 inches (609.6 mm)

- total axles = 3
- drive axles = 2
- truck weight = 10 ton (equally divided between front and rear axles)
- counterweight = 35 ton (on drive axles only)

How much pulling force can this truck generate when using 1st main gear and first auxiliary gear?

F1 total = max torque * main gear ratio * aux gear ratio * diff gear ratio * gear eff / tyre radius / gravitation
= 1,560 * 16.42 * 2.37 * 8.27 * 0.9 / (609.6/1000) / (9.81*1000)
= 75.56 mTon
F1 axle = 37.78 mTon per drive axle (83,216 LBS)

This is the maximum tractive force that the engine can supply to the tyres of the drive axles.

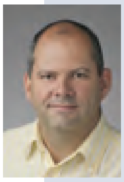
This force, however, can only be transferred to the road surface (and move the truck forward) if there is sufficient down force, in the form of counterweights, on the drive axles.

If there is not enough counterweight on the drive axles, there will not be enough traction between the tyres and the road surface and the tyres will just slip or spin under the torque. The maximum traction or rim pull can be calculated as follows:

Rim pull = (drive axle weight + counter weight) * static friction

The static friction is an empirical number that is dependent upon the road surface. Dry asphalt without any foreign contamination, such as sand or water, has a static friction between a minimum of 0.6 and a maximum of about 0.8 with rubber tyres.

ABOUT THE AUTHOR



Marco van Daal has been in the heavy lift and transport industry since 1993. He started at Mammoet Transport from the Netherlands and later with Fagioli PSC from Italy, both leading companies in the industry. His 20-year plus experience extends to five continents and more than 55 countries. It resulted in a book *The Art of Heavy Transport*, available at: www.khl.com/books/the-art-of-heavy-transport/

Van Daal has a real passion for sharing knowledge and experience – the primary reason for the seminars he holds around the world.

Figure 1

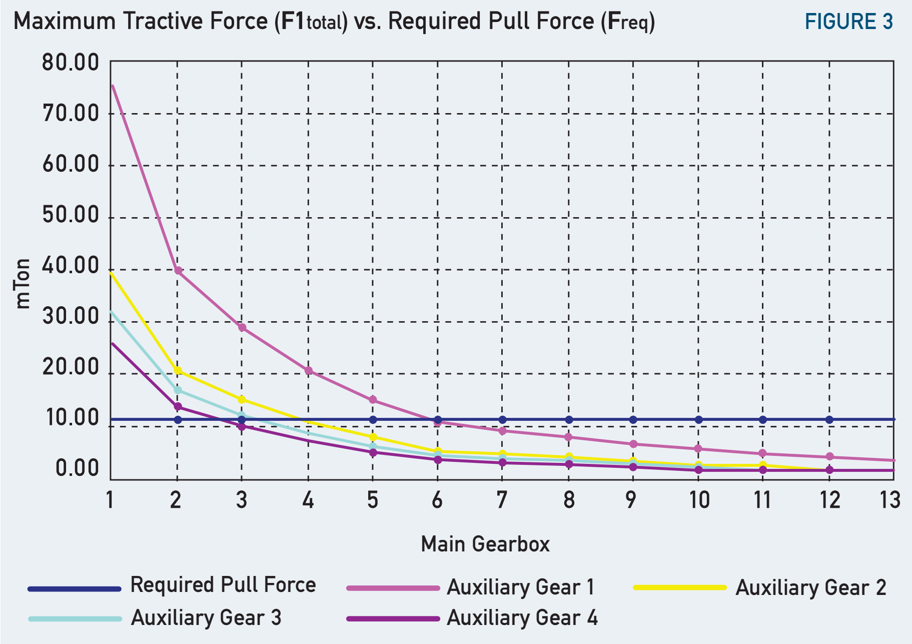


FIGURE 3

Rim pull min = (5 + 35) * 0.6 = 24 m ton
or (Frp axle) 12 m ton per drive axle
(26,432 LBS)
Rim pull max = (5 + 35) * 0.8 = 32 m ton
or (Frp axle) 16 m ton per drive axle
(35,242 LBS)

