Motor Sizing Principles

1. General Concepts

Motor: Converts electrical energy into mechanical energy. In this course we will be considering motors which rotate (spin)

Mechanical Power: The mechanical output of the motor (P) measured in Watts. Older motors and USA motors measure power in Horse Power (Hp).

Conversion Factor: 1 Hp = 746 W

For reference: A 2 Litre petrol Engine at full throttle can produce around 90 kW
A fit human on a bicycle produces a maximum of about 400W.

Sample Problem: i)How many horsepower is a typical 2 litre petrol engine?
ii) How many Watts is 15 Hp?

Speed: The number of revolutions per minute of the motor. Usually denoted "N" and measures in rpm (revs per minute). In some formulae speed is measured in revs per second and denoted "n". In academic works a different units called radians per second is often used and denoted "ω" The reason this unit I sused is becaue it simplifies some of the formulae.

Conversion Factors:
$n=N/60$
$\omega=2\pi N/60$

Torque: The force with which a motor turns is called Torque measured in Newton metres (Nm). A motor with high Torque accelerates quickly and can drive a heavy load. In the USA torque is often measured in foot-pounds (ft-lb)

2. The relationship between Power, Speed and Torque

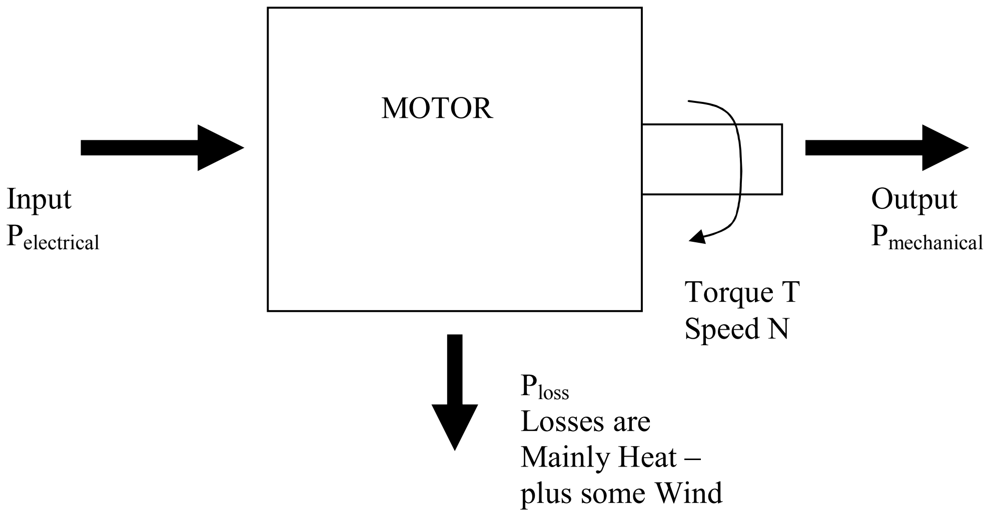
The higher the speed the more power, the higher the torque the more power. In fact the power depends on Torque multiplied by Speed.

Important Formula

$$P = \frac{2 \times \pi \times T \times N}{60}$$

Sample Problems iii) If T = 10Nm, N = 1000 rpm what is P? (1.05kW)
iv) If P=2kW, N = 1450 rpm what is T? (13.2Nm)
v) If P = 4 Hp, T = 10 Nm, what is N? (2850rpm)

3. Losses and Efficiency



Important Formula

$$Input = Output + Losses$$

$$P_{electrical} = P_{mechanical} + P_{loss}$$

Important Formula

$$Efficiency = \eta = \frac{Output}{Input} \times 100\%$$

$$\eta = \frac{P_{mechanical}}{P_{electrical}} \times 100\%$$

Sample Questions

vi) An electric motor is delivering 1kW of mechanical power and consuming 1200W of electrical power. What are the losses? What is the efficiency? (83.3%)

vii) An electric motor operating at 85% efficiency is delivering 2kW of mechanical power. What is the electrical input power? What are the losses?(2353W)

4. **Motor Sizing**
   Motor sizing refers to the process of picking the correct motor for a given load. It sis important to size a motor correctly because:
   a. If a motor is **too small** for an application it may not have sufficient torque to start the load and run it up to the correct speed. Even if it does get the load up to speed the motor will overheat and burnout if it is too small for the application.
   b. If a motor is **too large** for an application then money has been wasted in purchasing such a large motor. Also motors typically operate inefficiently when they are run well below rated load. So money is also wasted in running costs.

