EM FIELD OF A CIRCULAR COIL

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Aim

The practical aimed to find what factors affect the magnetic field strength in a circular coil as pictured in figure 1. This was done by passing an AC current carrying search coil into the circular coil. The results were then compared to Biot-Savart's law.

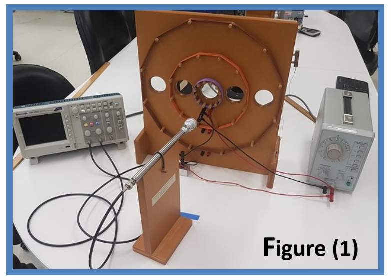


Figure (1)

Background Physics

When current travels through a wire it creates a magnetic field. The magnetic field can be measured by measuring the current in a wire in the field. The calculations showing this is possible are given below.

Magnetic Flux through a search coil located at an angle α above an imaginary line drawn through the field coils centre is given by :

$$\Phi = BA\cos(\alpha)$$

Where B is magnetic field strength and A is the cross sectional area of the search coil. Through using Faraday's Law of Induction the equation can be expressed in terms of the voltage induced in the search coil:

$$V_{SC} = -N\frac{d\Phi}{dt}$$

$$V_{SC} = -NA\cos(\alpha)\frac{dB}{dt}$$

To solve for B, the following steps are taken:

$$\int V_{SC}\,dt = -\int NA\cos(\alpha)\,dB$$

Expressing the voltage in the search coil in terms of its resistance and current and integrating:

$$R_{SC}\frac{I_0}{\omega}\sin(\omega t) = NA\cos(\alpha)$$

$$\int R_{SC}I_0\cos(\omega t)\,dt = -\int NA\cos(\alpha)\,dB$$

As α will be kept at 90°, cos(α) will always equal 1. B can then be solved:

$$B = \frac{V_0\cos(\omega t)}{\omega NA}$$

This equation tells us there is a direct proportionality between magnetic field strength and search coil voltage and current.

To find the σ value we can manipulate Biot-Savart's Law:

$$B = \frac{\upsilon_0 NI}{2a}\left(1+\left(\frac{x}{a}\right)^2\right)^{\sigma}$$

Provided field coil number (N), current (I) and radius (a) are kept constant since μ_0 is also a constant, it can be rewritten as:

$$B = C\left(1+\left(\frac{x}{a}\right)^2\right)^{\sigma} \qquad \log(B) = \log(C) + \sigma\log\left(1+\left(\frac{x}{a}\right)^2\right)$$

This equation is of a linear form with σ as the gradient and so a straight line graph can be drawn.

Method

1. Set up the equipment, as shown in figure (2).

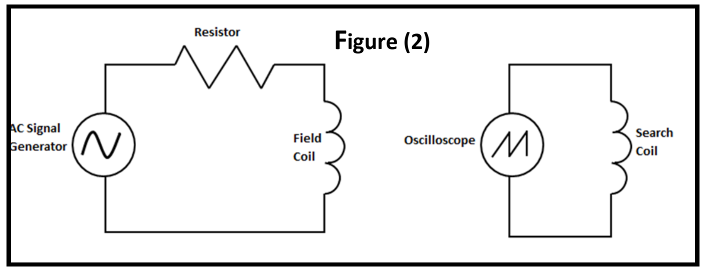
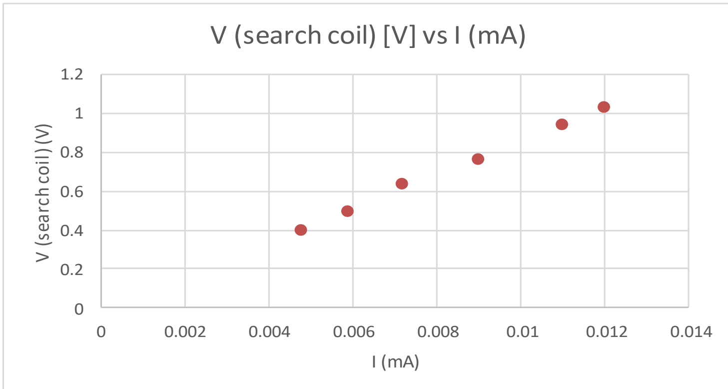


Figure (2)

2. Once the equipment is set-up, determine the optimum frequency of the signal generator by adjusting frequency until the current in the search coil is maximum.

