THE ENGINE TORQUE

What are the essential characteristics of a motor vehicle? Marketing departments know that it is the power and maximum speed which, at first, focused public attention because it is the most rewarding data for the buyer.

But as for the technician for the discerning driver, it is the mass of the car, its engine torque and the engine rotation speed at which it is available which are essential data, because they determine the behavior of the vehicle in real situations, the service that it can make and its cost price. Here are some explanations...

The origin of the movement

From point of view of physics, create movement comprises to accelerate a mass with a force. That is the driving force. It is exercised in contact with the ground through the drive wheels.

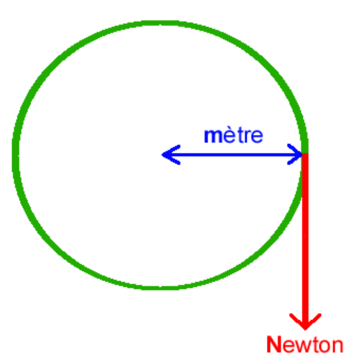
But what makes the drive wheels turn? That is the engine torque!

Torque Definition

The torque combines two sizes: a force and a lever arm.

In a heat engine, this force is that gas pressure exerted on the pistons; the lever arm is the length of the crank of the crankshaft.

Since 1954, the international unit of torque is the newton-meter (Nm symbol), it is the product of a force expressed in newtons (N) and a lever arm expressed in meters (m): 1 Nm is the torque produced by a force of 1 N which is exerted on a lever arm of 1 m.



Torque is the product of two quantities: a force and a lever arm.

Measure the engine torque

How can we measure the torque of an engine?

It is used a 'dynamometer' which is a device equipped with a tachometer and a brake[(1)].

The operation is to run the engine at full speed and then gradually apply the brake until the motor rotation speed is stabilized, while the control of gas remains wide open: at the moment, the maximum engine torque is exactly equal to the torque braking.

So just know the intensity of the braking force to deduce the value of the maximum engine torque[(2)].

The specific torque

The engine torque for the purpose of accelerating a mass or tow the coast, it is obvious that its value should be reported to the vehicle mass.

Hence the notion of 'specific torque' which is expressed in Newton-meter per ton (symbol $Nm.t^{-1}$).

For example:

- a truck delivering an engine torque of 2,000 Nm to a weight of 40 tons has a specific 50 $Nm.t^{-1}$ torque.
- a car delivering a torque of 300 Nm for a mass of 1.5 tons has a specific torque of 200 $Nm.t^{-1}$, four times.

Torque and power

These are the two essential characteristics of an engine. However, for the technician as to the driver, these two quantities does not have the same interest.

Indeed, power is a theoretical value obtained by combining the torque and engine rotation speed, so obviously dependent on high rotation speeds.

Besides the power claimed by the manufacturers is always a maximum value, available only at the specified rotation speed, and provided only if the throttle is wide open.

If one of these two conditions is not fulfilled or let alone both, the driver will have only just part of the announced power. But advertisers are careful not to specify this.

Unlike power, maximum torque is available only to intermediate rotation speeds (from 1,500 rpm to some recent diesel cars, sometimes as early as 1,000 rpm for some trucks), over a range of about 500 to 1,000 revolutions per minute only but never to extreme rotation speed. Hence the interest to have a rev counter.

This availability can obviously vary from one model to another, especially of a drive to another, but generally follows the same rules, regardless of the brand or vehicle models.

The torque and engine speed override power because they determine the actual performance, ie the performance acceleration or when it comes to tow a load uphill.

