Solenoids and DC Motors

Gabriel Hugh Elkaim
Questions?
ROBUST!!  SIMPLE IS BETTER
Solenoids and DC Motors

- What they are
- How they work
- Snubbing

Why you have to
Solenoids

- Back Stop
- Coil
- Housing
- Plunger
- Mounting Mechanism
- Ferrous Metal
- Spring
Common Solenoid Types

- **Push**
- **Open Frame**
- **Rotary**

0 - 90°
Solenoid Characteristics

Typical Pull Force versus Stroke

These force curves do not account for return spring. The typical return spring force is 0.4/1.0 oz as shown.

205 AT (100%)
290 AT (50%)
410 AT (25%)
650 AT (10%)
SPRING

0.1 inch
Design and Stoke vs. Force
### Typical Solenoid Spec.’s

<table>
<thead>
<tr>
<th>Duty Cycle</th>
<th>Maximum &quot;ON&quot; Time, (Sec.)</th>
<th>Watts</th>
<th>Approximate Ampere Turns</th>
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<tr>
<td></td>
<td></td>
<td>1/2</td>
<td>25</td>
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<td>1/4</td>
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<table>
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<th>AWG Number</th>
<th>Resistance</th>
<th>Volts DC</th>
<th>Volts DC</th>
<th>Volts DC</th>
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<td>27</td>
<td>0.39</td>
<td>0.9</td>
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<td>1.6</td>
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<td>281</td>
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DC Motors

- Provide Rotory motion
  When do I find them?

Keywords:
- Appliance
- Fan
- Power Tools
- Saws
- Paper motor
- Computer
- Fan
The Permanent Magnet DC Motor

1. Rotor (armature) - Part that spins
2. Brush
3. Commutator
4. Stator (permanent magnet for field flux)
5. Housing

The part that switches the coils in the wrong order (magic)

Graphite (precious metal)

Part that does not spin

Fig. 1.1. A cutaway view of a DC motor.
Commutation

Fig. 3.37 Arrangement of coil, commutator segments, and brushes in a DC motor: (a) exploded diagram of lap winding; (b) coil connections.
Electrical Model of a DC Motor

Back E.M.F. (electromotive force)

Torque is unique to each motor speed constant
DC Motor Relationships (1.3)

\[ V = IR + K_e \omega \]

\[ T = K_T I \implies I = \frac{T}{K_T} \]

\[ V = \frac{TR}{K_T} + K_e \omega \]

@ \omega = 0: \quad V = \frac{TR}{K_T}

@ T = 0: \quad V = K_e \omega

\[ \omega_{NL} = \frac{V}{K_e} \quad \text{no load speed} \]

\[ T_{stall} = \frac{V K_T}{R} = \text{stall torque} \]

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DC Motor Relationships (2.3)

\[ V = \frac{TR}{K_T} + K_e \omega \]
\[ V - \frac{TR}{K_T} = K_e \omega \]

\[ \frac{V}{K_e} - \frac{TR}{k_T K_e} = \omega \]
\[ \omega_s = \omega_{nl} - R_m T \]

Motor speed regulation concept
DC Motor Relationships (3.3)

\[ P = T \omega \]

\[ P = T (\omega_{nl} - R_m T) \]

\[ = \frac{VT}{k_e} - R_m T^2 \]

\[ \omega = \omega_{nl} - R_m T \]

\[ L \Rightarrow \omega_m = \frac{V}{k_e} \]

\[ \text{const. torque} \]

\[ \Delta P \propto \Delta V \]

\[ P_i = \alpha V - \beta \]

\[ P_f = \alpha 3V - \beta \]

