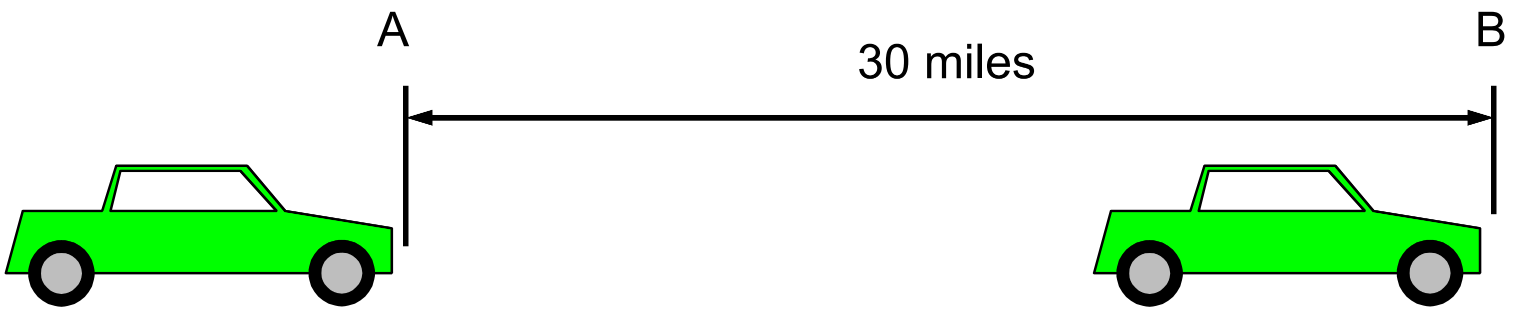
Mechanical Concepts for Drives

Quantifying Motion

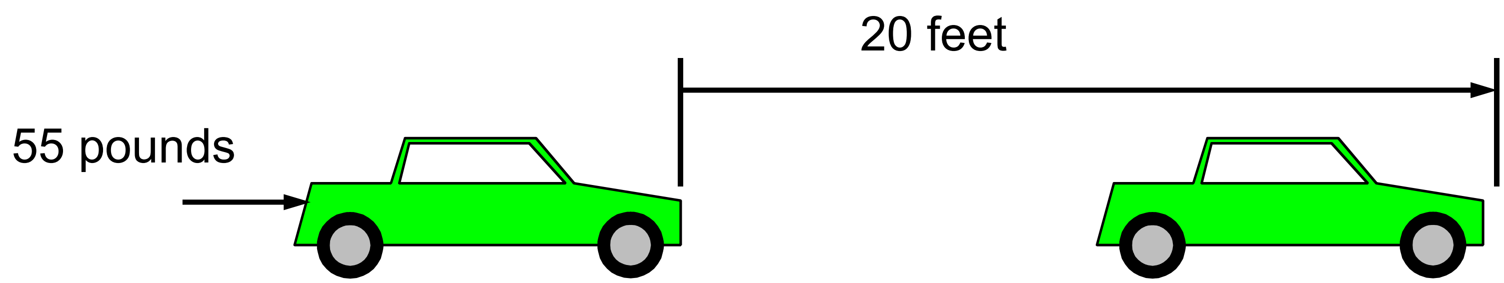
- Position, Speed, Acceleration
  - If you drive your car from point A to point B, you change its position by 30 miles. If it took a half-hour to go from A to B, the average speed was:
    30 miles/0.5 hour = 60 miles per hour or 88 feet per second.
  - **Average speed = distance of position change/time to change position**
  - If it takes 22 seconds to go from a standstill to 88 feet per second, the average rate of acceleration is:
    88 feet per second/22 seconds or 4 feet per second per second or 4 $ft./s^2$.
  - **Average acceleration rate = speed change/time required to change speed**



Mechanical Concepts for Drives

Quantifying Motion

- Work and Energy
  - **Work is done when a force applied to an object causes the object to move.**
  - If your car is on a level surface, let us assume that you can move it by pushing it by hand with a force of 55 pounds.
  - If you push the car 20 feet, the work done is 55 lbs. × 20 ft. = 1100 ft.-lbs.
  - **Work = Force × Distance**