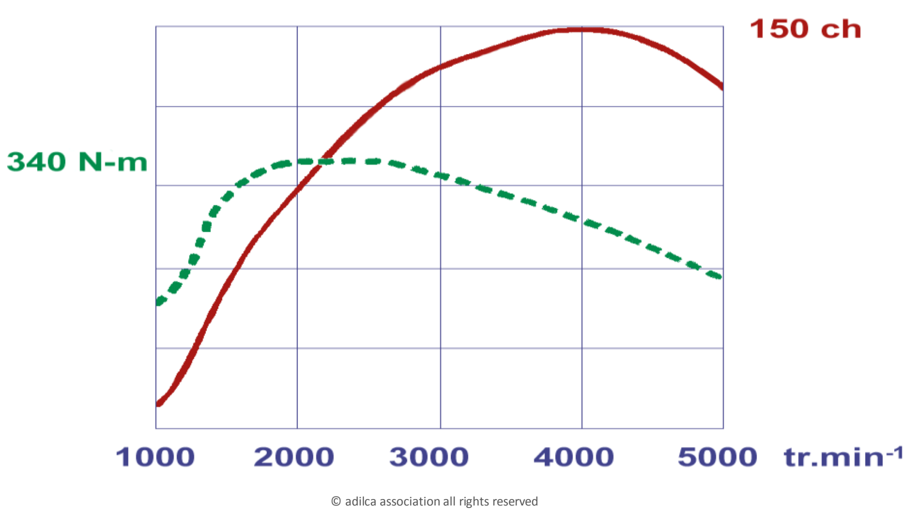
That's the whole point of the diesel engines because of more generous torque available at lower rotation speeds and on a wider range than that of gasoline engines.

A numerical example

Take for example the Renault 2.0 DCI 150 engine whose characteristics are:

- maximum engine power 150 hp (150 ch, 110 kW) at 4,000 rpm (4,000 $tr.min^{-1}$)

- maximum engine torque 340 Nm at 2,000 rpm (2,000 $tr.min^{-1}$)



Torque curves and engine power 2.0 DCI 150 Renault (Renault document).

A quick calculation shows that at maximum torque speed (2,000 rpm), the available power is only 97 hp (71 kW)! But available as long as the driver keeps his foot on the accelerator fully! If this is not the case, less than 97 hp are working.

Another equally rapid calculation shows that at maximum rotation speed (4,000 rpm), the engine torque available is only 260 Nm! It is clear that between the power and torque, it must choose!

Why privilege the torque?

The value of the torque depends on the ability of an engine to be introduced into the cylinders a perfectly homogeneous air-fuel mixture, and especially its ability to get the most energy during combustion.

The motor torque is still relatively small at low rotation speed, it reaches its maximum value with intermediate regimes then decreases inexorably as the speed increases, as if the engine ended with asphyxiate.

As the engine operates in its maximum torque speed range, fuel consumption, environmental pollution and therefore the cost of the kilometer remain at the lowest values which the vehicle is capable.

For all these reasons, it is preferred that the maximum torque is delivered to a diet not too high.

Focus on torque rather than power!
And above all: the speed at which it is issued (here: 275 Nm at 1,800 rpm)!

The role of the transmission

What is the role of the transmission?

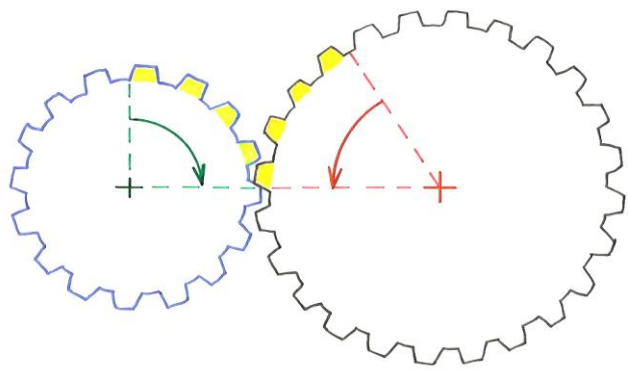
The transmission acts as a torque multiplier, which is why we distinguish the engine torque (available at the crankshaft) and the drive torque (available at the drive wheels).

