Torque and **Power**

Torque and power are the vital statistics of an engine, but often they are poorly understood or completely mis-understood. Because of our links to England, our European present and a romantic relationship with horses, we also have a confusion of units. The Institute of the Motor Industry (IMI) sets out to explain where these terms come from and what they mean.

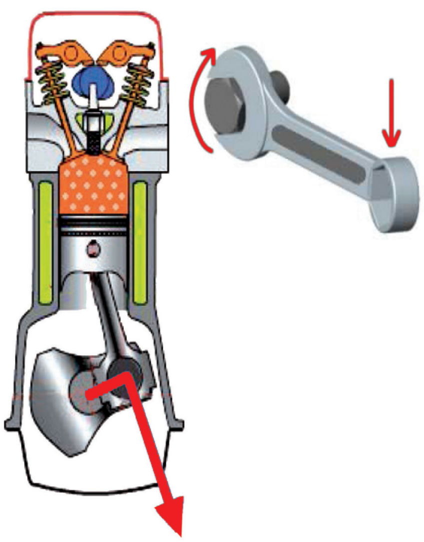
Work is a force applied over a distance, like pushing a car. Power takes into account how long it takes to push the car, more power means you will be able to push it more quickly.

Torque

We all use torque wrenches, so the idea of torque should be clear. Just for clarification, here's a bit about it. Torque is a twisting force; that when applied it will, or will try, to turn something. This means that torque doesn't need to be moving anything, it might just be trying to. Importantly, you cannot apply a torque if there is no resistance. Torque is measured in Newton metres. This is the International System (SI) and they named it after Isaac Newton. Pounds feet is also commonly used but makes further calculations of Brake Thermal Efficiency and Specific Fuel Consumption clumsy. Look on your torque wrench for a quick conversion. A rule of thumb: 80Nm is about 60lbft or Nm = lbft x1.35.

Torque is the result of a force acting at a distance from the centre of rotation. Increasing the applied force, or the radius, increases the torque. Torque is simple to calculate: torque = force x radius.

Engines cannot produce static torque, so the torque has to be measured while the engine is running. Torque measurement is done with a brake dynamometer which can be electrical, hydraulic or friction.



Torque is easy to understand, you apply a force that may cause an object to rotate, but it may also not rotate

Work

Work is done when a force is applied and movement takes place. If a bolt is being tightened and movement takes place, then work is being done. But if a bolt is tight and no movement takes place, then no work is being done. In both situations torque is applied. Here is where confusion can happen. Work is also measured in Newton metres; this time it is the force applied in Newtons and the distance moved in metres. If you apply a force of 400 Newtons to make a car move 20 metres, you have done 20 x 400 = 8000Nm of work. To distinguish Nm of torque from Nm of work, we use the unit Joule for work so you have done 8000 Joules or 8kJ of work.

Power

Power is the rate at which work is done and is measured in Newton metres per second or Watts, named after James Watt. Let's do some harder work. The challenge is to push the same car a distance of 200 metres as fast as you can. It takes 400N to move the vehicle, so the work done is 400N x 200m = 80,000 Joules or 80kJ. Let's say it took 200 seconds; then the power you put into moving the car would be:

$$\frac{80{,}000\ \text{Joules}}{200\ \text{seconds}} = 400\ \text{Newton metres per second}$$

or 400 Watts. Now let's say another man is set the same challenge and completes it in 160 seconds, so the power would now be:

$$\frac{80{,}000\ \text{Joules}}{160\ \text{seconds}} = 500\ \text{Newton metres per second}$$

or 500 Watts. Same work, different power. The faster that work is done, the more power is required.

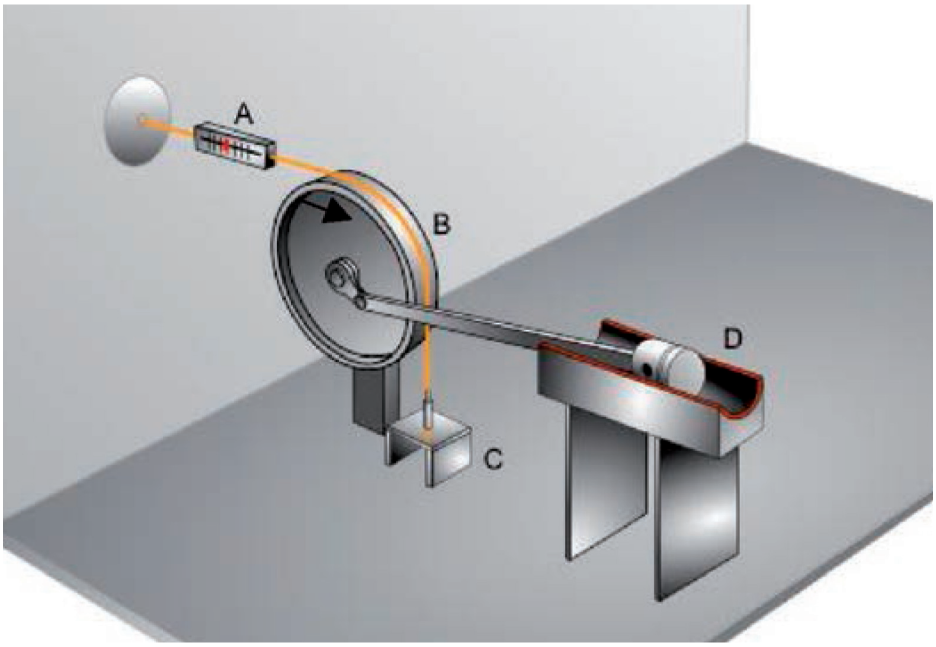
So to recap:

Torque is equal to **force x radius** and is measured in **Newton metres.**
Work is equal to **force x distance moved** and is measured in **Joules**.
Power is equal to **force x distance/time** and is measured in **Watts**.