Mechanical Concepts for Drives

Quantifying Motion

- Work and Energy
  - **Energy is required to do work and is often defined as the capacity for doing work.**
  - Energy can be neither created nor destroyed, it can only be converted from one form to another and transferred from one place to another.
  - **Energy has the same units of measurement as work**, ft.-lbs. for example.
  - When work is done energy is transferred from the source of the force to the object that moves.
    - ≡ The amount of energy transferred is the same as the work done.
    - ≡ Some of the energy transferred is used to overcome friction. As friction is overcome, the energy used is converted to heat.
    - ≡ Some energy is stored in the moving mass of the object that was moved.

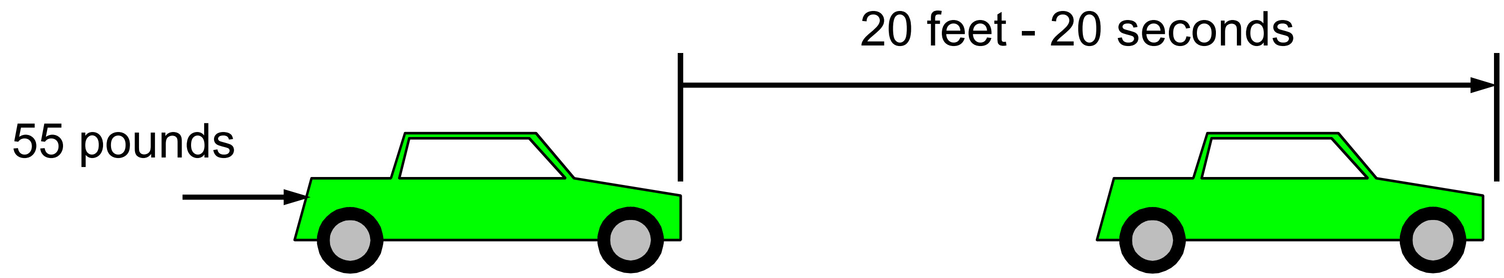
Quantifying Motion

- Work and Energy
  - The energy stored in a mass (m) moving at a velocity (v) is given by: $E = 1/2mv^2$.
  - Energy stored in a moving mass is called ***kinetic energy***.
  - Usually the energy stored in a mass is ultimately converted to heat when braking or some other friction brings the mass to a stop.

Mechanical Concepts for Drives

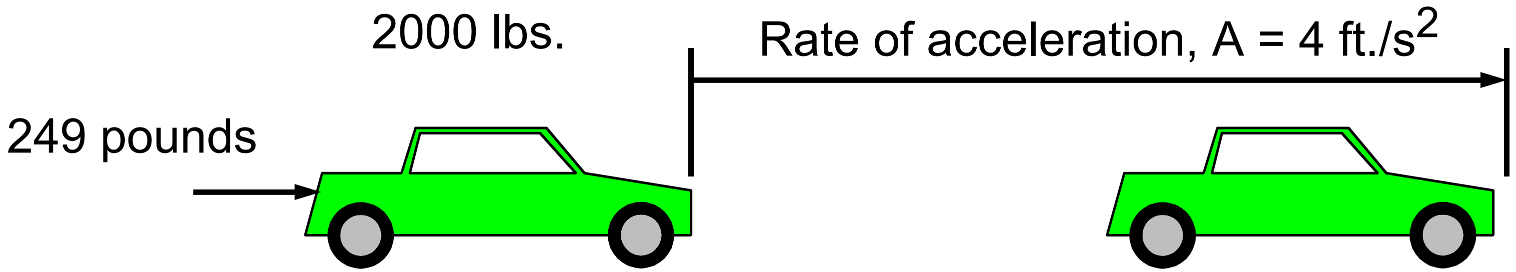
Quantifying Motion

- Power
  - **Power is the rate of energy usage** or the work done in a given period of time.
  - If it took 20 seconds to move the car, the rate of energy usage or power is 1100 ft.-lbs./20 seconds or 50 ft.-lbs. per second.
  - Since one horsepower is 550 ft.-lbs. per second the work was done at a rate of 1/10th horsepower.



