8. Rotating Coil Magnetometer: Earth's Field Measurement

A rotating coil in a static magnetic field can have a voltage induced on it. This voltage is related to the strength of the field, the number of turns in the coil, and the rate of rotation. The apparatus in Figure 8.1 has one coil which rotates and its rotational velocity controlled. A second stationary set of coils can be used to produce a static field. Depending on conditions such as direction of current and orientation, these secondary coils can be used to cancel or amplify the earth's field.

8.1. Direct Measurement of Earth's field

The first method is a direct way of determining the earth's magnetic field. That is, the earth's field will be directly producing the observed and measured voltage.

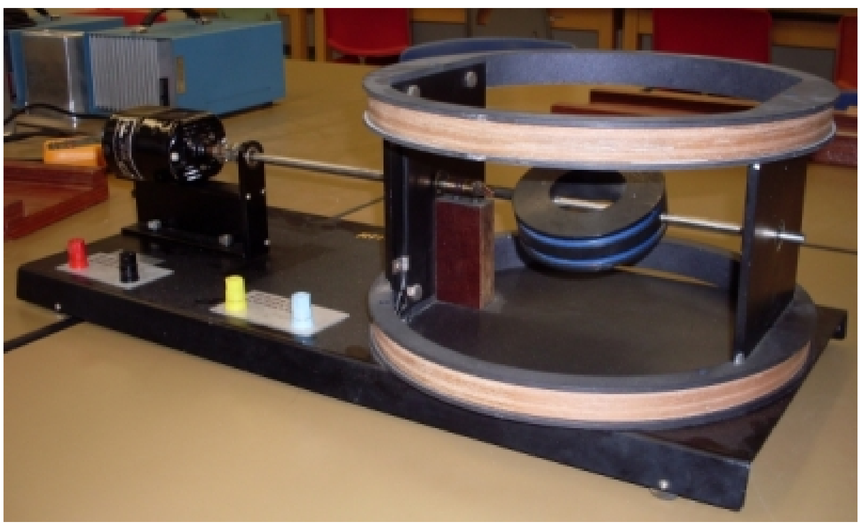

Figure 8.1.: Rotating coil magnetometer showing motor, rotating coil and Helmholtz coils.

8.1.1. Theory

When a coil of area A with N turns is situated in a uniform magnetic field and is rotated about a diameter, the flux through the coil is given by:

$$\phi_m = N \int_A \vec{B} \cdot \hat{n} \, dA = NBA \cos\theta$$

where θ is the minimum angle between $\hat{n}$ and $\vec{B}$. If we define α to be the angle between the plane of the coil and the plane of the field (see Figure 8.2) then the formula for the flux can be written:

$$\phi = NBA \sin\alpha.$$

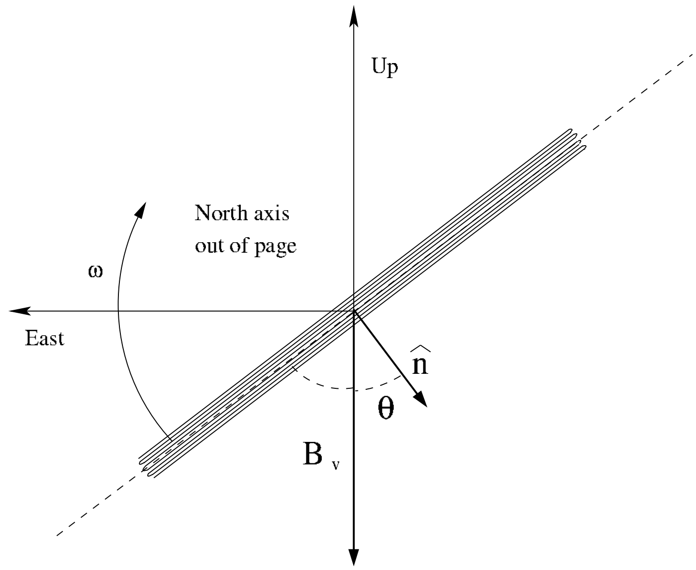

Figure 8.2.: Definition of angles for flux through rotating coil.

The magnetic flux through a rotating coil in the presence of a homogeneous magnetic field is continuously changing, and by Faraday's law an EMF is induced in the coil according to:

$$E(t) = -N\frac{d\phi}{dt} = -NBA\,\frac{d\,(\sin\alpha)}{dt}.$$

If the coil is rotating with constant angular velocity ω, then the angle changes according to the formula $\alpha = \omega t$ and the induced EMF is then given by:

$$E(t) = -\omega NBA\,\cos\omega t. \tag{8.1}$$

The induced EMF varies sinusoidally with time with an amplitude of ωNBA Volts.

If N and A of the coil are known and $E_{pk} = |-\omega NBA|$ and ω are measured, B can be determined. In this experiment, the vertical component of earth's magnetic field will be measured this way (see Figure 8.3).

The rotation rate of the coil is variable and can be adjusted using the variac. The angular velocity of the rotation is related to the period, T, of the voltage oscillation by:

$$\omega = \frac{2\pi}{T}$$

8.1.2. Apparatus

- Rotating coil magnetometer, oscilloscope, variac (Variable AC power supply), RL high frequency filter circuit.

