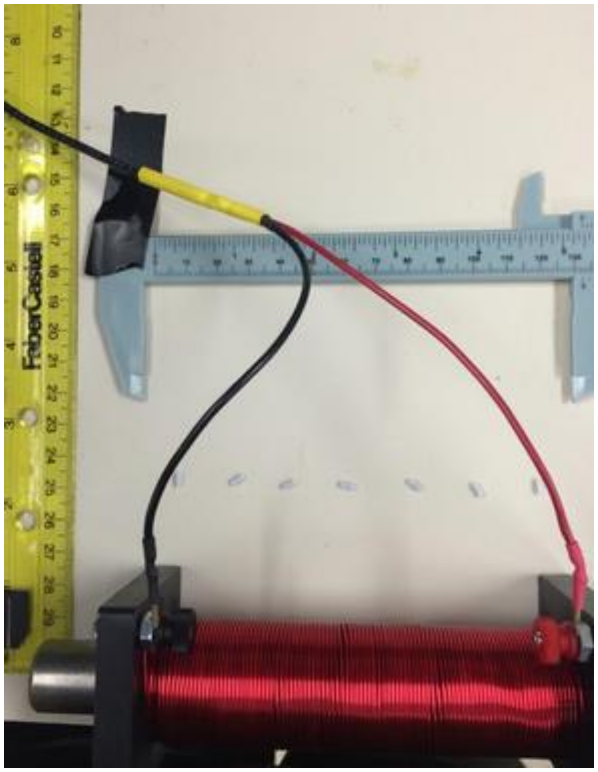
Note: These are just protocols and pictures. Actual data sheets can be found in the Testing Directory in the Team MARK GitHub repository.

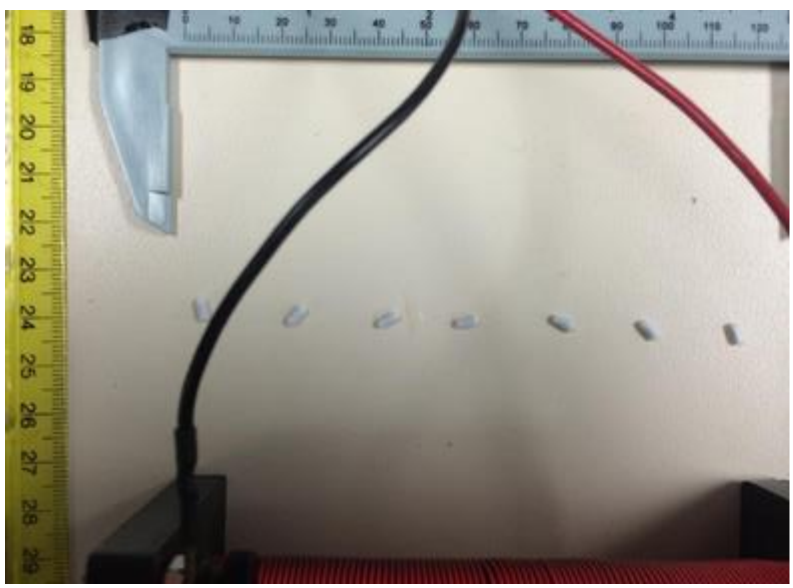
Testing Protocol 1: First Pass

1. Align the electromagnet with the edge of a table
2. Tape down a ruler down next to the electromagnet to track seed distance from electromagnet. Origin/zero point is the center of the electromagnet.
3. Tape down calipers ~12 cm from the center of the electromagnet to track seed position along the electromagnet.
4. Arrange the seeds at 20 cm interval 5 cm from the center of the electromagnet (seed at 0 cm, 20 cm, 40 cm,... 120 cm). Seeds should be perpendicular to the axis of the magnet (originally we did this perpendicular, but that meant that some of the seeds were already aligned to the field and we couldn't see them move).
5. Starting from 0 A, slowing increase the current going through the electromagnet. Pause with each current adjustment to allow time for the seeds to adjust. When any of the seeds move, pause and write down which seeds moved (the seeds at 40 cm and 60 cm, for example) and at which current they moved.
6. Keep increasing current till device begins to overload. At this point, stop and adjust the current back to zero. Record the overload voltage also. The trail is over.
7. Reset the seeds perpendicular to the magnet.
8. Repeat Steps 5-7 for a total of three trials.
9. Move the seeds up 1 cm further from the magnet (so they are 6 cm from the center) and repeat steps 5-8.
10. Repeat Steps 5-9 till the seeds are 10 cm from the center of the magnet. This is the final measurement.

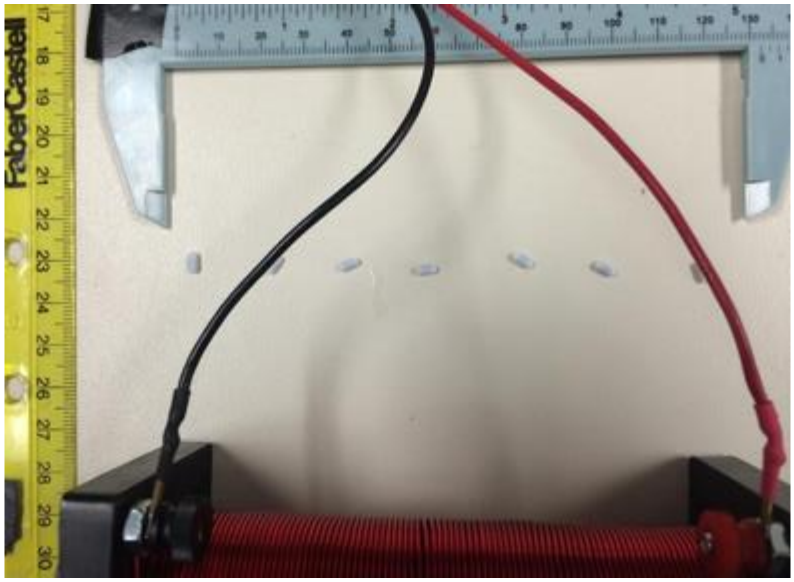
Pictures from test:

