Lab-6, Build a Magnetometer

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The magnitude and direction of a magnetic field are important parameters in many laboratory experiments. The most useful method for measuring a magnetic field relies on the Hall effect, and consequently most "gaussmeters" measure a Hall voltage.

On the other hand, a simple and straightforward method for measuring a magnetic field (albeit not the most precise) is to measure the voltage induced in a coil of wire, which is induced by a change in magnetic flux. In this experiment, the flux is changed by moving a magnet into the coil. The magnetic field entering the coil is proportional to the total change in magnetic flux, from an initial flux of zero when the magnet is far from the coil to maximum flux when the magnet is fully inserted in the coil. Since the flux is related to only these two values and not the details of motion, the magnitude of the field is obtained from the voltage *integrated* over the motion. Here you will build a magnetometer using only an integrating op-amp circuit and a coil of wire.

Items needed:

- ±15 V DC power supply, oscilloscope
- 741 and OP07 op-amps
- Resistor 10 kΩ, Capacitor 1.0 µF
- Coil of insulated copper “magnet” wire
- High-field NdFeB magnet (McMaster-Carr) **DO NOT GET 2 MAGNETS CLOSE TOGETHER**

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I. Experiment Design

Before considering a coil and designing an integrating op-amp circuit, some tests and "*back of the envelope*" calculations should be made to determine the design parameters. First, estimate the magnetic-field-induced voltage from the coil alone. You want the voltage from the coil (ΔV_{in}) to be larger than the 741 input offset voltage (~1 mV).

Compute V_{in} for a field of ΔB=1 tesla, N=100 turns of coil wire and magnet area of 10^{-4} m^2 (use SI units).

II. Construct Magnetometer

Construct an integrating circuit (make sure you have the two extra wires for discharging the capacitor).

Attach the N=100 turn premade coil to the input, or you may make your own coil.

The coils are delicate, so treat them gently.

1. Measure the output voltage drift (dV_o/dt) of your circuit.

2. In your report, discuss the origin and magnitude of the drift.

Test the magnetometer circuit by looking at the circuit output on the scope as you move the magnet quickly into the coil. You will need to discharge the capacitor occasionally when $|V_o|$ increases to the supply voltage (>10 V).

II. Measure the Magnetic Field

Quickly insert then quickly remove the high-field magnet from the coil several times, keeping it in or out for about 3 sec. You should see the voltage change on the scope when the magnet is brought close to the coil. The voltage changes will appear on a sloping background.

Now, capture the voltage changes on the scope and make a copy for your lab report. You will probably need to discharge the capacitor occasionally and press the Run/Stop button on the scope to start and stop the scope trace.

1. Capture a scope trace that has at least 3 equal voltage changes, ΔV_o. Include the plot in your report.

2. Reverse the orientation of the magnet and capture a similar scope trace. Discuss the difference.

3. Compute B for the high-field magnet, using SI units.

4. Compute the uncertainty in B from the uncertainties in ΔV_o and the area A. See below.
   Write you final result as B = XXX ± X tesla (Note: use either tesla or simply T, not **T**esla)

5. Make a test to see how the speed of insertion affects your ΔV_o. Discuss.

6. Would the measured B change if you used a 10% smaller or larger diameter coil? Why?

IV. Summary

Include a table of values along with a summary of the experiment.

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The uncertainty in z is found from the uncertainties in *n, a, b* and *c* using the following.

$$For\ z = \frac{a^n b}{c}, \quad then \quad z \pm \sigma_z,$$

$$where \left(\frac{\sigma_z}{z}\right)^2 = n^2\left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2 + \left(\frac{\sigma_c}{c}\right)^2.$$