Faraday’s and Ampere’s Laws

Equipment list

<table>
<thead>
<tr>
<th>Qty</th>
<th>Items</th>
<th>Parts Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Voltage Sensor</td>
<td>CI-6503</td>
</tr>
<tr>
<td>1</td>
<td>AC/DC Electronics Laboratory</td>
<td>EM-8656</td>
</tr>
<tr>
<td>1</td>
<td>Coil Set</td>
<td>SF-8616</td>
</tr>
<tr>
<td>1</td>
<td>Bar Magnet</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Padding</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Large metal rod</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Universal Table Clamp</td>
<td>ME-9376B</td>
</tr>
<tr>
<td>1</td>
<td>Magnetic Field Sensor</td>
<td>CI-6520A</td>
</tr>
<tr>
<td>1</td>
<td>Rotary Motion Sensor</td>
<td>CI-6538</td>
</tr>
<tr>
<td>1</td>
<td>Linear Translator</td>
<td>OS-8535</td>
</tr>
</tbody>
</table>

Purpose

The purpose of this activity is examine some basic results of both Faraday’s Law, and Ampere’s Law. Faraday’s law will be examined by measuring the induced potential difference that induced when a wire coil of conducting material is exposed to a changing magnetic field. Ampere’s laws will be examined by measuring both the external and internal magnetic field induced by a current carrying coil of wire.

Theory

When a current passes through a wire it generates a magnetic field in the space that surrounds the wire. It turns out that a similar yet reverse process is true as well. A changing magnetic field will generate an electric potential difference (aka; an induced electromagnetic force, $\mathcal{E}$) in a nearby conductor, which can in turn generate a current in that conductor. In a particular case when a magnet is passed through a conducting wire coil there is a changing magnetic flux through the coil that induces an electromagnetic force in the coil. According to Faraday’s Law of Induction the induced electromagnetic force will be equal to:

$$\mathcal{E} = -N \frac{\Delta \Phi}{\Delta t}$$
Where $N$ is the number of loops in the coil, and $\frac{\Delta \Phi}{\Delta t}$ is the rate of change of the magnetic flux through the cross-section area of the coils. The negative sign indicates that the induced electromagnetic force will have the opposite orientation than the change of magnetic flux has. (Our equation is NOT Faraday’s law, but rather a result of it.)

Magnetic flux, itself, is how much magnetic field is penetrating a surface area, and that related to the magnitude of the magnetic field, the size of the surface area, and the orientation of the magnetic field lines to the normal direction of the surface area.

$$\Phi = BA \cos(\theta)$$

So changes in either, the magnitude of the magnetic field, the size of the surface area, the directional orientation between the magnetic field and the surface area, or the number of loops in the coil will change the electromagnetic force induced in the wire. (The equation is usually written with the assumption that the number of loops in the coil will be constant.)

$$\mathcal{E} = -N \frac{\Delta \Phi}{\Delta t} - N \frac{\Delta BA \cos(\theta)}{\Delta t}$$

It turns out that a similar but opposite physical phenomenon is true too. As a fluctuating magnetic field around a coil of conducting material will induce an electric potential difference inside the conducting material, it is also true that if you apply an electric potential difference to a coil of conducting material it will induce a magnetic field in the space around the coil. A result of **Ampere’s Law** is that a current carrying wire will produce an magnetic field in the space
surrounding the wire, and the magnetic field is induced in this manner is described by the equation,

\[ B = \frac{\mu_0 i}{2\pi r} \]

Where \( i \) is the current running through the wire, \( \mu_0 = 4\pi \cdot 10^{-7} \ T \cdot m/A \) is the permeability constant, and \( r \) is the radial direction outward from the current carrying wire. (Our equation is NOT Ampere’s Law, but rather a result of it.)