\[ \Delta P = 2\alpha V \]
DC Motor Graphs

**Speed vs. Torque**

- $U_3 = 36$ Volt
- $U_2 = 24$ Volt
- $U_1 = 12$ Volt

**Power vs. Torque**

- $U_3 = 36$ Volt
- $U_2 = 24$ Volt
- $U_1 = 12$ Volt

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\[ P_{\text{max}} \] \[ \begin{align*} P &= \frac{TV}{k_e} - R_m T^2 \\
\frac{dP}{dT} &= \phi = \frac{V}{k_e} - 2R_m T = \phi \\
T_{pp} &= \frac{V}{2R_m k_e} = \frac{V}{2K_v k_e} - \frac{V}{K_t k_e} \\
I_{\text{stall}} &= \frac{V}{k_e} = 2R_m T \\
\frac{V}{k_e} &= 2R_m T \\
T_{pp} &= \frac{T_{\text{stall}} k_t}{2} \\
I_{\text{stall}} &= \frac{I_{\text{stall}} k_t}{2} \\
T_{pp} &= \frac{T_{\text{stall}}}{2} \end{align*} \]
DC Motors: $P_{\text{max}}$

$$P_{\text{max}} = \frac{V}{K_e} \left( \frac{V}{2K_e R_m} \right) - K_{f\alpha} \left( \frac{V^2}{fK_e^2 R_m} \right)$$

$$= \frac{V^2}{2K_e^2 R_m} - \frac{V^2}{4K_e^2 R_m} = \frac{V^2}{4K_e^2 R_m}$$

$$= \frac{V^2}{4K_e^2 R_m} \cdot \frac{1}{K_{f\alpha} K_e}$$

$$= \frac{1}{4} \frac{V}{K_e} \cdot \frac{I_f}{K_e} \cdot \frac{1}{R_m}$$

$$= \frac{1}{4} \frac{V}{N M L} T_{\text{stall}}$$

$P_{\text{max}} = \frac{1}{4} \frac{V}{N M L} T_{\text{stall}}$

$\eta = \frac{\text{mechanical power}}{\text{electrical power}}$
Torque vs. Everything

The diagram shows the most important motor and operating characteristics.

\[(\frac{2}{3} - \frac{2}{9}) \omega_m\]

- \(\omega_m\)
- \(P_{2\max}\)
- \(M_B\)
- \(M_H\)
- \(P_{max}\)
- \(m\text{Nm}\)
- \(m\text{W}\)
- \(m\text{rpm}\)
- \(m\text{mA}\)
- \(\%\)

\(\frac{1}{2} T_{slall}\)