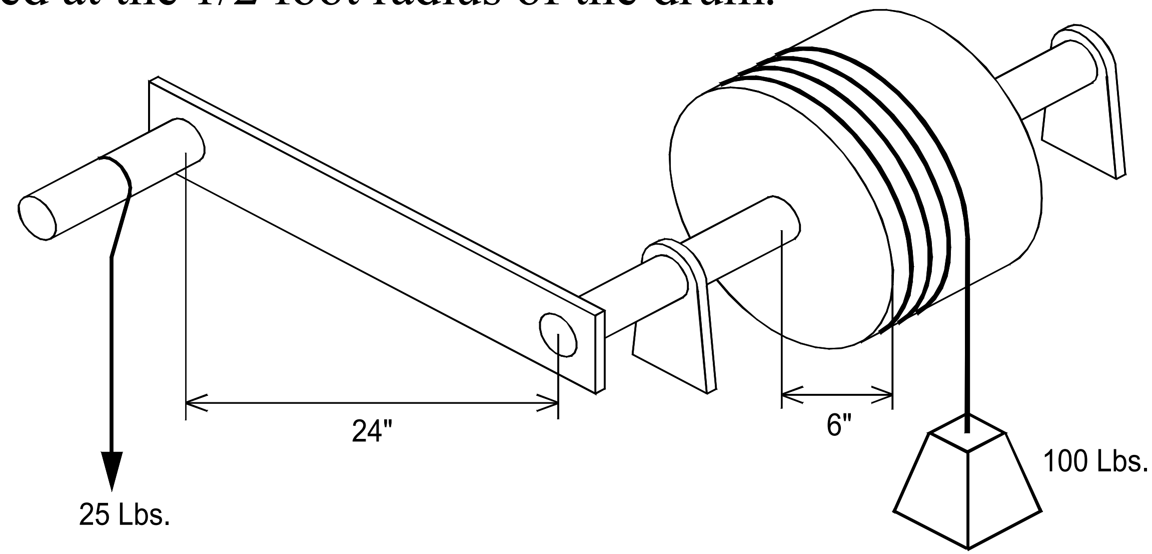
Accelerating Force

- The force required to accelerate a mass is equal to the mass times the rate of acceleration, **F = m × A**
  - Mass is weight divided by the acceleration of gravity, 32.17 ft./s^2
  - Force (lbs.) = Weight (lbs.) × Acceleration (ft./s^2) / 32.17 ft./s^2
  - The force required to accelerate a 2000 pound car at a rate of 4 ft./s^2 is 2000 × 4 / 32.17 = 249 pounds



Rotary Motion

- Torque
  - Torque is an expression of the **force applied to turn a shaft**.
  - In the figure, a force of 25 pounds is being exerted on the crank handle.
  - The 25 pound force multiplied by the 2 foot radius of the crank results in 50 lbs-ft of torque applied to the shaft.
  - Note that the torque is transmitted through the shaft to the drum and results in a 100 pound force applied at the 1/2 foot radius of the drum.



Mechanical Concepts for Drives

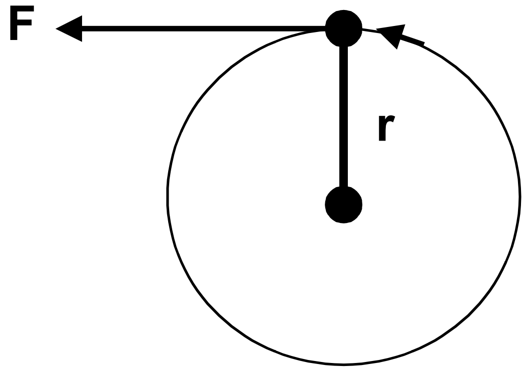
Rotary Motion

- Speed
  - The speed of rotary motion is usually stated in revolutions per minute (RPM).