As you can see, the rim pull is about half of the tractive effort. This means that at 1,200 RPM (the RPM that generates maximum torque) the tyres will spin. There are three possible solutions for this (in best practical order):

1: try to move the transport combination at a lower RPM and therefore lower rim pull
2: shift to a higher gear with a lower gear ratio
3: add counterweight to increase the rim pull

Using second auxiliary gear, with a 1.24 gear ratio, results in a total tractive effort of 39.5 m ton or 19.76 m ton per drive axle (43,538 LBS). Theoretically this is still too much but this is easily controlled by RPM. See Figure 2 for a graphical representation of these numbers.

Now we know that this prime mover in its current configuration is best used in 2nd auxiliary gear as the "drive away" gear.

Last test that still needs to be performed is if the rim pull is sufficient to start moving the transport combination.

Let's assume that this truck is pulling a 12 axle hydraulic transporter (weight 40 ton) with a 200 ton load on it. The road is assumed to be level.

GVW = truck weight + transporter weight + load weight
= 10 + 35 + 40 + 200 = 285 mTon
(627,753 LBS)

With a rolling resistance of 4 % or 0.04 the required rim pull (Freq) is 285 ton * 0.04 = 11.4 mTon (25,110 LBS).

This turns out to be more than enough to start this transport combination moving. See Figure 3.

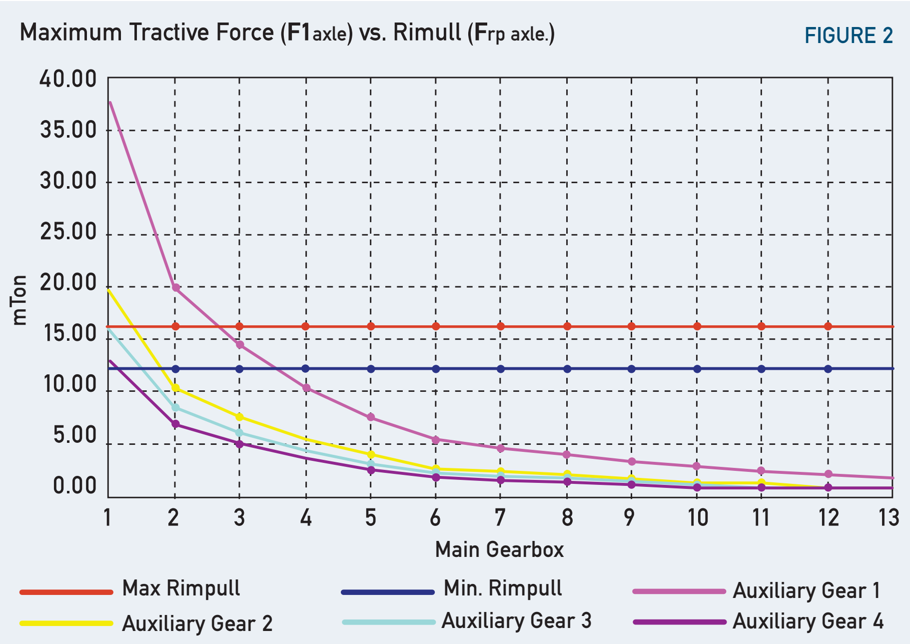


FIGURE 2

Engine speed

There are many design factors that play a role in this but generally engines with a longer stroke produce more torque than speed and engines with a shorter stroke produce more speed than torque. In a short stroke engine the piston travels a much shorter distance and can therefore achieve much higher RPM. High RPM are synonymous with high speed, but less torque. Even though it is officially limited to 15,000 RPM, a Formula 1 racing car engine can easily achieve 19,000 RPM with its extremely short stroke. They are made for speed and don't have much torque.

