Motor selection
What I learned from battlebots
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ME-2110 Creative Decisions and Design
Battlebots and ME2110 robots

Both battlebots and ME2110 robots operate off a single principle:
Convert electric potential into controlled movement!
The components of a battlebot

- Motors
- Motor controllers
- Batteries
- RC receiver (to talk to the controller)
- Force transmission (gears, chains, etc.)
- Wheels
- Weapon
- Shell/armor

Beetleweight category (3lb)
Textbook weight

Heavyweight (220 lb)
Doomba

Heavyweight (220 lb)
Tombstone

Heavyweight (220 lb)
Duck!

Antweight category (150g)
As heavy as a very large apple

Fleaweight category (75g)
Slightly heavier than a tennis ball

Battlebot design is an **iterative process**, just like your ME2110 robot. The design starts with motors!
What we will cover today

1. What is an electric motor?
2. How do you choose a motor type?
3. You have a motor. What can you do with it?
What is an electric motor?
A brief history of the electric motor

1820
A Danish physicist named **Hans Oersted** noticed how changing the current in a wire moved the needle of a nearby compass.

1827
A Hungarian physicist named **Anyos Jedlik** wound wire into coils and placed the coils inside a magnetic field. Changing the current in the coils caused coil rotation. Jedlik called his invention the electromagnetic self-rotor.

1832
A British physicist named **William Sturgeon** created the first commutator DC electric motor capable of turning machinery.

1837
**Thomas Davenport**, an American inventor, patented a similar motor to Sturgeon’s motor. This motor ran up to 600 rpm, and powered machine tools and a printing press.
Motors now:

**Rotor:** the part that moves  
**Stator:** the part that doesn’t move

There is a multitude of ways that the rotor and stator are arrayed.
How do you choose a motor type?
So many electric motor options...

DC brushed motor

DC brushless motor

Servo motor

AC synchronous motor

AC asynchronous motor

Stepper motor
How to choose? Use this flowchart!
Brushed vs brushless motors

**Question:** How can you tell the difference between a brushed and brushless motor?

**Answer:**
- Brushless motors have **3 leads**
- Brushed motors have **2 leads**
DC motors: brushed vs brushless

**Brushed motor**
Coils are on the rotor, magnets on the stator

1. Fixed brushes make contact with a rotating commutator, supplying current to coils
2. “Like repels like” – energized coils rotate
3. Commutator rotates → reverse current is supplied
4. Coils now “chase” the unlike poles on the stator

**Pros:**
- Cheap!
- Simple to control
- Linear performance characteristics

**Cons:**
- Brushes/commutators wear quickly from friction
- Inefficient
- Fast RPM → need gearing

**Brushless motor**
Magnets are on the rotor, coils on the stator

1. Each coil on the stator is charged in sequence
2. Rotation controlled by adjusting magnitude and direction of the current into each coil

**Pros:**
- No brushes = longer life
- Efficient
- Can deliver precise torque & rotation
- Higher speed range
- Less noisy than brushed

**Cons:**
- More expensive
- Complicated control
Where are brushed and brushless motors used?

- Trolling motor
- Floppy disk drive
- Golf cart
- Quadcopter
- Windshield wiper

Old: brushed  New: brushless
Steppers and servomotors

Do you want a motor that turns with a specific angle and/or speed? Use stepper or servo motors

**Stepper motor**

**Operation:**
- Rotates through precise angle and then **stops**
- Speed/torque not as important

**Servomotor**

**Operation:**
- Rotates through precise angle and then **continues to rotate**
- A servo controller can configure rotational speed and acceleration
Stepper motors

3 categories of stepper motors:
- Permanent motor (PM)
- Variable reluctance (VR)
- Hybrid (HY)

Permanent motor (PM)
High torque, poor angular resolution
- Like a brushless DC motor
- Common steps: 30°, 15° and 7.5°

Variable reluctance (VR)
Great angular resolution, low torque
- Like a PM, but no magnets on rotor
- Rotor is iron toothed structure
- Controller energizes pair of opposite windings independently

Hybrid (HY)
Good torque & angular resolution, expensive
- Hybrid steppers commonly have 50-60 teeth on a rotor pole
- Steps as low as 1.8° and 0.9°
Servomotors can do everything a stepper motor can, and more! Servomotors have **positional feedback**, and can be AC, DC, brushed, or brushless.

**True servomotors**

- Adding a rotary encoder can convert any motor into a servomotor
- Challenging to control
- PID (proportional-integral-differential) control typically used
  - Responds to error

**Hobbyist servos**

- A DC motor with no feedback
- Controlled using pulse width modulation (PWM)
- Controller sets rotor angle by sending pulses to servo
  - As rotor approaches desired position, power diminishes to zero

**Example specifications**

- **Internal structure**: Brushed DC motor
- **Input voltage**: 4.8–6 V
- **Stall torque**: 60.56 oz-in. (4.8 V) or 83.47 oz-in. (6.0 V)
- **No-load speed**: 55.5 RPM (4.8 V) or 62.5 RPM (6.0 V)
- **Running degree**: $180^\circ \pm 5^\circ$
- **Pulse width range**: 0.7–2.3 ms
- **Neutral position**: 1.5 ms
- **Dead bandwidth**: 0.005 ms