\(T_{slall}\)
# DC Motor Spec.'s

<table>
<thead>
<tr>
<th>Motor Data</th>
<th>Winding number</th>
<th>930</th>
<th>933</th>
<th>934</th>
<th>948</th>
<th>936</th>
<th>944</th>
<th>937</th>
<th>938</th>
<th>945</th>
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<td>1 Assigned power rating</td>
<td>W</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
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<tr>
<td>2 Nominal voltage</td>
<td>Volt</td>
<td>3.0</td>
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<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>15.0</td>
<td>18.0</td>
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<tr>
<td>3 No load speed</td>
<td>rpm</td>
<td>5080</td>
<td>9270</td>
<td>9460</td>
<td>10700</td>
<td>8110</td>
<td>7770</td>
<td>8460</td>
<td>8240</td>
<td>8010</td>
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<td>4 Stall torque</td>
<td>mNm</td>
<td>20.9</td>
<td>42.5</td>
<td>45.7</td>
<td>10700</td>
<td>42.7</td>
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<td>43.0</td>
<td>38.0</td>
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<td>5 Speed/torque gradient</td>
<td>rpm/mNm</td>
<td>260</td>
<td>225</td>
<td>213</td>
<td>211</td>
<td>194</td>
<td>227</td>
<td>194</td>
<td>195</td>
<td>215</td>
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<td>6 No load current</td>
<td>mA</td>
<td>114</td>
<td>101</td>
<td>83</td>
<td>73</td>
<td>50</td>
<td>47</td>
<td>42</td>
<td>34</td>
<td>33</td>
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<td>7 Starting current</td>
<td>mA</td>
<td>3960</td>
<td>5910</td>
<td>5160</td>
<td>4920</td>
<td>3090</td>
<td>2440</td>
<td>2680</td>
<td>2100</td>
<td>1810</td>
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<td>8 Terminal resistance</td>
<td>Ohm</td>
<td>0.757</td>
<td>1.22</td>
<td>1.74</td>
<td>2.44</td>
<td>3.88</td>
<td>4.92</td>
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<td>8.56</td>
<td>9.96</td>
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<td>9 Max. permissible speed</td>
<td>rpm</td>
<td>11000</td>
<td>11000</td>
<td>11000</td>
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<td>10 Max. continuous current</td>
<td>mA</td>
<td>1500</td>
<td>1500</td>
<td>1440</td>
<td>1220</td>
<td>972</td>
<td>865</td>
<td>809</td>
<td>656</td>
<td>609</td>
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<td>11 Max. continuous torque</td>
<td>mNm</td>
<td>7.92</td>
<td>10.8</td>
<td>12.7</td>
<td>12.8</td>
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<td>12 Max. power output at nominal voltage</td>
<td>mW</td>
<td>2460</td>
<td>9620</td>
<td>10800</td>
<td>13900</td>
<td>8770</td>
<td>6920</td>
<td>9590</td>
<td>9070</td>
<td>7780</td>
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<td>13 Max. efficiency</td>
<td>%</td>
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<td>73</td>
<td>75</td>
<td>76</td>
<td>75</td>
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<td>14 Torque constant</td>
<td>mNm/A</td>
<td>5.28</td>
<td>7.19</td>
<td>8.85</td>
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<td>14.4</td>
<td>16.6</td>
<td>20.5</td>
<td>21.0</td>
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<td>15 Speed constant</td>
<td>rpm/V</td>
<td>1810</td>
<td>1330</td>
<td>1080</td>
<td>909</td>
<td>691</td>
<td>664</td>
<td>576</td>
<td>467</td>
<td>455</td>
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<td>16 Mechanical time constant</td>
<td>ms</td>
<td>29</td>
<td>22</td>
<td>20</td>
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<td>18</td>
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<td>17 Rotor inertia</td>
<td>gcm²</td>
<td>10.8</td>
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<td>9.07</td>
<td>8.68</td>
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<td>18 Terminal inductance</td>
<td>mH</td>
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<td>0.18</td>
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<td>0.45</td>
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<td>0.64</td>
<td>0.98</td>
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<td>19 Thermal resistance housing-ambient</td>
<td>K/W</td>
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<td>17</td>
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<td>20 Thermal resistance rotor-housing</td>
<td>K/W</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
<td>2.4</td>
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<td>21 Thermal time constant winding</td>
<td>s</td>
<td>7</td>
<td>6</td>
<td>6</td>
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<td>6</td>
<td>5</td>
<td>6</td>
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</table>
\[ V = IR - K_e u_w \]

\[ 12 = \left( \frac{23}{1000} \right) 2.14 - K_e \left( \frac{10700}{1000} \right) \]

\[ \therefore K_e = \frac{12 - 0.17812}{10.700} = 1.105 \text{ V/kRpm} \]

\[ K_T = 1.4444 \text{ oz-in/s} \]

\[ T_{nl} = \left( \frac{23}{1000} \right) (1.444) = 0.11 \text{ oz-in} \]

\[ \omega_{nl} = \frac{12}{1.105} = 10.861 \text{ kRpm} \]

\[ \omega_{ny} = 10.861 \text{ kRpm} \]
\[ K_E = k_T \]
\[ \frac{V_{\text{rad/s}}}{N_m} = \frac{N_m}{A} \]

\[ K_E = \frac{1}{1.3529} \left( \frac{k_T}{\text{deg-in}} \right) \]
\[ \frac{V_{\text{rpm}}}{k_{\text{rpm}}} \]
Operating Ranges

Recommended operating range
Continuous operation
In observation of above listed thermal resistances (lines 19 and 20) the maximum permissible rotor temperature will be reached during continuous operation at 25°C ambient.
= Thermal limit

Short term operation
The motor may be briefly overloaded (recurring).