So how does this work in engines? The diagram to the right shows a dynamometer, that is simplified version of a real dynamometer. It uses a rope brake "B" to put a frictional load onto the flywheel. The amount of load is adjusted at "C" and the tension in the rope is indicated on a spring balance at "A". Power is force x distance calculated over time. If we consider the amount of power being generated over 1 minute: The force will be the force indicated on the spring balance. The distance will be the circumference of the flywheel multiplied by the number of rotations it makes in 1 minute. The time will be 60 seconds. So our calculation will be:

$$\text{Power} = \frac{\text{force} \times 2\pi r \times n}{60 \text{ seconds}}$$

where r is the radius of the flywheel and n is the number of revolutions per minute.



A simplified version of a dynamometer testing an engine. This simple arrangement can determine the torque and power of the engine being tested.

But have you noticed there is both force and radius in the Power and Torque equations? If we replace them we get:

$$\text{Power} = \frac{2\pi nt \text{ Watts}}{60} \quad \text{or}$$

$$\text{Power} = \frac{2\pi nt \text{ kilowatts}}{60{,}000}$$

So let's say our engine is turning at 200 rpm and the spring balance measures 400N and the radius of the flywheel is 1 metre:

$$\text{Power} = \frac{400 \text{x} 2 \text{x} 3.142 \text{x} 1 \text{x} 200}{60000} = 8.4 \text{ kW}$$

This power is called Brake Power, because a brake is used to control the engine speed.

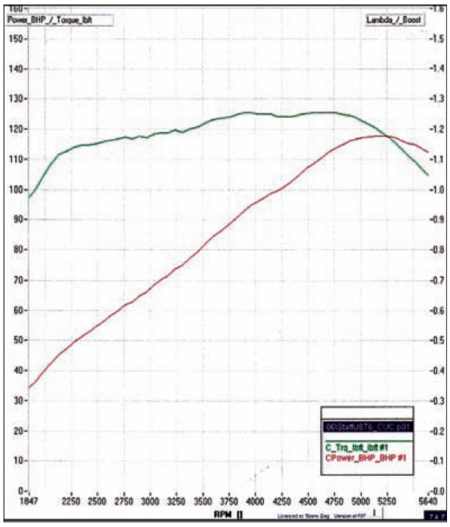
Brake horsepower (BHP)
When engines were first developed, they were compared with what they were normally replacing, horses. In the early 1700s, James Watt conducted an experiment to find out how powerful a horse was and calculated that it could raise a 33,000 lb weight one foot in height in one minute, or more reasonably 330 lbs raised 100 feet in one minute. This became the standard in the UK and the US. Europe, however, adopted another version of horsepower: PS DIN (Pferdetarke Deutsches Institut fur Normung), which just means horse power German Standard. Since the 1970s, the Irish motor industry has dithered - you will see power quoted in kW, BHP and PS DIN.

$$\text{BHP} = \frac{\text{torque (lbft)} \times 2\pi \times \text{rpm}}{33000}$$

Converting kW to BHP:
1PS DIN is equal to 0.735 kW.
1BHP (US) is equal to 0.745 kW

If you like, 100BHP is 74.5kW or 100PS DIN is equal to 73.5kW.

Torque and power curves
Engine power is the result of torque and speed. The more torque an engine can produce, and the faster it can do it, the more power the engine will develop. The problem with engines is that they cannot produce the same torque across the engine speed range. The reason for this is mostly to do with volumetric efficiency, which is how effectively the cylinder is filled and is an entirely different topic that we won't get into here. Normal everyday engines are designed to produce their highest torque at midrange - about 2000rpm for diesel and 3500rpm for petrol. This makes the engine flexible and improves drivability.



A typical torque/power graph for a mid-performance, naturally aspirated, petrol engine

Performance engines will be designed to rev higher and will generally arrange the maximum torque higher in the engine speed range. This gives them much more power. They do their hardest work faster. As you can imagine, there is a limit to the speed of an engine in terms of the stresses on the components. Above is a torque/power graph for a mid performance, naturally aspirated, petrol engine. As you can see, the torque (green) is low at low rpm's as the camshaft timing and overlap interferes with the air flow, and low again at high rpm's as the induction tract and valve timing restrict the air entering the cylinder. However, the power curve (red) shows that even though the torque is dropping at 4700, the power is still building. Think of our formula; both torque and speed contribute to engine power, so even though the torque is dropping the engine is still producing that torque at higher speed. It is only when the rate of fall of torque is greater than the rate of increase in speed that the power starts to drop.

The torque and power curves describe the driving characteristics of the vehicle and the type of gearbox that is needed.

In a future article, we will be looking at performance curves for modern petrol and diesel engines and how they can be modified.

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