Ampere's Law

Equipment

1	Ampere's Law Accessory	EM-6720
1	Wireless 3-Axis Magnetic Field Sensor	PS-3221
1	Wireless Rotary Motion Sensor	PS-3220
1	Field Coil (500-Turn)	EM-6723
1	Zero Gauss Chamber	EM-8652
Required but not included:		
1	850 Universal Interface	UI-5000
	PASCO Capstone Software	

Introduction

In this experiment, we will verify Ampere's Law experimentally by graphing the magnetic field strength that is tangent to the path taken along a closed path that encloses a current source.

Figure 1: The coil's magnetic field lines are shown in red. The closed path is shown as a dotted white line.

The magnetic field strength is measured with a wireless magnetic field sensor which rides on a rotary motion sensor. The rotary motion sensor, which rolls on its wheel, is pushed along a closed path.

Since the magnetic field sensor element is positioned tangent to the Rotary Motion sensor's wheel, the dot product in Ampere's Law is performed because only the component of the magnetic field that is tangent to the path is recorded.

Theory

Ampere's Law states:

$$\oint \vec{B} \cdot \vec{dl} = \mu_o N I_{enclosed}$$

The left side of the equation can be evaluated by plotting the magnetic field that is tangent to the path versus the path length and then find the area under the curve. The closed integral indicates that the path traversed must be closed.
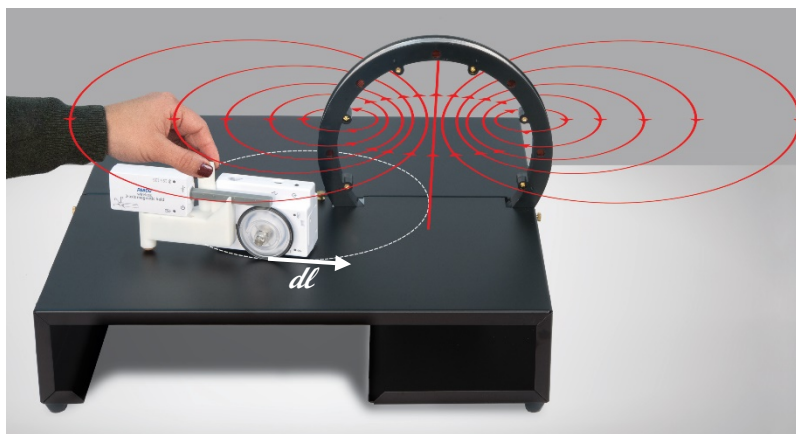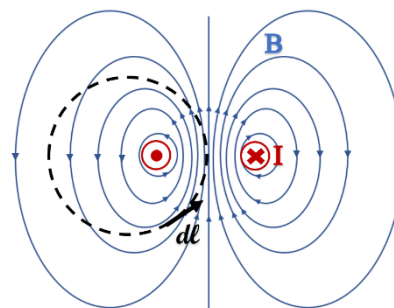

Figure 2: Top View of Coil (red) The current comes out of the page on the left and goes into the page on the right. The black dotted path is the closed path that encloses the left coil. The magnetic field is in blue.

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$$\oint \vec{B} \cdot \vec{dl} = area\ under\ B_{\parallel}\ vs.\ distance\ curve$$

The right side of the equation can be evaluated by determining how much current is enclosed in the path.

If you traverse a path that does not enclose any current source, the area under the curve is zero. The magnetic field of the Earth or any nearby source are measured but they will cancel out in a closed loop that encloses no current.

Setup

1. Put the O-ring on the pulley of the Rotary Motion sensor. Attach the 3-step pulley to the Rotary Motion Sensor with the largest step closest to the Rotary Motion Sensor. Attach the Rotary Motion sensor to the sensor bracket. Don't attach the Magnetic Field sensor to the bracket yet because the sensor has to be zeroed.

Figure 3: Magnetic Field Sensor Mounted on the Rotary Motion Sensor

2. Turn on the wireless sensors. In PASCO Capstone, connect wirelessly to the Wireless Rotary Motion sensor and the Wireless 3-Axis Magnetic Field sensor. Keep the default sample rate of 20 Hz.

3. Create a graph of the x-axis of the Magnetic Field vs. Position and a graph of the x-axis of the Magnetic Field vs. Time.

4. Connect Output 1 of the 850 Universal Interface to the coil.

5. In PASCO Capstone, in the Hardware Setup, click on Output 1 and select the Voltage/Current sensor.

6. Open the Signal Generator and set it to DC with an amplitude of 15 V. Set it on Auto.

7. Create the following calculations in the Capstone calculator:
   $\mu_{o}NI$ = [Permeability constant (H/m)]*N*I*10000   with units of Gm
   N = 500   unitless
   I = [Output Current (A)]   with units of A

8. Create a Digits display and select the calculation $\mu_{o}NI$.

Procedure: Path Encloses Current

1. Put a small sticker on the platform to indicate the starting position of the rotary motion sensor. Since Ampere's Law has a closed integral, you must start and end the loop on the same point.

2. To zero the Magnetic Field sensor, insert the probe into the Zero Gauss Chamber. You must make sure that the Magnetic Field sensor is selected in the sample rate window. Looking at the X-Magnetic Field vs. Time graph, start recording, and click on the zero button that is in Capstone on the bottom bar next to the sample rate. Make sure that the sensor reads zero. If not, click the zero button again. Then stop recording and delete the last run.

3. Attach the Magnetic Field sensor to the sensor bracket and place the wheel of the Rotary Motion sensor on your starting position. Note which direction you are pointing the Magnetic Field Sensor so you can return it to the same orientation when you return to this spot as you close the loop.

4. Start recording. The power to the coil will automatically turn on when you start recording. Slowly move the sensors around the path you choose through the coil, returning to the starting point, with the sensor pointing in the same direction as when you started. Then stop recording.

5. On the graph, find the area under the curve. Is it equal to $\mu_o NI$? Find the percent difference.

6. Try starting at a different spot and traversing a different closed path that encloses the coil.

7. Try setting the voltage to 12 V so the current is different.

Procedure: Path Does Not Enclose Current

8. Open the Signal Generator in Capstone and uncheck Auto so the power will remain off when recording starts.

9. Place the wheel of the Rotary Motion sensor on your starting position.

10. Start recording. Slowly move the sensors around the path you choose through the coil, returning to the starting point. Then stop recording.

11. On the graph, find the area under the curve. Is it equal to $\mu_o NI$?

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Analysis

1. For the run with the current enclosed, was the area more or less than the calculated value of $\mu_o NI$? What could account for this difference?

2. For the run with no current enclosed, select the area that is above the x-axis to determine the positive area. Then select the area that is below the x-axis to determine the negative area. To evaluate how close to zero the total area is, compare these areas with a percent difference.

Further Investigations

Enclosing the Whole Coil:

1. If you have a second platform available, put it next to the coil side of your platform so you can traverse a path that encloses the entire coil.

2. Open the Signal Generator in Capstone and check the Auto. Start at a particular point, start recording, and traverse a path that encloses the whole coil.

3. How much current is enclosed?

4. On the graph, find the area under the curve. Is it equal to $\mu_o NI$?

5. Now, traverse the two sides of the coil in a figure 8. How much current is enclosed?

Enclosing a Bar Magnet:

6. If you have a bar magnet available, set it on the platform near your path. Perform the experiment again, making a closed loop around the bar magnet, but not including the coil.

7. How much current is enclosed?

8. On the graph, find the area under the curve. Is it equal to $\mu_o NI$?