Experiment 2: Magnetic Field and Induction

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**Introduction**

The objective of this experiment, Magnetic Field and Induction, was to determine the permeability of Nylon. This was achieved by two different ways. Both ways utilized a solenoid and a pick up coil.

A solenoid is a device that is cylindrical and hollow. A magnetic field is produced when a wire with a current is wrapped around it. The direction of this current would be along the axis the solenoid is in. In this experiment a pick up coil is inserted inside the solenoid to “pick up” the magnetic field. The current that flows through the wire and creates the magnetic field is an alternating one. An alternating current fluctuates with time. The formula of an alternating current is shown below.

(2.1)

In formula 2.1, I represent current, represents the maximum value of the current, represents angular frequency of the oscillation and t represents the time. Because the current flowing through the wire is fluctuating, the magnetic field inside the solenoid also fluctuates. The formula of the magnetic field is shown below.

(2.2)

In formula 2.2, B represents magnetic field, represents the maximum magnetic field. In both formulas, angular frequency is needed. The formula for angular frequency is shown below.

In the formula shown above, T represents the period.

By using formulas 2.1 and 2.2, a relationship between the amplitudes of magnetic field and current can be made. This is shown in the formula below.

(2.3)

In formula 2.3, n, l and d represents the number of turns that the wire has around the solenoid, the length of the solenoid and the diameter of the solenoid, respectively. The remaining variable,, is a constant that represents the permeability of the substance inside the solenoid. The permeability of free space, vacuum, is measured to be .

By using Faraday’s law of induction, it can be predicted that a magnetic field inside the solenoid creates an electromotive force. The pickup coil that was inserted inside is able to pick up the electromotive force as a voltage. Since both the current and the magnetic field are oscillating, the electromotive force, voltage, also oscillates. This is shown in the formula below.

(2.4)

The variable φ represents the phase shift of the sine curve between the magnetic field and the electromotive force. Similar to the relationship between the amplitude of the magnetic field and current, there is also relationship between magnetic field and voltage. This relationship is shown in the formula below.

(2.5)

In formula 2.5, A represents the cross sectional area of the pickup coil and represents the amount of turns the wire has on the pickup coil. When combining equations 2.3 and 2.5 and solving for voltage amplitude, one is able to determine the new relationship shown below.

(2.6)

For the purpose of finding the permeability of nylon in this experiment, the constant C was used. C represents the constants from equation 2.6. The formula for C is shown below.

(2.11)

Therefore substituting C in formula 2.5 creates the formula shown below

(2.10)

The first method to find the permeability of nylon is done part A of the experiment. In the first method, the period is constant. By keeping the period constant, the angular frequency is also constant. The next step is to graph amplitude of voltage vs. amplitude of current chart. The slope of this line is then plugged into equation 2.10 along with C and the angular frequency. By solving for the permeability of nylon in formula 2.10, a new resultant formula is created. This is shown below.

(2.12)

M represents the slope of the graph.

Similar to part A of the experiment, part B utilizes the same formula. However, angular frequency is not kept constant anymore, only the amplitude of current is constant. This will also require the graph of amplitude of voltage vs. angular frequency. The results are then plugged into formula 2.10 and the resultant formula is shown below.

(2.13)

**Initial Data**

Below shows tables of the initial data collected throughout the entire experiment in SI units. The first chart shown below shows the measurements of the geometry of both the solenoid and the pickup coil.

|  |  |  |
| --- | --- | --- |
|  | **Solenoid** | **Pick up coil** |
| **Diameter, m** | 0.0337 | 0.0191 |
| **Length, m** | 0.1092 |  |
| **Number of Turns** | 2920 | 176 |
| **Diameter Uncertainty, m** | 0.000036 | 0.000047 |
| **Length Uncertainty, m** | 0.00008 |  |