Motor with high resistance winding (Line 8)
Motor with low resistance winding (Line 8)

Speed (n), torque (M), current (I):
The outer edges of the values depicted represent limits for continuous and short term motor operation. Values listed in the tables (lines 3, 4, 6, 7, 12 and 13) are valid for operation at nominal voltage (line 2). These are therefore values which are only reached when operating the motor at higher voltages

- Assigned Power Rating $P_{2T}$ (W) (Line 1)
- Starting current $I_A$ at nominal voltage (Line 7) as well as related stall torque

$M_H$ (mNm) (Line 4) $I_A = \frac{U}{R} \cdot 10^3$ (mA)

- Winding number with the related current curve at the appropriate torque.
Defining “Short Term Operation”

Current Ratio

**Short Term Operation**

- **ON**: Motor in operation
- **OFF**: Motor inoperative
- **I**: Max. peak current
- **I_{cont.}**: Max. permissible continuous current
- **t_{ON}**: ON time
- **T**: Cycle time \( t_{ON} + t_{OFF} \)
- **DCy**: Duty Cycle in percent of the Cycle Time \( T \). The motor may be overloaded by the relationship \( \frac{I}{I_{cont.}} \) during X% of the total Cycle Time.
An example problem (1.2)

• You have been assigned to follow up on the design of a former employee who had not taken CMPE-118.
• Your supervisor suspects that they didn't know what they were doing.
• The only documentation that you can find shows that the motor chosen has $K_t = 9.33\ \text{in.-oz./A}$ and produces $2.8\ \text{in.-oz. at stall}$ when driven at $12\text{V}$.
• The design requires that the motor deliver $0.4\ \text{in.-oz. at 1500 rpm}$.
• The motor was supposed to be driven from a $12\text{V}$ supply and switched by a ULN2003. Your boss has asked you:
An example problem (2.2)

1. How can I find out how much current the motor will draw at stall?
2. Can the **ULN2003** safely switch the required current? **YES (only one output)**
3. How can I find the NL Speed? **1789 rpm**
4. How can I find the coil resistance? **90Ω**
5. How can I find the torque at a given speed? **YES**
6. Will the design meet the requirements for torque & speed? If not, what changes could you suggest? **RAISE Vcc, ~43mV**
7. To estimate the current required when running at the design point.
8. You may assume that there are no internal losses within the motor.
9. \( K_T = 1.3524KE \) [oz-in/A ; V/krpm]
Motor Design Solution (1.3)

\[ T_{\text{stall}} = 2.8 \text{ in.-oz.} \]
\[ V_{\text{stall}} = 12 \text{ V} \]
\[ I_{\text{stall}} = \frac{T_{\text{stall}}}{K_T} = \frac{2.8 \text{ in.-oz.}}{9.33} = 0.3 \text{ A} \]

\[ \omega_{\text{req}} = \frac{V}{K_e} = \frac{12 \text{ V}}{6.899} = 1.739 \text{ krpm} \]
\[ \omega_{\text{req}} = 1500 \text{ rpm} \]
\[ K_T = 1.3524 K_e [\text{oz-in/A ; V/krpm}] \]
\[ K_e = \frac{K_T}{1.3524} = \frac{9.33}{1.3524} = 6.899 \text{ Y/krpm} \]
Motor Design Solution (2.3)

\[ R = \frac{12}{V_{\text{stall}}} \]

\[ T_{\text{stall}} = K_t I_{\text{stall}} \]

\[ K_t = 9.33 \text{ in.-oz./A} \]

\[ T_{\text{stall}} = 2.8 \text{ in.-oz.} \]

\[ V_{\text{stall}} = 12 \text{V.} \]

\[ T_{\text{req}} = 0.4 \text{ in.-oz.} \]

\[ \omega_{\text{req}} = 1500 \text{ rpm.} \]

\[ K_T = 1.3524 K_E [\text{oz-in/A; V/krpm}] \]

\[ T = f(\omega) \rightarrow T = \frac{3m - 3}{R_m} \]

\[ R_m = \frac{R}{K_t K_E} = \frac{40}{(9.33)(6.899)} \]

\[ T = 2.94 (m - \omega) = 5.11 \omega - 0.00294 \omega \]

\[ \omega \text{ in. k rpm.} \]
Motor Design Solution (3.3)