- **A pulse of 1.5 ms = neutral position**
- **A pulse of 0.7 ms turns rotor to full left position**
- **A pulse of 2.3 ms turns rotor to full right position**
AC motors

**Synchronous**
Speed of the stator’s rotating field = speed of shaft

**Asynchronous (Induction)**
Speed of the stator’s rotating field ≠ speed of shaft
Rotor turns at a speed < synchronous speed

Single phase AC power (household power)

![Single phase AC power diagram](image)

Each phase of input power is delivered to a corresponding phase in the stator

Three phase AC power

![Three phase AC power diagram](image)

Common AC appliance motor

For more details on AC motors, please refer to reference slide
Your options

Scenario 1: Have specs, choose motor

In typical engineering design, you would determine required forces/speeds, then size your motors to those forces

Scenario 2: Have motor, determine limitations

For ME2110, you are in scenario #2
You have a motor. What can you do with it?
You have a motor. Now what?

Permanent Magnet (PM) DC Motors with Spur Gearboxes

- Brushed DC motor with gearbox
- No encoder → not a servomotor

### Specification sheet

<table>
<thead>
<tr>
<th>Item</th>
<th>Gear Ratio</th>
<th>Rated Torque (oz-in)</th>
<th>Peak Torque (oz-in)</th>
<th>No Load Speed (rpm)</th>
<th>Rated Speed (rpm)</th>
<th>Nominal Voltage (V)</th>
<th>Rated Current (A)</th>
<th>Output Power (W)</th>
<th>Body Diameter (mm)</th>
<th>Total Length (mm)</th>
<th>Gearbox Length &quot;L&quot; (mm)</th>
<th>Shaft Diameter (mm)</th>
<th>Weight (lbs)</th>
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</tr>
</tbody>
</table>

Spec's to pay attention to:

- Torque ratings
- Speed ratings
- Speed controller specifications
**Torque and speed curves**

**At 12V, how fast will your motor shaft spin?**

1. Determine torque applied on your shaft
   \[ T = rF \]

2. Assuming a linear fit, use torque-speed curves above to determine rotational speed

**No-load speed:** maximum speed of shaft when no torque is applied to the axle

**Stall torque:** maximum amount of torque that the motor is capable of exerting (no rotation speed)

\[ F = mg \]

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**BDSG-37-30-12V-5000-R75**

Torque (oz in) vs. Rotational Speed (rpm)

- Stall torque: 166.65 oz in at 65 rpm
- No load speed: 50 rpm

**BDSG-37-30-12V-5000-R100**

Torque (oz in) vs. Rotational Speed (rpm)

- Stall torque: 166.65 oz in at 50 rpm
- No load speed: 50 rpm
How to control a DC brushed motor

Microcontrollers should **NOT** be directly connected to the DC brushed motor!!!*

**Why?** Microcontrollers can **not supply the current needed** to power the motor. Microcontrollers can **supply a low current signal**, which can provide instructions to a motor controller.

*With the very limited exception of this teeny tiny 6V motor, which has low current draw.
DC brushed motor controller options

Option 1
Transistor
Like opening a flood gate

Instructions:
1. Vary voltage to B to vary high current flow from C to E

Option 2
IC chip
Benefit: can reverse motor direction

Instructions:
1. Supply PWM signal or voltage from microcontroller

Your ME2110 Arduino shield uses transistors
Other types of motor controllers

- **Stepper**: Pololu Tic T825
- **AC**: VEK2646
- **Hobby servo**: HIDmaker FS
- **Brushless DC (BLDC)**: A more traditional BLDC controller

BLDC controllers are also known as ESC’s (electronic speed controllers), and can be found on hobby websites:
Bombshell Heavyweight (220lb) - motor selection

Battlebot service life is less than 5 minutes, so [as a designer] you target for robustness. You can get a lot of power out of a motor if you don’t mind it ending up on fire at the end.

~ Matthew Carroll, Bombshell Team

Heavyweight bot designs use only a few motor options, just like your ME2110 robot

Drive motors
- Brushed DC A28-150

Weapon motor
- Brushed DC A28-400

DC brushed motor controller
- RageBridge v2

Newer battlebot designs are experimenting with brushless DC

Brushless DC motors with Trampa VESC

Brushless DC tends to have trouble with startup and low-speed torque

VESC 100/250
BB-H8 Beetleweight (3lb) - motor selection

Motor selection for lower class battlebots is the same as for the large behemoth bots

The challenge for smaller weight class battlebots is balancing the weight: every motor, controller, or armor piece must be carefully selected to stay below 3 lb. This can often end up in an iterative process!

- **Drive motors**
  - Brushed DC 12V gearmotor

- **DC brushed motor controller**
  - Vex motor controller 29

- **Weapon motor**
  - Brushless DC NTM 28-26

- **BLDC ESC motor controller**
  - Vex motor controller 29
References

• For a useful overview of motors, refer to M. Scarpino’s “Motors for Makers”

• Motors, motor controllers, and encoders can be found at these websites:

  Adafruit.com
  Sparkfun.com
  Pololu.com
  Robotshop.com
  Digikey.com
  Hobbyking.com