To give an idea of this role, just know that the combination corresponding to the first gear multiplies engine torque on average by 15 for cars, on average by 50 for trucks. Some trucks then have a drive torque of a value greater than 100,000 Nm!

Here is an example of gear ratios values corresponding to an average range of car diesel engine, equipped with a 5-speed gearbox:

speed	1ère	2ème	3ème	4ème	5ème
transmission ratio	16	8.5	6	4.6	3.6

Warning ! The counterpart of this multiplication is an equivalent reduction of the speed of rotation. In other words, by reducing the speed of rotation of the wheels, the transmission is increasing the drive torque, and *vice versa*.



Principle of the transmission(3)
A 16 teeth wheel (green arrow) drives a 24 teeth wheel (red arrow).
In this example, the transmission ratio is 24/16 = 1.5.
So, the engine torque is multiplied by 1.5 while the rotation speed is divided by 1.5.

The driving force

The driving force means the force exerted on the periphery of the drive wheels in contact with the ground to create or maintain the movement of the car.

The intensity of this force is a function of the engine torque, the transmission ratio and the radius of the drive wheels.

In the example cited above (mid-range diesel engine, 5-speed gearbox), the driving force delivered in contact with the soil and ranges(4) is:

speed	1ère	2ème	3ème	4ème	5ème
driving force (N)	12,000	6,375	4,500	3,450	2,700

The counter-torque

Impossible to speak of engine torque without mentioning the counter-torque, usually unrecognized greatness but whose value is yet another essential technical feature of a car motor.

The counter-torque is the technical term for what drivers commonly call the 'engine brake'.

Indeed, any engine rotating inevitably delivers an opposing torque that occurs as soon as you remove the fuel supply.

Where the counter-torque comes from?

The so-called 'thermal' petrol or diesel engines all operate according to the principle cycle four stroke one of whose features is a fairly low yield of 25-45% depending on the conditions.

These small values are due to many resistors accompanying the progress of a cycle: inertia of the gas admission, reciprocating pistons and valves, compression of the air (or air-fuel mixture) in the chamber combustion, friction of the pistons in the cylinders, rubbing trees on bearings, peripheral parts of rotation (distribution, oil pump, water pump, alternator) and comfort accessories (audience, air conditioning).

Therefore, if one ceases to power the motor, these resistors create ample counter torque to slow the car, although its effectiveness will never equal that of the brakes.

The availability of the counter torque does not obey the same laws as the engine torque. In fact, the counter-torque is always proportional to the rotational speed of the engine, which means that the highest value is obtained at the maximum speed set by the manufacturer. Hence the interest to have a rev counter

As the engine torque, counter-torque is relayed and therefore multiplied by the transmission, which brings the necessary distinction between counter-torque (crankshaft) and engine brake force (axle shafts).

Measure the counter-torque

The manufacturers give no indication as the value of the counter-torque and that's a shame, but it is nevertheless always possible to indirectly calculate its value, with a very easy to achieve experience.

Imagine stabilize the car speed downhill through the sole action of engine brake force.

It would suffice to know the mass of the car, its speed, its technical characteristics (transmission ratio, aerodynamic characteristics) and the gradient of the road then to calculate all other movement parameters (air resistance, component weight parallel to the road, etc.).

Once these known parameters, it could be possible to isolate the value of the counter-torque[5].

The results of the experiment

Such an experience, completely new, was held May 25, 2001 on the slopes of the Puy de Dôme (volcano eponymous in Auvergne state, France), site chosen because of its slope both strong (12%) and regular (4.1 km).

The full results of this experiment are detailed in the 'GUIDE TO PHYSICAL LAWS OF AUTOMOBILE', they showed that the value of the counter-torque of a diesel engine passenger car is 25 Nm per engine liter with the engine running at the maximum rotation speed permitted by the manufacturer.

Other experiments have shown that at equal displacement, the value of the counter-torque is substantially proportional to the mass of the pistons, the compression ratio and the engine rotational speed.