Excellent web Reference:

A very good reference on motor sizing can be found on the web at:
http://www.electricmotors.com/sizing.html

Read this and in particular pay attention to the definitions of **Starting torque**, **Pull up torque**, **Breakdown torque** and **Full load torque**.

Warning You will also come across the term pullout torque for induction motors. Please note that pull out torque is the peak point of the troque versus speed curve and is not the same as pull up torque.

Warning Because this is an American website it uses horsepower for Power and Foot-Pounds for torque.

Important Concept: Ratings
Every Motor will have a rated values of voltage, current, speed and power (and frequency for an ac motor). Normally these are visible on the motors nameplate but in any case they will be given in the documentation. In general rated values represent the maximum values that the motor should be subjected to in normal use however there are some slight differences in the meaning of the different ratings:

1. **Rated Voltage** should never be exceeded. There is a risk of damaging the machine or exposing the user to an electric shock hazard.

2. **Rated Current** – Should not be exceeded for any prolonged time. The rated current may be exceeded temporarily during transient events (eg starting the motor). There is a risk of overheating and burning out the motor windings.

3. **Rated Speed** should generally not be exceeded however induction motors are designed to run slightly faster than rated speed (up to a speed called synchronous speed) when they are lightly loaded. For example an induction motor with rated speed of 1450rpm may have a synchronous speed of 1500rpm and would be safe up to this speed. There is a risk of mechanical failure due to centrifugal force on the rotating components.

4. **Rated Power** should generally not be exceeded. However some motors have a service factor which allows the motor to be used at more than the rated power for short periods. This can be useful for dealing with variable loads that may exceed the rated power requirement for short times during the operating cycle. Exceeding rated power risks overheating and in extreme cases may also risk mechanical failure.

5. **Rated Torque** Often this is not given on the nameplate but it I sa very important parameter for appropriately sizing the motor. In both DC motors and AC induction motors operating current is proportional to Torque so exceeding rated torque is likely to lead to overheating and burnout of the motor windings. Exceeding rated torque also risks mechanical damage to couplings and drive shaft. Rated torque can be calculated from rated power and rated speed.

   Important Formula

   $$Rated\,Torque = \frac{60 \times P_{rated}}{2\pi \times N_{rated}}$$

Choosing the right motor
At its simplest: if the load is constant then sizing the motor consists of choosing a motor whose rated torque is slightly above the torque required by the load. The load torque should be between 75%-100% of the rated motor toque with 95% being an ideal choice.

For constant speed applications where the motor will run continuously at rated speed you do not need to work out torque. You can simply look at load power and motor power and use the same 75%-100% rule. This is the case for standard induction motors without a variable speed drive.

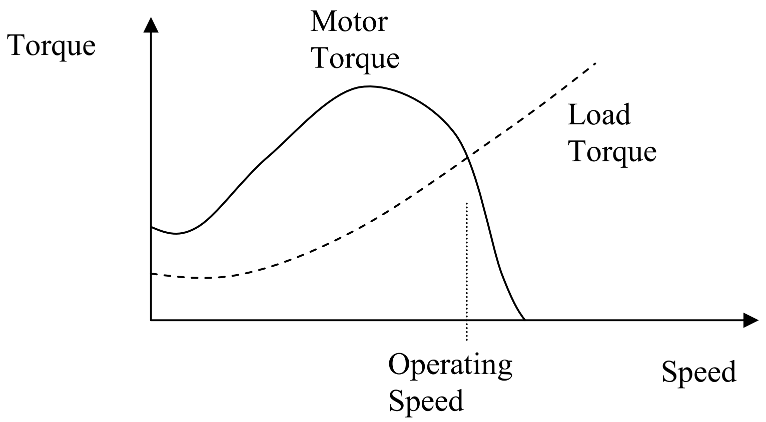
Looking Deeper – Can the motor start the load?

In order to get the load up to speed the motor must start off from zero speed and accelerate the load up to speed. Torque is what causes acceleration. The motor torque will cause the load to accelerate but the load produces its own torque which resists acceleration.