The second table, shown below, is the initial data in part A of the experiment. Part A of the experiment consisted of seven trials. Each trial would measure the current amplitude of the solenoid, its standard deviation, and its instrumental uncertainty. The measurements of the amplitude of voltage from the pickup coil, its standard deviation and instrumental uncertainty were also measured. Lastly in the last three columns of the chart shows the period, uncertainty of period and the instrumental uncertainty.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Solenoid Current, A** | | | **Pick Up Coil Voltage, V** | | | **Period, s** | | |
| **Trial** | **IO** | **σI** | **∆I Instru** | **V0** | **σV** | **∆V instru** | **T** | **∆T trial** | **∆T instru** |
| **1** | 0.031890 | 0.000040 | 0.000030 | 0.222000 | 0.004000 | 0.003000 | 0.001330 | 0.000080 | 0.000040 |
| **2** | 0.029620 | 0.000030 | 0.000030 | 0.208000 | 0.000000 | 0.003000 | 0.001330 | 0.000010 | 0.000040 |
| **3** | 0.025880 | 0.000130 | 0.000030 | 0.183000 | 0.000000 | 0.003000 | 0.001330 | 0.000010 | 0.000040 |
| **4** | 0.024210 | 0.000030 | 0.000030 | 0.171000 | 0.000000 | 0.003000 | 0.001330 | 0.000010 | 0.000040 |
| **5** | 0.021240 | 0.000030 | 0.000030 | 0.150000 | 0.001000 | 0.003000 | 0.001330 | 0.000010 | 0.000040 |
| **6** | 0.018220 | 0.000040 | 0.000030 | 0.128000 | 0.000000 | 0.003000 | 0.001310 | 0.000130 | 0.000040 |
| **7** | 0.014590 | 0.000030 | 0.000030 | 0.103000 | 0.001000 | 0.003000 | 0.001330 | 0.000010 | 0.000040 |

The third table, shown below, is the initial data in part B of the experiment. The table is shows the similar measurements as part A.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Solenoid Current, A** | | | **Pick Up Coil Voltage, V** | | | **Period, s** | | |
| **Trial** | **IO** | **σI** | **∆I Instru** | **V0** | **σV** | **∆V instru** | **T** | **∆T trial** | **∆T instru** |
| **1** | 0.025350 | 0.000140 | 0.000890 | 0.227000 | 0.002000 | 0.002000 | 0.001070 | 0.000080 | 0.000030 |
| **2** | 0.025200 | 0.000100 | 0.000890 | 0.205000 | 0.001000 | 0.002000 | 0.001160 | 0.000070 | 0.000030 |
| **3** | 0.025420 | 0.000200 | 0.000890 | 0.161000 | 0.001000 | 0.002000 | 0.001500 | 0.000070 | 0.000030 |
| **4** | 0.025450 | 0.000080 | 0.000890 | 0.161000 | 0.001000 | 0.002000 | 0.001500 | 0.000070 | 0.000030 |
| **5** | 0.025610 | 0.000070 | 0.000890 | 0.137000 | 0.001000 | 0.002000 | 0.001730 | 0.000110 | 0.000030 |
| **6** | 0.025180 | 0.000020 | 0.000890 | 0.112000 | 0.001000 | 0.002000 | 0.002110 | 0.000090 | 0.000030 |
| **7** | 0.025260 | 0.000070 | 0.000890 | 0.088000 | 0.000000 | 0.002000 | 0.002680 | 0.000050 | 0.000030 |

**Analysis**

**Preliminary Data**

The first task in analyzing the data is to calculate the constant C. This is done with formulas 2.10 and 2.11. In order to calculate C, the cross sectional area was needed. The calculations for the cross sectional area is shown below.

The calculation for the uncertainty of area is shown below

The next unknown was the number of turns per length. The calculation is shown below.

The calculation for the uncertainty of turns per length is shown below.

After finding n, all of the unknowns for formula 2.11 are now known. The calculations for C are shown below.

The uncertainty of C is shown below. The uncertainties for the diameter and length are neglected.

|  |  |
| --- | --- |
| **Area, m^2** | 0.0002876 |
| **∆ Area, m^2** | 1.412E-06 |
| **n, turns/m** | 26737.478 |
| **∆ n, turns/m** | 19.830929 |
| **C** | 1235.3195 |
| **∆C A** | 6.646187 |
| **∆C n** | 1.0037123 |
| **∆C** | 6.7215504 |

**Part A**

The first step in Part A of the analysis was to find the best estimate value of the period. This is done by taking the average of all the periods using the AVERAGE function in excel.

The next step was to calculate the uncertainty due to time. This was done by taking the average of the instrumental uncertainty and the trial uncertainty. The AVERAGE function in excel was used again.

The calculations for the total uncertainty of time are shown below.

The next step was to calculate the angular frequency and its uncertainty. The calculations for angular uncertainty are shown below.

The calculations for the uncertainties of angular frequency are shown below.

|  |  |
| --- | --- |
| **T average, s** | 0.001327 |
| **∆T trial** | 0.000037 |
| **∆T instru** | 0.000040 |
| **∆T** | 5.45856E-05 |
|  |  |
| **w** | 4731.96986 |
| **∆w** | 194.6268186 |

After finding the angular frequency, the graph of vs. was plotted and their uncertainties were found. The calculations for the uncertainties are shown below.

