A Quantitative Lenz’s Law Demonstration

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Outline

- Motivation
- Experimental Setup
- Induced Current and Force on the Coil
- The Coil
- Determination of the Resistance of the Coil
- The Magnet
- Measurements of the Force on the Coil and it’s Velocity
- Comparison of Predicted and Measured Forces
- Conclusion
Motivation

Lenz’s law is often illustrated with qualitative demonstration experiments such as dropping a button magnet through a conducting pipe. Computer data acquisition makes it possible to measure the force on a coil as the secondary effect opposing its motion through a magnetic field.
Experimental Setup

- Coil Magnet
- Force Sensor
- Supporting Wire
- Smart Pulley
- Plywood Frame
- Magnet
- Wire
Experimental Setup
Equipment

- Pasco Science Workshop 750 Interface
- Dell Optiplex Pentium III 550 MHz
- Coil and Plywood Frame
- Magnet
- Dual Range Force Sensor
- Pasco Smart Pulley
- F. W. Bell 4048 Gauss Meter
- Low Friction Pulleys
- Dial Calipers
Voltage Induced in the Coil

\[ V = \nu N w B \]

Current Induced in the Coil

\[ I = \frac{V}{R} = \frac{\nu N w B}{R} \]

Force on the Coil because of the Induced Current

\[ F = I N w B = \frac{(N w B)^2}{R} \nu \]

where \( \nu \) is the coil velocity, \( N \) is the number of coil turns, \( w \) is the width of the coil, \( B \) is the magnetic field strength and \( R \) is the resistance of the coil.
Coil Properties

- **Coil Size:** 7mm by 17 mm
- **Number of Turns:** 50
- **Wire Gauge:** 14

**Width Determination**

- **Average inside width** 0.0528 m
- **Average outside width** 0.0796 m
- **Average coil width** 0.0662 m
Coil Resistance

Voltage vs. Current for 50 turn 14 gauge coil

R = slope = 0.1902 Ohms  Intercept = -0.0026 V
The magnet

A U-shaped steel frame with a 4 inch x 6 inch x 1 inch ceramic magnet on each side.

A magnetic field of about 1750 gauss in an air gap of 1.5 inches.
Y Component of the B Field of the Ceramic Magnets in the frame along the X-Axis
Y Component of the B Field of the Ceramic Magnet in the frame along the Y-Axis
Y Component of the B Field of the Ceramic Magnet in the frame along the Z-Axis
Determination of the Average B Field over the Coil Width

An average of the measurements of the magnetic field over the coil width indicated by * gives the result

\[ B_{\text{ave}} = 0.165 \, \text{T} \]
Force and Velocity Data for Run 10

$F_{off} = -0.043 \text{ N}$

$F_{r1} = 0.780 \text{ N}$

$F_1 = 0.823 \text{ N}$

$v_1 = 0.545 \text{ m/s}$

$F_{p1} = 0.844 \text{ N}$

$F_{r2} = 0.800 \text{ N}$

$F_2 = 0.843 \text{ N}$

$v_1 = 0.530 \text{ m/s}$

$F_{p1} = 0.844 \text{ N}$
Determination of Coil Average Width on Each Half

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<th>Dist</th>
<th>Wout</th>
<th>Win</th>
<th>Wave 2-7</th>
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<td>0.05332</td>
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## Results for 10 Runs

*Lenz's Law, Measurement of Reaction Force on a Coil as Magnet Sweeps Past*

July 2, 2002

<table>
<thead>
<tr>
<th>Run#</th>
<th>Force of</th>
<th>F1</th>
<th>V1</th>
<th>F1meas</th>
<th>F1pred</th>
<th>F1meas/V1</th>
<th>F2</th>
<th>V2</th>
<th>F2meas</th>
<th>F2pred</th>
<th>F2meas/V2</th>
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<td>0.769</td>
<td>0.542</td>
<td>0.811</td>
<td>0.8397</td>
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<td>0.571</td>
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<td>0.530</td>
<td>0.843</td>
<td>0.8438</td>
<td>1.5906</td>
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</table>

### Summary

- **F1pred/V1**: 1.5493
- **F1meas/V1**: 1.5106
- **% error**: 2.50
- **stand dev**: 0.0396

- **F2pred/V2**: 1.5920
- **F2meas/V2**: 1.6274
- **% error**: 2.22
- **stand dev**: 0.0321
Conclusion

- Computer data acquisition provides a means to observe the force on a coil as a result of current induced in it as predicted by Lenz’s law.
- Equipment required is readily available or can easily be constructed.
- Care must be taken to suppress normal modes of oscillation.
- Careful measurements must be made of average magnetic field over the coil width and of the average width of the coil since the forces increases quadratically with these variables.
- Predicted and measured values of the force agree to within errors of about 2.5%, consistent with the standard deviation of the force determined over 10 experimental repetition.
- The force versus time graph provides a visual representation that reinforces the teaching of Lenz’s law.