# 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

Figure 1

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
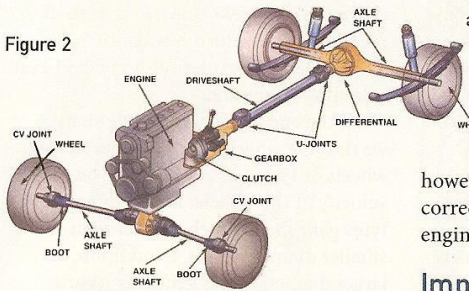
ABOUT THE AUTHOR

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.

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 >
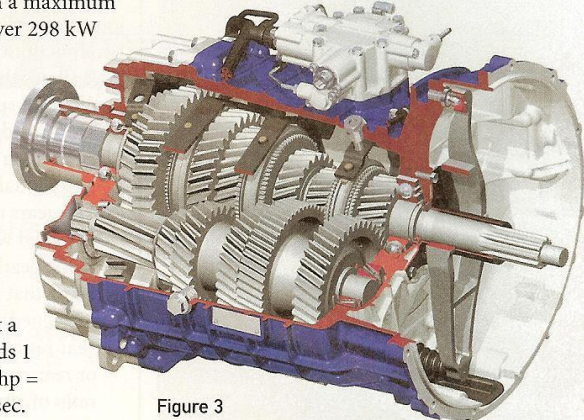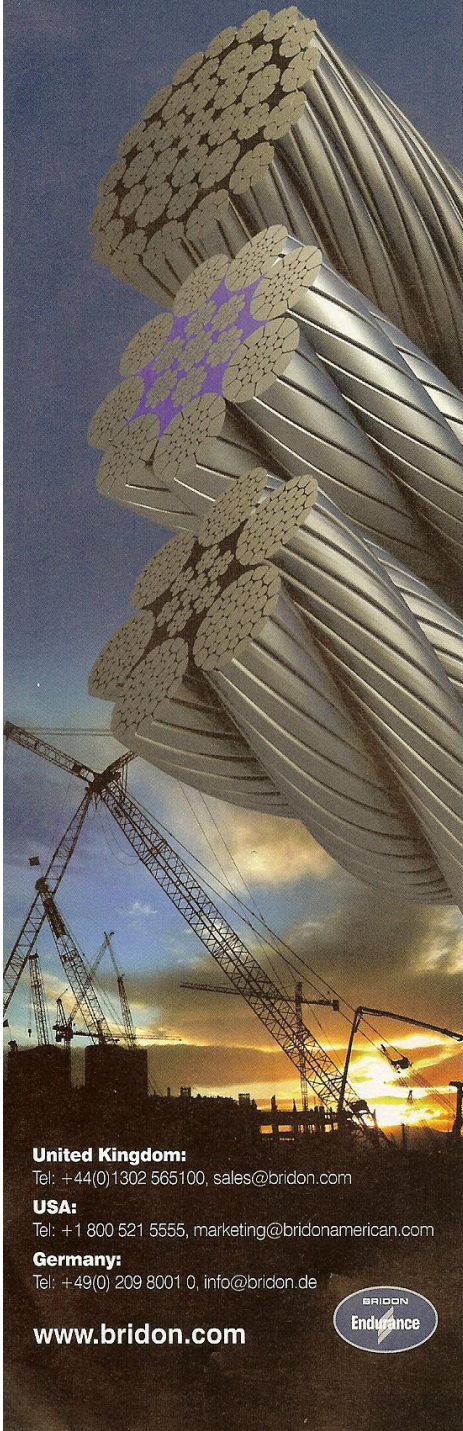

Figure 3

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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
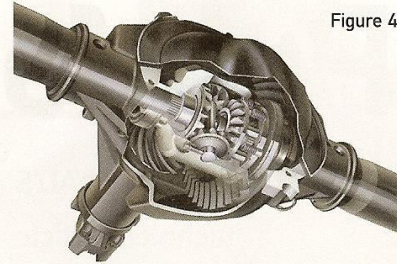 ratio of 10 means that it takes 10 drive

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.
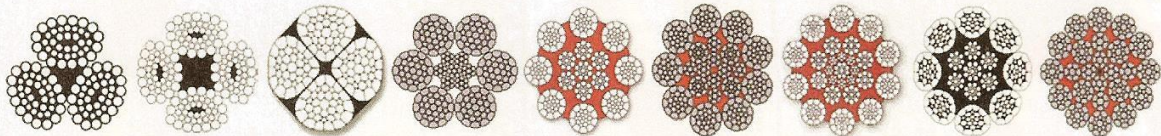
Several cautionary notes follow here:

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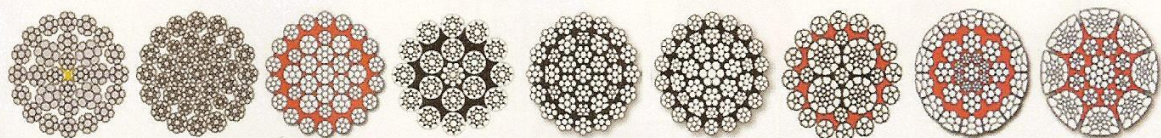
NOTE: Every effort is made to ensure the accuracy of the contents of these articles. If you find any mistakes, a brief notification and explanation would be appreciated.