A really interesting thing occurs when the current carrying wire is curled up in a coil. All the magnetic field lines from each level of the coil combine, and collectively produce a magnetic field that is extremely similar to that of a simple bar magnet. From the magnetic field diagram we can see that the magnetic field lines inside the coil are nearly uniform, which means that the magnetic field inside the coil should be nearly uniform. While the magnetic field outside of the coil along the central axis of the coil is described by the following equation;

\[ B = \frac{\mu_0 i R^2}{2(R^2 + z^2)^{3/2}} \]

Here \( R \) is the radius of curvature of the coils, and \( z \) is the distance along the central axis, and outside of the coil to the location the magnetic field is being measured. From this equation we see that outside, and along the central axis of the coil the magnetic should decrease exponentially as an inverse square law.
Setup Part 1

NOTE: During this experiment keep the magnet away from the computers, your phones, and away from your flash/thumb drives.

1. Double click on the Capstone icon to open the Capstone software.
2. In the Tool Bar, which is on the left hand side of the screen, click on the Hardware Setup icon. This will open the Hardware Setup window.
   - An image of the 850 Pasco Interface should be in the Hardware Setup window. If not click on the Choose Interface tab. The Choose Interface widow will open, select Passport: Automatically detect. Click ok.
3. On the 850 Pasco Interface image click on the Analog Ch(A), a sensor list will appear, scroll down, and select Voltage sense. The voltage sensor icon should now be showing connected to the Analog Ch(A).
4. At the bottom center of the screen you will see that the voltage sensor is set to 20.0 Hz, change it to 200.0 Hz.
5. Close the Tool Bar.
6. In the Display Bar, on the right hand side of the screen, double click the Graph icon. This will create a graph to appear. For the y-axis click on Select Measurements, and select Voltage (V). The computer will automatically select time (s) for the x-axis.
7. Plug in the voltage sensor to Analog Ch(A), then plug the voltage sensors probes into one of the induction coils.

Procedure Part 1

1. Place the pad on the floor right next to your lab table.
2. Place the induction coil right at the edge of the table, right over the pad, such that the coil is vertical, and the coil itself is over the edge of the table. You will have to hold the coil so it doesn’t fall.
3. Hold the magnetic vertically, with its south end pointing downwards, just about one centimeter above the opening of the coil such that when you release the magnet it will fall right through the coil.
4. Near the Bottom left of the screen click on the big red circle to start recording data, wait about one second then drop the magnet. After the magnet hits the pad click on what is now a big red square to stop recording data.
5. Repeat Procedure steps 1 - 4, but this time with the north end of the magnet pointing downwards.

6. Shift and rescale the graph as needed so that you can clearly see the regions that show the induced EMF in the coil. Each graph should have a region where the curve is beneath the x-axis, and a region where the curve is above the x-axis.

7. For the graph with the south end facing downwards highlight the first region of the curve.
   - Once the region is highlighted click on the Area Under the Curve icon that is among the icons at the top of the graph. Record the value for the area in the data table
   - Now repeat for the second region.

8. Click on the Coordinate icon which is among the icons at the top of the graph, and the coordinate tool should appear on the graph.
   - Left click and hold on the coordinate tool to move it around the graph.
   - Use the coordinate tool to determine the voltage value of the peak of the two regions of the graph. Record those voltage values in the data table.

9. Repeat steps 7, and 8 for the graph with the north end facing downwards.

Setup Part 2

1. To reopen the Tool Bar click on the ‘Change properties of current page and Tools Palette’ icon near to the left of the Page #1 tab. This will open the Properties window.
   - In the Properties window click on Page Options to open the options list.
   - Check Show Tools Palette to reopen the Tool Bar, and click Ok in the Properties window.

2. In the Hardware setup window right click on the voltage sensor icon, and then click remove hardware.
   - Unplug the voltage sensor from the PASCO Universal Interface

3. On the image of the PASCO Universal Interface in the Hardware setup window click on the Analog input Ch(A) to open the sensor list.
   - Scroll down, and select the Magnetic Field Sensor

4. On the image of the PASCO Universal Interface in the Hardware setup window click on the Output Ch (1) to open its sensor list.
   - In the list click on Output Voltage-Current Sensor

5. On the image of the PASCO Universal Interface in the Hardware setup window click on the Digital Input Ch (1) to open the digital sensor list.
   - Scroll down, and select Rotary Motion Sensor.