Mechanical Concepts for Drives

Rotary Motion

- Energy
  - The energy require to turn a crank one revolution is the force applied to the handle multiplied by the distance the handle moves.
  - In one revolution, the distance that handle moves is the circumference of a circle with a radius equal to the length of the crank.
  - Energy(ft.-lbs.) = F(lbs.) × r(ft.) X 2π
  - Since Torque = F × r   Energy = Torque(lbs.-ft.) × 2π



Mechanical Concepts for Drives

Rotary Motion

- Power
  - Since power is the energy expended divided by time

$$\text{Power (ft.-lbs./min.)} = \frac{\text{Torque (lbs.-ft.)} \times 2\pi}{\text{Time of 1 revolution}}$$

Time of 1 revolution = 1/RPM

1 Horsepower = 33,000 ft.-lbs./min.

$$\text{Horsepower} = \frac{\text{Torque (lbs.-ft.)} \times 2\pi \times \text{RPM}}{33{,}000}$$

$$\textbf{Horsepower} = \frac{\textbf{Torque (lbs.-ft.)} \times \textbf{RPM}}{\textbf{5252}}$$

One of the formulas most often used in drive calculations

Mechanical Concepts for Drives

Rotary Motion

- Torque required for acceleration
  - The torque required to accelerate a rotating mass is given by:

$$\text{Torque (lbs.-ft.)} = \frac{WK^2\ (\text{lbs.-ft.}^2) \times \Delta\ \text{RPM}}{308 \times \Delta\ t\ (\text{sec.})}$$

Another often-used formula

  - ΔRPM is a change in speed and Δt is the time taken to accomplish that change.
  - WK^2 is the weight of a rotating mass times its radius of gyration.
  - References are available with formulas and tables for determining WK^2 of various shapes and materials.

Mechanical Concepts for Drives

Utilization of energy

- The energy supplied by the drive to the driven machine or process is ultimately dissipated as heat in the following ways:
  - Friction in the Machinery
  - Changing the Physical Shape of the Material
  - Changing the Physical Location of the Material

Utilization of energy

- Friction in the Machinery
  - In moving the driven machinery, power is used to overcome friction between the various parts.
  - There may also be friction between the machinery and the process material.
    - When water is pumped through a pipe, there is friction between the pipe and the flowing water.
    - The force of the pump overcomes the friction and the mechanical energy used is converted to heat in the water and piping.

Mechanical Concepts for Drives

Utilization of energy

- Changing the Physical Shape of the Material
  - Energy is used when the shape of the process material is changed by the driven machinery.
  - Energy is used when the work piece or process material is cut, formed, drawn, bent compressed, mixed or extruded.

Mechanical Concepts for Drives

Utilization of energy

- Changing the Physical Location of the Material
  - In changing the physical location of the work piece or process material, energy is used to increase the velocity of the material.
  - The kinetic energy stored in the machinery and material is ultimately dissipated as heat when the machinery is stopped.