Finally, and contrary to popular belief, this value varies little from one engine to another, gasoline engine offsetting the lower mass of pistons and a smaller compression a higher rotation speed.

What is the use of engine brake force?

Where and how to use the engine brake force, what it can serve and why is it such an important value?

The engine brake force occurs as soon as you cut power to the motor, it is sufficient for the driver to release the accelerator to benefit!

The engine brake force serves to stabilize the car speed downhill, as we have said about the experience mentioned above. That's not bad, but it is not enough!

The proper use of engine brake force is the key to what is commonly called rational driving and eco-driving.

Indeed and provided early enough to go, the engine brake force is sufficient most of the time to slow the car in almost all non-emergency driving situations!

The first advantage of this maneuver is to save fuel for the duration of the downturn, since all modern vehicles have, through electronic injection, a total cut power to the motor during deceleration.

The second advantage of this maneuver is to avoid the use of brake wear and the issue of micro-particles in the atmosphere.

These savings are probably negligible on a single slowdown but multiplied by the number of situations encountered, they quickly become substantial, particularly in town.

Modern engines ...

Note that the technical development of modern engines (overeating, alloy materials, downsizing[6]...) to increase the torque and availability at low rpm the unfortunate effect was to significantly reduce the value of the counter-torque.

A few data to compare:

- in 1991, a Citroen ZX 1.9 D diesel entry-aspirated engine equipped with a 2 liter engine delivered an engine torque of 120 Nm at 2,000 rpm and a counter-torque of 53 Nm at 4,600 rpm.

- in 2006, equipped with a supercharged engine with a displacement reduced to 1.6 liters, diesel Citroën C4 1.6 HDI 92 delivered an engine torque of 215 Nm at 1,750 rpm, but had to settle for a counter-torque of only 44 Nm at 4,800 rpm.

To achieve such a result, technicians and engineers have produced a real tour de force: 20 % of capacity in less than 79 % of engine torque and more, available in addition to a rotation speed 12.5 % lower.

Yes feat, but unfortunately at the expense of counter torque! Especially in the meantime, to meet the new comfort and safety standards, the mass of the empty car and in running order increased from 2,277 lb (1,035 kg) to 2,765 lb (1,257 kg): + 21.5 %!

All characteristics to consider for those who want to practice eco-driving successfully!

Torques and driving

Note the plural! The problem of driving boils indeed exploit torques, right time and right place.

To achieve this, the driver has at his disposal:

- the throttle (the opening or closing conditions the quantity of fuel introduced into the cylinders, and thus the intensity of the engine torque or the counter-torque),

- the rev counter (it can control the motor works as often as possible in one of two favorable rotation speed range)

- the gearbox (the transmission ratio determines the traction torque or counter-torque corresponding to the requested work).

(1) *Where the expression 'brake horsepower' often used. There are many brake systems, friction, hydraulic resistance, electrical or electromagnetic, but all work on the same principle: the motor is coupled to a disk on which exerts a braking force. Despite their names, these devices do not measure the power but only the maximum torque and the way it evolves according to the engine rotation speed. The power results from a subsequent calculation that combines two variables: the torque and rotation speed (see ADILCA folder 'engine power').*

(2) *Therefore, the technical data always refer to a 'maximum torque' and the corresponding engine rotation speed, which means that the throttle is wide open. If this is not the case, only part of the torque indicated is available.*

(3) *A principle easy to display: at the contact point of the two wheels, the force received by the 24 teeth wheel is exactly equal to the force transmitted by the 16 teeth wheel. The torque being the product of a force by a radius and circumference being related to the radius by a constant (2 π), we deduce that the available torque on the axis of the 24 teeth wheel is 24/16th of the initial torque. Moreover, when the 16 teeth wheel makes one revolution, the 24 teeth wheel makes only 16/24th of a turn; therefore, its rotational speed is reduced in the same ratio.*