\[ V = IR + K_e w \quad T = K_T I \]

\[ V = \frac{TR}{K_T} + K_e w \]

\[ T = K_T \left( V - K_e w \right) \]

\[ R = \frac{11.2}{9.33} \]

\[ T = 9.33 \left( 12 - 6.7 \times 1.5 \right) \]

\[ = 0.38 \text{ in.-oz} @ 12V. \]

\[ T = K_T I \quad I = \frac{T}{K_T} = \frac{0.38}{9.33} \approx 0.04 \]

\[ 93 \text{ mA} \]

\[ K_t = 9.33 \text{ in.-oz./A} \]

\[ T_{\text{stall}} = 2.8 \text{ in.-oz.} \]

\[ V_{\text{stall}} = 12V. \]

\[ T_{\text{req}} = 0.4 \text{ in.-oz.} \]

\[ \omega_{\text{req}} = 1500 \text{ rpm.} \]

\[ K_T = 1.3524 K_E \text{ [oz-in/A ; V/krpm]} \]
Change supply to 15V. \( v_{cc} = 0.8V \).

\[ V = 1R + K e_{nis} \]

\[ 15 = \left( \frac{43}{1000} \right) 40 + 6.9 e_{nis} \quad \therefore \quad e_{nis} = 15 - \left( \frac{43}{1000} \right) 40 \]

\[ w = 1.925 \text{ rpm} = 1925 \text{ rpm} \]

\[ V = \left( \frac{43}{1200} \right) 140 + (6.9)(1.5) = 12.05V \]

\[ V = 12.87V \]

\[ \text{ Duty cycle} = \frac{12.87}{15} \times 100 = 85.8\% \]
How to Change Directions

PNP on top

N-BRIDGE

NPOn bottom
The H-Bridge

DIR

EN

SHOOT TURN

+$V$

$R_M$

$LS$ - SN754410E
$1.8A$ - C298
$3A$ - 8814

$5A$ - T04

FETS
GEARHEAD motor

4-20V range

50 - 200 RPM

TOYS R' US

Fidget spinners

$3 each
Pulse Width Modulation

Too low - Torque ripple
Too high - $\frac{V}{f}$

$V_{\text{eff}} = V_{ac} \times \text{duty cycle}

\text{duty cycle} = \frac{\text{on time}}{\text{period}}$
DC Motor Drive Simulation

\[ V = L \frac{di}{dt} \approx L \frac{\Delta i}{\Delta t} \]

PWM Enable EDGE
Drive Waveform
Transistor Current
Inductor Current

Current vs. Time Graph

- Axis Labels:
  - Current
  - Time (μs)

- Graph Details:
  - Red line represents inductor current
  - Reference ground indicated
  - Bi and BT markings

- Scale:
  - Current: -1.0x to 472.0m
  - Time: 0 to 1m

Gabriel Hugh Elkaim
Collector Voltage

V_{CE} BREAKDOWN

INDUCTIVE KICK/SPike
Snubbing: Diode Snubber
Inductor Current w/Diode Snubber
Collector Voltage w/Diode Snubber
Where to put the diodes?

"Fast recovery"

\[ F = \frac{1}{2} L \left( \frac{dI}{dt} \right)^2 \]

Clamp diodes

Flyback diodes

PWM \( C_{D3} \)

\[ 2 \left( \frac{1}{2} L \left( \frac{dI}{dt} \right)^2 \right) \text{ watts} \]
Snubbing: Diode + Zener
Inductor Current w/ Diode + Zener Snubber

