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Edo Mor

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Introduction

The goal of this experiment is to investigate characteristics of Magnetism, such as the magnetic field, magnetic force, induction and ferromagnetism.

Theoretical background for Weeks I and II

Lorentz force law

This law connects the electric and magnetic forces under the equation:

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B} \tag{1}$$

where:
$\vec{F}$ is the Lorentz force
q is the charge
$\vec{E}$ is the electric field
$\vec{v}$ is the velocity
$\vec{B}$ is the magnetic field
The direction of the force is given by the right hand rule.

Magnectic Field

The Magnetic field is a vector field represented by the Latin letter **B**. It is produced by electric currents and it is defined in terms of the force applied to a moving charge, as was shown in Lorentz force law. The sources of a magnetic field are always bipolar. The poles are divided in north and south. A magnetic field is expressed in units called Tesla, which is the same as: $\frac{Newton \cdot \sec ond}{Coulomb \cdot meter}$ A smaller unit is a Gauss. One Tesla corresponds to 10,000 Gauss.

Week I

Part I

Field on a solenoid

Theoretical background

Solenoids are wire coils in cylindrical form, which can be used to generate a nearly uniform magnetic field. This field is similar to the one produced by a magnetic bar. By adding an iron bar to the center of the solenoid, an electromagnet is created. The external magnetic field is weak and divergent.
The magnetic field is derived from Ampere's Law. The integral form of the law is:

$\oint_C \mathbf{B} \cdot dl = \mu_0 \iint_S J \cdot dS = \mu_0 I_enc$
Its differential form is:
$\nabla \times B = \mu_0 J$ where:
B: is the magnetic field
l: is the length
μ_0: is the magnetic constant or $4\pi 10^{-7} \frac{T}{amp \cdot meter}$
I: is the current
J: is the current density
From there, it can be derived:
$Bl = \mu NI$
where:
μ: $k\mu_0$ and k is the relative permeability
N: is the number of turns
Then, B is isolated on the right hand side:
$B = \mu \frac{N}{l} I$ and $\frac{N}{l}$ is substituted by n, which represents the turns by unit length, i.e. turn density.
In the following section, it will be presented the work done during the first part of the experiment.

Methods

The goal in this part of the experiment was to draw the fading of the magnetic field in the vicinity of a solenoid. In order to do this, the changes in the magnetic field along the length of the axis were plotted. The system used appears below:
Two solenoids were used. The larger one had 3400 turns and measured 0.09m in length. This translates into a turn density of 37777.78 turns per meter. The smaller one had 800 turns, measuring 0.04m in length. Its turn density is of 20000 turns per meter. The larger solenoid was placed at the center of the plate and connected to a power supply, which was set to $18V$ or approximately $0.3A$. In practice, the current varied between $0.26 - 0.27A$. The perpendicular and the axial magnetic fields were measured with the help of a Hall probe connected to the computer and to the Pasco software. Measurements were taken. The solenoid was moved by $\frac{\pi}{2}$ and other measurements were taken again.Then, a smaller coil was taken and connected to a power supply, which was set to $4V$. And similar measurements were taken.

Results

In order to calculate the magnetic field in the smaller solenoid the following equation was used:

$$B = \mu \frac{N}{(l - d + p)} I \tag{2}$$

where:
d: is the location of the probe
p: is the length of the Hall probe used to acquire the measurements
All other parameters have already been presented. The current I was taken to be 0.27.

The larger solenoid has 3400 turns. The distance was divided into 27 smaller parts and measurements were taken for each part. Below, it is shown a graph of the magnetic field as a function of the distance.