1.15 A, 5 cm from middle of electromagnet:

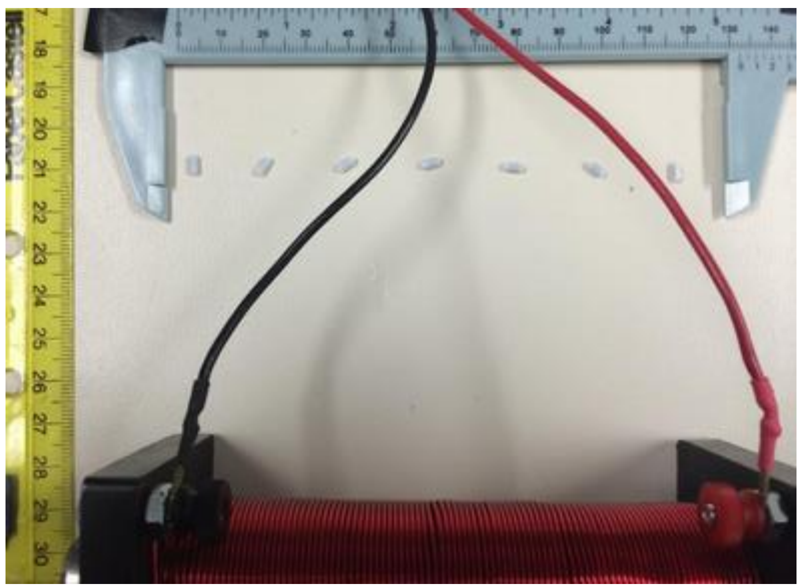


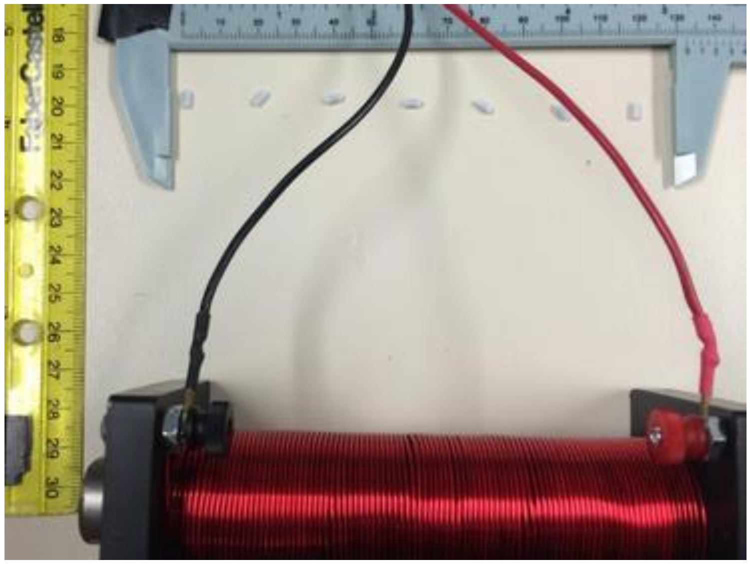
1.4 A, 6 cm: 

1.4A, 7cm:



1.4A, 9cm:

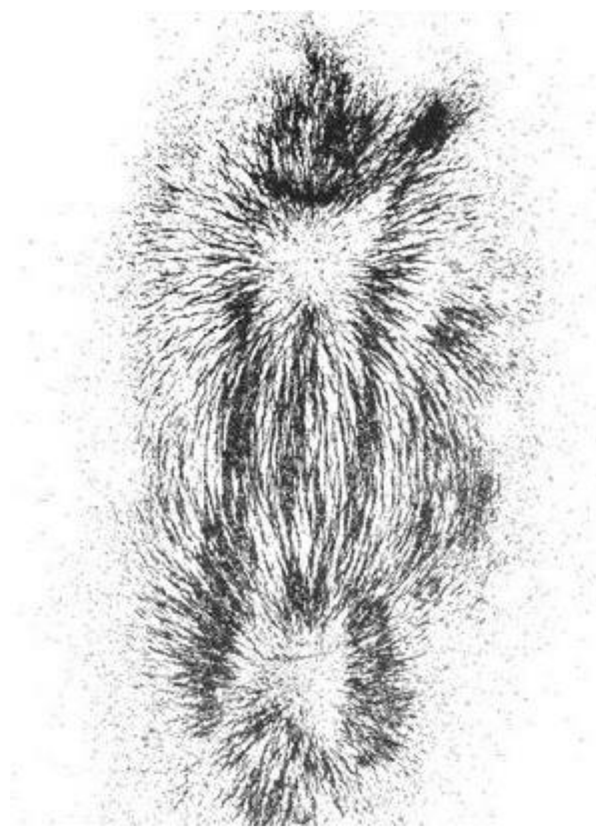


1.4A, 10cm: 

