Experiment 34: Ferromagnetism

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Abstract

The purpose of the experiment is to study some magnetic properties of ferromagnetic materials. Ferromagnetic materials are an interesting subject of study as the material retains history of its previous magnetic state. This experiment mainly deals with the Hysteresis loop and what the area of the loop represents, which is work per unit time, as well as the magnetic susceptibility that can be determined from it. The final results found for area of the loop and magnetic susceptibility were $462.2 \pm 50[T * A/m]$ *and* $1.055 \pm 20\%[Gauss * m/A]$*, respectively. These were found by plotting a graph of the magnetic field strength, H vs. the magnetic induction, B and measuring the area and slope.*

1 Introduction

This experiment studies the magnetic properties of ferromagnetic materials. Ferromagnetic materials produces magnetization in the direction and proportional to the applied field. This magnetization state is dependent on the history of the sample. A current distribution creates a magnetic field, the strength of which can be shown by the quantity, H. H is the magnetic field strength. The magnetization M, which is the vector sum of the atomic magnetic moments in a substance, in the case of this experiment the toroid, will be useful in determining the magnetic induction, B. B is the magnetic induction and is the combination of H and M, but can be related to only the magnetic field strength H. A toroid with a coil wrapped tightly around it can carry a current which creates a magnetic field H. The magnitude of H can is then related to the number of turns of the coil, the current through it, and the length, which is given by the circumference. The sample of ferromagnetic material used in the experiment will have a "history" of magnetization within it because its magnetization can be retained after a magnetic field is removed. A hysteresis loop is something that can be created by plotting B and H. This loop ranges from a minimum and maximum H values that changes B, and since the process is non-conservative, instead of a one-to-one relationship a loop is created that can cover some area. This area can be measured to get the energy per unit volume. The reason for this approach is that the loop is created because of the intrinsic properties of the ferromagnetic material and measuring the area inside the loop would produce a result with the relevant units of work per unit volume and the maximum slope produced from the initial phase from zero to H-max would produce the constant by which the $\vec{B}$ is related to $\vec{H}$, which will help determine the magnetic susceptibility. It would then be expected to find results that match the theoretical values for this given material by relating B and H to each other in graphical form.

1.1 Equations

$$\frac{W}{V} = \oint \vec{B} \cdot d\vec{H} \tag{1}$$

The Integrated Hysteresis loop is a measure of the work done per unit volume as shown by this equation.

$$\vec{B} = \mu \cdot \vec{H} \tag{2}$$

B is related to the magnetic field strength through μ which is the equal to $\mu_0(1+x)$ where x is the magnetic susceptibility, and $\mu_0 = 4\pi \times 10^{-7} N/A^2$.

$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{M} \tag{3}$$

The relationship of $\vec{B}$ to the magnetic field and magnetization.

$$\Delta T = \frac{c\rho}{A} \tag{4}$$

This equation gives the increase in temperature in the core due to a single Hysteresis cycle. $\rho = 7.8 \times 10^3 Kg/m^3$ is the density of steel and $c = 420 J/(Kg^0C)$ is the specific heat. A is the area that's determined via the integration of the Hysteresis loop, see equation 1.

$$|\vec{H}| = \frac{N \cdot i}{2\pi r} \tag{5}$$

This is the magnitude of the applied field that's within the toroid core. Where N=1000 turns of the coil, i is the current acquired from the measured voltage and resistance, and the denominator is the length of the toroid where r is its radius.

$$x = \frac{\mu}{\mu_0} - 1 \tag{6}$$

The magnetic susceptibility can be calculated with this equation, with the value of the maximum slope substituted for μ.

1.2 Sample Calculations

$$\begin{aligned}\frac{W}{V} &= \oint \vec{B} \cdot d\vec{H} \\ &= 462.2[J/m^3] \pm 50[J/m^3]\end{aligned}$$

Answer is determined from LoggerPro integration of the Hysteresis loop.

$$\begin{aligned}x &= \frac{\mu}{\mu_0} - 1 \\ &= \frac{1.055 \times 10^{-4}[T * m/A] \pm 20\%}{4\pi \times 10^{-7}[N/A^2]} - 1 \\ &= 82.95 \pm 16.59\end{aligned}$$

The magnetic susceptibility is determined from using $\mu = \mu_0(1+x)$ and solving for

x. The maximum slope is the value used for μ.

$$\begin{aligned}\Delta T &= \frac{c\rho}{A} \\ &= \frac{(420[J/(Kg^0C)])(7.8\times 10^3[Kg/m^3])}{462.2[J/m^3]\pm 50[J/m^3]} \\ &= 1.411\times 10^{-4}C^o \pm 10.8\%\end{aligned}$$

$$\begin{aligned}|360\pm 50 - 462.2\pm 50| &<= 50+50[J/m^3] \\ |102.2| &<= 100[J/m^3]\end{aligned} \tag{7}$$

