PH102 Lab: Axial Field of a current loop

Introduction

The magnetic field along the axis of a current loop is given by:

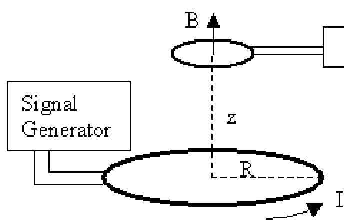
$$B = \frac{\mu_0 N I R^2}{2\left(R^2 + z^2\right)^{3/2}} \tag{1}$$

where N is the number of turns, R is the radius of the loop, and z is the distance from the center of the loop. You can easily verify that if $z \to 0$, this reduces to the formula for the field at the center of a current loop. Deriving this full formula requires some calculus; don't worry about it.

We also know that if a loop of wire has a time-changing magnetic flux through it, a voltage is induced around the loop, according to Faraday's law of induction:

$$\Delta V = -N \frac{\Delta \Phi_B}{\Delta t} \tag{2}$$

In this experiment you will use two coils examine Eqs. (1) and (2). An AC (time-varying) current will be applied to one coil, which will create a time-varying magnetic field whose magnitude follows Eq. (1). A second coil placed coaxially will be used to sense that varying magnetic field through Faraday's law, Eq. (2).



Procedure

Connect one coil to the output of your function generator (perhaps labeled as the "50 Ω" output, *NOT* the "TTL" output). This is the coil providing the time-varying magnetic field. Set the generator frequency f to 10 kHz. Set the waveform to a sine wave, and the amplitude at about halfway. Measure the voltage across the coil using the handheld meter in "ac volts" mode (the setting with a "V" and a sine wave next to it). Note this value in Volts for later.

After you have done this, connect the second coil to the handheld voltmeter. This is the "pickup" coil. Measure the ac voltage induced in the small coil as a function of distance from the axial distance between the two coils, up to about 40 cm. Plot the measured voltage on the pickup coil versus the separation distance z in excel as an x-y scatter chart (we want the separation distance z on the x axis in the chart).

Analysis

We can more easily test Eq.(1) if we put it into a linear form:

$$\frac{1}{B^{2/3}} = \frac{R^2 + z^2}{\mu_0 N I R^2/2} \tag{3}$$

The voltage induced in the second "pickup" coil is proportional to this B produced by the primary coil. Combining the equation above with Faraday's law, then we have something like this:

$$V_{\text{pickup}}^{-2/3}(z) = (\text{const})(R^2 + z^2) \tag{4}$$

here again z is the distance between the two coils and R is the radius of the primary coil.

Now plot $V_{\text{pickup}}^{-2/3}$ versus z^2 in excel. To get arbitrary powers in excel, you can type *=power(cell,power)*, or something like *=power(A2,-2/3)* to calculate the value of the contents of cell A2 to the -2/3 power.

Do you get a straight line? From the x-axis intercept, you should be able to determine R. Noting that the slope is C and the intercept is CR^2, if you *divide the intercept by the slope* and take the square root, you should get R.

Questions:

How well does your data obey Eq.(1)? What are some sources of discrepancy? *Hint: what about the radius of the pickup coil?*

How big is the "pickup" voltage compared the the signal generator's voltage, at best? How could you make the ratio larger?

How does your value for R compare to the physical dimensions of the primary coil?

Turn in:

Plot of $V_{\text{pickup}}^{-2/3}$ versus z^2

Value of the voltage applied to the primary coil

Estimated value of R for the primary coil

Answers to questions above