6. At the bottom of the main screen make sure the frequency setting Common Rate, and set the rate to 20 Hz.

7. In the Tool Bar click on the Data Summary icon to open the Data Summary page.

8. In the Data Summary Page click on the properties icon that is to the left of the words Magnetic Field Sensor, to open its properties page.
   - In the Properties page set the Gain to 100x

9. On the magnetic sensor itself,
   - Set the Range switch is set to 100x, the click Ok.
   - Set the direction switch is set to AXIL.
10. In the Data Summary Page click on the properties icon that is to the left of the words Rotary Motion Sensor, to open its properties page.
   • In the Properties page set the Linear Accessory to Rack & Pinion, then click Ok.
11. In the Tool Bar click on the Signal Generator icon to open the Signal Generator window.
12. In the Signal Generator window click on 850 Output 1 to open its setting options.
   • Set Waveform to DC.
   • Set DC Voltage to 5 V.
   • Set Voltage limit to 10 V.
   • Click on the Auto tab, to set the voltage to turn on and off when you start and stop recording data.
13. Close the Tool Bar.
14. Use two patch cords to connect the Output 1 to the AC/DC Electronics Laboratory.
15. Then use two of the jump cords to complete a simple circuit containing the cylinder wire coil on the AC/DC Electronics Laboratory as show in first picture.
16. Using the provided equipment construct the setup shown in the following picture
   • Plug the magnetic field sensor into Analog Inputs Ch(A)
   • Plug the rotary motion sensor into Digital Inputs Ch(1), and Ch(2), yellow in Ch(1).
17. Then using the Universal table clamp, the metal rod, and the setup finally position the magnetic field sensor as shown
   - Make sure that the probe of the magnetic field sensor is centered on the circular opening of the cylinder wire coil, and the tip of the probe should be near the bottom of the coil when the rotational motion sensor is at its lowest position.
18. From the QuickStart Templates select Two Displays.
   - For the top display click on the center icon and select Graph.
   - For the y-axis for the bottom graph click on select measurements and select magnetic field strength (100x) (T)
   - The computer will select time (s) for the x-axis. You need to click on the word time along the x-axis, then change it to Position (m).
   - For the bottom display click on the center icon and select Digits
   - Click Select Measurements, and select Output Current (A).

Procedure Part 2

1. Click the Tare button on the side of the magnetic field sensor to calibrate the sensor.
2. Near the bottom left of the main screen click on the Record button.
3. Slowly, and with a nice clear motion lift the rotary motion sensor, and therefore the magnetic field sensor along with it, all the way up the linear translator, then click on the Stop button to stop recording data.
   - You may have to repeat this a few times till you get a nice clean graph.
Analysis

Part 1

Table (10 Points)

<table>
<thead>
<tr>
<th></th>
<th>South</th>
<th>North</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Area of first region (V \cdot s)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Area of second region (V \cdot s)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>First peak (V)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Second peak (V)</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. For each time you dropped the magnet through the coil was the ingoing flux equal to the outgoing flux? Take the % difference of their magnitudes. (10 points)

2. Why must the flux of the two regions be the same? (10 points)

3. For both runs the peak of the second region was larger than the first. Why is that? (10 points)

4. Why are there two regions for each drop? (10 points)
5. For each drop one region was below the x-axis, and one was above. When you flip the magnet the order of which one is above the x-axis and which one is below changes. Why is that? (10 points)

Part 2

6. According to your data is the induced magnetic field that is in the center of the coils themselves uniform? If not, give reasons why it isn’t. (10 points)

7. The theory predicts that the induced magnetic field outside the coils will decrease exponentially as you move away from the coils? Does you data support this claim? If not, give reasons why it doesn’t. (10 points)