Consistency check with the given accepted value of the work per unit volume of the Hysteresis loop. The result is inconsistent with the accepted value.

$$\begin{aligned}|82.95-90| &<= 16.59+20 \\ |7.05| &<= 36.59\end{aligned} \tag{8}$$

Consistency check with the given magnetic susceptibility value of steel of 90 ± 20. The result is consistent with the given value

2 Experimental Procedure and Design

The equipment used for this experiment included a toroid, magnetic sensor, Gaussmeter, commutator switch, a power supply, and wires to connect devices, as well as LoggerPro software to produce the graphs from the collected data.

A point by point procedure can be outlined via:

1. The first measurement made was of the resistance of the coil resistance using the DMM. Then, the experiment was connected using the diagram in figure 1.

2. Refer to figure 2 for a visual aid to the following experiment procedure. Since this experiment deals with ferromagnetism, this sample must be demagnetized by alternating the field direction while decreasing the current through the coil by small increments. The magnitude of the H field will decrease with the current. To do this, the current was increased to 2Amps with the commutator switch on one side then the commutator switch was used to alternate the field direction while slowly decreasing the current from 2Amps to zero. This made the Gaussmeter record the lowest possible value for B.

3. The LoggerPro software was setup to record the potential, which could be used to set up a calculated data column that calculated a value for the magnitude of H. A Gaussmeter was recording a value for B, which was entered manually. These are the two variables that were plotted to create the Hysteresis loop.

4. The loop was created by first going through the initial phase, which started from the origin of the graph (or close to it) and increased with the increase of current from zero to 2Amps, while the commutator switch was on one side.

5. Once, the maximum value of 2Amps was reached, the commutator switch reversed the direction and the current was slowly decremented until it

reached zero once again. This process created the first half of the loop, where the magnitude of B went from positive to negative as the magnitude of H went from maximum to minimum. The Gaussmeter values were manually inputted into LoggerPro to create the graph of the loop.

6. The polarity was reversed again using the switch and the current was slowly incremented until it reached 2Amps, which returned the results to the start of the loop.

7. Using LoggerPro the area could be determined by using the in-built integration function of the software. If the area was not properly being calculated by the software because there were gaps in the loop and the data could be taken and used to "close" the loop by graphing the loop again, but making the first and last values of the coordinates the same.

8. The final task after acquiring the integrated value is to find the maximum slope of the initial phase of the experiment where we start from near the origin and go towards point a.

3 Results

The final results of the Integrated area was $462.2T * m/A \pm 50T * m/A$ and the maximum slope of the initial phase was $1.055 Gauss * m/A \pm 20\%$. The slope helped determine the value of the magnetic susceptibility x which was 82.95 ± 16.59. The results for the the work per unit volume integrated from the Hysteresis loop were inconsistent with the accepted value, and the result for the magnetic susceptibility were consistent with the given value for steel.

4 Discussion

From the data collected and the results of the experiment from calculations or LoggerPro, the experiment was a success in that it fulfilled its objective to study the magnetic properties of ferromagnetic materials. As shown, the results for the integrated Hysteresis loop and the magnetic susceptibility value were inconsistent and consistent, respectively with the given accepted values. The deviations from the accepted values are largely the result of random error occurring in the experiment. The recording of the magnetic field (B) values that were being recorded entry by entry with a Gaussmeter was a large source of random error as the data would be different if the measurement was taken at the same point multiple times. This resulted in a large uncertainty in the value for work per unit volume from the Hysteresis loop. The same argument can be made for the measurement of the maximum slope of the initial phase of the graph.

5 Conclusion

The purpose of this experiment was to study some magnetic properties of ferromagnetic materials. The main results were the work per unit volume determined from the Hysteresis loop and the value for the magnetic susceptibility, which were inconsistent and consistent, respectively with the given accepted values. With these results it can be concluded that the experiment was a success in accomplishing our objective.