Mechanical Concepts for Drives

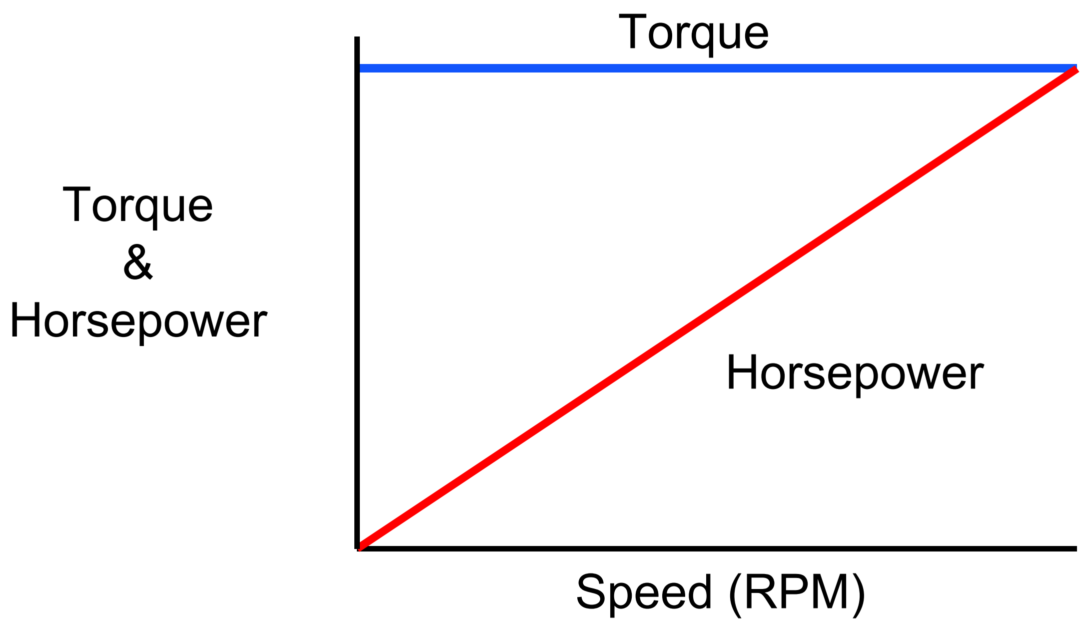
Load Torque vs. Speed

- The relationship between the speed of a driven machine and the torque required to drive it can be described by drawing a graph of torque vs. speed.
  - This graph, the machine or load torque-speed curve indicates what torque is required to keep the machine moving at any given speed.
  - Torque-speed curves are generally grouped into three characteristic shape categories:
    - Constant torque loads
    - Variable torque loads
    - Constant horsepower loads
    - Actual loads do not perfectly conform to these characteristic shapes, but these three categories are very useful in analyzing applications.

Mechanical Concepts for Drives

Load Torque vs. Speed

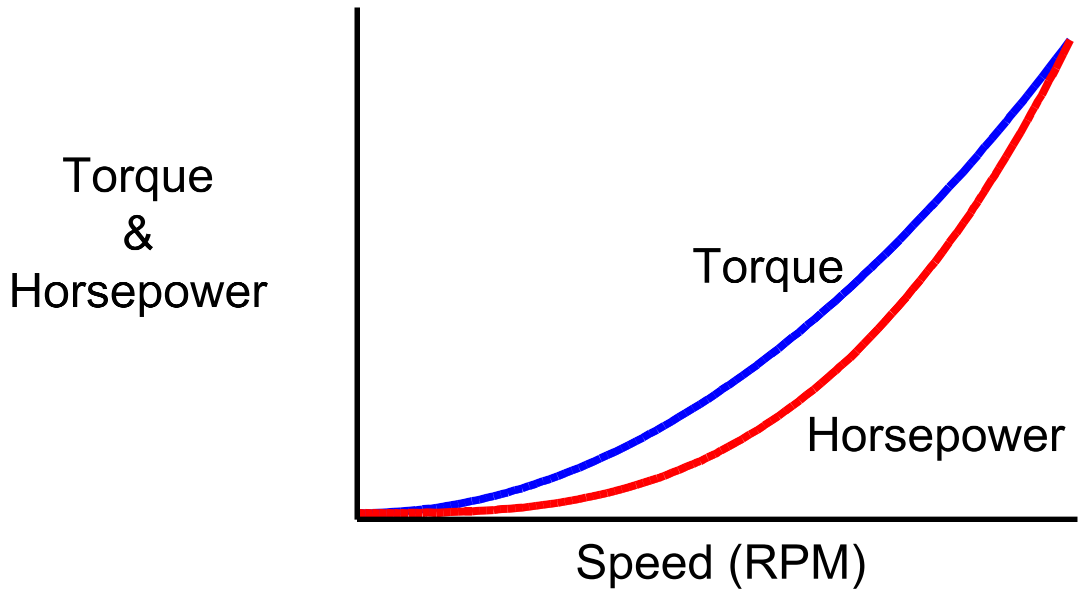
- Constant Torque Loads
  - Constant torque loads require essentially the same torque at all operating speeds. T = K
  - Horsepower is directly proportional to operating speed. $T = K \times RPM$