Current

-42.5 m

-141 m

-326 m

-809 m

-893 m

-877 m

167 u

333 u

500 u

667 u

1 m

r=Ground X=107uS/Div

6T
Collector Voltage w/ Diode + Zener
Inductor Current with Zener Only Snubber

Current

-1.08 m
-0.877 m
-0.894 m
-0.910 m
-0.926 m
-1.048 m
-1.149 m

167 μs
335 μs
667 μs
833 μs
1 ms
Collector Voltage w/ Zener Only

Collector Voltage with Zener Only Snubber

Voltage

\[ V_z \]
Where to put the Zeners?
Snubbers Compared

Inductor Current Decay Comparison

- **Diode Only**
- **Resistor + Diode**
- **Zener Only**
- **Diode + Zener**

*Graph showing current decay with different snubber configurations.*
Tamsont

P.D.R.
**Brushless DC Motors**

**BLDC / PMSM**

---

**Fig. 4.1.** Disassembled view of a brushless DC motor: permanent magnet rotor, winding, and Hall element.
Fig. 4.2. Three-phase unipolar-driven brushless DC motor.
Hall Sensor Based Commutation

Sensorless Drive

$V_t$

Sine-ideal

Block Commutation

Toroidal Commutation

Fig. 4.20. Torque generation, revolution, and switching.
# Brushed vs. Brushless

<table>
<thead>
<tr>
<th>Mechanical Structure</th>
<th>Brushed Motor</th>
<th>Brushless Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Magnets on stator Windings on Rotor</td>
<td>Field Magnets on Rotor Windings on stator</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Commutation Method</th>
<th>Brushed Motor</th>
<th>Brushless Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical contact between brushes and commutator added friction, brush debris, RFI</td>
<td>Electronic switching using transistors low frequency harmonics due to ripple</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotor Position Detection</th>
<th>Brushed Motor</th>
<th>Brushless Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatically detected by brushes</td>
<td>Hall Element, optical encoder, Back EMF</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reversing Method</th>
<th>Brushed Motor</th>
<th>Brushless Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse terminal voltage</td>
<td>Rearrange logic sequencer</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distinctive Features</th>
<th>Brushed Motor</th>
<th>Brushless Motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quick response</td>
<td>Long Lasting</td>
<td></td>
</tr>
<tr>
<td>Excellent controllability</td>
<td>Easy or no maintenance</td>
<td></td>
</tr>
<tr>
<td>Current limited by brush/commutator interface</td>
<td>Current limited by winding resistance only</td>
<td></td>
</tr>
<tr>
<td>Speed limited by brush bounce</td>
<td>No fundamental high frequency (speed) limit</td>
<td></td>
</tr>
<tr>
<td>Usually more efficient than brushed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions?
DON'T WORK IN OTHER LABS!!
Don't worry

185 points

Grade it gently.

Turn for paper exam — end of class.

Opportunity for feedback.
30 - 5 \rightarrow 17.5
TEAM ASSIGNMENTS

HORSE TRAINING RULES

(1) You have 24 hours

(2) One swap between two teams

- On team members (6) total

(3) One swap per team
- Work in your team.
- Do what you are bad at.
- Do it together.

- Prime/secondary

1 → 2 → 3
1 → 2

CMPE 118/218 – Intro. to Mechatronics
- Open loop Positioning
- Torque w/o current “Holding Torque”

Stepper Motors

Gabriel Hugh Elkaim
Stepper Motors

- Different types of stepper motors
- Differences in Characteristics
- Stepper Drive Techniques
- Stepper Dynamics
Permanent Magnet (PM) Stepper Motor

24 steps/rev ($15°/\text{step}$)
96 steps/rev ($7.5°/\text{step}$)
PM Stepper Motor Operation

1 → 3
2 → 4
3 → 1
4 → 2
Torque vs. Angular Displacement

Static Torque

Holding Torque

Angular Displacement

$\theta_m$
Variable Reluctance (VR) Stepper Motor

Rrotor - laminated steel

Stator - positions/slots

PM  VR

High Torque

Low inductance

Higher Speed

Higher Noise
Hybrid Stepper Motor

Good parts of 80W

- Torque characteristics are
  significantly

  200 rad/m/rev (1.5°)
  400 rad/s/rev (0.7°)
Hybrid Rotor

- Laminated core of silicon steel
- Permanent magnet
Hybrid Rotor Offset Teeth
Fig. 2.74. Examples of $T/I$ characteristics: (a) a 1.8° four-phase VR motor; and (b) a 1.8° four-phase hybrid motor. (After Ref. [17].)
Stepper Motor Wiring