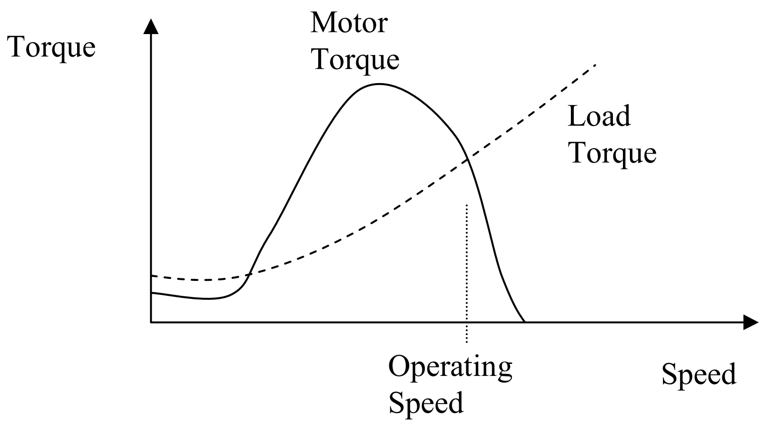
The torque produced by a motor varies with speed and the torque produced by a load also varies with speed. If the motor torque is greater than the load torque then the load will accelerate. If the load torque is greater than the motor torque then the load will decelerate.

Accelerating Torque: = T_{motor}-T_{load}

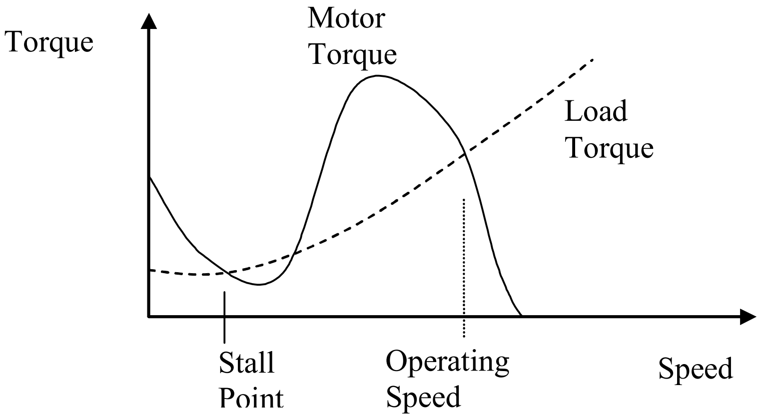
In order for the motor to start the load and get it up to correct speed then the motor torque must be higher than the load torque at zero speed (starting torque) and at every speed up to the desired operating speed. If the load torque ever exceeds the motor torque at any intermediate speed the motor will stall at that speed and the system will not start up correctly.



This motor will start the load and get it up to speed correctly.



This motor will never even start



This motor will start the load but it will get stuck at the stall point.

How long will the system take to get up to operating speed?
It is beyond the scope of this course to calculate this but it is worth noting that the time it takes the motor to get up to full speed can be calculated from the area between the motor torque speed curve and the load torque speed curve. The bigger this area the quicker the system will get up to speed.

What if the load varies?

Some loads do not present a constant torque even after they have got up to full speed. This presents a variable power to the motor and complicates the sizing problem.

In general we should ensure that

1. Peak load torque (or power) < Rated Motor torque (or power) x (1+Service factor/100%)
2. The root mean square load torque (power) requirement must be less than 100% of the rated motor torque (power) and ideally greater than 75% of rated motor torque (power).
3. Check that the Motor can start the load and get it up to speed.

First Example: <u>Constant speed operation at **rated speed** but with variable torque</u> eg Induction motor running at constant speed. Since the load is running at rated motor speed we do not need to calculate torques but can work in power instead.

