Overview

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

Today you will start to design your 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?

Effect of adding more windings.

<table>
<thead>
<tr>
<th>1 bobbin</th>
<th>2 bobbin stack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air core</td>
<td>0.0097 T</td>
</tr>
<tr>
<td>Steel core</td>
<td>0.0449 T</td>
</tr>
</tbody>
</table>

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

Adding a ferrous core had a big effect.

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

We measured how quickly magnetic forces decrease with distance.

<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 (×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!

Last Time: Conclusions
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.

Program
Use these results to develop a control program.

For clockwise motion ...
• H2=South → C2,C4 to left
• H1=North → C1,C3 downward
• H2=North → C2,C4 to right
• H1=South → C1,C2 upward

For counterclockwise motion, use same coils but opposite polarity.
• H2=South → C2,C4 to right
• H1=North → C1,C3 upward
• H2=North → C2,C4 to left
• H1=South → C1,C2 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.

Twelve magnets and six customized coils.

Two magnets and two coils, vertical design.

Surprise.

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
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.
Here is a finished rotor / stator assembly.

Holding coils in place with angle brackets.

These are the smaller of our two sizes.

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.

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

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

Or even just use a protoboard.
Motor Design Issues
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.