Testing Protocol 2: Iron Shavings

1. Set electromagnet on a sturdy table or bench, ensuring that the surface is flat.
2. Connect the electromagnet to a power source which has been tuned to provide ~0.5 A to the magnet.
3. Trace the outline of the electromagnet on a piece of plain, unlined white paper.
4. Place a thin piece of cardboard over the electromagnet, also ensuring that it lies flat.
5. Place the white paper with the outline on top of the cardboard, with the trace lining up with the electromagnet properly.
6. Lightly sprinkle the iron filings provided uniformly over the paper.
7. Turn on the power source, allowing current to flow through the electromagnet and create an electromagnetic field.
8. Tap the paper with the iron filings gently to make the filings align with the field.
9. Take a picture of the resulting formation. This is a visualization of the EMF lines.
10. Lift up the paper carefully so as to not spill any of the filings, and funnel them back into your filings jar.

Picture taken:



Testing Protocol 3: Power Testing

Pretesting: In order to figure out how and where to position the ultrasound probe, conduct a small scale test with the electromagnet and a seed in hair gel and the small glass cuvette. Use this to see how the seed moves. In the following test, the US probe will need to be positioned so that the movement of the seed is toward/away from the seed (parallel to the plane of the probe) for maximum robustness.

NOTE: At all times, be aware of how hot the electromagnet or the hardware components are getting, and be carefully watching the current to ensure nothing overloads.

1. To set up, take a large glass box and fill it evenly with ultrasound gel (concern: will the glass be a problem? Will it weaken the effect of the electromagnet? If so, maybe make a quick trip to Quenchers and get one of the plastic tupperware things)
2. Insert the seed into the gel, ensuring that it is level with the bench top, not crooked. If possible, place the seed close to the side of the box (so visualization may be possible with the naked eye) and near the top of the box (for maximum proximity to electromagnet)
3. Place the electromagnet right next to the glass, by the seed. Ensure that the seed is positioned so that it is perpendicular to the electromagnet field lines. Measure the distance between the seed and the electromagnet. It should be under 3 cm. Record this measurement.
4. Place the ultrasound probe in the ring stand
5. Either:
   a) Place the ultrasound probe and ring stand in the gel, ensuring that the movement of the seed will be toward/away from the probe when vibration beings or b) Place the ultrasound probe and ring stand on top of the box, directly on top of the seed, with the probe touching the gel and ensuring that the movement of the seed will be toward/away from the probe when vibration beings
6. Ensure that the starting voltage of power source is 0V.
7. Turn on the ultrasound machine and set it in M mode.
8. Turn on the device, set frequency at 5 Hz and increase the voltage to 3V. This will be the starting point.
   1. Setting software:
      1. Set AmplitudeThe Amplitude set screen will be the first menu screen to appear. Use the up and down buttons to navigate to one of the three prompts:
         UP - Increases Amplitude by 1
         DOWN - Decreases Amplitude by 1
         BACK - Returns to main menu
         Pressing the "select" button will activate the functionality of whichever menu option that the cursor is at. The Amplitude varies from 0 to 10 by increments of 1. The units are arbitrary, with 10 being the highest amplitude option. The default setting is 5
      2. Set FrequencyThe Frequency set screen can be navigated to on the main menu by using the "up" and "down" buttons to move the cursor to the "set frequency" option, and then press "select". Use the up and down buttons to navigate to one of the three prompts:
         UP - Increases Frequency by 1
         DOWN - Decreases Frequency by 1
         BACK - Returns to main menu
         Pressing the "select" button will activate the functionality of whichever menu option that the cursor is at. The Frequency varies from 0 to 50 by increments of 1. The units are in Hz. The default setting is 1 Hz
      3. Set BacklightThe Backlight set screen can be navigated to on the main menu by using the "up" and "down" buttons to move the cursor to the "set backlight" option, and then press "select". Use the up and down buttons to navigate to one of the three prompts:
         UP - Increases Backlight brightness by 1
         DOWN - Decreases Backlight brightness by 1

BACK - Returns to main menu

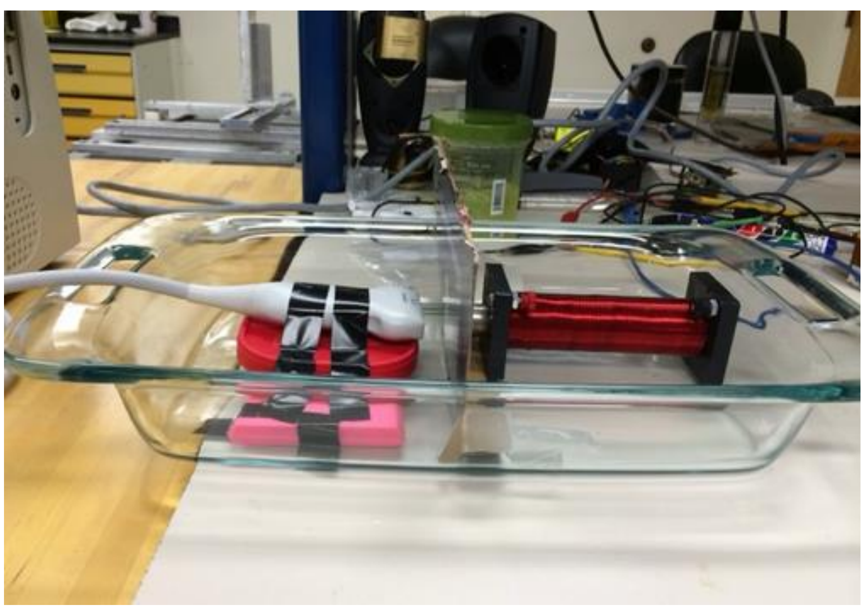
Pressing the "select" button will activate the functionality of whichever menu option that the cursor is at. The Backlight varies from 0 to 6 by increments of 1. The units are arbitrary, with 6 being the brightest option. The default setting is 0.