3. Check for any potential interference from the wires. Measure current in the search coil when no current is in the field coil.

4. Find the effect of current on magnetic field by measuring current in the search coil at x = 0 for varying current (I) values.



5. Find the effect of field coil area on magnetic field by measuring search coil current at x = 0 for varying radii (Figure 3).

6. Finally, measure the voltage at the search coil at varying x values, where the current and 'a' values are constant (Figure 3).

7. Plot log(V) against log(1+(x^2/a^2)).

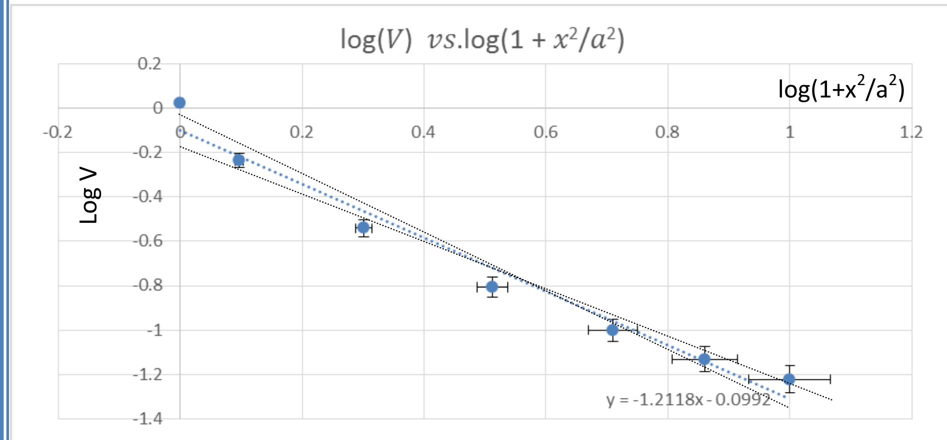
8. Hence, determine the line of best fit and the slope, the slope being the δ value.

Figure (3)

Voltage Vs. radius	
V (V)	a (m)
1.05	0.04
0.462	0.1075
0.27	0.19

Voltage Vs. distance	
V (V)	x (m)
1.06	0
0.58	0.02
0.288	0.04
0.156	0.06
0.1	0.08
0.074	0.1
0.06	0.12

Analysis of Results



The experimental value of δ from the Biot-Savart Law was found to be about-1.21 ± 0.125. The expected value is -1.5. This value was calculated by using the average slope by constructing a maximum and minimum slope line. While somewhat accurate, given the near 20% difference of values, some form of systematic error was likely present. The absolute uncertainty in the value of δ was small enough to conclude that random error was minimised sufficiently, especially in comparison to the massive apparent effect of systematic error on the obtained δ value. Random error and hence uncertainty was minimised by use of an average slope.

Errors

Potential sources of systematic error would include a zero error with any of the equipment, for instance the display or functionality of the oscilloscope could have caused a shift of results to result in a less negative slope. Since the sensor probe was assumed to be at the x=0 mark by use of calibrating its position with maximum induction measured, which if improperly determined, could have resulted in lower magnetic induction strength than intended, therefore lower measured probe voltage and thus an inaccurate δ. Another source of error, while assumedly negligible, EM interference of currents flowing through wire is difficult to due to the nature of magnetic induction (B) fields; causing consistently inaccurate voltage readings for the probe.

As for random error, it was found to be insignificant in comparison to the systematic error. However, one such source of error could have been present due to parallax/measuring errors using a 30cm ruler to measure the distance of the coil to the probe; which could have been mitigated by using callipers or by repeated observations.

Conclusion

In conclusion, the experimental value of δ (-1.21 ± 0.125) compared to the actual value (-1.5) was sufficiently precise but inaccurate due to a slew of systematic errors. In future, these errors must be mitigated to allow more accurate measurements of δ experimentally. Most notably, the calibration of the probes position relative to the centre of the coil and EM interference contributed to inaccuracy, whereas uncertainty was mitigated efficiently.