Faraday's Law of Induction

Materials

1. Ceramic magnets (taped-together stack)
2. Clamp for test tube
3. Large horseshoe magnet
4. Long wires with banana leads
5. Outer calorimeter can and foam inside
6. PVC pipe with small home-wound coil at end
7. Pasco 850 Interface
8. Plastic Vernier Caliper
9. Plastic pipe
10. Plastic ruler
11. Right-angle clamp
12. Solenoid (concentric with iron rod core)
13. Table clamp and rod
14. Voltage probes (x2)

Introduction

According to Faraday's Law a changing magnetic flux causes an induced emf in a coil of N turns given by

$$V = -N\, d\Phi/dt,$$

where the magnetic flux Φ is related to the field $\vec{B}$ by an integral over area,

$$\Phi = \int \vec{B} . d\vec{A}$$

The significance of the minus sign is given by Lenz's Law. It says that the induced current in the loop will be in a direction that opposes the change that produces it. That is, the flux due to the field produced by the induced current will add vectorially to the applied field in such a way as to reduce the amount of flux change.

For several situations you will use the computer as both a signal generator and a digital storage oscilloscope for observing voltages induced by changing magnetic flux. There should be a two-wire lead connected to both the A and B analog channels of the Pasco 850 Interface.

Procedure

Computer Setup

1. Double-click the "Pasco Capstone" icon on the desktop.
2. Click on "Hardware Setup" in the "tools" window panel at the left side of your screen and change the analog sensors for A and B to "Voltage Sensor". This should place voltage sensors in Channel A and B (on your picture of the interface).
3. In the "Controls" window panel at the bottom of your screen, change the sampling rate to 200 Hz.
4. In the "Displays" window to your right, double click on "Graph"; click on "Select Measurement" on your vertical axis and choose "Voltage, ChA (V)". You should now see a graph of voltage vs time for the Channel-A Voltage.

Moving Magnet

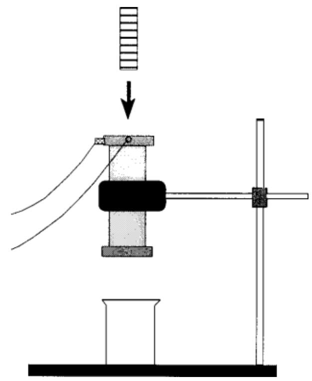

Figure 1: *Setup*

Connect the Channel A wires to the larger of the two solenoid coils—the one with the larger radius. You can use the stack of ceramic magnets to change the flux in this coil. Hold the stack above the hole through the coil. Change the sampling mode to "Fast Monitor" then press "Monitor" and then immediately stick the magnet into the coil and hold it there (then "Stop"). (Note which end of the magnet your placing into the coil.) You'll probably need to click the autoscale  tool to get a good look at your trace. Then look at a new trace by pressing "Monitor", and then pulling the magnet from the coil (then "Stop"). Now flip the magnet to let the other end enter the coil and repeat the process. Explain your observations in terms of Lenz's Law. Switch ends of the magnet and repeat the two traces.

Next you will be dropping the magnet through the coil while using the computer to monitor the coil voltage. How do you expect the trace to look? (Sketch your expectation.) Now, mount the coil vertically by means of the stand and clamps. Place the padded can below the coil to catch the magnet. Hold the magnet vertically about one-half inch above the hole in the coil. Click on the "Experiment" tab at the top of your screen and choose "Delete All Data Runs". Click [Start] then drop the magnet through the coil (then [Stop]). Why are the two voltage pulses of different signs? Why is the second taller?

Now we'll consider flux changes by having the computer perform the integration

$$\int V dt = -N\int \left(\frac{d\Phi}{dt}\right) dt = -N\Delta\Phi$$

How do you expect $\Delta\Phi_{in}$ for the magnet entering the coil to compare with $\Delta\Phi_{out}$ for the magnet leaving? What do you expect for $\Delta\Phi_{total}$ for the whole trip through the coil?

To perform the integration on your graph, click on the "Area" tool  to display the area under active data. Now, use the "Data Highlighter"  tool to select the data across the first peak, and take note of the area (the units are volt-seconds, or V s). Repeat this for the second peak and for the combined area. Record $N\Delta\Phi_{in}$, $N\Delta\Phi_{out}$, and $N\Delta\Phi_{total}$.

Repeat these measurements for a magnet dropped from much higher above the coil. Place the plastic tube against the top of the coil to assist you in this drop. How do the sizes of the induced voltages and flux changes in this case compare to those for the first drop? Use Faraday's Law in explaining the similarities and differences. Be sure to clear your data runs

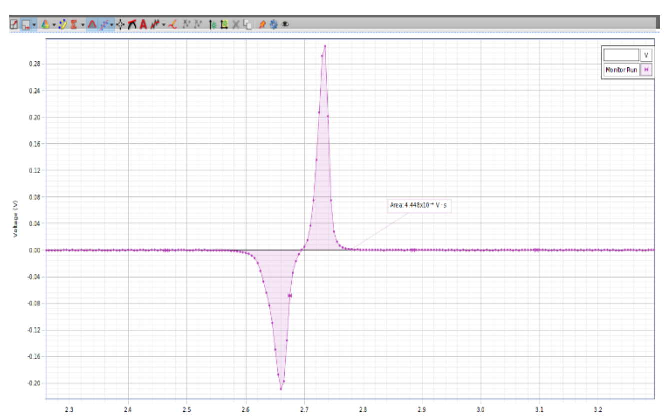

Figure 2: *Plot*

again before proceeding.