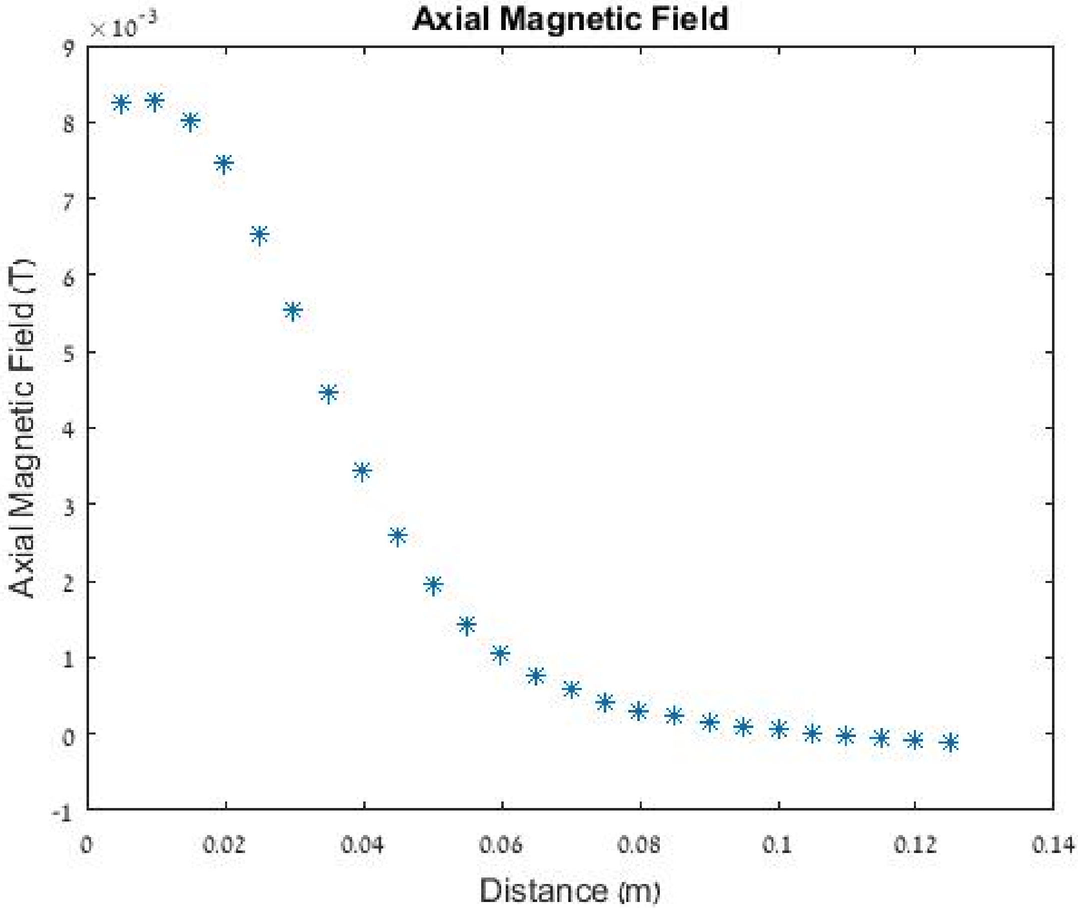

Figure 1: Axial Magnetic Field as a function of the distance - larger solenoid - primary axis

The plot was fit to a Fourier series of two terms.

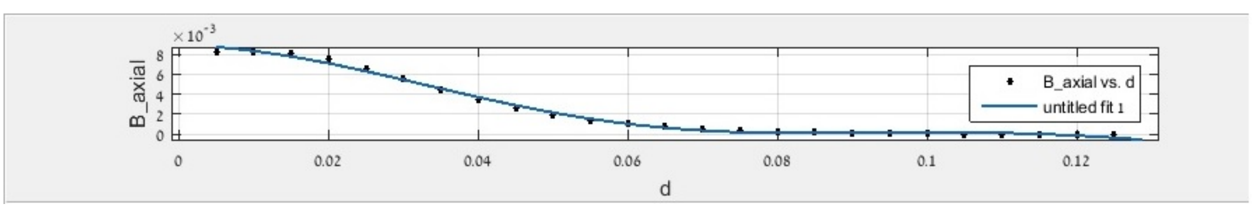

Figure 2: Fourier Fitting

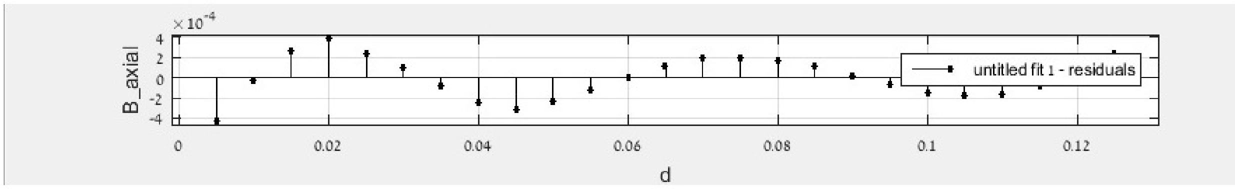

Figure 3: Residual plot for the axial magnetic field of the larger solenoid

The perpendicular magnetic field was also measured. Its plot appears below:

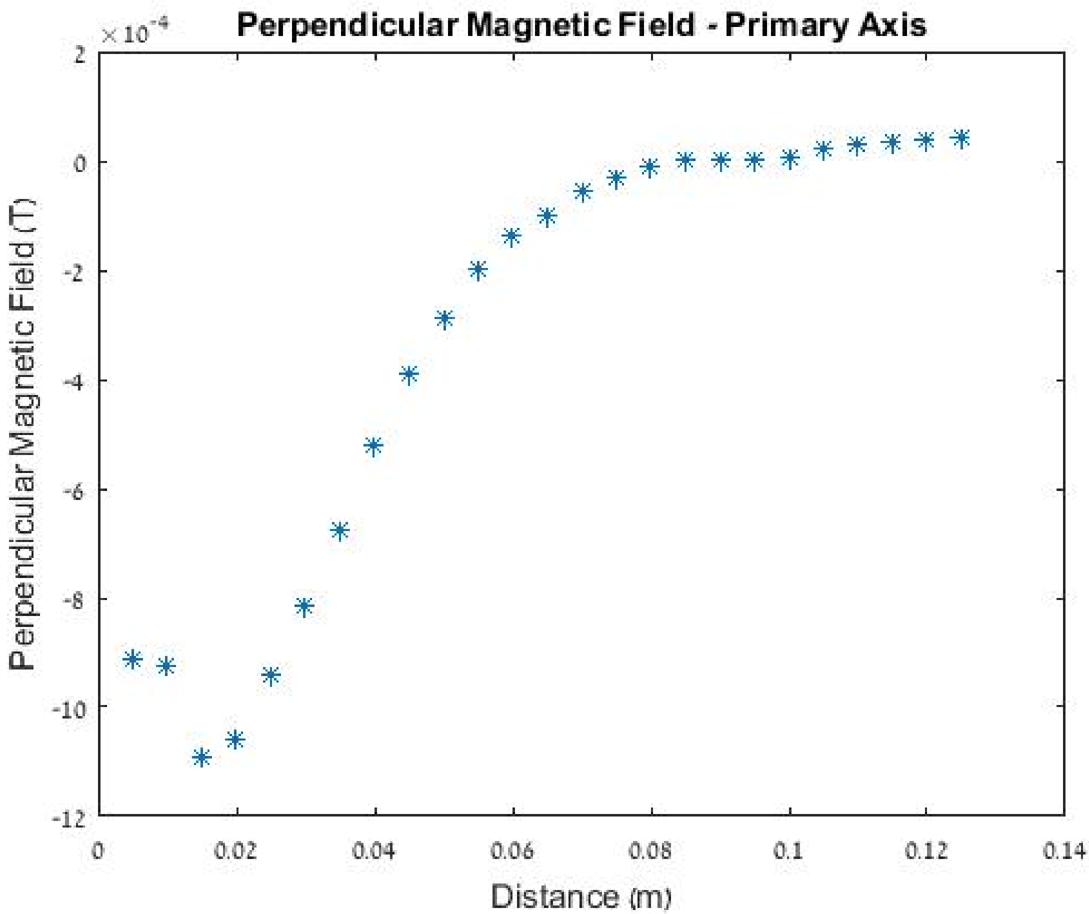

Figure 4: Perpendicular magnetic field - primary axis

The graph was fitted to a Fourier Series of two terms.

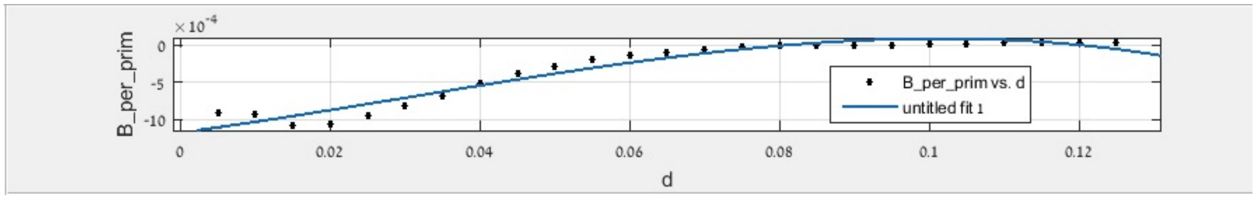

Figure 5: Fitting plot

The residual plot is:

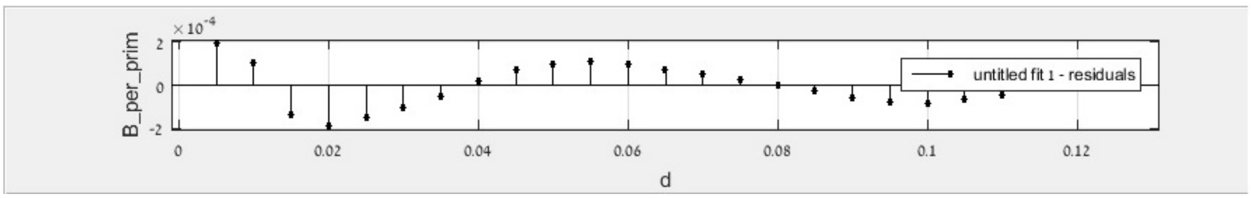

Figure 6: Resdidual plot

The larger solenoid was turned ninety degrees and other measurements were taken. Here, due to restrictions of time only ten (10) samples were taken.

