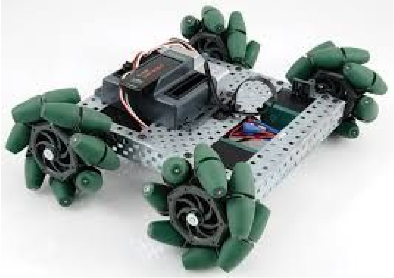
Robot Drive Systems

Key Concepts to help you choose
Motors, Wheels and Gearboxes

Types of Drive Systems and Motors

Differential Drive

Holomonic / Mecanum



Turn Steer

Brushed DC

Brushless

Stepper

This presentation will focus on differential drive systems with brushed DC motors

Key Concepts

Power

Efficiency

Torque

Coefficient of Friction

Motor Curves

Dead Band

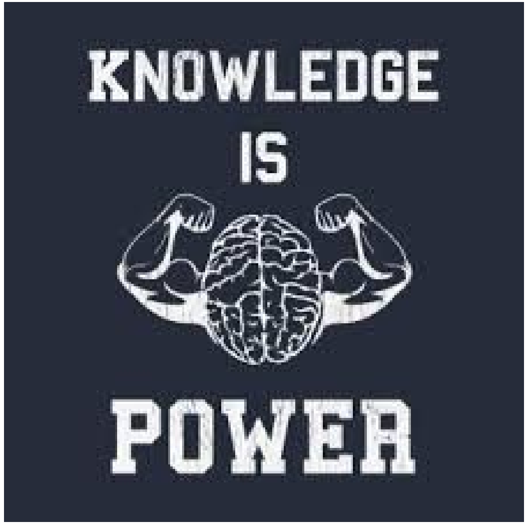
Cogging

Friction and Drag

Learn More:

https://curriculum.vexrobotics.com/curriculum.html

Calculating Power



Mechanical Power = Drag Force * Linear Speed

Mechanical Power = Torque * Angular Speed

Electrical Power = Voltage * Current

Hydraulic Power = Pressure * Flow Rate

Efficiency

INPUT

Volts * Amps

Plant or

Process

WASTED OUTPUT

Heat

USEFUL OUTPUT

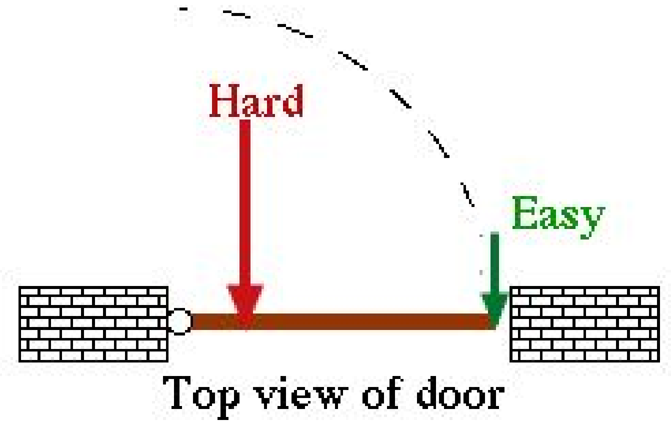
Torque * Angular

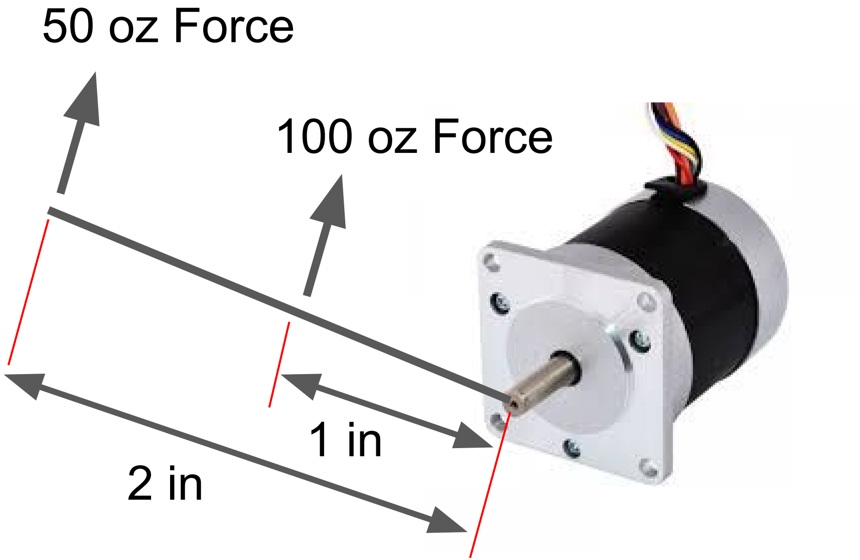
$$\text{Efficiency} = \frac{\text{Useful Output Power}}{\text{Input Power}}$$

Input Power = Useful Output Power + Wasted Power → Power is Conserved!

Torque is a Twisting Force

TORQUE = FORCE * DISTANCE





Motor Torque Example:
100 oz*in

100 oz*in = 100 oz * 1 in
OR
100 oz*in = 50 oz * 2 in

Calculating Weight Distribution

TORQUE = FORCE * DISTANCE

Move your battery around until the center of mass is right above the wheels for Max pushing force!