Root Mean Square Power is calculated as follows:

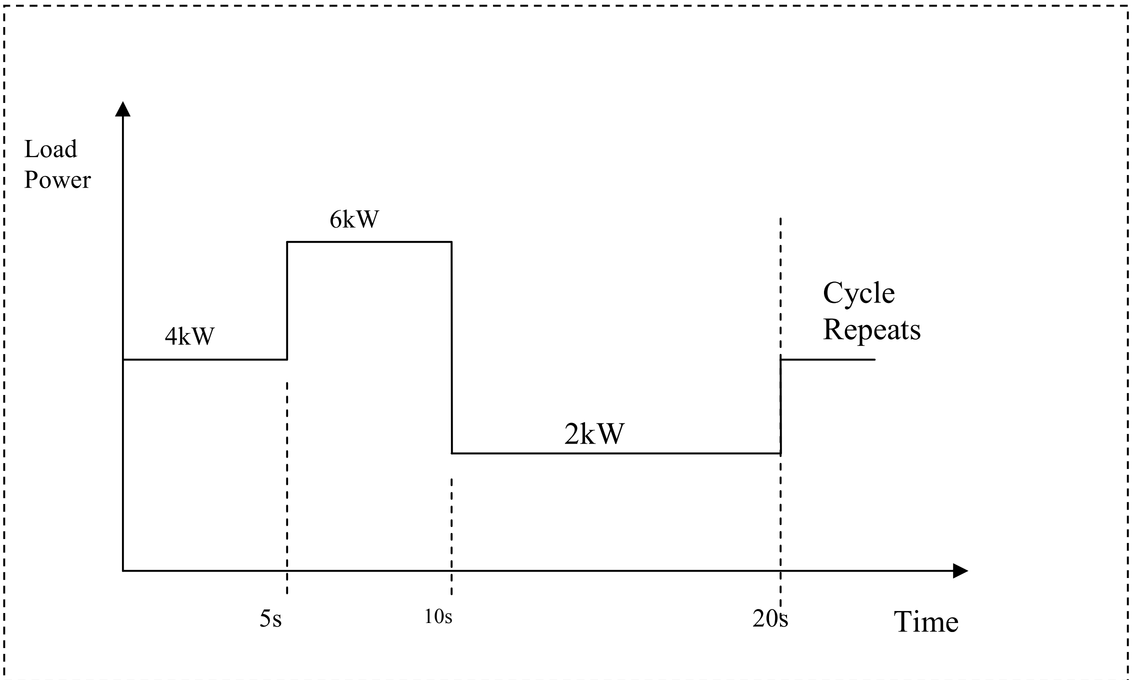
For a load which requires power P_1 for time t_1 followed by P_2 for time t_2 followed by P_3 for time t_3 … and so on up to P_n for time t_n in a cycle which repeats:

Important Formula

$$RMSpower = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + P_3^2 t_3 + ... + P_n^2 t_n}{t_1 + t_2 + t_3 + ... + t_n}}$$

Example

The following load torque profile was measured for a constant speed load. Choose an appropriately sized motor to drive this load assuming a service factor of 20%. You do not need to consider starting performance.



Sizing the motor

1. Peak Load Power requirement = 6kW.
   Peak load power must be less than Rated Motor Power x Service Factor
   => 6kW < P_{motor} x 1.2
   => P_{motor}>6/1.2 = 5kW

2. The RMS load power should ideally be between 75% and 100% of Rated Motor Power.

$$RMSLoadpower = \sqrt{\frac{P_1^2 t_1 + P_2^2 t_2 + P_3^2 t_3 + ... + P_n^2 t_n}{t_1 + t_2 + t_3 + ... + t_n}} = \sqrt{\frac{4^2 \times 5 + 6^2 \times 5 + 2^2 \times 10}{5 + 5 + 10}} = 4.16kW$$

If we choose P_{motor}=5kW then RMS load power = 4.16/5*100% = 83% of P_{motor}which is acceptable.

NB Important If RMS load power turned out to be less than 75% of 5kW we soul dstill need to choose a 5kW motor in order to be able to supply the peak power requirement. However if RMS load power was great than 100% of rated motor power we would need to choose a bigger motor to meet this requirement.

3. Starting Performance – Not a requirement in this case:

Answer: Choose a 5kW motor.

Second Example: Contant Speed variable torque at a **speed below rated speed** (Example a DC motor running at less than rated speed).

This is very similar to the first example but in this case In this case we must work in torque rather than power. Work out load torque requirements (peak and rms and compare with rated motor torque).

Third Example: **Variable Speed** load. (EG variable speed induction motor drive).

In this case we must work with torque rather than power. Also we must take accelerating torque into account. This depends on the desired speed versus time profile and the moment of inertia of the motor and load.