CAUTION: The rotating coil is exposed. Keep hands and equipment away from it at all times. Impact with it could lead to serious injury.

8.1.3. Procedure

The Helmholtz coils are not used for this experiment.

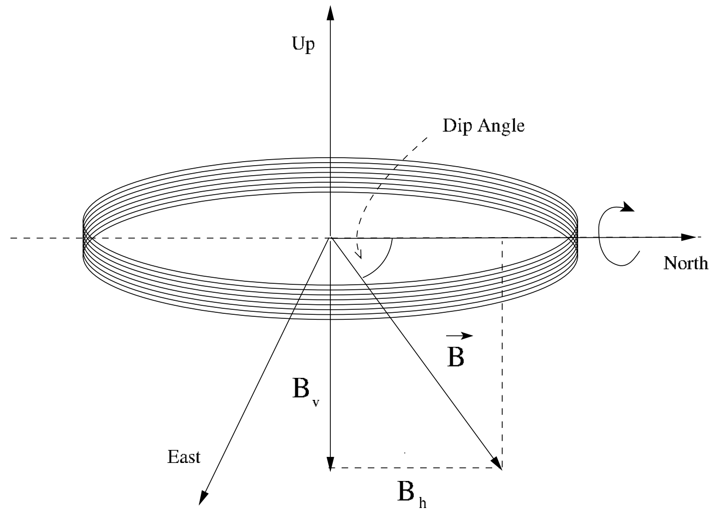

Figure 8.3.: Rotating coil magnetometer directly measuring vertical component of Earth's magnetic field.

1. Position the rotating coil magnetometer so that its axis of rotation is parallel to magnetic north-south using a compass as a guide. This ensures that the horizontal component of the earth's field is directed parallel to the plane of the coil and will not contribute to the flux through the coil. Therefore, only the vertical field component, B_v, will be determined.
   - Note: Magnetic north is approximately 10° east of geographic north at Brandon, and the building's rebar etc, can alter this somewhat.
2. Connect the rotating coil terminals to the filter input.
3. Connect the filter output to the channel 1 input of the oscilloscope.
4. Record the all coil specifications, making sure you can identify which specifications go with each coil later.
5. Vary the coil's rotation rate and measure the peak induced voltage in the coil for several speeds.
6. Measure and record E_{pk} for each trial and f and T for each trial so that ω can be determined.
7. Do not run the coil at high rotational speed for prolonged periods of time. The oscilloscope's trace can be stopped for examination using the run/stop button.
8. Use the resulting data to calculate B_v for each trial.

8.2. Indirect Method of Measuring Earth's Field

8.2.1. Theory

In the second part of the lab both the vertical component of the magnetic field B_v will be determined using an indirect, null technique.

The coil is situated at the center of a Helmholtz coil arrangement. These coils are used to create a known, uniform magnetic field at the vicinity of the rotating coil. They are configured so that their radius is the coil separation. The combination of the coils produce a field at the location of the rotating coil given by:

$$B_{HH} = \left(9.0 \times 10^{-7} \frac{T\,m}{A}\right) \frac{N_H I}{r} \,, \tag{8.2}$$

where N_H are the number of turns in each Helmholtz coil, r is the average radius of each coil and I is the current through the coils. The DC current through the coils is supplied by a power supply and will be measured with an ammeter. Thus the magnetic field produced by the Helmholtz coils will be controlled by varying the current through coils.

The Helmholtz arrangement will be used to create a magnetic field opposite in direction to the component of the earth's magnetic field being measured. If the Helmholtz field exactly cancels the component of the earth's field which the rotating coil magnetometer is sensitive to, then the EMF induced in the rotating coil should vanish. Therefore, in theory, the magnitude of a component of the earth's magnetic field can be determined by finding the Helmholtz current for which the induced EMF in the rotating coil vanishes. and plugging this value into equation (8.2).

Due to incomplete cancellation of all magnetic fields present it may be impossible to reduce the induced EMF in the rotating coil to zero. Instead, it will be necessary to determine the Helmholtz current corresponding to a minimum induced voltage rather than a null or zero voltage.

8.2.2. Additional Apparatus

Helmholtz coils, CVCC (Constant Voltage Constant Current) Power supply, Ammeter

8.2.3. Procedure

1. Connect the DC ammeter and power supply to the Helmholz coil terminals.
2. Measure the peak induced EMF from the rotating coil the same way as in the direct measurement.
3. Maintain the same angular velocity for the rotating coil while taking these measurements.
4. Vary the DC current through the Helmholz coils and see if the magnitude of E_{pk} reduces, then grows again. If it only grows, then the current direction must be reversed so that the Helmholz field is opposing B_v.
5. Record the resulting peak EMF induced in the rotating coil. Take measurements for a range of induced peak EMFs above and below the $\mathcal{E}_{min}$ of the rotating coil.

8.2.4. Analysis

1. Plot $\mathcal{E}_{peak}$ versus I to in order to determine an approximate measure of Helmholz current corresponding to $\mathcal{E}_{min}$.
2. Determine B_v of the earth's field.
3. Compare your values with the known values at Brandon which can be calculated using `www.ngdc.noaa.gov/geomag-web`.

8.3. Question

1. How would you modify the apparatus setup to measure the horizontal component of the earth's field?