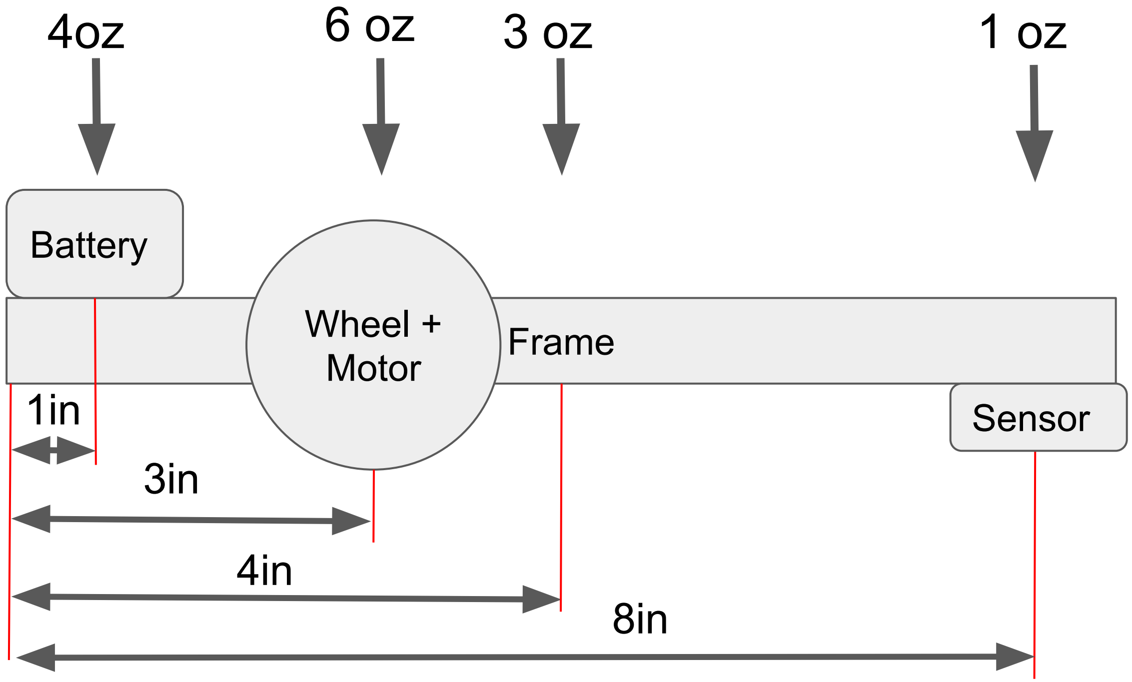
Center of Mass is the location where all the Torques balance out

Sum of Torque = (4oz*1in) + (6oz*3in) + (3oz*4in) + (1oz*8in) = 42 oz-in

Sum of Mass = 14 oz

Location of center of mass = Torque/Mass = 42/14 = 3 in

3 in is right above the wheels!



Gearbox - Trading Speed for Torque

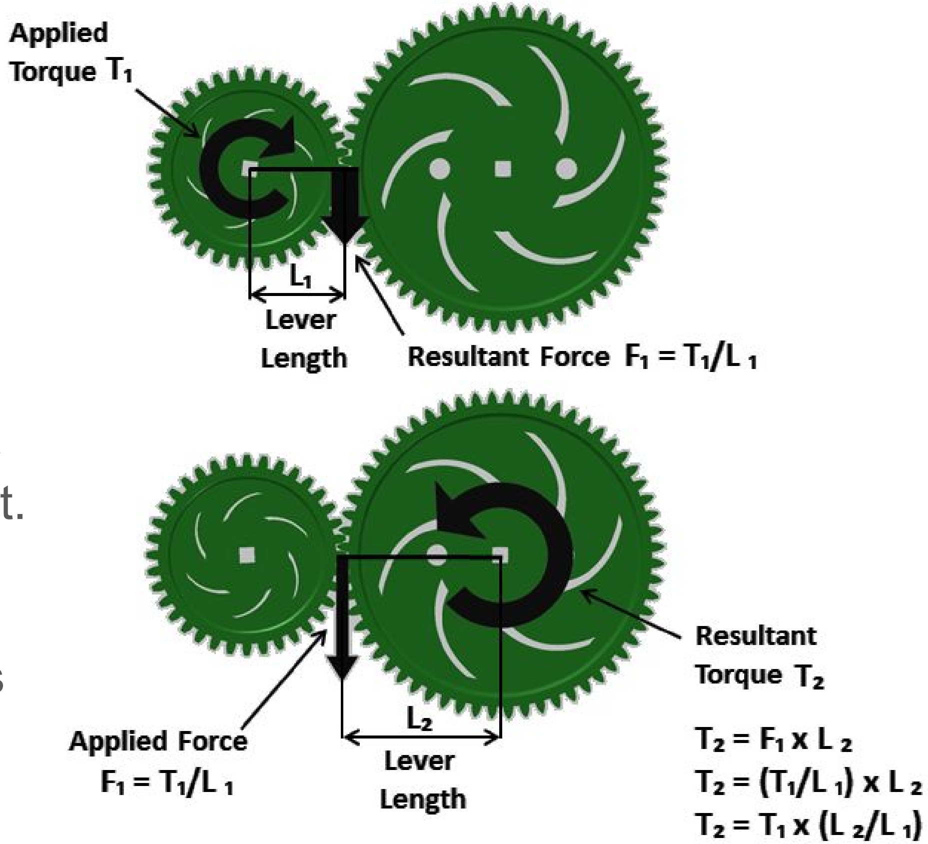
Ideal Gearbox

Input Speed / Ratio = Output Speed

Input Torque * Ratio = Output Torque

If gear ratio = 10, the output will have 10x the torque and 1/10 the speed of the input.

Gearboxes are never ideal. Some power will be lost as heat, maybe 10% to 40% is lost.