Moving-Coil Measurement of the Field

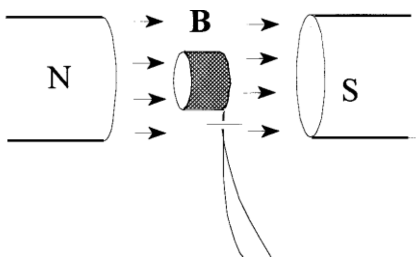

Figure 3: *Moving Coil*

Attach Channel A to the small coil at the end of the white plastic pipe. If you place the coil, which has 100 turns, be- tween the poles of the large magnet with the coil axis perpendicular to the pole faces, to the extent that the field is uniform, the flux through

the coil should have magnitude

$$|\Phi| = |\int B\, dA\,| = \ BA$$

where A is the circular area, πr^2, enclosed by the coil. If the field direction or the coil were flipped 180°, Φ would be the same size but would change sign. Place the coil in the field, click "Record", and then quickly pull out the coil. Note: do not press "Stop" until you see a peak. The field through the coil changes from B to zero, and the flux changes from BA to zero. Therefore, the magnitude of the field should be related to the integral of the coil voltage by

$$NBA = |\int V\, dt\,|$$

Use these ideas to obtain B. You'll once again want to make use of the area function of your graph (for the integral). Make sure that the integral (the area) is in volt-seconds to get the field in tesla. Convert your result to gauss. (1 tesla = 10,000 gauss.) Make the measurement several times using differing speeds of removal of the coil from the magnet.

Next start your graph with the coil in the field, as before; then spin the pipe smoothly about its axis one half turn to flip the coil 180° without removing it from the field (wait again before hitting "Stop").

Explain the resulting trace. How could you use this graph to get the field? Again, delete all data runs before you proceed.

Transformer

Place the smaller solenoid inside the larger one; reconnect channel A to the outer coil and channel B to the inner coil. Connect a set of wires from the back of the channel B wires at the inner coil to the signal generator (OUTPUT 1) on the interface. Close the graph used in the previous section. Click on "Hardware Setup", then click on the yellow circle to the top far right of your PASCO 850 interface and select "Output Voltage-Current Sensor". Click on “Signal Generator” in the “Tools” window panel. Select “850 Output 1” then set the voltage to 0.100 volts and the frequency to 60Hz. Click “On” to turn on the signal generator. You will use an oscilloscope to observe your transformer. Double-click on “Scope” in the Displays window panel. Click on “Select Measurement” on your y-axis and choose “Voltage, ChA”. Click on the “Add Trace” tool to create an additional y-axis to the right of your scope. Change the quantity being measured on the trace to "Voltage, Ch B". You should now have a scope that will display both channel A and B voltages on the y-axis. On the "Controls" window panel at the bottom of your screen, change the sampling mode to "Fast Monitor", then click "Monitor" and observe the voltages from channels A and B. Adjust the voltage and time per division for each channel to get a good picture of your waves (be sure that your voltage per division is the same for both channels). Click [Stop]. What is the source of the signal coming from the outer core (channel A)? Use Faraday’s Law in your answer to this question. What is the ratio of the two peak voltages? Would you call this a step-up or step-down transformer? Insert the iron rod into the hole in the coils. How does this “iron core” affect the ratio of the two signals? Now, what is the ratio of the two peak voltages? What must the rod have done to the size of the magnetic field inside the inner coil? Keep in mind that it is the changing flux that gives the induced voltage. Do you see why most practical transformers have iron cores?

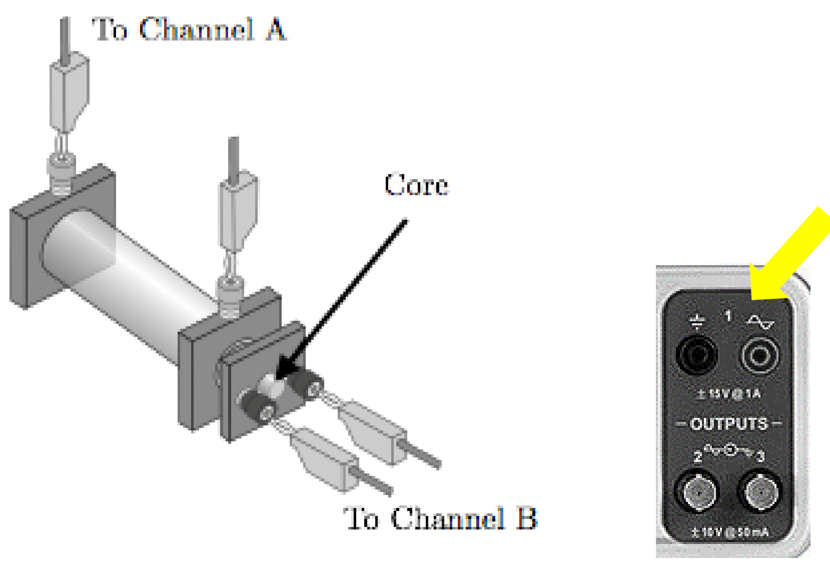

Figure 4: *Setup. Connect one set of wires from the inner core to Channel B and another to the signal generator (OUTPUT).*