THE ENGINE POWER

Have you leaf through the catalog of a major car manufacturer? Each model is available in several versions, the differences focusing on engine power. The choice is vast and you get lost: 80 hp, 100 hp, 120 hp, 150 hp...

What these numbers really mean? What is power? How do we measure? What is the relationship between power and speed? Here are some answers...

Power and Energy

Generally, the power means production, consumption, or the energy conversion per unit time.

For a car, this energy is primarily chemical in nature (burning of fuel), and then kinetic in nature (acceleration and speed on a level road) and gravitational (road gradient).

The power of a heat engine thus relates to the energy delivered per unit of time, but also the energy consumed as fuel at the same time (see ADILCA folder '*fuel combustion*').

The mass / power ratio

The power determines the acceleration, climbing capability and, incidentally, the top speed of land vehicles.

The acceleration means the ability of communicating energy (kinetic energy in the first case, gravitational energy in the latter) to a mass, it means that the engine power must be assessed in terms of the mass of the vehicle.

In other words, more than the raw power, the mass / power ratio is the real indicator of the performance of a vehicle.

Some examples

First example: comparing two cars, one of mass 1,000 kg and 100 hp power, the other of mass 1,500 kg and power 150 hp; mass / power ratio (here equal to 10 kg per horse) shows that their performance in acceleration or hill will be very similar.

Second example: a 40 tons truck which accelerates from 0 to 36 $km.h^{-1}$ in 10 seconds mobilizes an average power of 270 hp. The same rate of change realized in 20 seconds mobilizes an average output of 135 hp.

Third example: a 40 tons truck climbing a slope of 10 % at a speed of 36 $km.h^{-1}$

mobilizes an instant power of 540 hp. The same slope climbed at speed 18 $km.h^{-1}$ mobilizes an instant power of 270 hp.

Naturally, the consideration of the applied power is instant consumption in relation to the required performance.

The power must be assessed in terms of the mass of the car, here 200 hp and 1,160 kg, a weight / power ratio equal to 5.8 kg / hp; to benefit from a favorable report, a 1,800 kg mass car should be equipped with a 310 hp engine.

Definition and units

The international unit of power is the watt (symbol W) or kilowatt (kW symbol): one watt is defined as one joule of work done in one second.

Specifically:

- one watt is the power required to move a force of 1 N over a distance of 1 meter in 1 second.

- one watt is the power required to lift about a glass of water to one meter in height in a second.

An equivalent definition applies to automobile engines: the power is the product of torque (expressed in Nm) by rotation speed (expressed in $rad.s^{-1}$). So, one watt is the power of an engine that delivers a torque of 1 Nm with a rotational speed of one radian per second(1).

Expression of power

It is still very common to express the power of an engine by horsepower (hp symbol), referring to the physical abilities of the animal.

Indeed, in a show jumping, a good horse is supposed to lift the body of a man of 75 kg (165 lb) to a meter in height in a second.

A quick calculation shows that it corresponds to a power equal to 735.5 watts exactly. Therefore, the conversion of the units is easy.

Measurement or calculation?

How does one determine the engine power? You can never measure it but you can calculate that, by combining the torque and rotational speed measured on a dynamometer.

Place motor bench is to couple it to a disk equipped with a brake and a tachometer: once the engine started at full speed, the operation is to gradually apply the brake until the engine rotational speed has stabilized, the control of the remaining gas wide open.

Indeed, a steady speed means that the engine torque is exactly equal to the braking torque: it suffices to know the intensity of the braking force to deduce the value of the engine torque.

In other words, what is wrongly called a 'dynamometer' only serves to measure the maximum torque and the way it evolves according to the engine rotation speed. The power results of a calculation, that is the product of these two quantities(2).

Some ideas about the power

More than the power, the torque and particularly the speed at which it is available is the essential feature of a car motor (see ADILCA folder '*engine torque*').

This confusion between power and torque is the source of many misunderstandings.

Thus the power claimed by the manufacturers is always a maximum value, available only at the specified speed ('red zone' on the rev counter!) and assuming that the throttle is wide open ('flat out'!). These two conditions are rarely met, and rarely for a longtime!

In any other situation, only one part of the power advertised is available, but never the whole. In other words, most drivers who merely travel at reasonable engine speeds will never require the advertised horsepower.