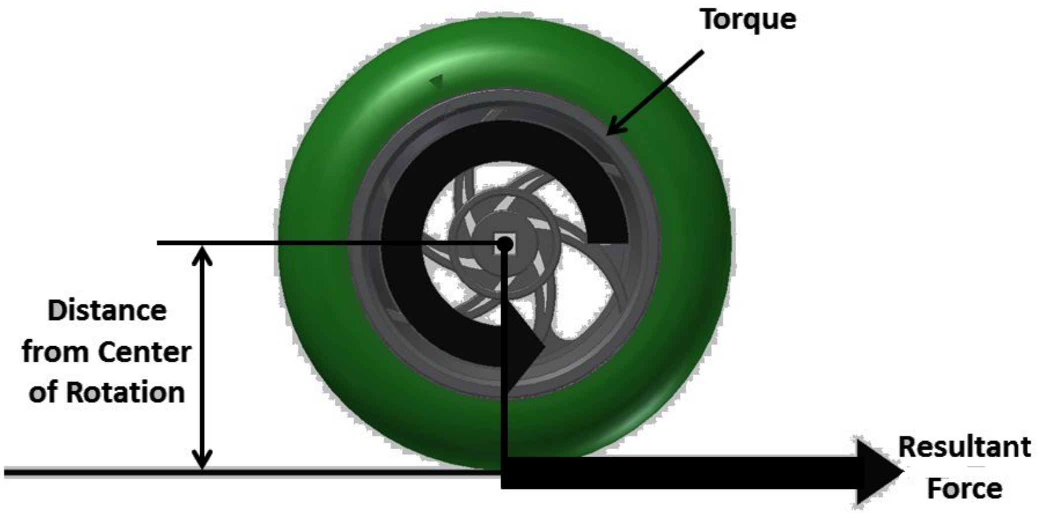


Wheels - Convert Torque to Pushing Force

FORCE = TORQUE / DISTANCE

Distance = Wheel Radius

Torque = Output torque of gearbox

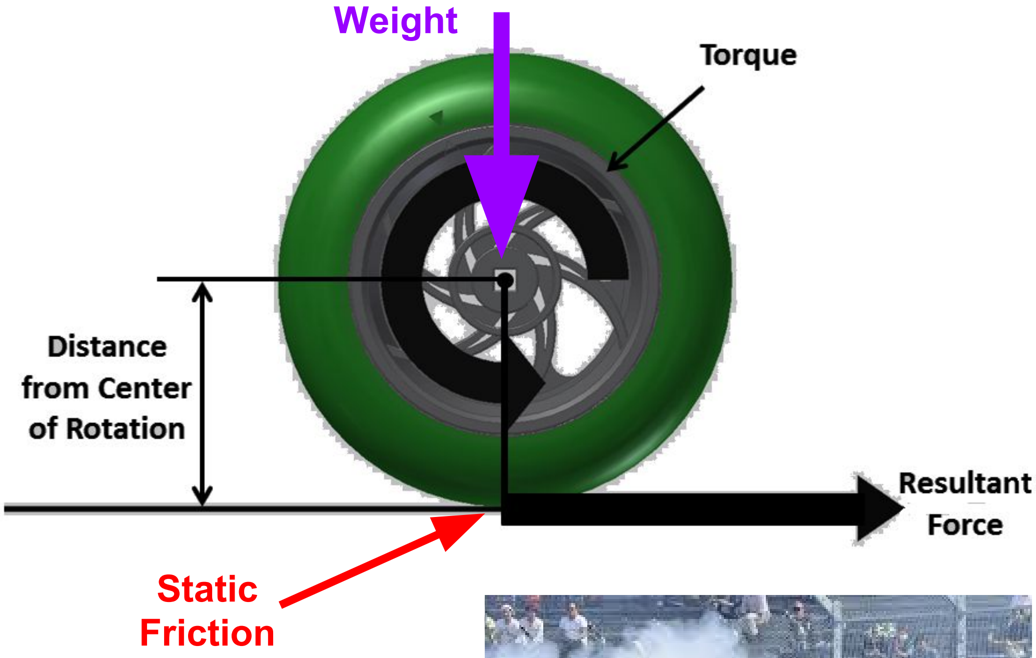


Coefficient of Friction

Why do wheels slip?

$$T = F * d \qquad F \le \mu_s * N$$

T = Torque
d = Tire Radius
F = Pushing Force
μ_s = Tire Coefficient of Static Friction
N = normal force, weight on the tire



Example:
1 kg robot, 2 wheels, ⌀5cm Tire, 0.5 μ

Max Pushing Force per Tire = 0.5 * (½ * 1kg) = 0.25 kg

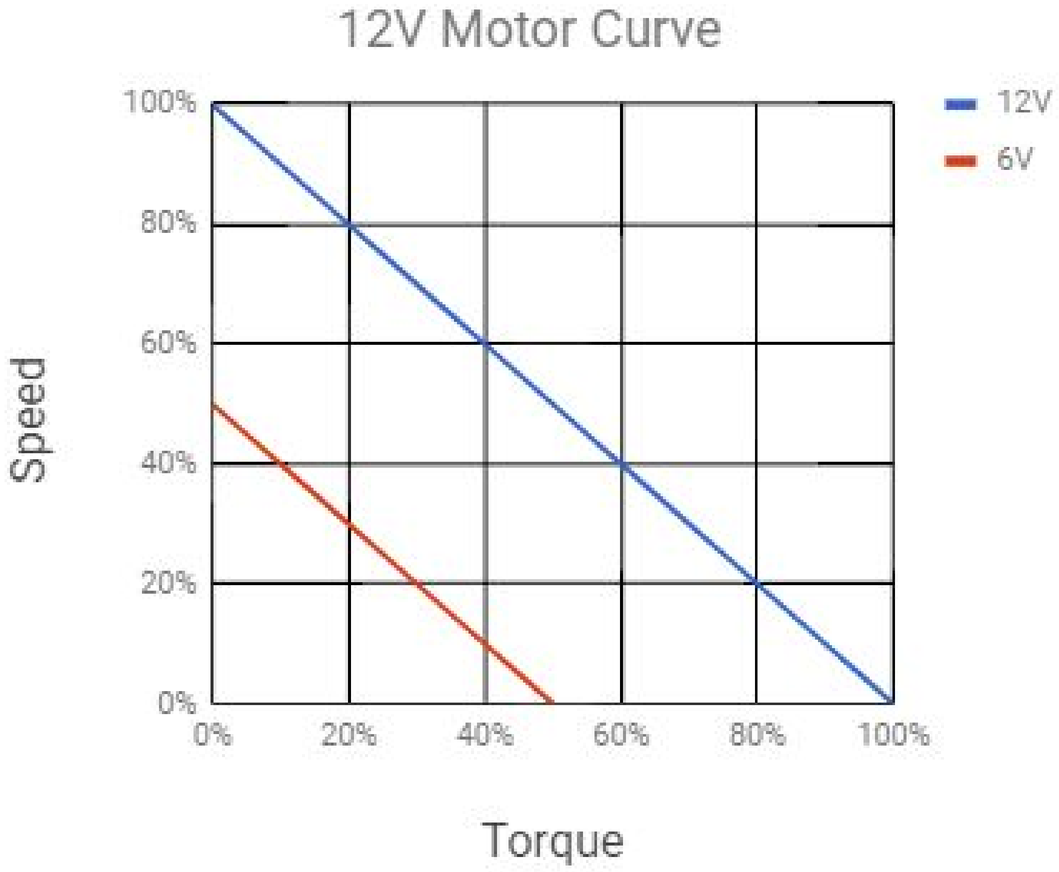
Torque at slip = 0.25 kg * (½ * 5 cm) = 0.63 kg*cm = 8.7 oz-in

