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

\[ \text{Efficiency} = \frac{\text{Useful Output Power}}{\text{Input Power}} \]

\[ \text{Input Power} = \text{Useful Output Power} + \text{Wasted Power} \]

\[ \text{Power is Conserved!} \]
Torque is a Twisting Force

\[ \text{TORQUE} = \text{FORCE} \times \text{DISTANCE} \]

Motor Torque Example:

- 100 oz*in
  - \(100 \text{ oz} \times 1 \text{ in}\)
  - \(50 \text{ oz} \times 2 \text{ in}\)
Calculating Weight Distribution

TORQUE = FORCE * DISTANCE

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!

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

\[ \text{FORCE} = \frac{\text{TORQUE}}{\text{DISTANCE}} \]

Distance = Wheel Radius

Torque = Output torque of gearbox
Coefficient of Friction

Why do wheels slip?

\[
T = F \times d \quad \text{F} \leq \mu_s \times N
\]

- \(T\) = Torque
- \(d\) = Tire Radius
- \(F\) = Pushing Force
- \(\mu_s\) = Tire Coefficient of Static Friction
- \(N\) = normal force, weight on the tire

Example:

1 kg robot, 2 wheels, \(\varnothing 5\text{cm}\) Tire, 0.5 \(\mu\)

Max Pushing Force per Tire = 0.5 \(\times (\frac{1}{2} \times 1\text{kg})\) = 0.25 kg

Torque at slip = 0.25 kg \(\times (\frac{1}{2} \times 5\text{ cm})\) = 0.63 kg\(\times\)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
Motor Curves

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Motor Output Power

\[ \text{Speed} \times \text{Torque} = \text{Output Power} \]

\[ 0 \text{ Speed} \times \text{Max Torque} = 0 \text{ Power} \]

\[ \text{Max Speed} \times 0 \text{ Torque} = 0 \text{ Power} \]

\[ \frac{1}{2} \text{ Speed} \times \frac{1}{2} \text{ Torque} = \text{Max Power} \]
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

12V Motor Curve

- Stall Current
- No Load Current

Speed vs. Torque graph showing the relationship between speed and torque for a 12V motor.
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: \((80\% \times 730 \text{ RPM}) \times (20\% \times 8 \text{ oz-in})\) = 0.7W

20D 12V Motor: \((80\% \times 570 \text{ RPM}) \times (20\% \times 26 \text{ oz-in})\) = 1.7W

25D 12V MP Motor: \((80\% \times 7,800 \text{ RPM}) \times (20\% \times 2.7 \text{ oz-in})\) = 2.4W

25D 12V HP Motor: \((80\% \times 10,200 \text{ RPM}) \times (20\% \times 5.5 \text{ oz-in})\) = 6.6W

37D Motor: \((80\% \times 11,000 \text{ RPM}) \times (20\% \times 5 \text{ oz-in})\) = 6.5W

Faulhaber 2342S012: \((80\% \times 8,100 \text{ RPM}) \times (20\% \times 11.3 \text{ oz-in})\) = 10.8W
Reverse Engineering the 3pi Robot

Robot Weight = 7 ounces, centered on the wheels
Motors = Micro Metal Gearsmotor 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 $\mu_s$ of 1.7
Assume, $\mu_s$ is only 1.2, so the maximum useful torque per motor is

$$T = F \times d = (\mu_s \times N) \times d = 1.2 \times (\frac{1}{2} \times 7\text{oz}) \times (\frac{1}{2} \times 1.34) \text{in} = 2.8 \text{oz-in}$$