Session #18
Motors

$T, \omega$

Figure by MIT OCW.

Dan Frey
Current versus Externally Applied Load

- I used a NiCd battery pack
- I discharged it across a (physically) big variable resistance

The model can’t fit the data well

Or else the model must include a resistance that is a function of current
A Better Way to Understand a Battery

Figure by MIT OCW.
A Better Model for Battery

$$i = kce^{-E_A/RT}$$

The variable $E_A$ denotes the reaction’s required activation energy which is proportional to voltage. So, we expect current ($i$) and terminal voltage ($v$) will be related by a rate equation of the form

$$i = ke^{cv} \quad \ln i = \ln k + cv$$
DC Permanent Magnet Motor

\[ \vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \]

Figure by MIT OCW.
Discussion Question:
How can I design a DC motor to provide high stall torque?

\[ \vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \]
A Model of a Motor (Steady State)

\[ E = V - R_w i \]
What is the Purpose of These Features?

Figure by MIT OCW.
Figure by MIT OCW.
Torque Speed Curves

Note, conventionally, speed is on the x axis and Torque is on the Y.
Why doesn’t intercept @ the origin?
Back $emf$ versus speed
Concept Question

As the resistance is increased:
1) The shaft speed rises monotonically
2) The shaft speed drops monotonically
3) The shaft speed rises, reaches a maximum, then falls
4) The shaft speed fall, reaches a minimum, then rises

Figure by MIT OCW.
Discussion Question:
How do the things I might do to raise stall torque affect back emf?

\[ E = V - R_w i \]
First Law Applied to a Motor (Steady State)

\[ T \omega = \eta Vi \]

![Diagram of a motor with symbols: \( T \), \( \omega \), \( R_w \), \( i \), \( E \), \( V \), and note "back emf".]
Speed Control for DC Motors

Figure removed for copyright reasons.
See datasheet information for “Jeti 300 MC” brush motor controller.
Modeling for Optimization

BATTERY LIFETIME

MOTOR POWER OUTPUT

Shaft Speed (rad/s)

Output Power (Watts)

Duration (minutes)

Throttle = 10%
Throttle = 100%
Throttle = 100%
Brushless DC Motors

Shaft position sensed. Based on position, different stator windings are energized

Pros
• More efficient
• Higher power density
• Less noise
• Longer life

Cons
• Control electronics
• Cost

Figure by MIT OCW.
High Power Electric Motors: Brushless vs. Brushed

**Predator** by Plettenberg Motors (Germany)
DC Brushless for R/C Aircraft
Peak Output: 11KW (14.75 HP)
Speed: 6,000 RPM
Power In: 51 V, 215 A
Mass: 1550 g (3.42 lbs)
Power Density: 7.1 KW/Kg

**S28-BP-400X** by Magmotor Corporation
DC Brushed Motor
Peak Output: 6 KW (8HP)
Speed: 4900 RPM
Power In: 48 V, 125 A
Mass: 3.13 Kg (6.9 lbs)
Power Density: 1.9 KW/Kg
Stepper Motors

Radially magnetized permanent magnet

Diagrams removed for copyright reasons.

Variable reluctance (no permanent magnet)
Single phase AC Motors

Figure by MIT OCW.
Three phase AC Motors

A phase sequence of 1-2-3 will spin the magnet in a clockwise direction. A phase sequence of 3-2-1 will spin the magnet in a counter-clockwise direction.

Figure by MIT OCW.
Figures removed for copyright reasons.  
Several screenshots of McMaster-Carr online catalog:  
• NEMA DC motors  
• Brushless NEMA DC motors  
• NEMA dual-mount single-phase AC motors  
• NEMA dual-mount three-phase AC motors
Next Steps

• Friday 28 April – Lab at 2PM
  – Now that there is no HW, lab is voluntary
  – I will tailor it to projects as requested

• Tuesday 2 May
  – Actuators?