Motor Curves

At a given Voltage, higher Torque or “Load” on the Motor will cause the Speed to drop

Lowering the Voltage will cause both Speed and Torque to drop

Speed vs Torque is linear for Brushed DC Motors



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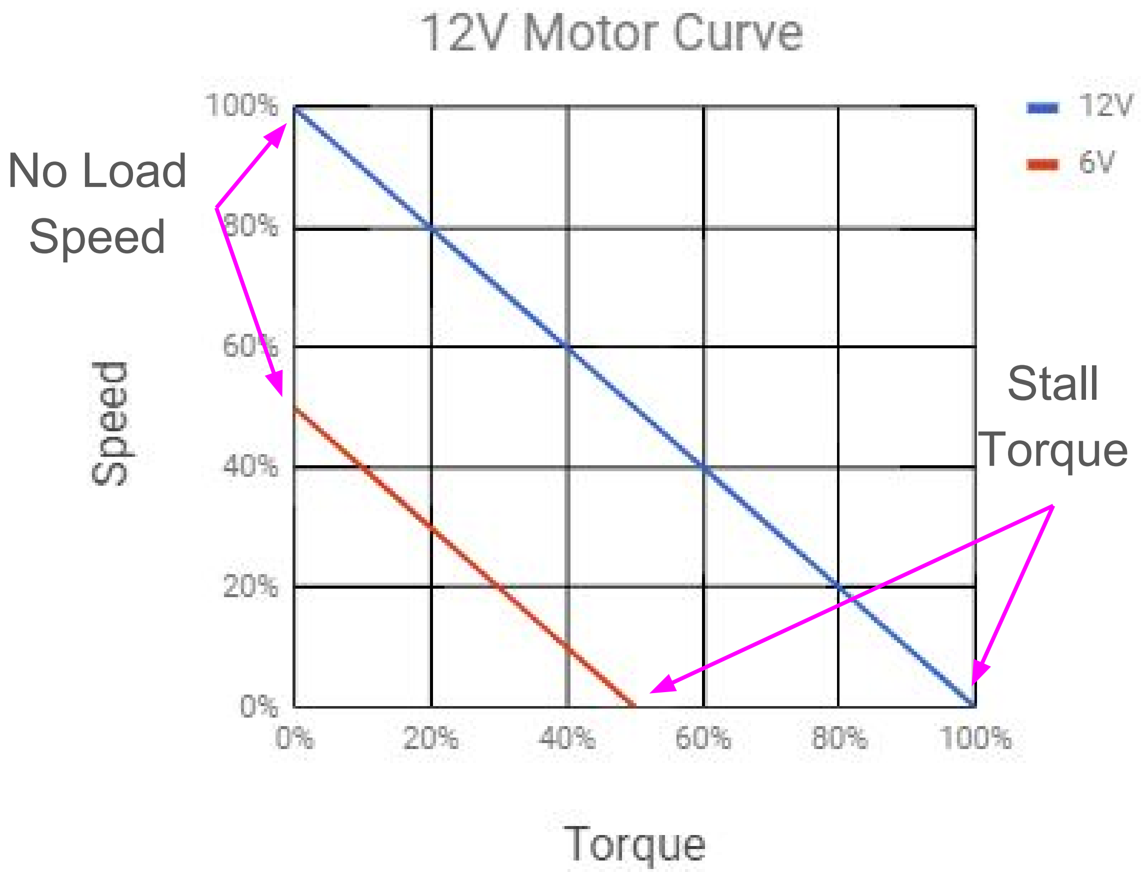