A Figures and Graphs

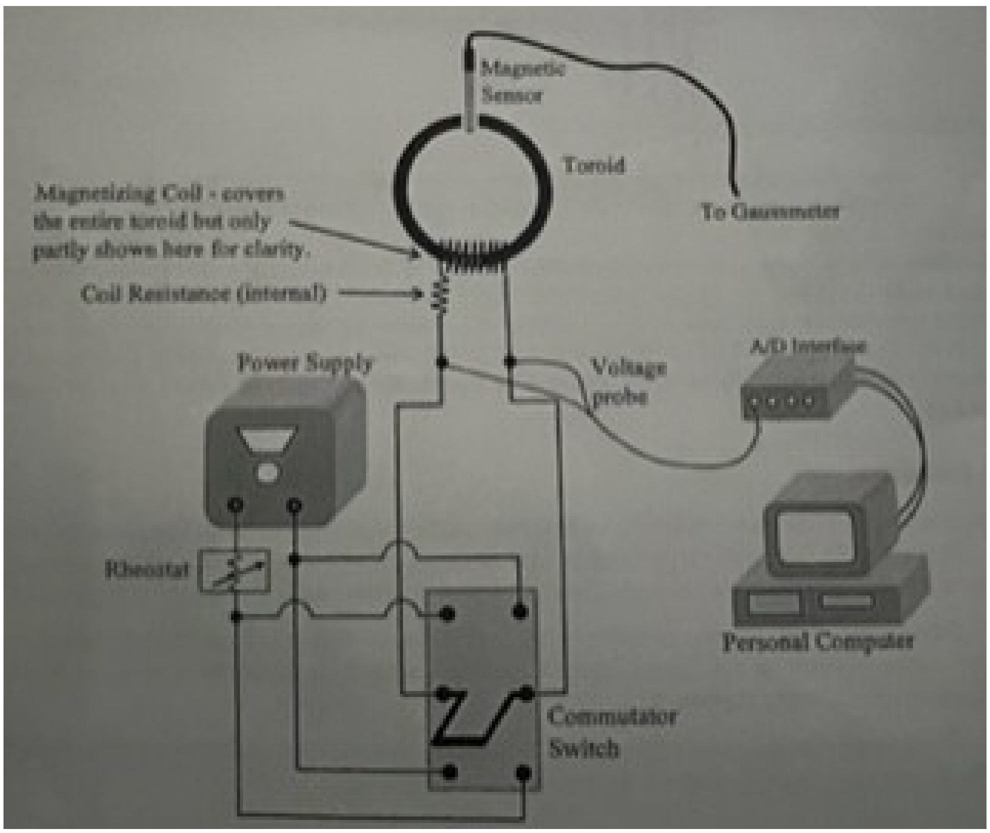

Figure 1: The set up for the experiment and the various connections are shown.

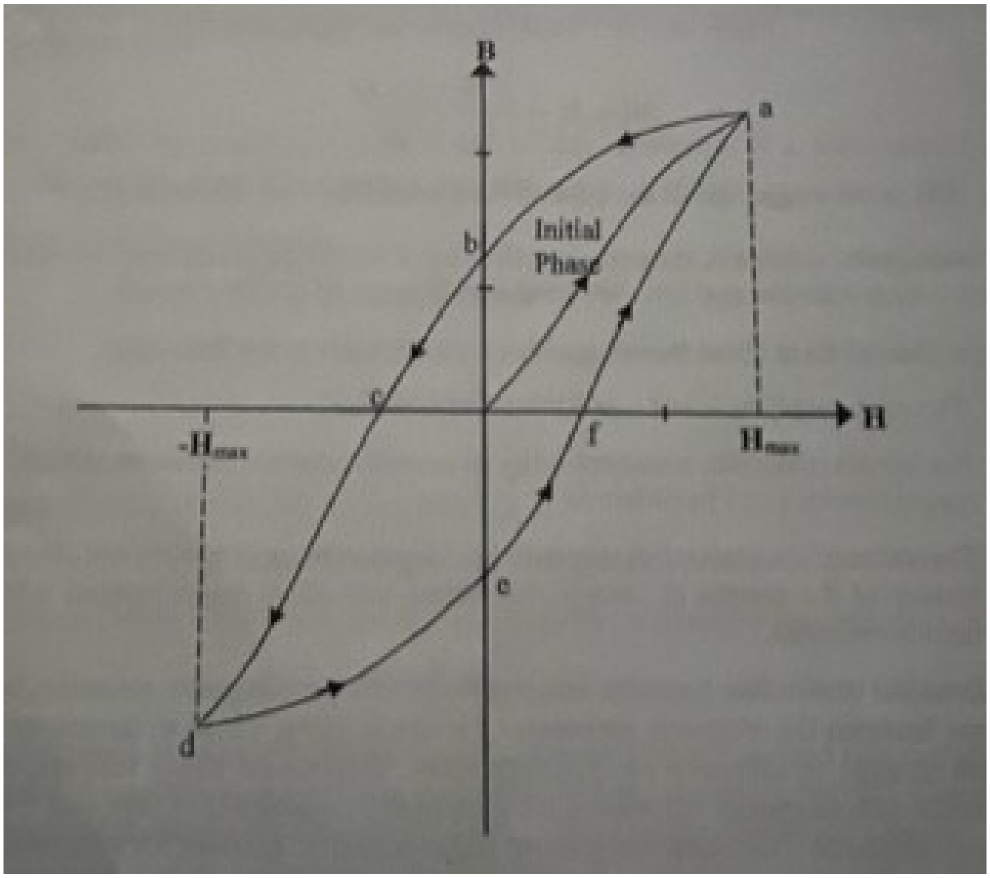

Figure 2: The Hysteresis graph should look like this basic version with maximum and minimum values for the magnitude of H and its relation to B.

