Overview

Last time, we used Hall-effect devices to measure magnetic fields, and looked at factors the affect magnetic force generated by a coil.

Today you will start to design you motor and lay it out using Fusion 360, so that you can fabricate your parts for next time.
Last Time

We used a Hall-effect device to measure the magnetic fields generated by permanent and electromagnets.

- Electromagnet: 0.01 T
- Permanent (neodymium) magnet: 0.50 T

Permanent magnet nearly 50 times stronger than this electromagnet.

Could we make stronger electromagnets?
Last Time

Effect of adding more windings.

| 1 bobbin air core | 2 bobbin stack | 0.0097 T | 0.0111 T (1.14×) |

Doubling the number of windings only increased the magnetic field 14%. Why so little?
**Last Time**

Adding a ferrous core had a big effect.

1 bobbin 2 bobbin stack

<table>
<thead>
<tr>
<th></th>
<th>1 bobbin</th>
<th>2 bobbin stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>air core</td>
<td>0.0097 T</td>
<td>0.0111 T</td>
</tr>
<tr>
<td>steel core</td>
<td>0.0449 T</td>
<td>0.0878 T</td>
</tr>
<tr>
<td></td>
<td>(4.62×)</td>
<td></td>
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</tbody>
</table>

Adding steel core increased field by factor of 4.62. Why?
Last Time

We measured how quickly magnetic forces decrease with distance.

![Image of electromagnet levitating a permanent magnet](image)

<table>
<thead>
<tr>
<th># of weights</th>
<th>gap [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.0</td>
</tr>
<tr>
<td>2</td>
<td>9.8</td>
</tr>
<tr>
<td>3</td>
<td>8.0</td>
</tr>
<tr>
<td>4</td>
<td>6.0</td>
</tr>
<tr>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>6</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>3.6</td>
</tr>
<tr>
<td>8</td>
<td>2.6</td>
</tr>
<tr>
<td>9</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>1.8</td>
</tr>
<tr>
<td>11</td>
<td>1.6</td>
</tr>
<tr>
<td>12</td>
<td>1.2</td>
</tr>
<tr>
<td>13</td>
<td>1.0</td>
</tr>
<tr>
<td>14</td>
<td>0.8</td>
</tr>
<tr>
<td>15</td>
<td>0.4</td>
</tr>
<tr>
<td>16</td>
<td>0.2</td>
</tr>
<tr>
<td>17</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Electromagnet levitates a permanent magnet about 12 mm. Increasing mass ($\times 12$) reduced levitation distance by factor of 10.
Last Time

We measured how quickly magnetic forces decrease with distance.

Very strong repulsion for short distances. Force falls by a factor of 2 in just 2 mm!
Optimizing electromagnetic force.

- Ferrous cores increase magnetic force by concentrating fields.
- Magnetic forces are strongest when air gaps are small.
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

For rotor position above, which coils can generate clockwise torque? What should be the polarities (north or south) of those coils?
Example with four electromagnets and six permanent magnets.
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

C1?: No. Symmetry → no torque.
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

C1?: No. Symmetry $\rightarrow$ no torque.
Same for opposite polarity. Same for C3.
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

C2?
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

C2?: Torque shown above is counterclockwise.
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

Flip polarity → torque is clockwise.
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

C4 can also generate clockwise torque (for above polarity).
Which coils should you use to generate clockwise torque?  \textbf{C2\&C4}

What should be the polarities of those coils?  \textbf{North to left}
Assume that the rotor has turned so that H1 senses a south pole. How to maximize clockwise torque?
Assume that the rotor has turned so that H1 senses a south pole. How to maximize clockwise torque?
Assume that the rotor has turned so that H1 senses a south pole. How to maximize clockwise torque? C2&C4 with north up
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

Are all eight Hall-effect sensors needed?
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

Are all eight Hall-effect sensors needed?
No. Just one of \([H2,H3,H6,H7]\) and one of \([H1,H4,H5,H8]\).
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

Are all four of the coils useful?
Brushless Motor Operation

Example with four electromagnets and six permanent magnets.

Are all four of the coils useful?
Yes. C1&C3 have similar function, torques add. Same for C2&C4.
Use these results to develop a control program.

For **clockwise** motion ...

- $H_2=$ South $\rightarrow$ $C_2,C_4$ to left
- $H_1=$ North $\rightarrow$ $C_1,C_3$ downward
- $H_2=$ North $\rightarrow$ $C_2,C_4$ to right
- $H_1=$ South $\rightarrow$ $C_1,C_2$ upward

For **counterclockwise** motion, use same coils but opposite polarity.

- $H_2=$ South $\rightarrow$ $C_2,C_4$ to right
- $H_1=$ North $\rightarrow$ $C_1,C_3$ upward
- $H_2=$ North $\rightarrow$ $C_2,C_4$ to left
- $H_1=$ South $\rightarrow$ $C_1,C_2$ downward
Today

Today’s lab has two parts:

- **Design** your brushless motor (pencil and paper)
- **Layout** your design in Fusion 360.

You will need the Fusion 360 layout to laser cut the parts.
Brushless Motor Examples

Four magnets and four coils.
Brushless Motor Examples

Six magnets and three coils.
Brushless Motor Examples

Twelve magnets and six customized coils.
Brushless Motor Examples

Two magnets and two coils, vertical design.
Brushless Motor Examples

Surprise.
Brushless Motor Examples

Rotor surrounds stator.
Motor Design Issues

Attaching the rotor.

The simplest kind of axle is a bolt.

For most purposes that is fine.
Motor Design Issues

Ball bearings are even better.

You could use a ball bearing that fits into a 1/2” hole and provides a freely rotating attachment to a 1/4” shaft.
Motor Design Issues

After assembly.
Motor Design Issues

Ball bearings work best when they are used in pairs. Here there is one on the top plate and a second on the base plate.
Motor Design Issues

We also have ball-bearing assemblies that simply screw in place.
Motor Design Issues

Attaching the Hall-effect sensors.
It’s easy to make a fixture to hold the Hall-effect sensors.

The fixture can then be attached to a base plate with screws.
Motor Design Issues

Hall-effects sensors can be directly integrated into the stator design.
Motor Design Issues

Here is a finished rotor / stator assembly.
Motor Design Issues

Holding coils in place with angle brackets.

These are the smaller of our two sizes.
Motor Design Issues

We will use a “Teensy 3.2” microcontroller (left) with separate H-bridges to control the coil currents (center) and a USB connector for power (right).

Here, these electrical components are built directly on the base plate of the motor.
Motor Design Issues

The electrical components have long leads so that we can connect wires using a wire-wrap tool.
Motor Design Issues

Alternatively, we could use a separate board for the electrical components.
Motor Design Issues

Or even just use a protoboard.
Motor Design Issues

Here is a finished assembly.
Here is a finished assembly.
Motor Design Issues

Similar design with pillow block bearing assembly.
Motor Design Issues

Planar design with no angle brackets.
Today’s Seminar

Work with a partner to design your motor.

Each individual should make their own design, but each partner should provide help and feedback on both designs.

When your design is complete, ask the staff for a checkoff.

Then start to lay out your parts using Fusion 360.

Note Parts List and specifications on the Parts tab of our website.