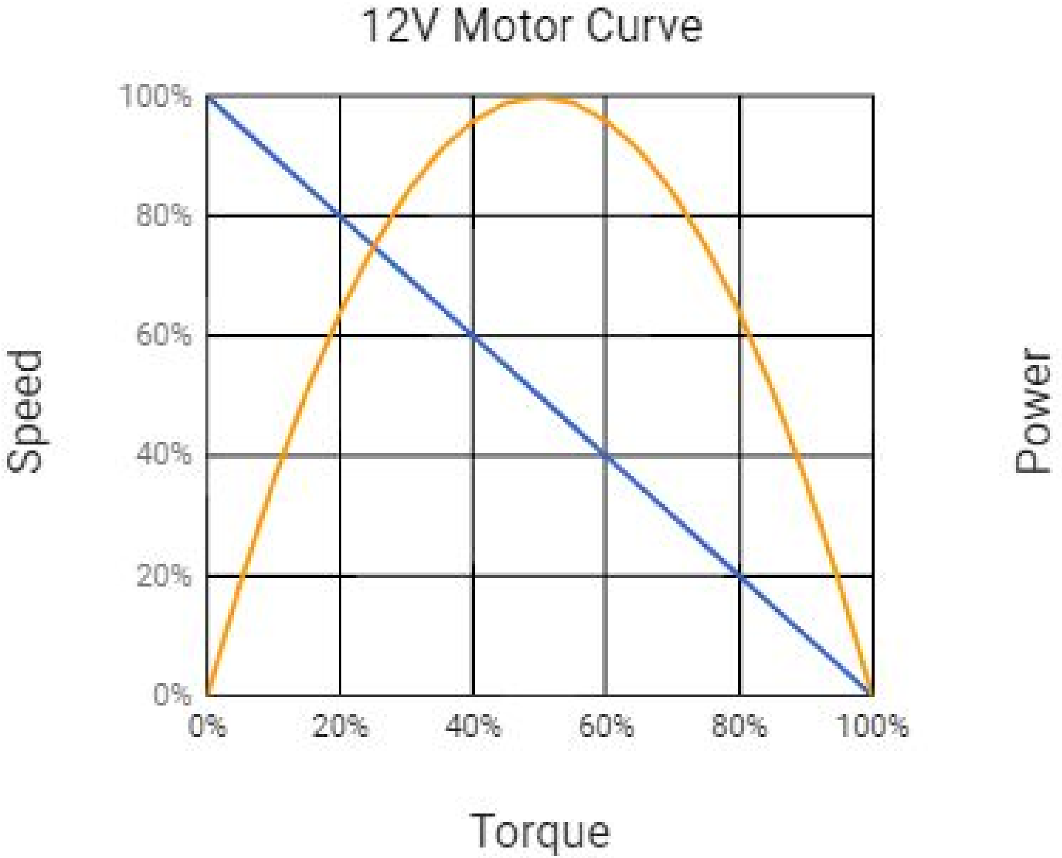
Motor Output Power

Speed * Torque = Output Power

0 Speed * Max Torque = 0 Power

Max Speed * 0 Torque = 0 Power

½ Speed * ½ Torque = Max Power

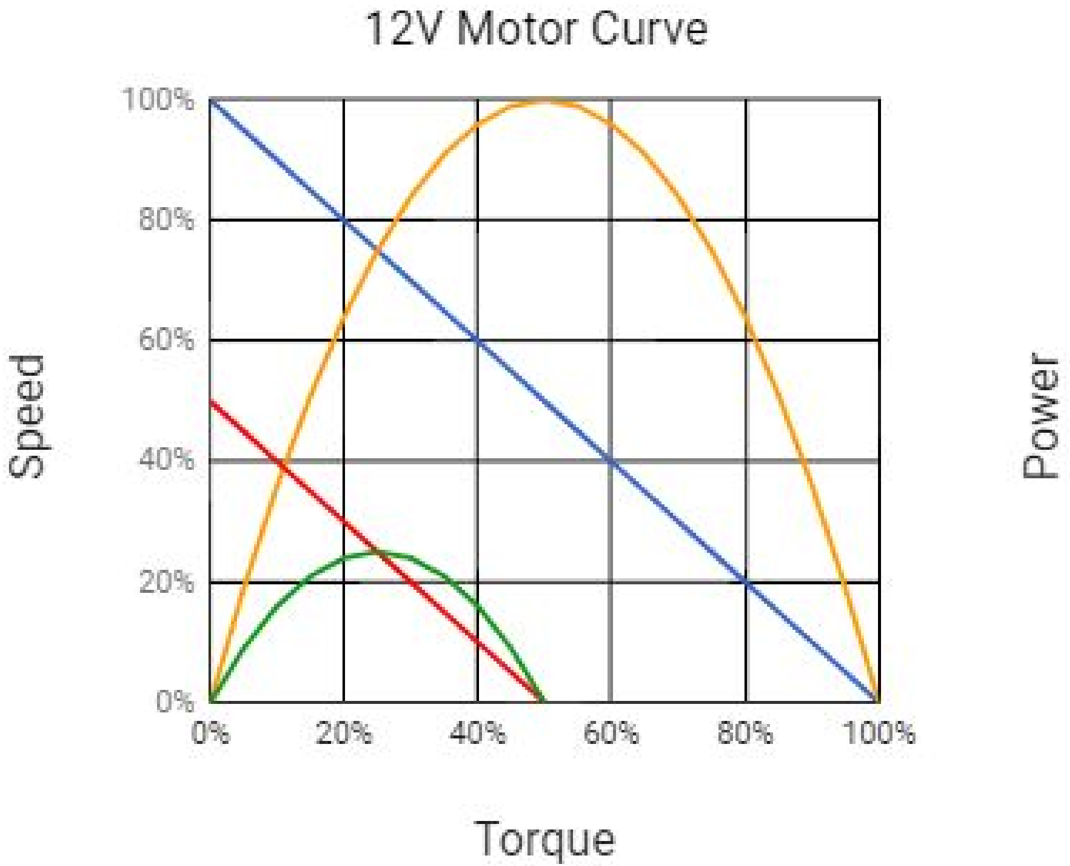


Motor Output Power

Speed * Torque = Output Power

If the voltage is cut in half,

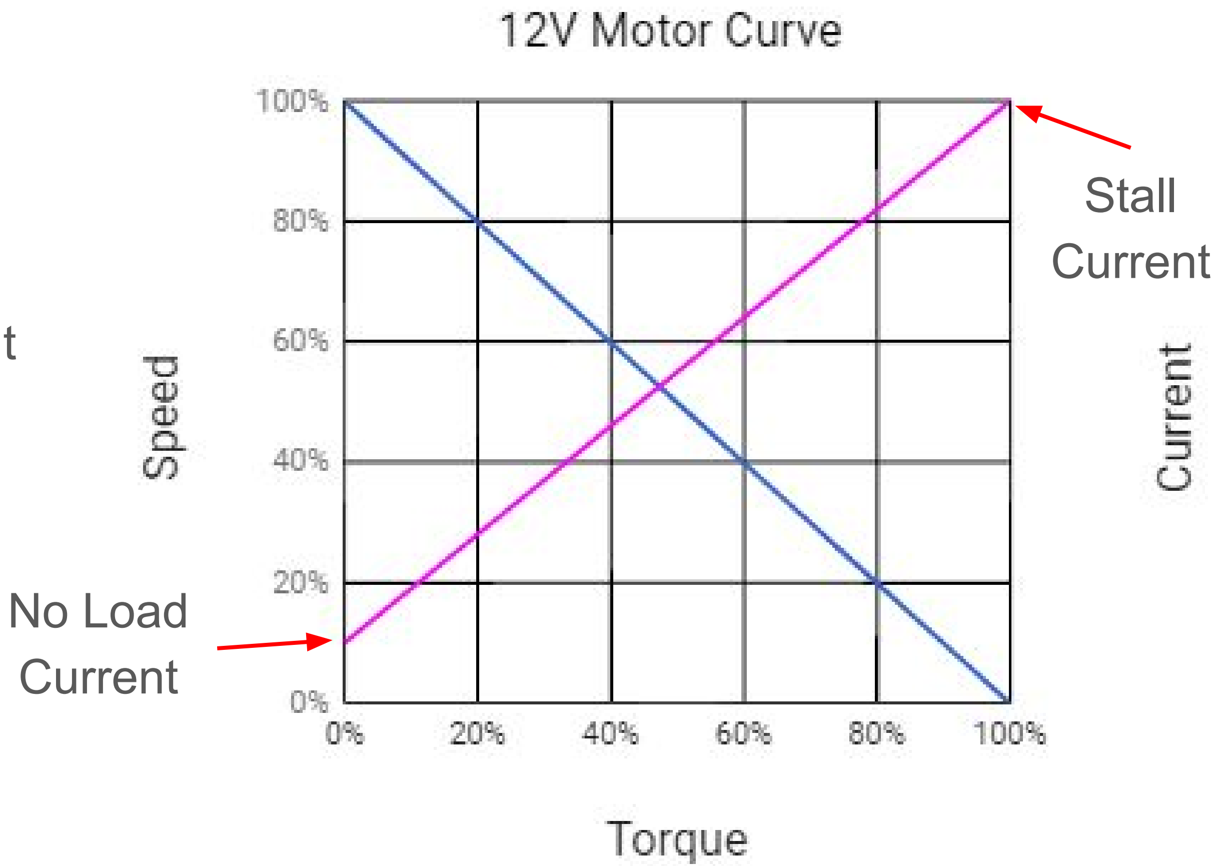
