Faraday’s Law

PRE-LAB

Review section 7.5 of Purcell. Also make sure you know the expression for $B_z(z)$ for a flat coil.

Pre-Lab Question 1: When winding the probe, or sensor, coil, why is it necessary to twist the ends of the wire leads and extend them back so far before you connect them to the oscilloscope?

Pre-Lab Question 2: The probe coil is placed inside the source coil. Why is there no signal in the probe coil if the axis of the probe coil is perpendicular to the axis of the source coil?

Pre-Lab Question 3: Propose a method for estimating the uncertainty in a quantity like B_{max}, which is calculated by numerically integrating experimental data.

EXPERIMENT

The purpose of this lab is twofold: to demonstrate Faraday’s law and also to learn something about pulsed power and instrument calibration. A large capacitor is charged to a high voltage, then the capacitor is discharged into a coil, producing a high-power pulse of current in the coil. We’ll determine the strength of the magnetic field pulse produced in this coil, called the source coil, by measuring the magnetic field induced in a neighboring probe coil by the field of the source coil (as determined by Faraday’s law). Then we’ll compare the strength of the source coil magnetic field determined from these measurements to that calculated using the Biot-Savart law.

The first step is to determine some parameters of the apparatus. Measure the diameter of the flat source coil, the thickness of the fiberglass spacers (should be close to 1 cm), and the diameter of the fiberglass probe forms (should be about 1/4”). Convert your measurements to meters.

Wind a new coil (we call this a probe or sensor coil) at the end of a probe form (5 or 10 turns is fine; be sure to record in your lab book how many turns you make). Wind the coil in the middle of the length of wire, and then twist the ends of the wire back about 30 cm. Carefully scrape the insulation off the ends of the wires using a razor blade and sandpaper, and clip on a pair of leads. Connect the leads to a scope with a coaxial cable. You will use this coil to measure the magnetic field of the source coil.

Note: the power supplies go up to 120 V. Even though the scope, probe and trigger are isolated from the high voltage, PLEASE be careful!!!

The circuit we’re using is shown below. Your instructor will describe how it works at the beginning of the laboratory, so don’t worry if you don’t understand it completely on reading this handout.

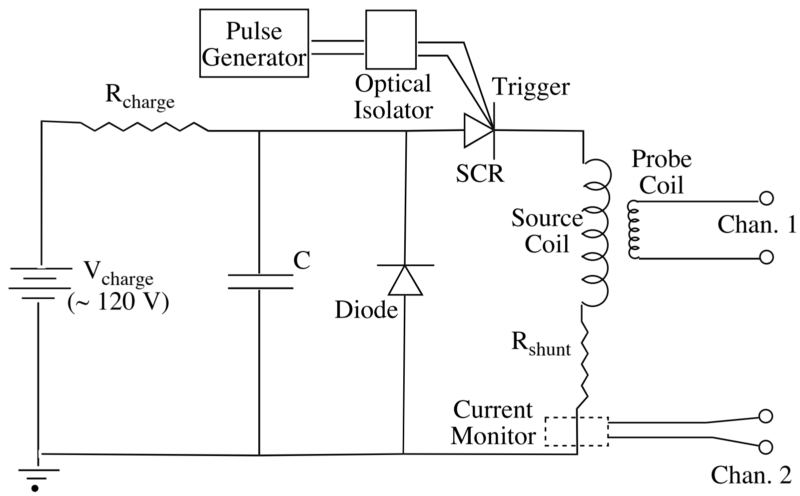

Figure 1. The pulsed-power circuit.

Place the probe coil near the center of the source coil with the axes of the coils parallel. (Ascertain that, as discussed in the prelab, you don't get any signal across the probe coil if the probe coil axis is perpendicular to the source coil axis.) Charge the capacitor to 120 V using the HP power supply. Discharge the capacitor through the source coil using the pulse generator in One Shot mode.

Download the data from the oscilloscope to the computer and open this data file in Kaleidagraph. Recall that the time in seconds is in the first column and voltage from Channel 1 is in the second column.

The induced emf across the probe coil is given by Faraday's Law.

$$\varepsilon = \Delta V_{probe} = -\frac{\partial \Phi_{probe}}{\partial t} = -N_{probe} A_{probe} \frac{\partial B}{\partial t}$$

So, the potential difference you measure across the probe coil is proportional to the time derivative of the magnetic field in the source coil. To find the maximum magnetic field in the source coil, perform the integral

$$B_{\max} = -\int_{B_{\max}}^{0} dB = \frac{1}{N_{probe} A_{probe}} \int_{t_{\Delta V = V_{\max}}}^{t_{\Delta V = 0}} \Delta V_{probe} dt$$

from the time at which $\Delta V_{\mathrm{probe}} = \Delta V_{\max}$ to the time at which $\Delta V_{\mathrm{probe}} = 0$. Use the "Integrate-Area" macro in Kaleidagraph to do this numerically.

Channel 2 of the oscilloscope records the current in the circuit. The conversion between voltage and current is written on the current monitor. You can use the on-screen cursors on the oscilloscope to find the maximum value of the current.

Using the expression for B(z) for a coil in SI units, which can be found using the Biot-Savart law,

$$B_{coil} = \frac{N\mu_0 a^2 I}{2\left(a^2 + z^2\right)^{3/2}},$$

calculate the peak magnetic field, B_{max}, from the peak current in the source coil. (The source coils have 10 turns each.) How does this compare to the value based on your probe reading? (Figure out a way of estimating experimental uncertainty in both values.) Be sure to complete this analysis before moving on to the next measurement.

Finally, measure $B(z)$ of the source coil at several values of z by shifting the z position of the probe using the 1 cm blocks. Download each run to the computer and calculate $B(z)$ based on $\Delta V_{\mathrm{probe}}$. Graph $B(z)$ vs. z and fit the above equation to the data using two parameters, I and a. How do your measured $B(z)$ values compare to the theoretical function? How do the two parameters from the fit compare to your measured values?

IF TIME PERMITS

The current in the circuit can also be measured by observing the voltage across the shunt resistor. Instead of measuring the probe coil voltage on Channel 1 of the oscilloscope, measure the voltage across the shunt resistor on Channel 1. Discharge the capacitor and observe the two traces on the oscilloscope. Both traces allow you to measure the maximum current in the circuit. Do the two measurements agree? If not, suggest a reason for the discrepancy.

LAB BOOK CHECKLIST

You should have:

- at least one plot of ΔV_{probe} and $\Delta V_{current\ monitor}$ vs. t from the oscilloscope
- a comparison of the theoretical prediction from the Biot-Savart law and the pulsed magnetic probe result (Faraday's law)
- plot of $B(z)$ vs. z with a best fit