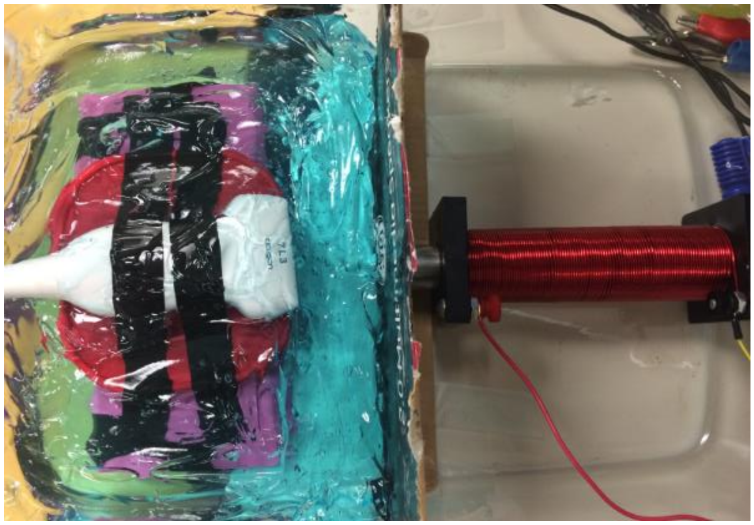
4. Output desired settings

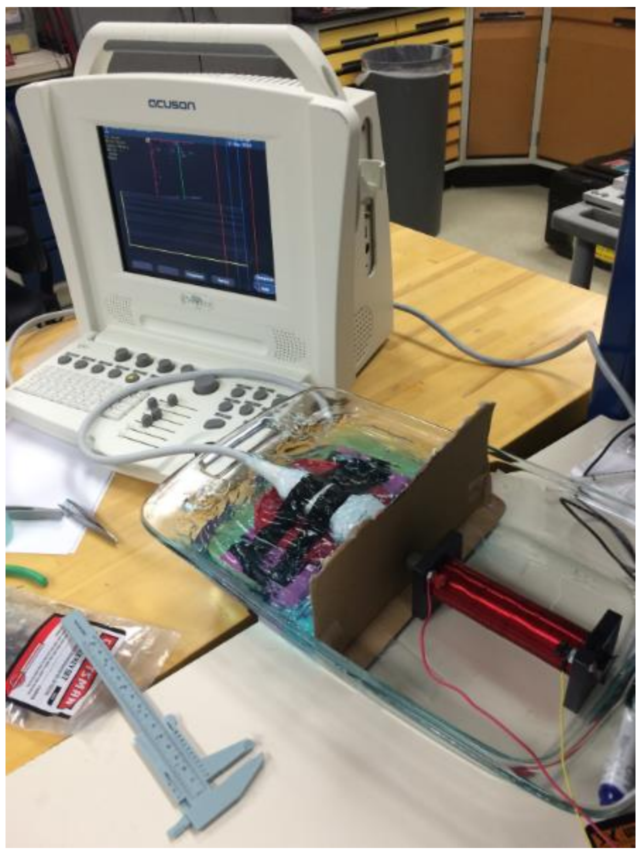
   To output the desired frequency and amplitude settings to the electromagnetic transducer, navigate to the "Start Output" menu option on the main menu, and press select. This will take you to the output menu screen, which displays the current frequency and amplitude output settings, which are now being outputted to the transducer, This will occur indefinitely. To change the settings and turn off the output, press the "up" button, which will return you to the main menu.

9. Record the voltage, the current (highest one, because it will be oscillating), the velocity, and take a picture of the M-mode screen. If there is vibration, a sinusoidal wave will be visible.
10. Increase the voltage by an increment of 0.5V, to 3.5V.
11. Wait for it to stabilize, then take another picture of the M-mode screen. Again, if there is vibration, a sinusoidal wave will be visible.
12. Repeat Steps 8-11 until a clear sinusoidal wave is visible. From here, increase the voltage by the 0.5V increment for 1.5 more volts (3 more trials), still recording the voltages, the currents, and taking pictures of the M-mode screen for each increment, after they have stabilized.
13. Turn the device off.
14. To calculate power, first convert the voltage to Vrms (Vmax/sqrt(2)) and convert current to Irms (Imax/sqrt(2)). The Vmax and Imax are measured values. Multiple the Vrms and Irms together to get power (P = Irms*Vrms).
15. Using the velocities and M-mode pictures, consult with the Hardware point person to find the optimal power needed for movement. This will be used to determine the power source necessary for the final device.