the Max Power is one fourth



Motor Current

High Torque ➡ Low Speed

Low Speed ➡ High Current



Motor Current

High Torque ➡ Low Speed

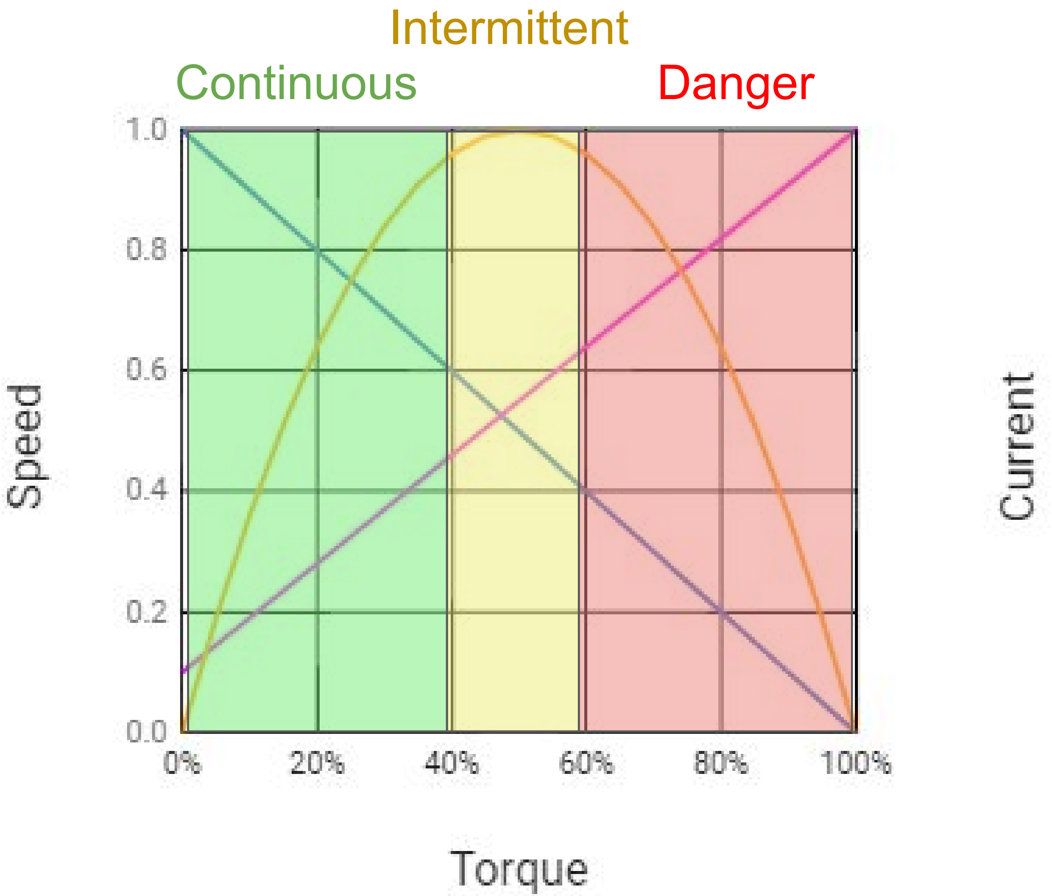
Low Speed ➡ High Current

High Current ➡ High Heat

Too Hot ➡ Dead Motor

Motor Manufacturer should specify safe operating zones

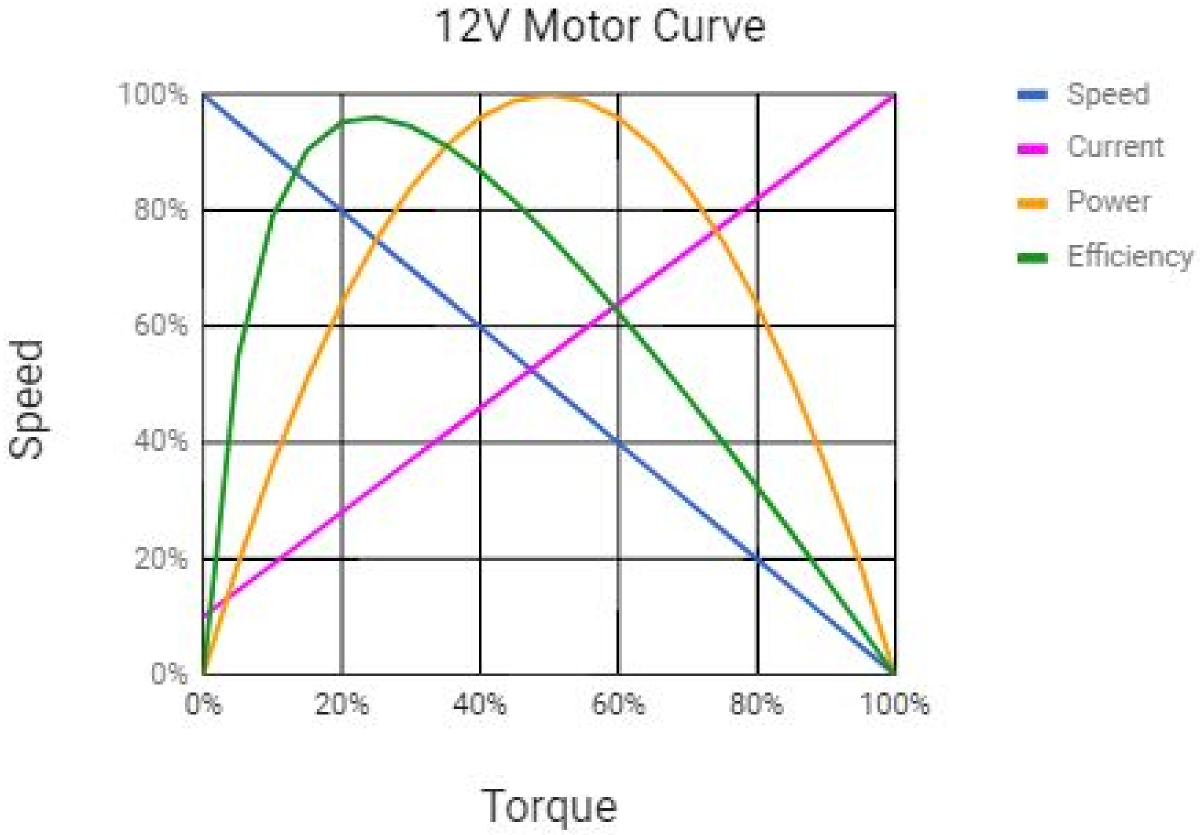