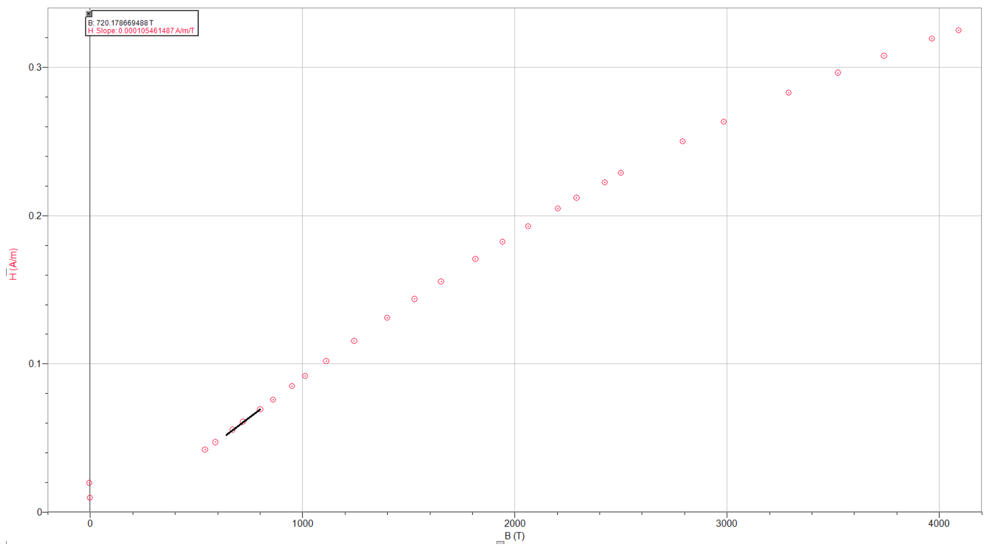

Figure 3: The initial slope with the maximum slope value labelled

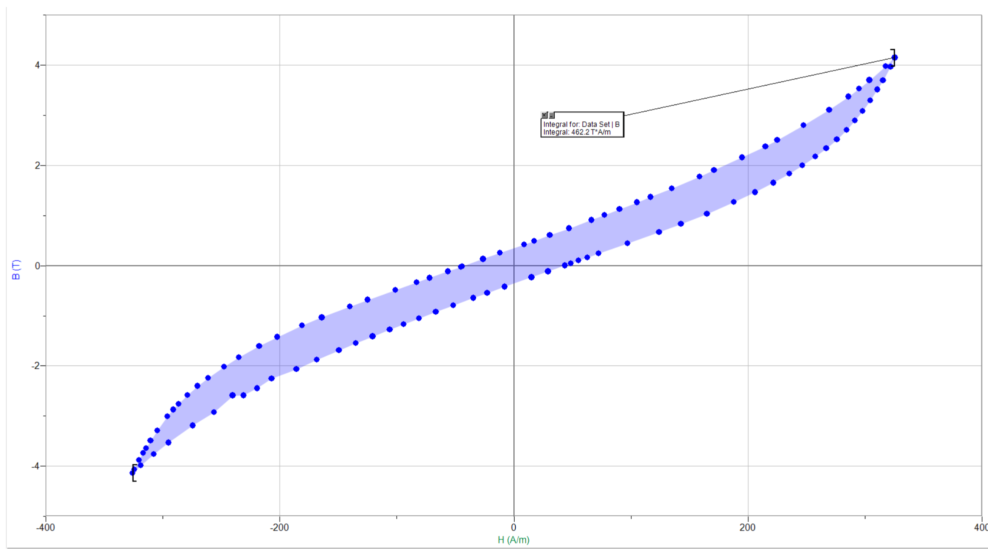

Figure 4: The Integrated Hysteresis loop with the value of the area shown.

A.1 Data Table

Table 1: Data collected from the experiment

$R[Ohm]$	$radius$	Integrated area	Max slope
$3.389 \pm 2\%$	$8.17cm \pm 1\%$	$462.2 \pm 50[T * A/m]$	$1.055 \pm 20\%$ [Gauss*m/A]