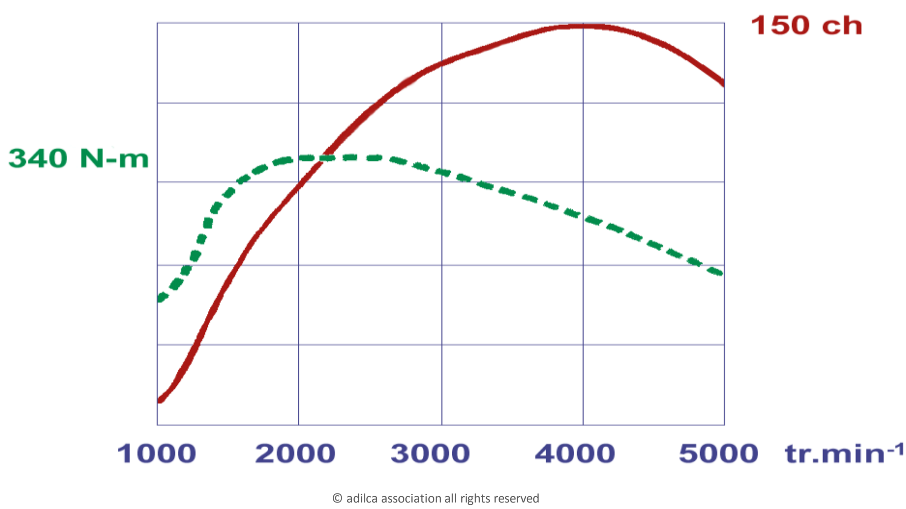
Figures that speak

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

- maximum power 110 kilowatts (150 hp) at 4,000 rpm

- maximum torque 340 Nm at 2,000 rpm

A quick calculation shows that at maximum torque speed (2,000 rpm), the available power is only 71 kW (97 hp)! And assuming that the driver keeps the throttle ‘full gas’! If it is not the case, only a part of the 97 horses will be at work.



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

Another rapid calculation shows that at maximum rotation speed (4,000 rpm), the engine torque available is only 260 Nm! Between power and torque, it must be choosen!

Power and transmission

Transmission's main role is to increase the torque by speed reduction of the wheel shafts and *vice versa*. The power is the product of a couple with an angular velocity, it demonstrates that it remains independent of the selected transmission ratio(3).

In other words, if one neglects the loss due to the rotation of the transmission (gearbox, differential), the power available to the drive wheels is always strictly identical to the one available to the crankshaft, it depends only on the engine rotation speed and the opening of the throttle.

A curious law

Another definition of power is the energy required to maintain a constant speed.

Indeed, any land vehicle (bicycle, car, train ...) moving on horizontal land must mobilize a certain power corresponding to the instantaneous work of the two resistance forces: rolling resistance and air resistance.

But in this case, the power is expressed as the product of a force by a speed, while the air resistance is a quantity that varies as the square of the speed (see ADILCA folder '*aerodynamic*').

We deduce that the power required to overcome air resistance varies as the cube of the speed!

Concretely, it means that this resistance absorbs 8 times more power at 100 $km.h^{-1}$ than at 50 $km.h^{-1}$, 27 times more power at 150 $km.h^{-1}$ than at 50 $km.h^{-1}$!

Power and speed

Some quick calculations that take into account the actual characteristics of land vehicles indeed confirm that small differences in speed actually induce large differences in power.

A passenger vehicle(4) traveling on a level road at a constant speed of 65 mph (30 $m.s^{-1}$) mobilizes an output of about 30 hp. The same car traveling at 80 mph (35 $m.s^{-1}$) should mobilize a power of about 50 hp! That means 2/3 of extra power for 15 mph gain only!

A truck(5) that runs on a level road at a constant speed of 50 mph (22 $m.s^{-1}$) mobilizes an output of about 120 hp. The same truck traveling at 55 mph (25 $m.s^{-1}$) should mobilize a power of 160 hp! That means 1/3 more power for 5 mph gain only!

Power and fuel consumption

Every driver should keep in mind that the requested power also reflects the rate at which the fuel is consumed.

Conclusion

Power can be defined as the speed with which energy is produced or consumed.

The power claimed by the manufacturers is a maximum value that is virtually never solicited by drivers.

However, the power required to maintain a steady speed is a key variable since it varies roughly as the cube of the speed.

This means that the more one wants to go faster, we must mobilize power, but in an amount unrelated to the gain obtained.