Your family car normally runs at 4,000 to 6,000 RPM and is generally designed as a happy medium vehicle (there are exceptions). It produces sufficient torque to still accelerate (which requires torque) with five passengers in it and reach decent speeds while travelling on the highways.

Trucks and prime movers have long stroke engines. Because the pistons travel a longer distance, the RPM is much lower. These engines are built for torque (pulling power) and are made to "carry" a load. The example truck had a maximum RPM of 2,100 revolutions per minute.

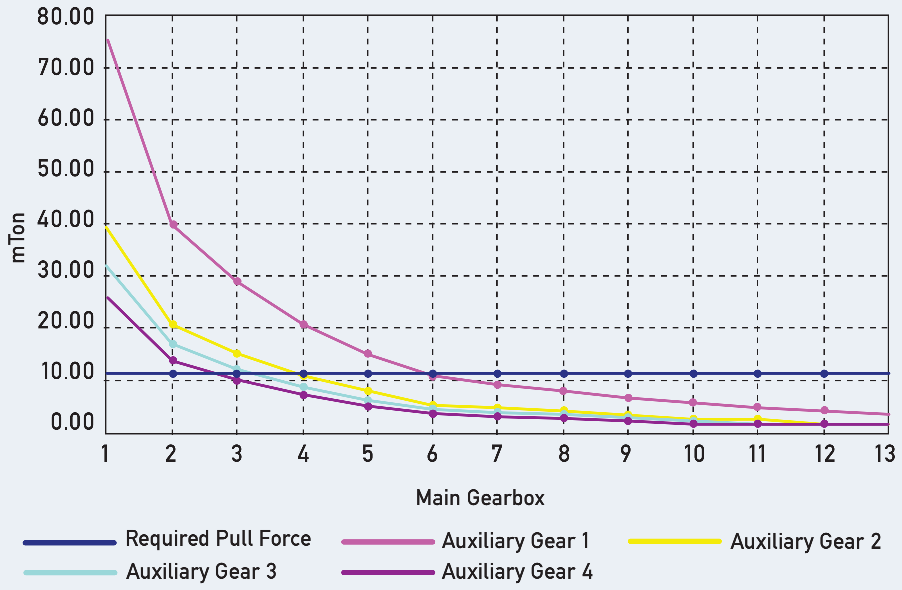
Here is an analogy with the world of sport. Let's take a sprinter and a body builder; the sprinter has a lean body and can run 100 metres in 10 seconds flat. If you give him a 20 LBS backpack his performance (speed) will drop drastically. He is built for speed.

The body builder, however, runs the 100 metres in a much slower time as his body is not as lean; he has a lot of muscle tissue. The 20 LBS backpack will not affect his performance much; he is used to lifting and carrying weights. He is built for torque.

Figure 1

Maximum Tractive Force ($F1_{total}$) vs. Required Pull Force (F_{req})

FIGURE 3



Rim pull min = (5 + 35) * 0.6 = 24 m ton or (Frp axle) 12 m ton per drive axle (26,432 LBS)
Rim pull max = (5 + 35) * 0.8 = 32 m ton or (Frp axle) 16 m ton per drive axle (35,242 LBS)

As you can see, the rim pull is about half of the tractive effort. This means that at 1,200 RPM (the RPM that generates maximum torque) the tyres will spin. There are three possible solutions for this (in best practical order):

1: try to move the transport combination at a lower RPM and therefore lower rim pull
2: shift to a higher gear with a lower gear ratio
3: add counterweight to increase the rim pull

Using second auxiliary gear, with a 1.24 gear ratio, results in a total tractive effort of 39.5 m ton or 19.76 m ton per drive axle (43,538 LBS). Theoretically this is still too much but this is easily controlled by RPM. See Figure 2 for a graphical representation of these numbers.

Now we know that this prime mover in its current configuration is best used in 2nd auxiliary gear as the "drive away" gear.