Mechanical Concepts for Drives

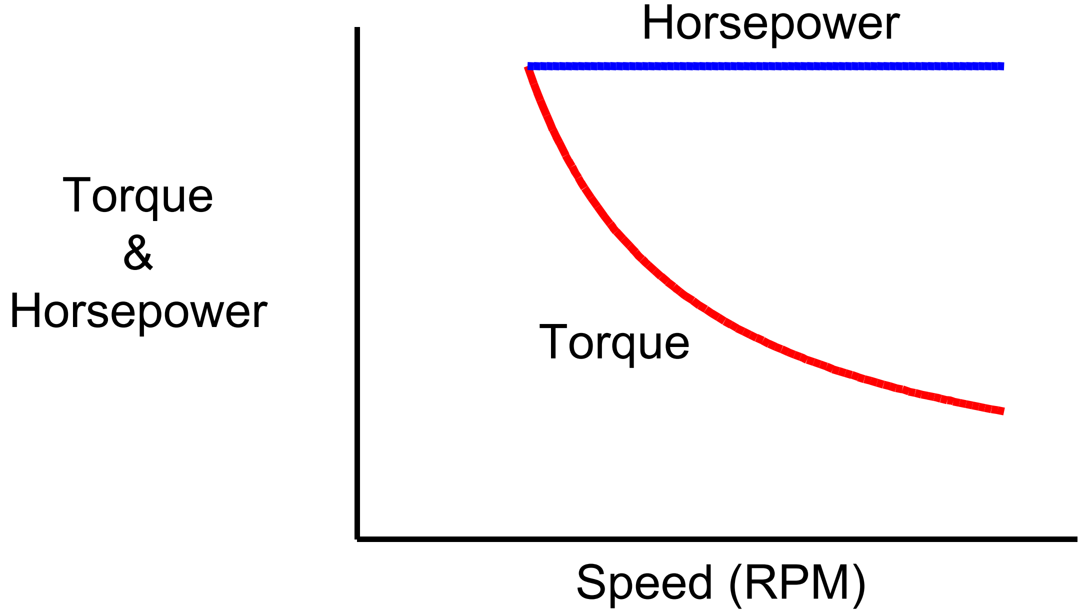
Load Torque vs. Speed

- Variable Torque Loads
  - A centrifugal pump or fan requires increased torque as the operating speed increases.
    - ≡ Torque is proportional to the square of speed, $T = K \times RPM^2$.
    - ≡ Horsepower is proportional to the cube of speed, $T = K \times RPM^3$.



Load Torque vs. Speed

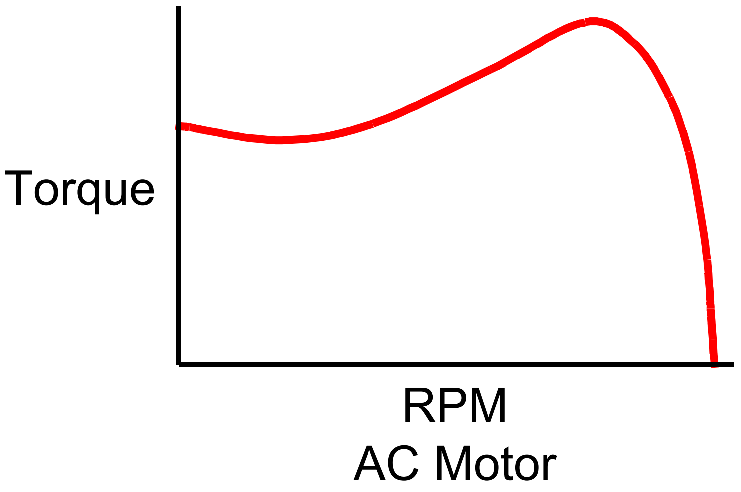
- Constant Horsepower Loads
  - With constant horsepower loads, the horsepower remains constant as the operating speed changes.
    - ≡ Hp = K
    - ≡ Since Hp = T × RPM/5252, T = K/RPM