Use a gearbox of appropriate ratio to convert motor speed to higher torque for the wheels



Motor Efficiency

Efficiency = Output / Input

Max Efficiency is typically at 75-80% of Max Speed



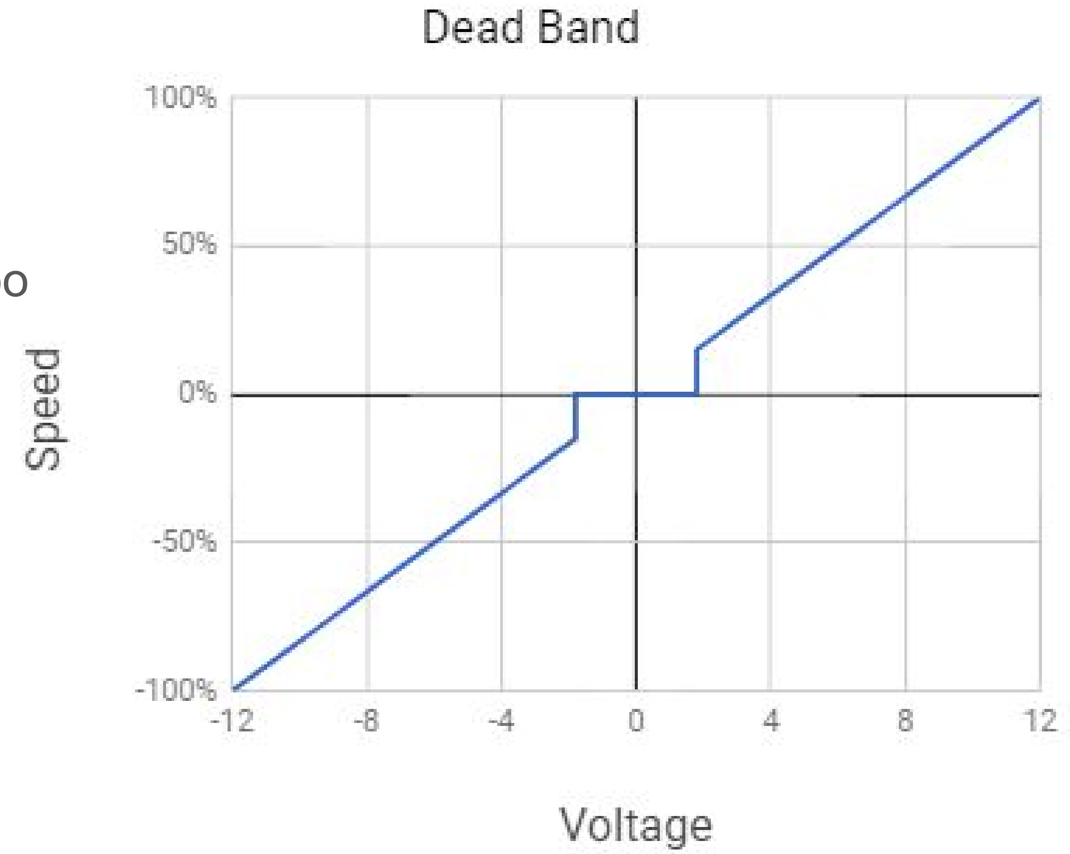
Dead Band

Voltage vs Speed is Linear

At low voltages, motor torque is too small to overcome static friction, motor doesn't turn.

Very low speeds may not be possible.