Last test that still needs to be performed is if the rim pull is sufficient to start moving the transport combination.

Let's assume that this truck is pulling a 12 axle hydraulic transporter (weight 40 ton) with a 200 ton load on it. The road is assumed to be level.

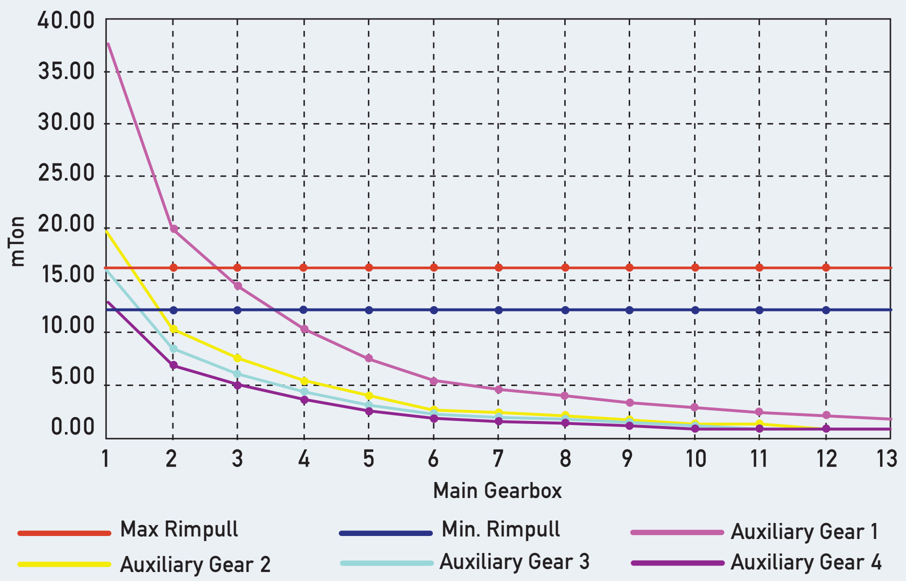
GVW = truck weight + transporter weight + load weight
= 10 + 35 + 40 + 200 = 285 mTon (627,753 LBS)

With a rolling resistance of 4 % or 0.04 the required rim pull (Freq) is 285 ton * 0.04 = 11.4 mTon (25,110 LBS).

This turns out to be more than enough to start this transport combination moving. See Figure 3.

Maximum Tractive Force ($F1_{axle}$) vs. Rimull ($F_{rp\ axle.}$)

FIGURE 2



Engine speed

There are many design factors that play a role in this but generally engines with a longer stroke produce more torque than speed and engines with a shorter stroke produce more speed than torque. In a short stroke engine the piston travels a much shorter distance and can therefore achieve much higher RPM. High RPM are synonymous with high speed, but less torque. Even though it is officially limited to 15,000 RPM, a Formula 1 racing car engine can easily achieve 19,000 RPM with its extremely short stroke. They are made for speed and don't have much torque.

Your family car normally runs at 4,000 to 6,000 RPM and is generally designed as a happy medium vehicle (there are exceptions). It produces sufficient torque to still accelerate (which requires torque) with five passengers in it and reach decent speeds while travelling on the highways.

Trucks and prime movers have long stroke engines. Because the pistons travel a longer distance, the RPM is much lower. These engines are built for torque (pulling power) and are made to "carry" a load. The example truck had a maximum RPM of 2,100 revolutions per minute.

Here is an analogy with the world of sport. Let's take a sprinter and a body builder; the sprinter has a lean body and can run 100 metres in 10 seconds flat. If you give him a 20 LBS backpack his performance (speed) will drop drastically. He is built for speed.

The body builder, however, runs the 100 metres in a much slower time as his body is not as lean; he has a lot of muscle tissue. The 20 LBS backpack will not affect his performance much; he is used to lifting and carrying weights. He is built for torque.