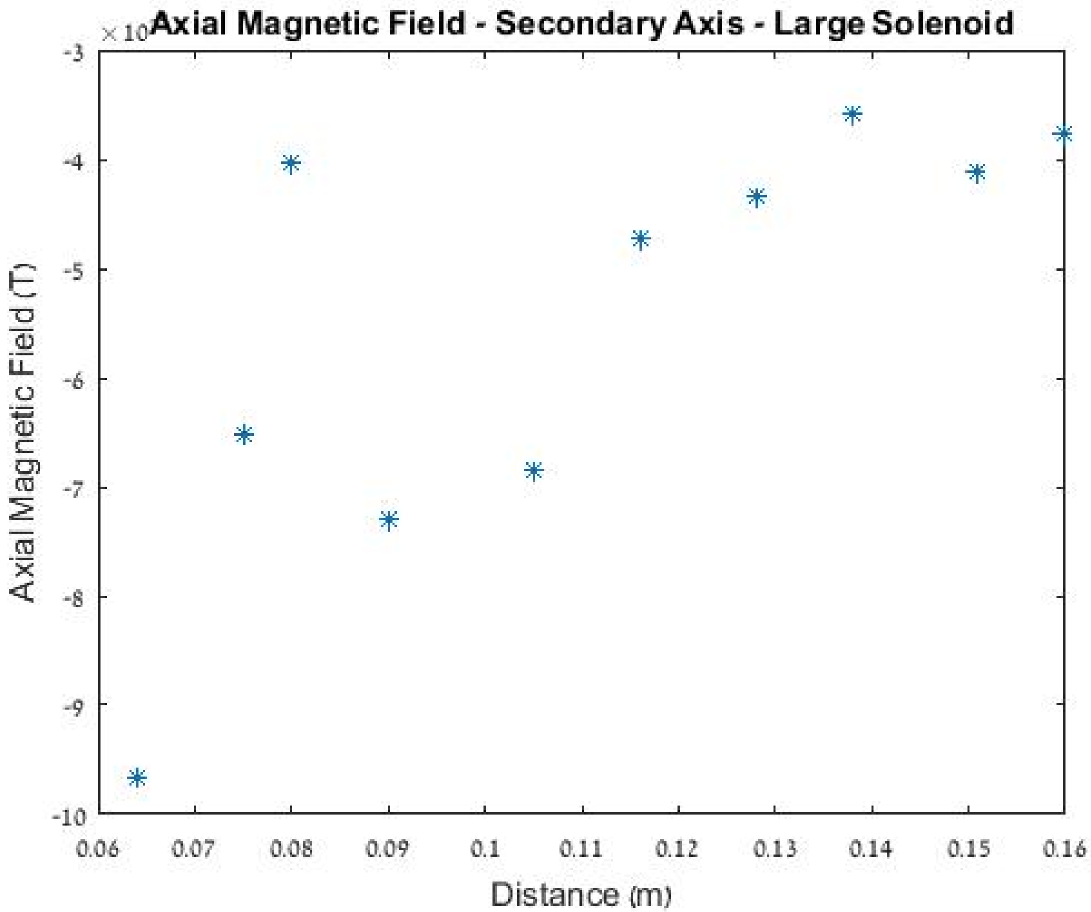

Figure 7: Axial Magnetic Field as a function of the distance - secondary axis

The graph above was fit to a second degree polynomial fitting.

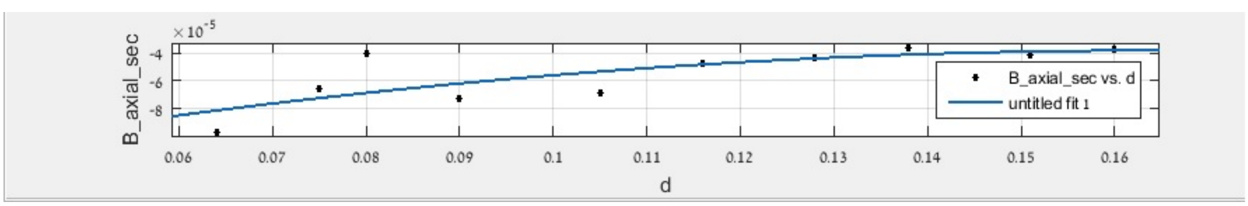

Figure 8: Fitting to polynomial equation

The residual plot appears below:

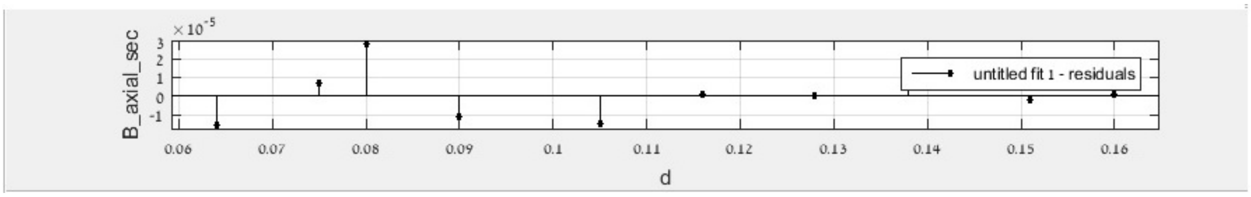

Figure 9: Residual plot for the secondary axis

The perpendicular magnetic field is plotted below:

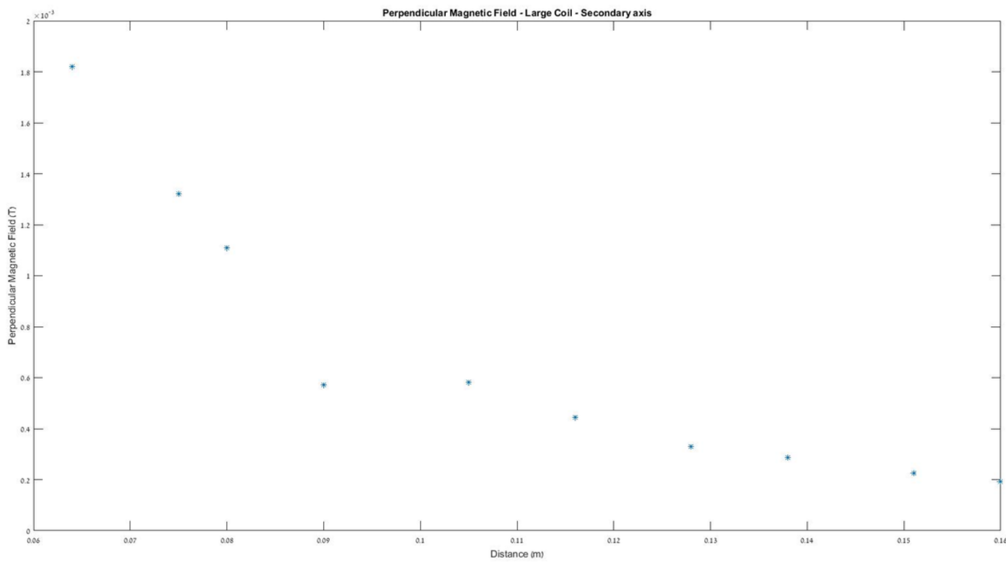

Figure 10: This is a caption

The smaller solenoid was connected to a power supply and then measurements were taken. Forty-four (44) samples were taken. With the data acquired, the following graph could be plotted:

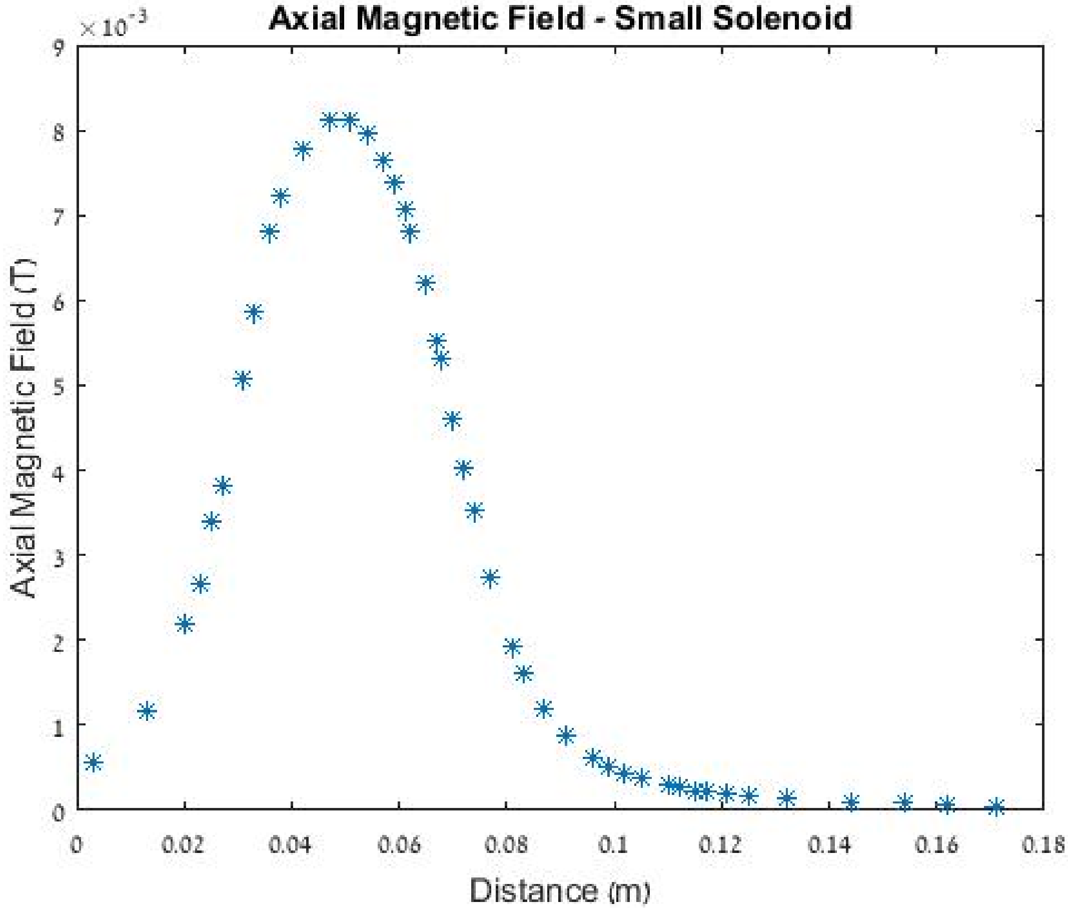

Figure 11: Axial Magnetic Field as a function of the distance

Using Matlab's fitting tool, it was possible to fit the graph to a Fourier series with three terms:

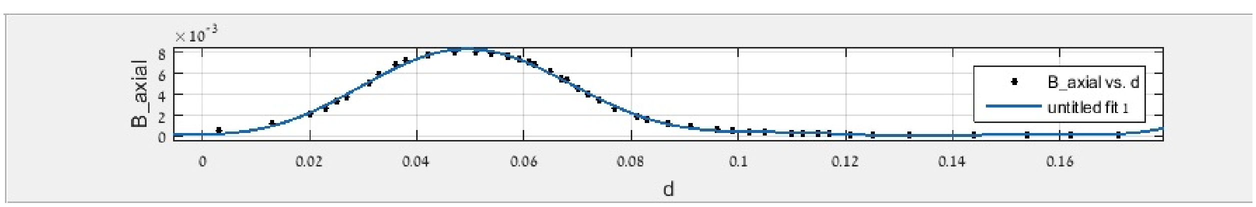

Figure 12: Fitting plot

The residual plot is shown below:

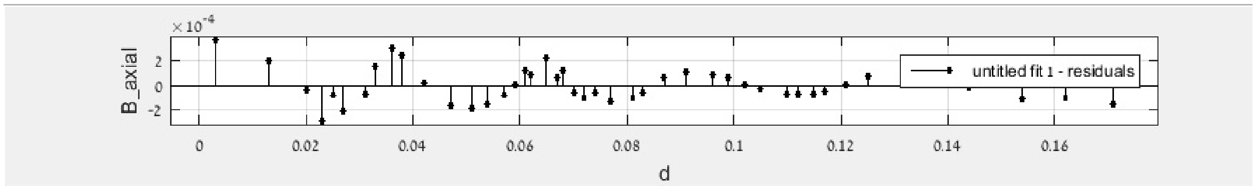

Figure 13: Residual plot for the axial magnetic field

The perpendicular magnetic field was measured. The same number of samples were taken here as in the previous measurements.

