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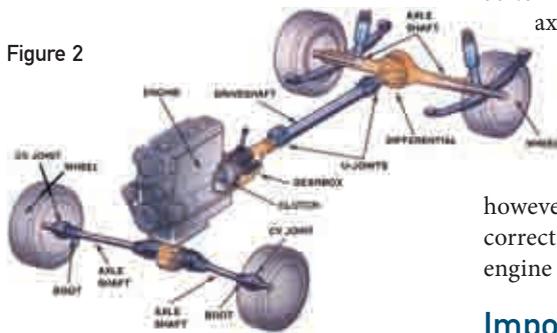
Pull force explained

MARCO VAN DAAL'S
technical article
this month is about
definitions and the ways
of calculating the pull
force of heavy haulage
tractor units

Pull Force is the force that a truck or prime mover can exert onto a transporter or any type of trailer for that matter. The end user is often just interested in how many tonnes or pounds the unit can pull.

To go from horsepower (hp) to pull force many terms and conversion factors are thrown on the table, including the number of driven axles, gearbox ratio,

Figure 2



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

rear end ratio, differential, tyre size, truck weight and fifth wheel capacity.

A truck can deliver a pull force equal to 80 to 90 % of the weight carried by the drive axles. The truck in Figure 1 weighs 35 tonnes. The rear two axles are drive axles and carry 10 tonnes each, the third rear axle and the steering axle carry 7.5 tonnes each. The maximum pull force this truck can generate is between 16 tonnes and 18 tonnes. This, however, will only be the case if the correct gear is chosen and if sufficient engine power is available.

Important factors

The power and torque of a truck is delivered by the engine and is expressed in hp / kW or lb-ft / Nm. A power of 1 hp equates to about 745 W and a torque of 1 lb-ft equates to about 1.36 Nm (Newton-metre). A 400 hp engine with a maximum torque of 1,500 lb-ft can deliver 298 kW and about 2,036 Nm.

To understand the difference between power and torque it is important to understand that power is a measure of the rate at which work is delivered and is measured per unit of time. It may help to know that the definition of horsepower is based on the assumption that a horse can move 33,000 pounds 1 foot per minute, therefore, 1 hp = 33,000 lb-ft/min = 550 lb-ft/sec.

Torque (lb-ft and Nm) is the measure of an object's tendency to rotate about a point and is not measured per unit of time but (in the case of engines) per crankshaft revolution. In terms of rating an engine, it is the application that determines whether power or torque is the more important measurement. When speed or a certain duty cycle is required, the engine power is of importance. When pull force is important the engine torque is of importance as this determines if the truck will be able to move the object.

How a truck works

For readers new to the industry, the following is a basic explanation of a typical truck driveline. In the engine the power and torque is created as the combustion energy is delivered to rotate the crankshaft via pistons and connecting rods (see Figure 2). The speed of this shaft is

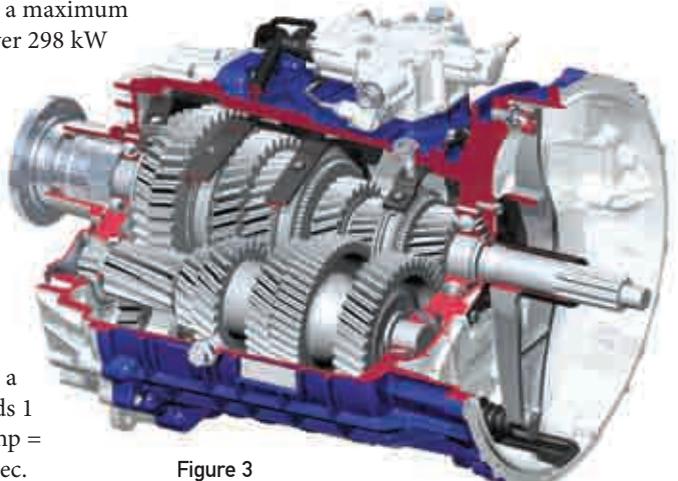


Figure 3

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determined by the engine RPM, which in turn is influenced by the throttle.

Engine power and torque is not required all the time, for example, when idling at a traffic light. Immediately behind the engine output shaft is the clutch, which can be engaged or disengaged. When the clutch is disengaged the engine runs but no power or torque is delivered to any mechanical part of the truck. When the clutch is engaged the engine power and torque sets an array of gears in motion.

In gear

The first set of gears are in the gearbox. Figure 3 shows an open gearbox. In it the protruding shaft connects to the engine output shaft. The large open bell-shaped housing bolts to the engine block and covers the flywheel. The flywheel is a large steel disc that rotates inside the bell housing. The function of the flywheel is to store kinetic energy. The speed of the flywheel is not easily changed because of its weight and momentum. This means that the flywheel helps to keep the shaft rotating at the same speed. It is useful because piston engines usually have uneven torque per piston and per firing.