Dead Bands can cause robot to overshoot or undershoot when attempting to drive to an exact location or angle.

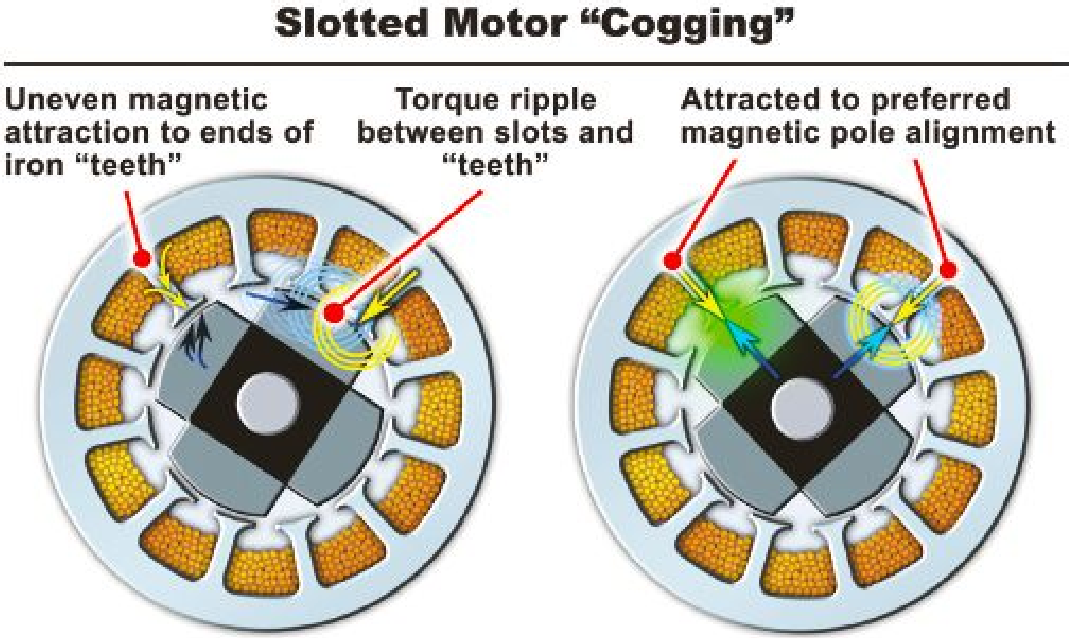


Cogging

Some motors have magnetic poles that want to jump to certain angles.

Controlling the motor's angle to a specific value may not be possible with this kind of motor.

Cogging can cause robot to overshoot or undershoot when attempting to drive to an exact location or angle.



Friction and Drag

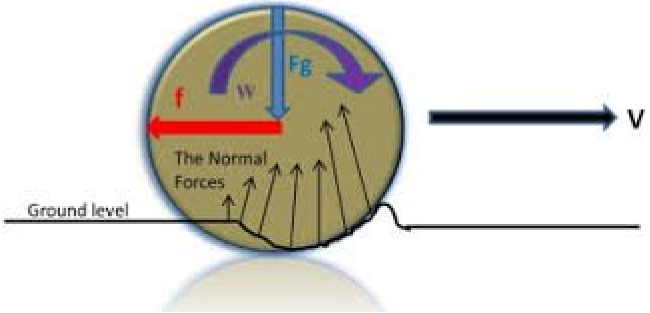
Wheel deformation

Carpet/Floor deformation

Bearings

Gears

Caster or Skid



Selecting Components

Start with the Motor - How much Power?

Select a Wheel

Select a Gearbox

Hub Adapter

Put it Together!

Designing a Robot

Estimate Robot Weight = 1 kg, 2.2 pounds

Desired Top Speed = 1.3 meter/sec, 4 ft/s

Power = Speed * Drag Force

Estimating Drag Force

- Typically between 5% to 50% of the robot's weight
- Wheels, Carpet, Casters, Bumps

Assume Drag Force is 25% of robot weight

Mechanical Power = 1.3 meter/sec * (25% * 1 kg) * 9.81 = 3.2 Watts

Assume efficiency of Drive Train (gearbox, bearings etc.) is 60%

Motor Output Power = Mechanical Power / Efficiency = 3.2 W / 60% = 5.3 W

2 Motors, each motor provides half the power, or 2.6 W per motor is required

How Much Power does the Motor provide?

Don’t run a motor at Max Power all the time, better to run it in the safe zone at 80% Max Speed and 20% Max Torque.

Micro Motor MP 6V:	(80% * 730 RPM) * (20% * 8 oz-in)	= 0.7W
20D 12V Motor:	(80% * 570 RPM) * (20% * 26 oz-in)	= 1.7W
25D 12V MP Motor:	(80% * 7,800 RPM) * (20% * 2.7 oz-in)	= 2.4W
25D 12V HP Motor:	(80% * 10,200 RPM) * (20% * 5.5 oz-in)	= 6.6W
37D Motor:	(80% * 11,000 RPM) * (20% * 5 oz-in)	= 6.5W
Faulhaber 2342S012:	(80% * 8,100 RPM) * (20% * 11.3 oz-in)	= 10.8W

Reverse Engineering the 3pi Robot

Robot Weight = 7 ounces, centered on the wheels

Motors = Micro Metal Gearmotor 6V MP w/ 30:1 Gearbox

Stall Torque = 8 oz-in

Max Speed = 730 RPM

Wheel Diameter = 34mm, 1.34 in

Max Robot Speed = Wheel Circumference * Wheel Speed

= (3.14 * 0.034m) * (730 RPM / 60) = 1.3 m/s = 4.2 ft/s

Max Push Force = Torque / Wheel Radius * Num Motors

= (8 oz-in) / (½ * 1.34in) * 2 = 12 oz

Is 12 oz of push force reasonable for a 7oz robot? This would require μ_s of 1.7

Assume, μ_s is only 1.2, so the maximum useful torque per motor is

$T = F * d = (\mu_s * N) * d = 1.2 * (½ * 7oz) * (½ * 1.34)$ in = 2.8 oz-in