2-phase 4-wire

3-phase 6-wire

4-phase 8-wire

Universal Drive

University Wound
Wiring Direction is Important

Bifilar winding
2-Phase Universal Wound vs. 4-Phase
Two Full H-Bridges / 4 Half H-Bridges

Driving Stepper Motors

[Diagram showing the connection of H-bridges to stepper motors, with annotations for phase connections.]
Stepper Sequences: Full Step
### Stepper Sequences: Full Step

#### Bipolar

<table>
<thead>
<tr>
<th>Step</th>
<th>Q1-Q4</th>
<th>Q2-Q3</th>
<th>Q5-Q8</th>
<th>Q6-Q7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>

#### CW Rotation

#### CCW Rotation
Stepper Sequences: Wave Drive
Stepper Sequences: Wave Drive

<table>
<thead>
<tr>
<th>Step</th>
<th>Q₁-Q₄</th>
<th>Q₂-Q₃</th>
<th>Q₅-Q₈</th>
<th>Q₆-Q₇</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
</tr>
<tr>
<td>3</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>4</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
</tbody>
</table>

CW ROTATION

CCW ROTATION

[Diagram of stepper motor wiring]
Stepper Sequences: Half-Step

Double 4 Steps

Torque Ripple

Gnd

V+

N

2

V-

Gnd
### Stepper Sequences: Wave Drive

<table>
<thead>
<tr>
<th>Step</th>
<th>Q₁-Q₄</th>
<th>Q₂-Q₃</th>
<th>Q₅-Q₈</th>
<th>Q₆-Q₇</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ON</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>2</td>
<td>ON</td>
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<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>7</td>
<td>OFF</td>
<td>ON</td>
<td>ON</td>
<td>OFF</td>
</tr>
<tr>
<td>8</td>
<td>OFF</td>
<td>OFF</td>
<td>ON</td>
<td>OFF</td>
</tr>
</tbody>
</table>

**CW Rotation**

**CCW Rotation**

![Stepper Motor Diagram]

- Q₁-Q₄: ... (Connections)
- Q₂-Q₃: ... (Connections)
- Q₅-Q₈: ... (Connections)
- Q₆-Q₇: ... (Connections)
Stepper Sequences: Micro-stepping

100%
75%
50%
25%
0

Yet finer motion
Generating the Drive

- Logic Sequencer
- Coil Drive
- Motor

Components:
- DRV 8811
- L-B MOSFET
- STM8L
- 1 amp
- 2.8 amp

Claims:
- DRV 8811

Author:
Gabriel Hugh Elkaim

Course:
CMPE 118/218 – Intro. to Mechatronics
Stepping Dynamics

![Graph showing stepping dynamics with labels for forward and reverse movements over time.]

- Forward
- Reverse

Time
Announcements

Fields (hall) tomorrow
Load Effects on Step Dynamics

Motor PH266-01

- No-Load
  - X axis: A 0.5 ms/div.
  - B 20ms/div.
  - Y axis: 0.9°/div.

- Inertia Load 0.82oz-in² (150g-cm²)
  - X axis: A 0.5ms/div.
  - B 20ms/div.
  - Y axis: 0.9°/div.

- Friction Load 6.9oz-in (4.9N-cm)
  - X axis: A 0.5ms/div.
  - B 20ms/div.
  - Y axis: 0.9°/div.
Drive Effects on Step Dynamics

Fig. 2.55. Difference in single-step response between the single-phase (a) and two-phase (b) excitation.
Stepper Motor Performance Curves
Stepper Motor Current Dynamics
L/nR Drive (1.3)
L/nR Drive (2.3)
L/R Drive (3-3)
2-Level Drive
Chopper Drive
Diode Snubber for H-bridge
Zener Snubber for H-bridge
Other Snubbing Alternatives (1.3)
Other Snubbing Alternatives (2.3)
Other Snubbing Alternatives (3.3)
Snubbing Techniques Compared (1.2)
Figure 6-5  Torque-speed curves of Oriental Motor PH266-01 stepping motor with no diode, diode + 150 ohm resistor and diode suppression circuits.
Questions?