(4) *These are values calculated from the maximum torque delivered by the engine in and measured at the end of the crankshaft. In other words, these values are purely theoretical: first, they assume that the engine is running at the appropriate rotation speed with the throttle wide open, secondly, they neglect related resistance to the rotation of the transmission (gearbox, drive shaft, differential, axle shafts). This resistance absorbs about 10 % of the initial energy.*

(5) *Unlike the engine torque is measured at the end of the crankshaft, the value of the counter-torque resulting from such an experiment is a global value that includes both the rolling resistance of the four wheels and that related to the rotation of the transmission (axle shafts, differential, drive shaft, gearbox).*

(6) *Downsizing: Technique that aims to reduce engine capacity and weight of the engine while getting more power and torque thanks to optimized cylinder charging.*

French old road sign (1937) at the foot of Puy de Dôme (meaning ''STEADY SLOPE'').

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SOME RELATIONSHIPS BETWEEN QUANTITIES ...

Engine torque :

Te = F . D

Te : engine torque, expressed in **Nm**
F : engine force, expressed in **N**
D : length of the lever, expressed in **m**
consistency of the units : **Te** = N . m = **Nm**

Example : calculate the engine torque under the following conditions: engine force of 4,000 N, 0.05 meter radius of the crankshaft:

Te = 4,000 x 0.05 = 200 Nm

Transmission ratio :

X = (n4 / n3) . (n2 / n1)

X : transmission ratio, dimensionless
n1 : number of teeth of the primary countershaft gear
n2 : number of teeth of the secondary countershaft gear
n3 : number of teeth of the differential driving pinion
n4 : number of teeth of the differential crown

Example : calculate the transmission ratio with the following combination (5th speed): primary countershaft gear teeth 43, secondary countershaft gear teeth 33, the differential driving pinion gear 13 teeth, differential crown teeth 61:

X = (61 / 13) x (33 / 43) = 4.692 x 0.767 = 3.6

Drive torque :

Td = Te . X

Td : drive torque, expressed in **Nm**
Te : engine torque, expressed in **Nm**
X : transmission ratio, dimensionless
consistency of the units : **Td** = **Nm**

Example : calculate the drive torque in the following conditions: engine torque of 200 Nm, 3.6 transmission ratio (fifth speed):

Td = 200 x 3.6 = 720 Nm

Drive force :

$$F = Td / R$$

F : drive force, expressed in **N**
Td : drive torque, expressed in **Nm**
R : radius of driving wheels, expressed in **m**
consistency of the units : $F = N.m \cdot m^{-1} = N$

Example : calculate the drive force which arises in contact with the ground under the following conditions: drive torque of 720 Nm, drive wheel radius 0.3 meters:

$$F = 720 / 0.3 = 2,400 \text{ N}$$

Engine brake force :

$$F = Ta \cdot X / R$$

F : engine brake force, expressed in **N**
Ta : antagonist torque, expressed in **Nm**
X : transmission ratio, dimensionless
R : radius of driving wheels, expressed in **m**
consistency of the units : $F = N.m \cdot m^{-1} = N$

Example : calculate the engine brake force exerted on ground engaging drive wheels of 0.3 m radius when an antagonist torque of 30 Nm is relayed by a 8.5 transmission ratio:

$$F = 30 \times 8.5 / 0.3 = 850 \text{ N}$$

Accélération :

$$\Upsilon = F / M$$

ϒ : accélération, expressed in $m.s^{-2}$
F : driving force, expressed in **N**
M : mass, expressed in **kg**
consistency of the units : $\Upsilon = N \cdot kg^{-1} = kg.m.s^{-2} \cdot kg^{-1} = m.s^{-2}$

Example : calculate the acceleration of a 3,300 lb (1,500 kg) car mass subjected to a 2,400 N driving force:

$$\Upsilon = 2,400 / 1,500 = 1.6 \text{ m.s}^{-2}$$

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