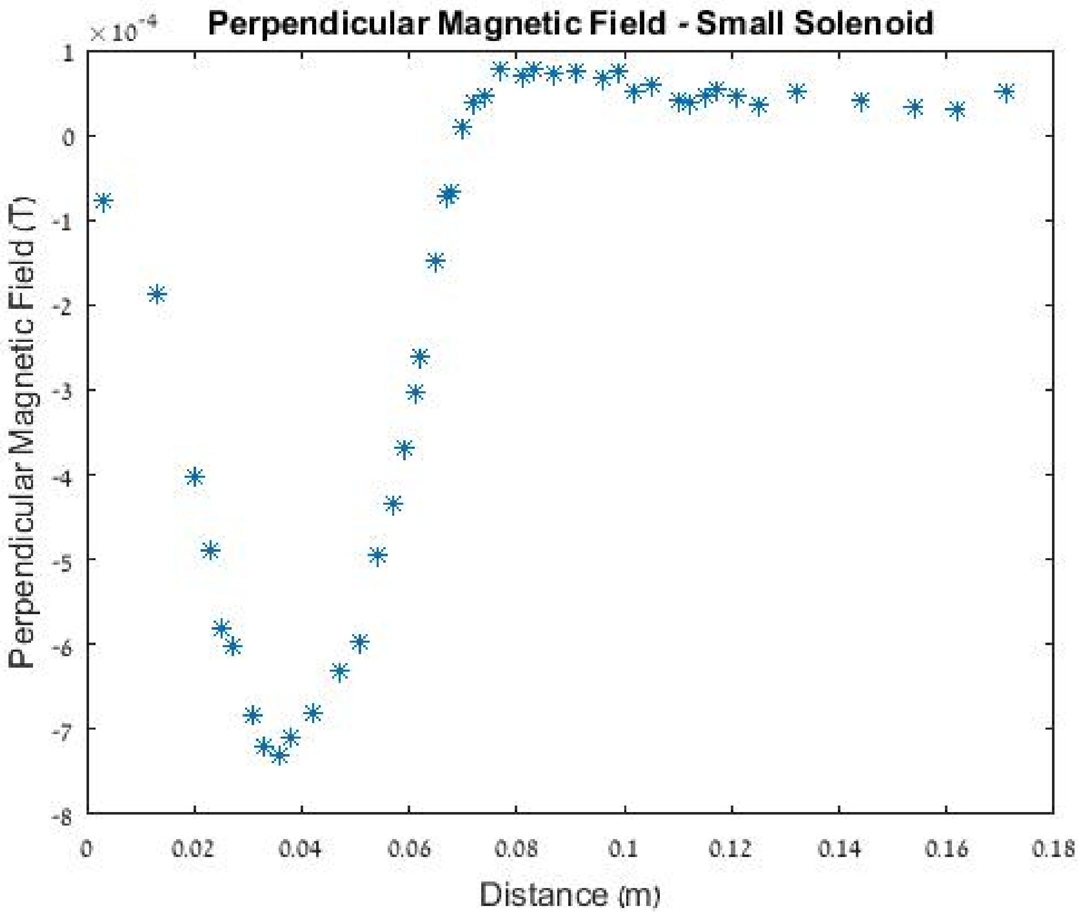

Figure 14: Perpendicular Magnetic Field as a function of the distance

The graph was fit to a Fourier series of three terms, exactly like the previous one:

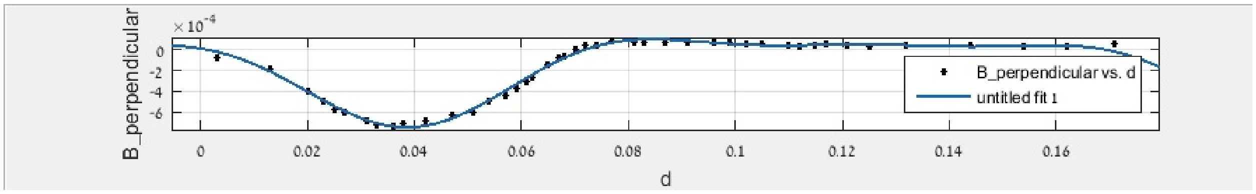

Figure 15: Plot Fitting

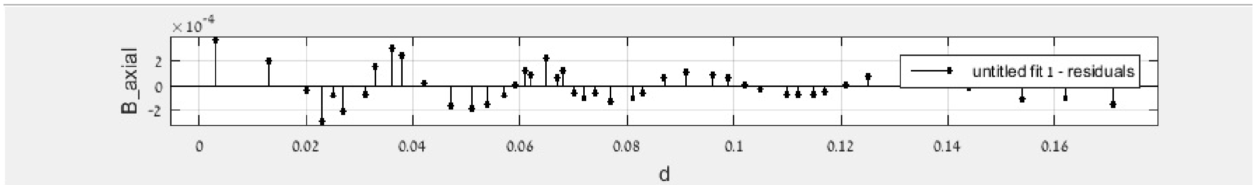

Figure 16: Residual plot

Part II

Force

Theoretical background

Lorentz Law

This law is also known as Lorentz force. The equation combines the electric and magnetic forces working on a point charge due to a magnetic field.

$$\vec{F} = q\vec{E} + q\vec{v} \times B \tag{3}$$

where:
q: is the point charge
$\vec{E}$: is the electric field
$\vec{v}$: is the velocity
$\vec{B}$: is the magnetic field
Since the Lorentz force is given by the calculation of a curl, its direction can be defined by the right-hand rule.
The same force can also be written as vector product of the current and the magnetic field.
$\vec{F} = l\vec{I} \times B$
where:
l: is the wire's length
$\vec{I}$: is the current flowing through the wire

This equation was used below in order to determine the magnetic force acting on the small solenoid. Since the current and the magnetic field are perpendicular, the vector product becomes a scalar product. And it comes from the identity:
$\vec{F} = l\vec{I}\vec{B}\sin(\theta)$
Being θ the angle between the current and the magnetic field.
All parts of the loop contribute to the magnetic field in the same direction inside the loop.