Set up:

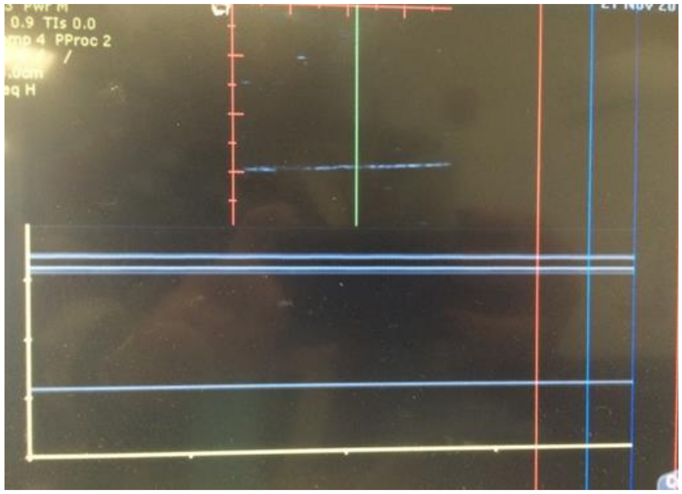




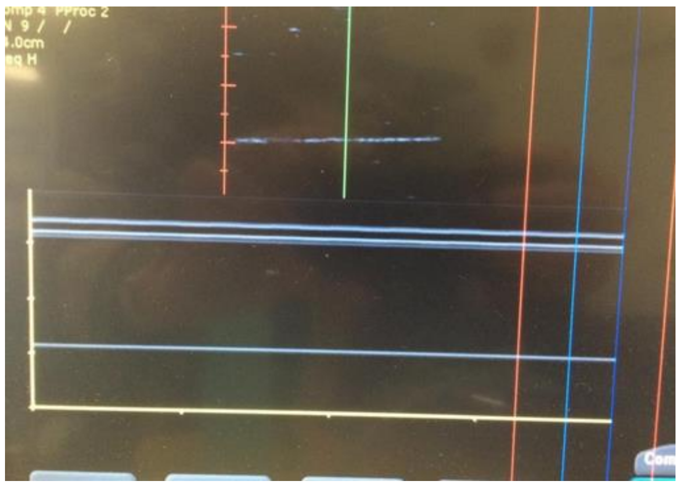


M-Mode pictures:

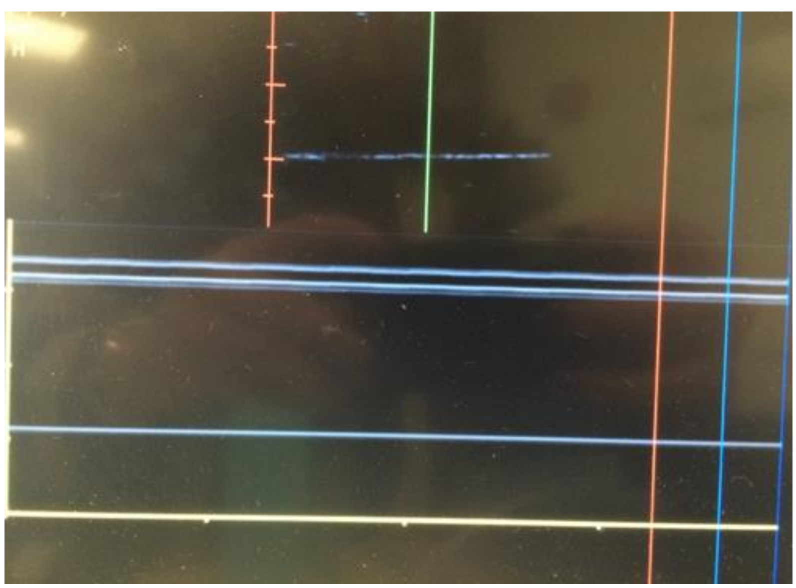
3V:

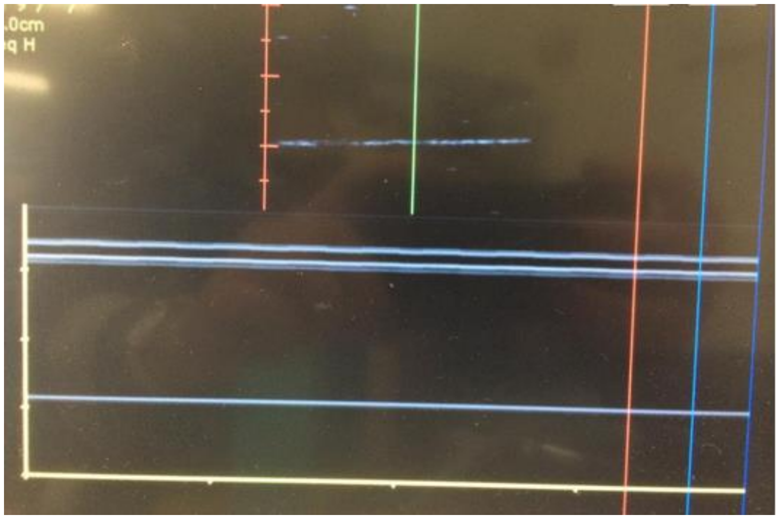


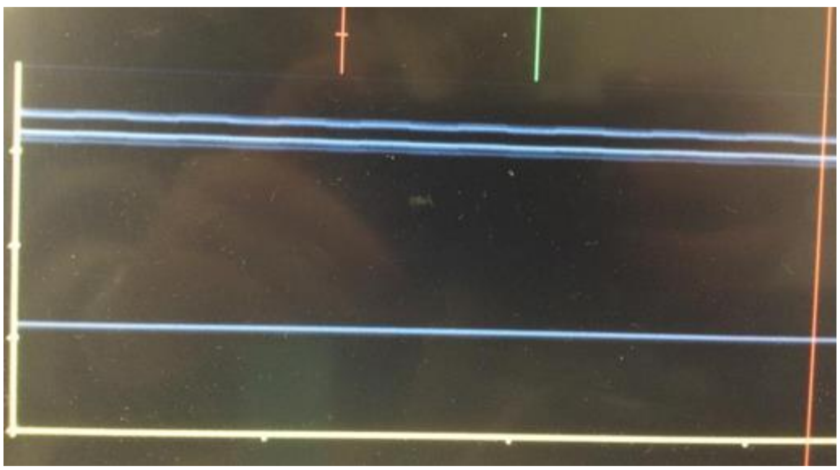
3.5V:

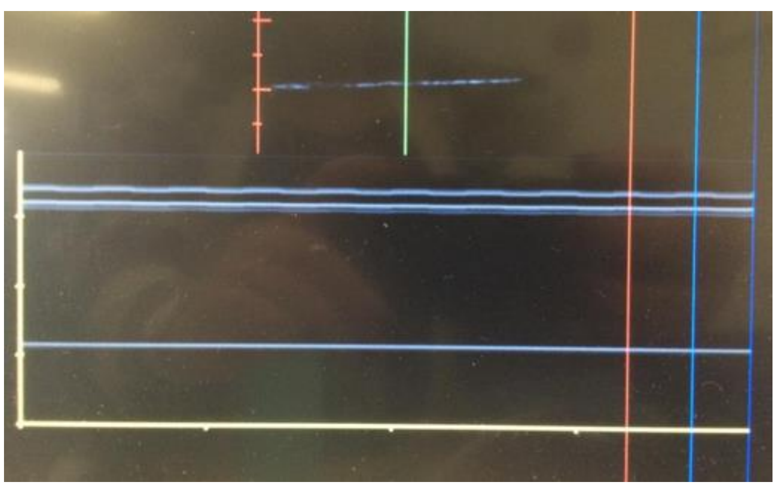


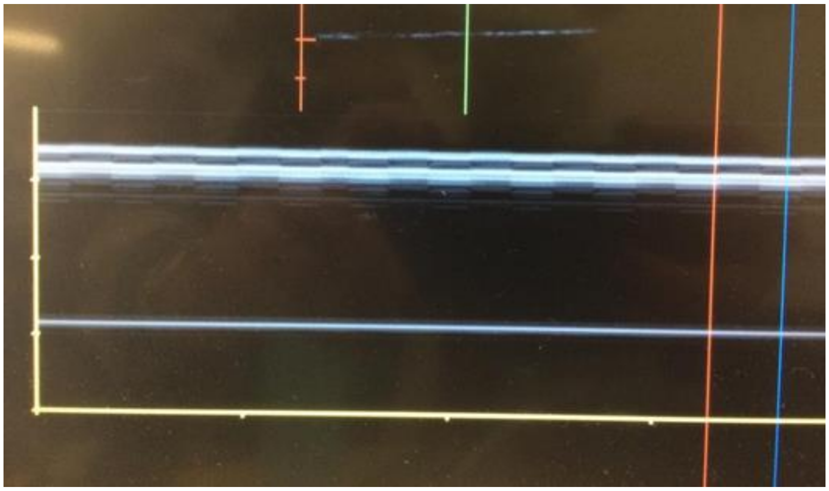
4V:



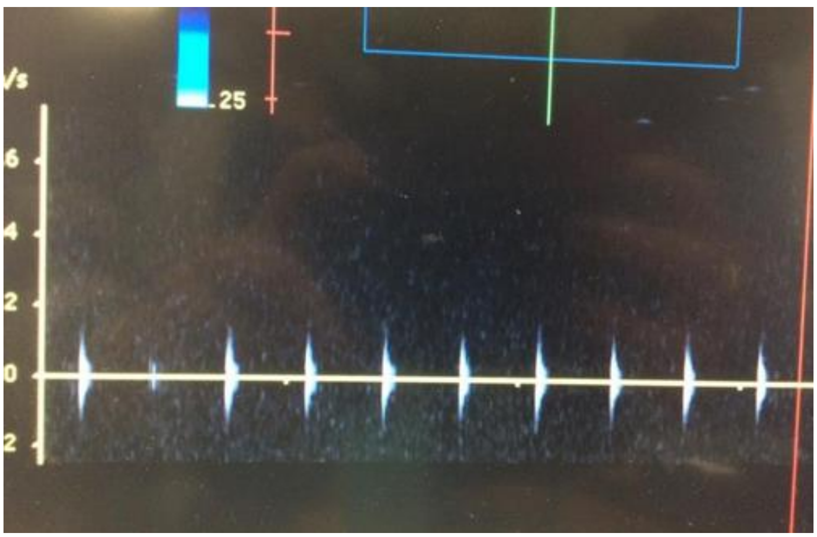
4.5V: 