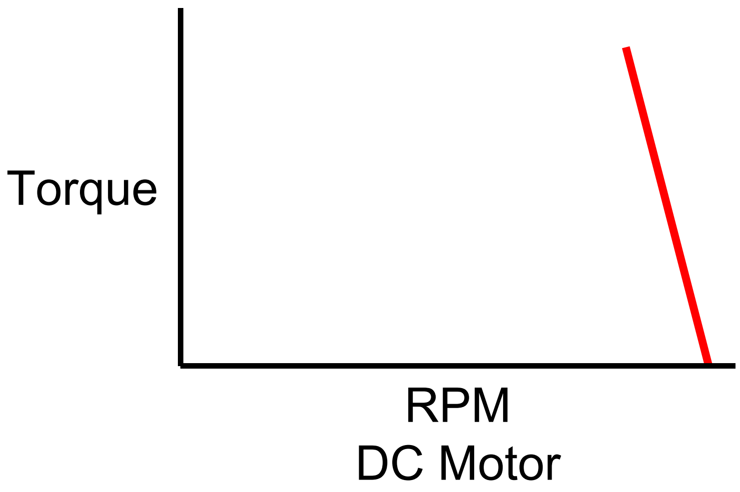


Mechanical Concepts for Drives

Motor Torque vs. Speed

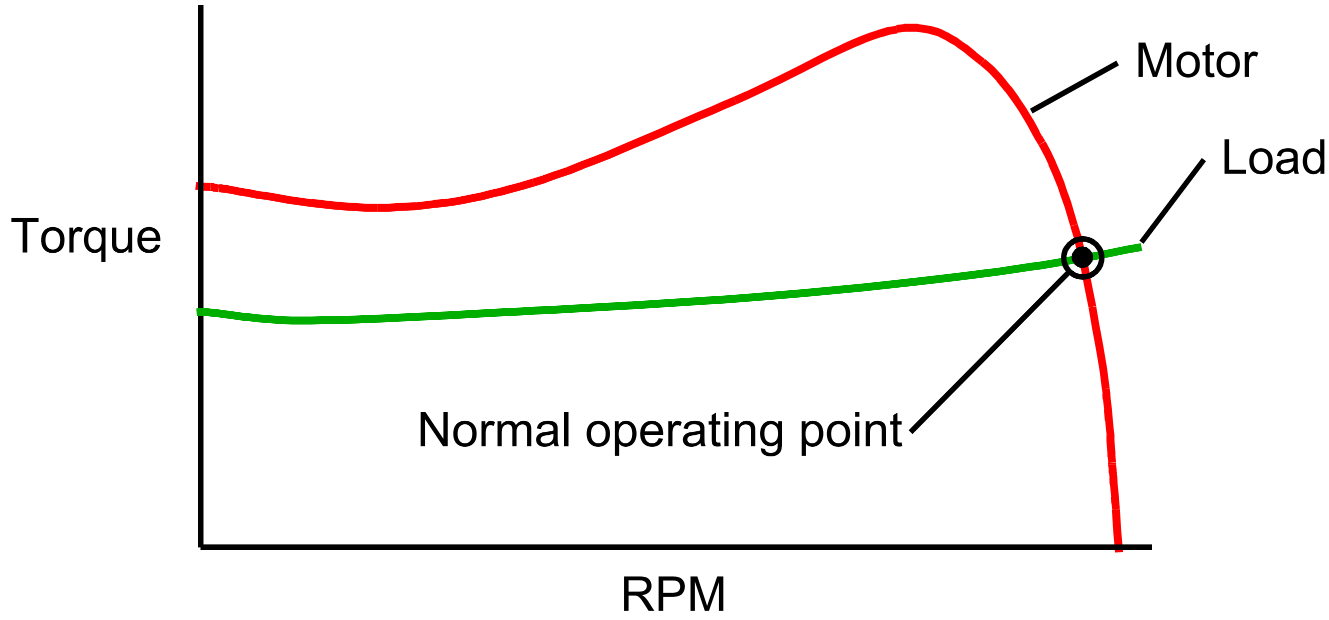
- Just as driven machine loads have certain characteristic torque-speed curves, motors and drives have characteristic torque-speed curves.
  - The torque-speed curve of a motor defines the torque that the motor is capable of producing at any given operating speed.
  - Conversely, the torque-speed curve defines the operating speed of a motor when loaded to a particular level of torque.





Motor Torque vs. Speed

- A motor normally operates at the intersection point of the motor's torque-speed curve and the torque-speed curve of the load.
  - If the motor is not operating at this point, it will accelerate or decelerate until it is operating at the normal operating point.



Motor Torque vs. Speed

- Accelerating and Decelerating Torque
  - The available accelerating or decelerating torque at any given operating speed is the difference between the load torque and motor torque at that speed.