The gears in the gearbox are different diameters, each set with its own ratio. The gear ratio is calculated from the number of teeth on each gear but that is cumbersome. The manufacturer can supply you with the ratio of each gear. First gear is most important as this is the one that will set the truck and transporter in motion. The ratio must be large enough to ensure a slow starting speed. Ratios of 16, 18 or 20 to 1 are not unheard of. For comparison your average car has a first gear ratio of 3.5 or 4 to 1. The output of the gearbox is connected to a drive shaft via a universal joint. In practical terms a gear ratio of 20:1 means that it takes 20 crankshaft revolutions of the engine to make one drive shaft revolution.

So now we have the drive shaft rotating. The drive shaft is connected by a universal joint to a differential. The differential has two functions:

- It allows the rear wheels to rotate at different speeds in turns and curves. The outside rear wheel needs to rotate faster than the inside rear wheel, the differential allows for this. See Figure 4.
- The gears in the differential are designed with a certain ratio, similar to the gearbox, with the difference being that the differential has one set (designed) gear ratio. This differential gear ratio is called the final drive ratio or rear end ratio. A differential gear ratio of 10 means that it takes 10 drive



Figure 4

shaft revolutions to make one drive axle shaft revolution.

The differential has a disadvantage. Since it allows differential speeds between the two wheels, in case one wheel loses traction and starts spinning, the entire power and torque goes into that wheel as this is the way of the least resistance. Many trucks nowadays have built-in differential locks. Once the lock is engaged both wheels rotate at the same speed no matter if one axle has lost traction.

Note: a differential lock can only be used on straight roads as it completely eliminates the possibility of speed differential between left and right sides of axles in turns.

If we now look at the total gear reduction between the gearbox (reduction 20) and the differential (reduction 10) we can conclude that it takes 20 crankshaft revolutions to make one drive shaft revolution and 10 drive shaft revolutions to make one rear axle shaft revolution. Therefore, it takes $10 * 20 = 200$ crank shaft revolutions to make 1 rear axle shaft revolution.

At the end of each drive axle shaft we find the wheels. The diameter of the wheels or tyres has an influence on the velocity of the vehicle. Larger diameter tyres gain speed much quicker than smaller diameter tyres. In addition, larger diameter tyres generally have a lower rolling resistance, particularly in off-road condition.

Below are a few definitions that will be used in next month's article to determine a truck's pull force and if this is sufficient for the application:

MAXIMUM TORQUE (TM)

The maximum twisting force the engine can produce at a certain RPM. Note: as we are interested in pull force the engine's power is not taken in consideration

MAXIMUM TRACTIVE FORCE (F1 TOTAL)

Maximum amount of force that the engine can supply to the tyres of the drive axles

MAXIMUM TRACTIVE FORCE PER AXLE (F1 AXLE)

Maximum amount of force divided by the number of driven axles

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MAXIMUM TRACTION OR MAXIMUM RIMPULL (FRP)

Maximum total amount of force that the tyres can apply to the road surface without slipping

MAXIMUM TRACTION OR MAXIMUM RIMPULL PER AXLE (FRP AXLE)

Maximum total amount of force per drive axle that the tyres can apply to the road surface without slipping

REQUIRED PULL FORCE (F REQ)

Force required to set the truck and transporter in motion.

- For the truck to start moving, two conditions should be met:
 - 1 Frp axle > F1 axle
The maximum force that the tyres can apply to the road (Frp axle) should be larger than the actual tractive force (F1 axle) applied. If this condition is not met, the truck's tyres will slip.
 - 2 F1 total > F req
The maximum force that the engine can supply (F1 total) should be larger than what the truck needs (F req) to start moving.

The information in this article is useful to determine the truck's pulling capacity, but it must be remembered that this is a theoretical number.



How do you really find out the power (pulling capacity) of a truck so you do not have

any surprises when it needs to deliver this force? The only real test is to put it to the test. This is not a test recommended by the manufacturers but it is one that will tell you the power of the truck. Connect the truck via a wire rope sling and a load cell to an immovable object. Let the truck pull in its lowest gear, slowly increasing the RPM, when the engine stalls or dies, you have reached the maximum for this truck. When the drive axles spin, you could add more counterweight and perform the test again, provided that the fifth wheel capacity and that of the axles and tyres is sufficient.

Several cautionary notes follow here:

Never stand between the truck and the immovable object.

When performing this test, be aware that in the chain of components between the engine and the rear axles, the drive shaft is often the weakest link (the cheapest components and the easiest to replace). The standard drive shaft may not be strong enough for this test and can suffer catastrophic failure. You may need a stronger drive shaft version for heavy pulling.

This test needs to be performed only once in the life time of a truck, unless an engine or gearbox is replaced. ■

NOTE: Every effort is made to ensure the accuracy of the contents of these articles. If you find any mistakes, a brief notification and explanation would be appreciated.



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