Induction in a loop

Introduction

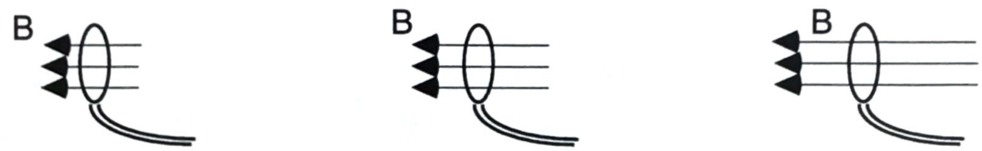
This laboratory provides the opportunity to make a quantitative investigation of the phenomena of induction. A successful outcome depends on Faraday's Law of Induction and on the expression for the magnetic field produced by a solenoid.

Theory

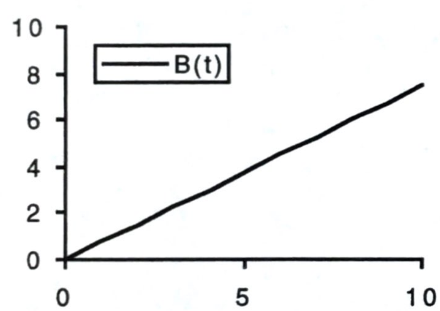
When the magnetic field passing through a circular loop is changing in time an EMF is produced. Faraday's Law predicts the strength of this EMF to be given by:

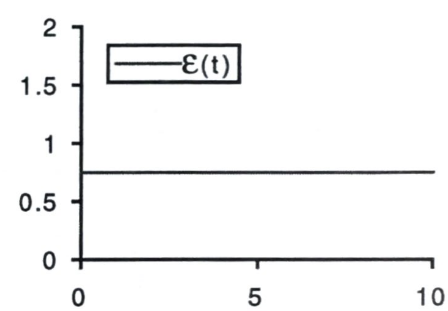
$$\mathcal{E} = -N\frac{d\phi_B}{dt} = -NA\frac{dB}{dt}$$

where A is the area of the magnetic flux and N is the number of turns in the loop.

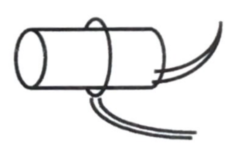


If the magnetic field is steadily increasing, as shown above, the EMF will have a constant value.



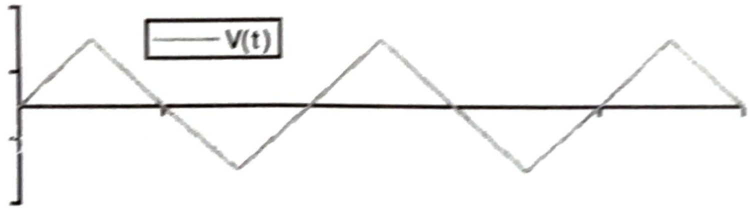


In the present experiment the magnetic field is produced by a solenoid. The magnetic field is give by $B = \mu_o In$. To produce an increasing B we must have an increasing current supplied to the solenoid. $\frac{dB}{dt} = \mu_o n\frac{dI}{dt}$



We will produce this changing current using a special power supply called a signal generator or function generator. The function generator can produce a variety of time dependent voltage functions V(t). This simply means that the function generator acts like a battery that is being turned up and down according to some desired function V(t).

We want to turn the battery up constantly. Of course this cannot go on forever because we would run out of power. So we turn the voltage up constantly then down at the same rate. This produces what is called a triangle wave function.



The current that flows in the solenoid is given by Ohm's Law, $I = \frac{V}{R}$. So $\frac{dI}{dt} = \frac{1}{R}\frac{dV}{dt}$.
Where dV/dt is the slope of the triangle wave.

Here is a summary of the physics, working backward from the signal generator to the induced EMF.

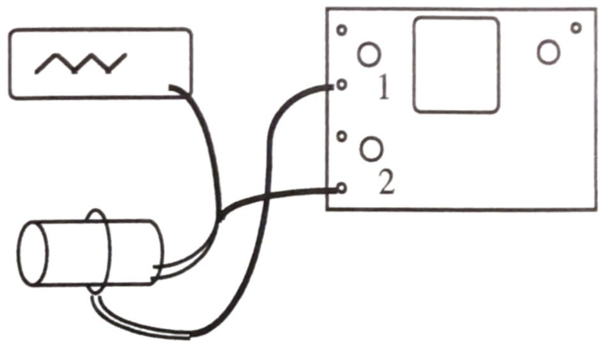
- A changing current is produced by a power supply that has changing voltage.
$$\frac{dI}{dt} = \frac{1}{R}\frac{dV}{dt}$$
- The changing current produces a changing magnetic field in the solenoid.
$$\frac{dB}{dt} = \mu_o n \frac{dI}{dt} = \frac{\mu_o n}{R}\frac{dV}{dt}$$
- The changing magnetic field produces an EMF in the pickup coil (the loop) that surrounds the solenoid.
$$\mathcal{E} = -N\frac{d\phi_B}{dt} = -NA\frac{dB}{dt} = -NA\mu_o n\frac{dI}{dt} = -\frac{NA\mu_o n}{R}\frac{dV}{dt}$$
- Ultimately the induced EMF in the pickup coil depends on the rate of change of voltage of the function generator.
$$\mathcal{E} = -\frac{NA\mu_o n}{R}\frac{dV}{dt}$$