(1) *Newton meter (Nm symbol) is defined as the torque produced by a force of 1 N exerted on a 1 meter long lever arm; the radian (rad symbol) is defined as the central angle intercepting an arc of length equal to the radius of the circle; 1 rotation = 360 ° = 2π radians = 6.28 radians, where 1 radian = 57.3 degrees.*

(2) *The engine torque is measured at the end of the crankshaft, it means that the torque and power values specified on the technical data do not take into account the resistance related to the rotation of the transmission (gearbox shafts, shaft transmission, differential, axle shafts). This resistance absorbs about 10% of the initial power.*

(3) *The power is defined as the ratio of energy and time, it can be no creation or spontaneous energy loss. Hence the general principle that conservation therefore also applies to the power. A principle often understood backwards, because it is precisely by virtue of this principle that the transmission can generate a torque multiplication and speed reduction equivalent (or the reverse). In other words, at constant power, the transmission allows the distribution of energy, not in time but in space.*

(4) *Car features: frontal 2.5 m²; Cx 0.35; rolling resistance (including transmission) 250 N, supposedly independent speed value.*

(5) *Truck features: frontal surface 10 m²; Cx 0.9; 12 tires each supporting an average load of 3.3 tons and generating a rolling resistance (including transmission) of 25 N / t, assumed to be independent of the speed value.*

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SOME RELATIONSHIPS BETWEEN QUANTITIES

Kinetic energy :

$$E = \frac{1}{2} M . V^2$$

E : kinetic energy, expressed in **J**
M : mass, expressed in **kg**
V : speed, expressed in $m.s^{-1}$
consistency of the units : **E** = kg . $(m.s^{-1})^2$ = kg . $m^2.s^{-2}$ = **J**

Example : calculate the kinetic energy of a 3,080 lb (1,400 kg) mass car traveling at a speed of 65 mph (30 $m.s^{-1}$):

$$E = ½ \times 1,400 \times 30^2 = 700 \times 900 = 630,000 \text{ J}$$

Gravitational energy :

$$E = M . g . H$$

E : gravitational energy, expressed in **J**
M : mass, expressed in **kg**
g : gravitational acceleration value (Earth : **g** = 9.8 $m.s^{-2}$)
H : height, expressed in **m**
consistency of the units : **E** = kg . $m.s^{-2}$. m = kg . $m^2.s^{-2}$ = **J**

Example : calculate the energy required to lift a mass of 3,080 lb (1,400 kg) to 1,000 meters high:

$$E = 1,400 \times 9.8 \times 1,000 = 13,720,000 \text{ J}$$

Power :

$$B = E / T$$

B : power, expressed in **W**
E : energy or work, expressed in **J**
T : duration, expressed in **s**
consistency of the units : **B** = $kg.m^2.s^{-2}$. s^{-1} = $kg.m^2.s^{-3}$ = **W**

Example : calculate the power required to produce a kinetic energy of 600 kJ in one minute (60 seconds):

$$B = 600,000 / 60 = 10,000 \text{ W}$$

Engine power :

$$\mathbf{B = T \cdot \omega}$$

B : engine power, expressed in **W**
T : engine torque, expressed in **Nm**
ω : angular velocity, expressed in **$rad.s^{-1}$**
consistency of the units : **B** = $N.m \cdot s^{-1} = kg.m^{+1}.s^{-2} \cdot m^{+1} \cdot s^{-1} = kg.m^2.s^{-3}$ = **W**
(*the radian is dimensionless*)

Example : calculate the power of an engine delivering a torque of 250 Nm at 1,800 rpm (190 $rad.s^{-1}$):

B = 250 x 190 = 47,500 W

Power absorbed by the speed :

$$\mathbf{B = F \cdot V}$$

B : power, expressed in **W**
F : resistance force, expressed in **N**
V : vitesse, expressed in **$m.s^{-1}$**
consistency of the units : **B** = $kg.m^{+1}.s^{-2} \cdot m^{+1}.s^{-1} = kg.m^2.s^{-3}$ = **W**

Example : calculate the power absorbed by a resistance force of 500 N when the car runs at a speed of 65 mph (30 $m.s^{-1}$) :

B = 500 x 30 = 15,000 W

Power absorbed by slope :

$$\mathbf{B = M \cdot g \cdot H / T}$$

B : power absorbed by slope, expressed in **W**
M : mass, expressed in **kg**
g : gravitational acceleration value (Earth : **g** = 9.8 $m.s^{-2}$)
H : height, expressed in **m**
T : temps, expressed in **s**
consistency of the units : **B** = $kg \cdot m^{+1}.s^{-2} \cdot m^{+1} \cdot s^{-1} = kg.m^2.s^{-3}$ = **W**

Example : calculate the power required to lift a weight of 3,080 lb (1,400 kg) at a height of 1,000 m in 10 minutes (600 seconds):

B = 1,400 x 9.8 x 1,000 / 600 = 22,900 W

Conversion of units :

1 hp = 735.5 W

1 kW = 1.36 hp

Example 1 : an engine delivers 200 horsepower; express this power in kilowatts:

B = 200 x 735.5 = 147,000 W = 147 kW

Example 2 : an engine delivers 73.5 kilowatts; express this power in horsepower:

B = 73.5 x 1.36 = 100 hp

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