Frequency Dependence of Maximum H-Field in RL Circuit

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I. Introduction

In any scientific experiment, it is important to document the physical limits of the apparatus used. It would be counterproductive to attempt data collection in a regime where the equipment cannot function properly or at all. In our laboratory, constant use of magnetic fields produced by alternating currents running through magnetic coils is needed, and it is very valuable to know the extent to which these coils can produce various field strengths. We wish to find the maximum magnetic field strength a given set of coils can produce at a range of different frequencies.

The circuit used is essentially a RL circuit consisting of a resistor and an inductor in series. The AC source can be assumed to be a purely sinusoidally oscillating potential difference.

$$V(t) = V_0 sin(\omega t)$$

In a series circuit consisting of a resistor and an inductor, the potential difference across the entire circuit can be defined purely in terms of the resistance R, the inductance L, and the alternating current.

$$V(t) = RI(t) + L\frac{dI(t)}{dt}$$

After assuming the current flowing through the circuit is a superposition of sine and cosine functions, the differential equation can be solved, yielding an expression for the current in the circuit, as well as its maximum.

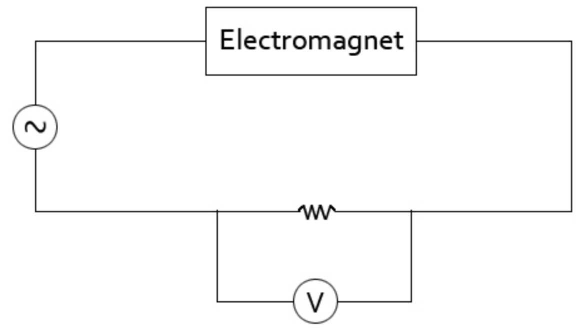

Figure 1: Experimental apparatus

$$I(t) = V_0\frac{R\sin\omega t - L\omega\cos\omega t}{R^2 + L^2\omega^2}$$

$$I_{MAX} = \frac{V_0}{\sqrt{R^2 + L^2\omega^2}}$$

Since the current flowing through the inductor is directly proportional to the magnetic field produced by it, the

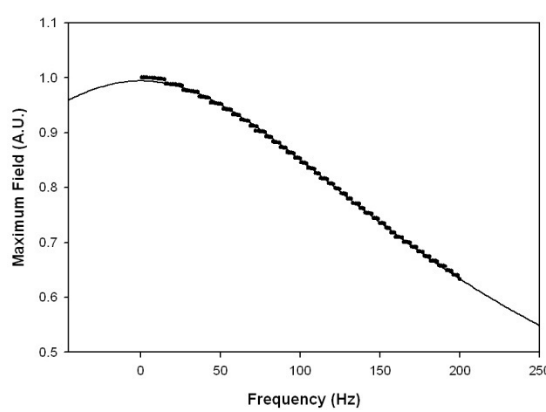

Figure 2: Maximum field as a function of AC frequency with fit curve

maximum field is related to the maximum current by a constant factor.

$$H_{MAX} = \frac{C}{\sqrt{R^2 + L^2\omega^2}}$$

II. Experimental Setup and Procedure

A function generator was set to output a sine wave with a peak-to-peak voltage of 1.000 V and an offset of 0.000 V. A resistor of known resistance was placed in series with the magnetic coils, and a voltmeter was placed in parallel to the resistor to measure the potential difference across the resistor (Figure 1).

Potential differences were measured across the resistor for a time equivalent to 10 periods of AC current at a given frequency. A range of frequencies from .0010 Hz to 200.0 Hz was tested. Using previous calibration, the calculated current flowing through the coils was converted to magnetic field strength. All parameters were controlled and set up with National Instruments' LabVIEW software.

III. Results

The maximum magnetic field as a function of AC frequency is shown in Figure 2. As can be seen, the highest maximum fields are seen with the lowest frequencies, decreasing rapidly until an inflection point. After this point, the maximum field approaches zero slowly as the frequency increases.

After fitting the predicted maximum field/frequency relationship to the data, it is apparent that the theory matches the experimental results quite well. The data shown in figure 2 differs from the value of the maximum magnetic field by just a constant. A simple calibration routine relating current flow in the circuit to the produced magnetic field would yield the correct values.