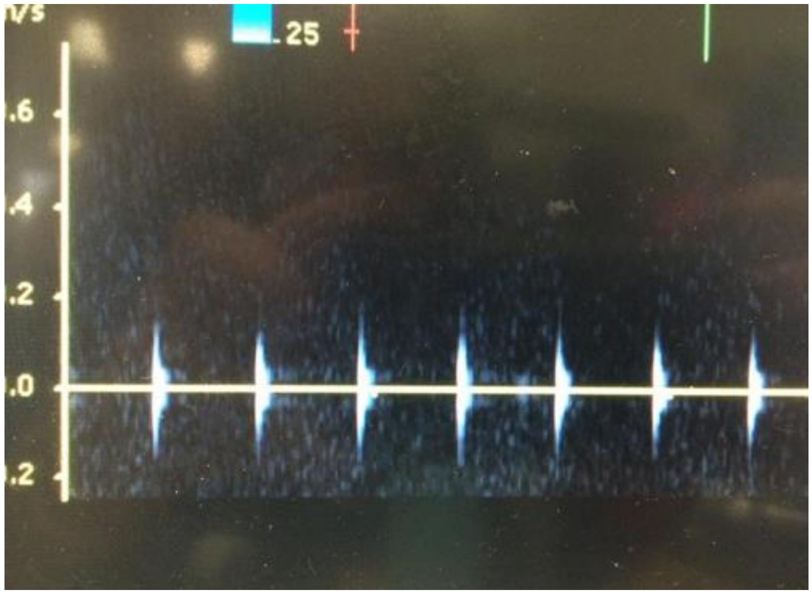
5V: 

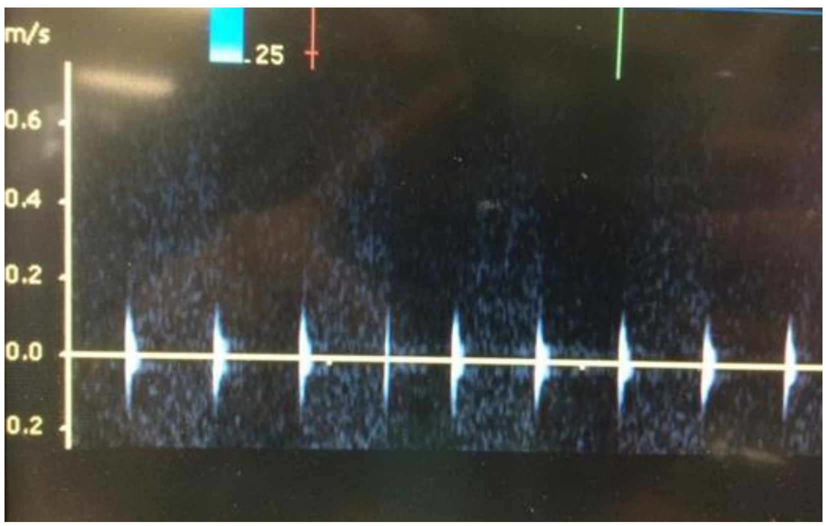
5.5V: 

6V: 

Some PW-mode mode pictures were taken:

3V: 

4.5V: 

6V: 

Testing Protocol 4: Amplitude Modulation

1. Set up device as per previous protocols
2. Set up and turn on Gaussmeter (making sure that it is zeroed before beginning), attaching it to a stand so that it is standing freely. The tip of the probe should be 3cm away from the end of the electromagnet, with the probe perpendicular to the field lines (so perpendicular to the table top).
3. Turn on device, setting amplitude at the lowest setting (0) and frequency at 5 Hz. Device should be powered with 6V.
4. Record the amplitude setting and the measured EMF. The measured EMF that is recorded should be the highest observed, since (because of the nature of the device), it will be oscillating.
5. Increase the amplitude by an increment of 0.5.
6. Record the amplitude setting and the measured EMF.

7. Repeat Steps 4-6 till the amplitude setting is maxed out to 5 or the device begins to overload (note: if overloading occurs first, immediately turn device off).
8. This experiment is finished. Turn off device and turn off gaussmeter. Repeat for a second trial if desired.
9. Run statistical analysis with MATLAB to see if there's a significant difference in the measured EMF according to the amplitude modulation (one-way ANOVA).

Testing Protocol 5: EMF Strength Testing

Pretesting: In order to figure out how and where to position the ultrasound probe, conduct a small scale test with the electromagnet and a seed in hair gel and the small glass cuvette. Use this to see how the seed moves. In the following test, the US probe will need to be positioned so that the movement of the seed is toward/away from the seed (parallel to the plane of the probe) for maximum robustness.

NOTE: At all times, be aware of how hot the electromagnet or the hardware components are getting, and be carefully watching the current to ensure nothing overloads.

NOTE: Set up pictures are like those of the power testing protocol

1. To set up, take a large glass box and fill it evenly with ultrasound gel (concern: will the glass be a problem? Will it weaken the effect of the electromagnet? If so, maybe make a quick trip to Quenchers and get one of the plastic tupperware things)
2. Insert the seed into the gel, ensuring that it is level with the bench top, not crooked. If possible, place the seed close to the side of the box (so visualization may be possible with the naked eye) and near the top of the box (for maximum proximity to electromagnet)
3. Place the electromagnet right next to the glass, by the seed. Ensure that the seed is positioned so that it is perpendicular to the electromagnet field lines. Measure the distance between the seed and the electromagnet. It should be under 3 cm. Record this measurement.
4. Place the ultrasound probe in the ring stand
5. Either:
   a) Place the ultrasound probe and ring stand in the gel, 0.5 cm from the seed, ensuring that the movement of the seed will be toward/away from the probe when vibration begins or b) Place the ultrasound probe and ring stand on top of the box, directly on top of the seed, with the probe touching the gel and ensuring that the movement of the seed will be toward/away from the probe when vibration beings
   1. NOTE: For the data presented here, the probe alone was put into the glass pan and was submerged in ultrasound gel with the seed at a starting point of 0.5cm away from it. The position of the seed along the ultrasound probe was chosen by looking at the ultrasound screen and ensuring it was visible. A cardboard wall served as a divider between the gel and the electromagnet, which also rested in the glass pan (see picture of set up).
6. Prepare the Gaussmeter (F.W. Bell, model 5080)
   1. Plug the gaussmeter into a wall outlet to power it
   2. Attach the probe to the main body of the gaussmeter
   3. To zero the gaussmeter, set the dial to 'measurement', put the tip of the probe into the little black box, and press and hold down 'zero' until the measurement stabilizes. Note that it might not stabilize exactly at zero, but it should be fairly close.
   4. Remove the tip from the black box. It is now ready to measure.
7. After covering the tip of the Gaussmeter with a protective wrap, such as Saran Wrap, position it so that the tip of the measuring tool is right in front of the seed, the flat portion perpendicular to the EMF lines.
8. Turn on the device, set frequency at 5 Hz and set the power source voltage to 6V
   1. Setting software:

1. Set AmplitudeThe Amplitude set screen will be the first menu screen to appear. Use the up and down buttons to navigate to one of the three prompts:
   UP - Increases Amplitude by 1
   DOWN - Decreases Amplitude by 1
   BACK - Returns to main menu
   Pressing the "select" button will activate the functionality of whichever menu option that the cursor is at. The Amplitude varies from 0 to 10 by increments of 1. The units are arbitrary, with 10 being the highest amplitude option. The default setting is 5
2. Set FrequencyThe Frequency set screen can be navigated to on the main menu by using the "up" and "down" buttons to move the cursor to the "set frequency" option, and then press "select". Use the up and down buttons to navigate to one of the three prompts:
   UP - Increases Frequency by 1
   DOWN - Decreases Frequency by 1
   BACK - Returns to main menu
   Pressing the "select" button will activate the functionality of whichever menu option that the cursor is at. The Frequency varies from 0 to 50 by increments of 1. The units are in Hz. The default setting is 1 Hz
3. Set BacklightThe Backlight set screen can be navigated to on the main menu by using the "up" and "down" buttons to move the cursor to the "set backlight" option, and then press "select". Use the up and down buttons to navigate to one of the three prompts:
   UP - Increases Backlight brightness by 1
   DOWN - Decreases Backlight brightness by 1
   BACK - Returns to main menu
   Pressing the "select" button will activate the functionality of whichever menu option that the cursor is at. The Backlight varies from 0 to 6 by increments of 1. The units are arbitrary, with 6 being the brightest option. The default setting is 0.
4. Output desired settings
   To output the desired frequency and amplitude settings to the electromagnetic transducer, navigate to the "Start Output" menu option on the main menu, and press select. This will take you to the output menu screen, which displays the current frequency and amplitude output settings, which are now being outputted to the transducer, This will occur indefinitely. To change the settings and turn off the output, press the "up" button, which will return you to the main menu.

9. Record the current through the magnet, the seed-to-magnet distance (tip of magnet to the seed), the measured EMF, and any observations about the seed movement. Record three measurements of measured EMF and current.
10. Increase the seed-to-magnet distance by 0.5 cm so it is now 1 cm.
11. Allow time for stabilization, the record the current through the magnet, the seed-to-magnet distance (tip of magnet to the seed), the measured EMF, and any observations.
12. Repeat Steps 10 and 11 until the seed-to-magnet distance is 3 cm. This is the last data point. Record all the necessary measurements.
13. Turn the device off.
14. Calculate the expected electromagnetic field strength based on the equation to the left.
15. Perform statistical analysis on the data as follows:
    1. Significance testing comparing the strength of field of the different distances (ANOVA)
    2. Significance testing between the measured and calculated electromagnetic fields (two-tailed t-test)

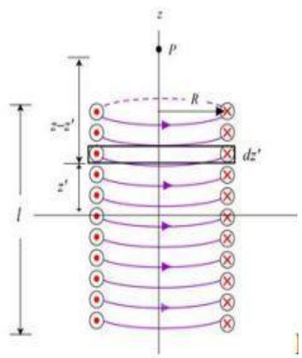
Analysis of data:

-Statistics on recorded measurements:

-Significance testing comparing the strength of field of the different distances (ANOVA on MATLAB or JMP)

-Significance testing between the measured and calculated electromagnetic fields (two-tailed t-test on MATLAB or JMP)

- Measured will come from gaussmeter, calculated from:



Integrating over the entire length of the solenoid, we obtain

$$B_z = \frac{\mu_0 n I R^2}{2}\int_{-l/2}^{l/2}\frac{dz'}{[(z-z')^2+R^2]^{3/2}} = \frac{\mu_0 n I R^2}{2}\left.\frac{z'-z}{R^2\sqrt{(z-z')^2+R^2}}\right|_{-l/2}^{l/2}$$

$$= \frac{\mu_0 n I}{2}\left[\frac{(l/2)-z}{\sqrt{(z-l/2)^2+R^2}}+\frac{(l/2)+z}{\sqrt{(z+l/2)^2+R^2}}\right]$$

Where $\mu_0 = 4\pi*10^{-7}$ N/A^2, z = the distance of the seed from the center of the electromagnet (on the z-axis), R = radius of the electromagnet (0.625 in), n = number of turns (300), l = length of the electromagnet (4.24 in), I = current

Equation for B distance z away from center of magnet (thank you MIT OCW) pg 9-22): http://ocw.mit.edu/courses/physics/8-02sc-physics-ii-electricity-and-magnetism-fall-2010/creating-magnetic-fields/biot-savart-law/MIT8_02SC_notes19to20.pdf