The laboratory activity will focus on this equation. You will be able to adjust the rate of change in voltage (the slope of the triangle wave). This will be your independent variable. You will directly measure the induced EMF in the pickup coil (your dependent variable). Thus a graph of induced EMF vs. Slope of the triangle wave should produce a straight line. This line will have a slope given by

$$-\frac{NA\mu_o n}{R}$$

In addition you will want to confirm the sign that appears in the above equations. To do so you must carefully note the winding directions of both coils, the ± lead connections to the devices, and the signs of the data displayed.

Procedure



The apparatus is sketched here. The function generator is connected to the solenoid. Also this signal is sent to channel 2 of the oscilloscope. This is where you will measure dV/dt. The pickup coil is connected to channel 1 of the oscilloscope. This is where you measure $\mathcal{E}$.

Connect the solenoid to the wave generator and select a triangle wave output. Connect channel two of the oscilloscope across the solenoid so that the input signal to the solenoid can be displayed on the screen. Connect a simple loop of wire to channel one of the oscilloscope. Have this loop pass once (or twice) around the outside of the solenoid NEAR ITS WAIST. Set the frequency of the wave generator to the kilo-hertz range.

Turn on the wave generator and the oscilloscope. Adjust the settings until you see the solenoid signal on channel two. The following settings are a good place to start.

- Triggering - Ch2
- Coupling - AC
- Mode - Auto
- Ch1 Volts/cm - 1-2 mV
- Ch2 Volts/cm - 1/2-2 V
- Time/Div - 1 ms

Set the volts per div. of channel one to 1 millivolt. Set the coupling to "gnd" and adjust the position until the trace is exactly on a grid mark. The first horizontal line above the half screen mark is a good choice. This becomes the "zero" line for EMFs in the loop. Due to variations in equipment you may want to get help finding the best settings for collecting data.

WHAT TO MEASURE

- n = # of turns per meter of the solenoid (Note the number of winding layers.)
- N = # of turns of the surrounding pickup coil.
- R = Resistance of the solenoid (Use the DMM for this.)
- A = Effective area where magnetic field penetrates the pickup coil. (What area is this?)
- dV/dt = Slope of the triangle wave displayed on channel 2 (You will change this variable).
- $\mathcal{E}$ = EMF displayed on channel 1 (Your dependent variable).
- Winding directions for both coils.
- Connection polarities.

R can be measured with a multimeter. To find n, count the number of windings in several centimeters of length of the solenoid. NOTE THE NUMBER OF WINDING LAYERS ALSO. There are calipers available to measure the diameter. Also note the direction of windings in both the solenoid and pickup loop and how these are connected to the oscilloscope. Do not rely on arrows drawn on the solenoids, you want to be certain of these directions for yourself.

You will measure the induced EMF (channel one) as a function of the slope of the applied voltage across the solenoid. Set the out put of the wave generator to its maximum value and the frequency to around 80 Hz. Measure the slope of the signal on channel two of the scope. BE SURE YOU RECORD THE SETTINGS OF THE 'SCOPE SO THAT THE DISPLAY SLOPE CAN BE CONVERTED TO VOLTS PER SECOND. Note the vertical displacement of the trace of channel one (in millivolts) from the "zero" line you chose above. Now when you select a higher frequency for the function generator, the slope of the triangle wave will increase (why?). Repeat your observations for higher frequency settings from the wave generator to produce your data set. Do not go above about 350 Hz.

Laboratory Report:

1. Follow the standards for a formal laboratory report. No clearly defined objective has been given in the handout. You must decide on a laboratory objective before you write up your results. Be sure you include he following:

2. Graph the induced $\mathcal{E}$ (displacement on channel 1) versus the slope of the input signal to the solenoid (slope of channel 2). Compare the slope of this graph to a theoretical value computed from the equations above. The particulars for this comparison will depend on your stated purpose.

3. Document and discuss confirmation of the sign that appears in our theoretical expression bases on your equipment and data.

4. Estimate the uncertainties for the measured values. Compute an uncertainty range for whatever experiment/theory comparison you make.

5. Include a section of the report that describes in words why this equipment does what it does. Be very alert to the requirement that this is presented in your own words.