Below shows the chart of the values and uncertainties used for to make the graph.

|  |  |  |  |
| --- | --- | --- | --- |
| **V0** | **IO** | **∆V0** | **∆IO** |
| 0.222000 | 0.031890 | 0.005 | 0.00005 |
| 0.208000 | 0.029620 | 0.003 | 4.24E-05 |
| 0.183000 | 0.025880 | 0.003 | 0.000133 |
| 0.171000 | 0.024210 | 0.003 | 4.24E-05 |
| 0.150000 | 0.021240 | 0.003162 | 4.24E-05 |
| 0.128000 | 0.018220 | 0.003 | 0.00005 |
| 0.103000 | 0.014590 | 0.003162 | 4.24E-05 |

Below shows the graph along with its error bars. The error bars are barely visible considering the small amount of uncertainties calculated.

Below shows the use of the LINEST function in excel to determine the slope, y intercept and their uncertainties.

|  |  |  |
| --- | --- | --- |
|  | **Slope** | **Intercept** |
|  | 6.934244 | 0.002335 |
| **Uncertainties** | 0.067575 | 0.001645 |

After finding the values uncertainty of the slope from LINEST, the uncertainty of the slope due to the worst fit lines was needed to calculate the total uncertainty of the slope. The calculations are shown below.

The x and y values for the steepest line is shown below.

These values were then plugged into the formula above.

The x and y values for the shallowest line is shown below.

The calculation for the total uncertainty of slope is shown below.

After uncertainty of slope, the permeability of nylon and its uncertainty could be calculated. The formula 2.12 was used. The calculations were shown below.

The calculations for the uncertainty are shown below.

**Part B**

Similar to part A of the experiment, the amplitude of current must be kept precise. In order to check this, the uncertainty of the amplitude of current must be calculated. The best value is found by using the AVERAGE function of excel.

Similar to part A, the total uncertainty of current was found.

|  |  |
| --- | --- |
| **I average, A** | 0.025353 |
| **I fluctuation** | 3.67165E-05 |
| **I instru** | 0.000890 |
| **∆IO** | 0.000890757 |

Since angular frequency was no constant for each trial, the angular frequency and its uncertainties were calculated for each trial and compared to the current amplitude. The calculation for the first angular frequency was shown below.

The uncertainties for time were needed to find the uncertainty of angular frequency. Similar to finding the uncertainty for current, the average was found from all the trials and plugged into the formula below.

|  |  |
| --- | --- |
| **∆T trial** | 0.000077 |
| **∆T instru** | 0.000030 |
| **∆T** | 8.27709E-05 |

The uncertainty of angular acceleration was found. The calculations are shown below.

After finding the uncertainties due to angular frequency, the relationship was graphed.

|  |  |  |  |
| --- | --- | --- | --- |
| **w** | **V0** | **∆w** | **∆V instru** |
| 5869.159 | 0.227000 | 454.0145 | 0.002138 |
| 5413.793 | 0.205000 | 386.297 | 0.002035 |
| 4186.667 | 0.161000 | 231.0228 | 0.002035 |
| 4186.667 | 0.161000 | 231.0228 | 0.002035 |
| 3630.058 | 0.137000 | 173.6781 | 0.002035 |
| 2976.303 | 0.112000 | 116.7542 | 0.002035 |
| 2343.284 | 0.088000 | 72.37152 | 0.002000 |

Below shows the slope and y intercept and their uncertainties from the LINEST function.

|  |  |  |
| --- | --- | --- |
|  | **slope** | **intercept** |
|  | 3.90566E-05 | -0.00375 |
| **uncertainties** | 5.4397E-07 | 0.002311 |

The graph created is shown below.

The next step was the find the total uncertainty of the slope similar to part A.

The x and y values for the steepest line is shown below.

These values were then plugged into the formula above.

The x and y values for the shallowest line is shown below.

The calculation for the total uncertainty of slope is shown below.

After find the uncertainty of the slope, the permeability of nylon and its uncertainty was calculated. The calculations are shown below.

**Results**

**Conclusion**

The chart above shows the comparison between the results from part A and B and the theoretical value, (4π )10-7 N/A2. From this graph, it can be concluded that the experiment was successful. The theoretical value falls in range with the results in both part A and part B. Both results were fairly close and consistent with the theoretical value. The only flaw in these results is the huge range of uncertainty in results of part B. When reviewing the calculations above, the greatest uncertainty that factored into the total uncertainty was the uncertainty of slope from the LINEST function. Since there is no error found in the calculations and the LINEST function of excel cannot be wrong, it can be concluded that part B of the experiment is not efficient. When conducting part B of the experiment, students had to randomly adjust the amplitude in order to maintain the same results for the first trial. Unlike part A of the experiment where students were given a specific range to adjust, part B seem to have a greater chance to gain imprecise results.