Methods

The goal of this part of the experiment was to characterize the dependence of the electromagnetic force on the solenoid in relation to the magnetic field and the current passing through it.
The small, 800 turns solenoid was placed on a plate and connected to a $18V$ direct current (DC) power supply. The solenoid was then placed on digital scales. Since there was no possible way to measure the magnetic force directly, the magnetic fields, both perpendicular and axial, were measured using the PASCO system. The intention was to calculate the magnetic force and plot the graph of this force as a function of the current flowing through the solenoid. The treatment of the data acquired can be seen at the next section.

Results

All through this part of the experiment, forty-three (43) samples were taken.

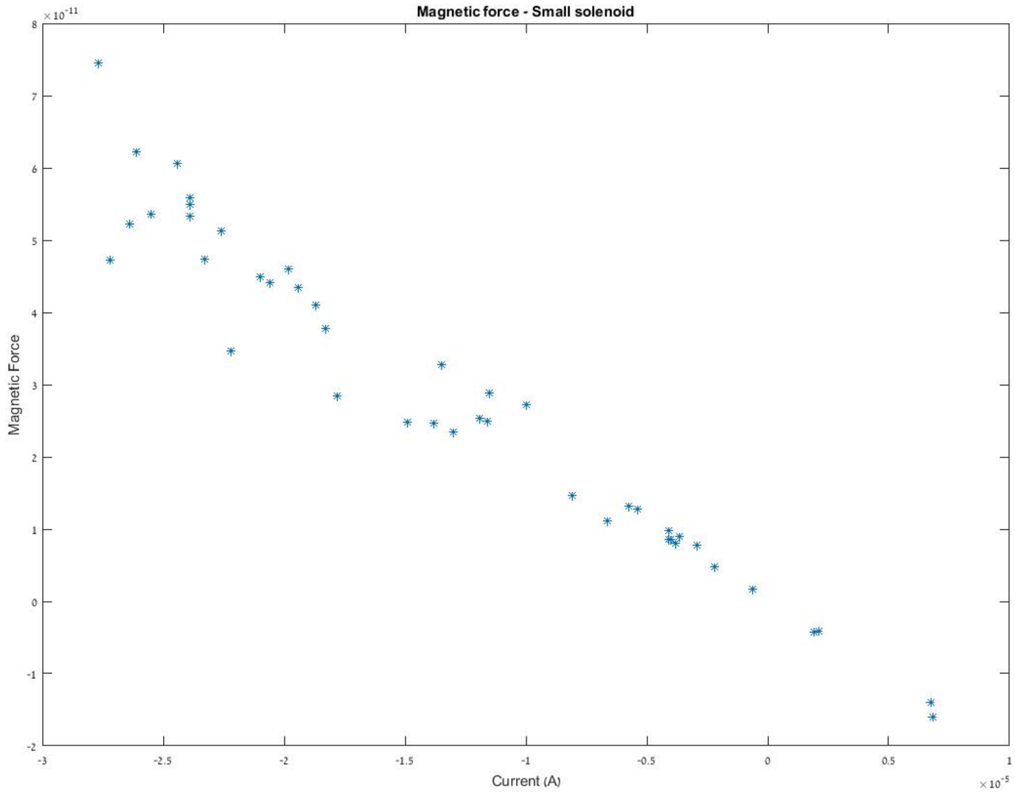

Figure 17: Magnetic force as a function of the current

The data used to build the graph above was fed to the curve fitting tool of the Matlab software. There, the graph was fit to a Fourier series of three terms, as it can be seen below:

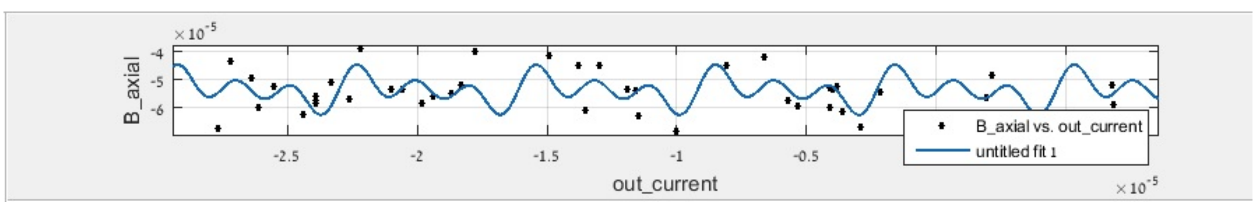

Figure 18: Fitting plot

The residual plot appears below:

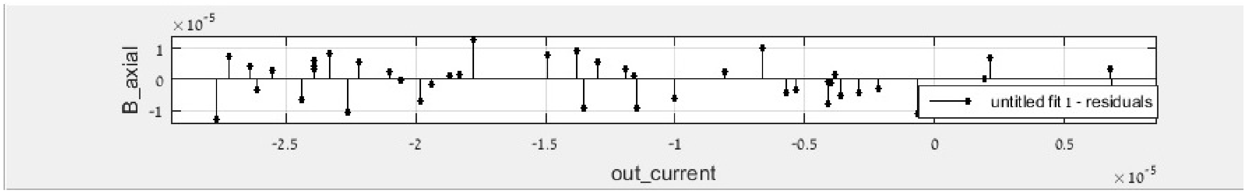

Figure 19: Residual plot

The force in the perpendicular axis appear in the plot below:

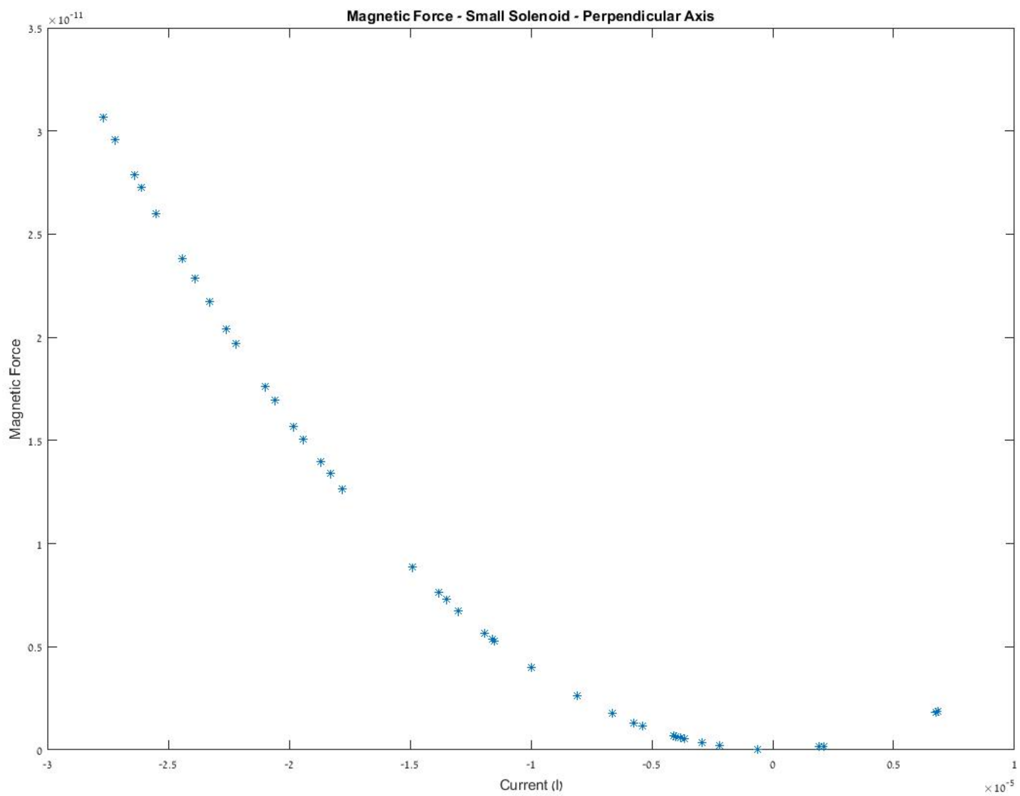

Figure 20: Magnetic force as a function of the current

The plot was fed to the curve fitting tool of Matlab. The fitting used was exponential.

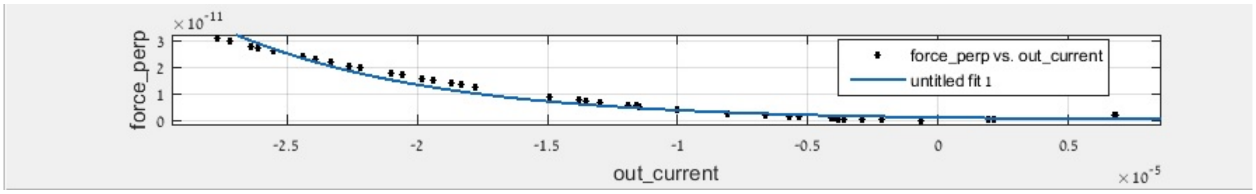

Figure 21: Plot fitting for exponential equation

The residual plot appears below:

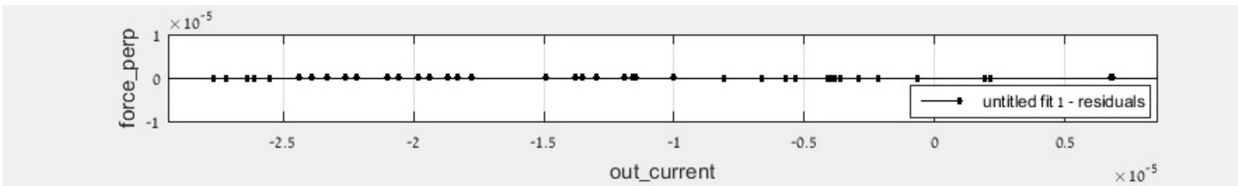

Figure 22: Residual plot

Conclusions

The dependence between the magnetic force acting on the perpendicular axis of the solenoid and the current behaves like $\frac{1}{e^x}$.
as predicted my the theoretical model eq.

Week II

Part III

Self Inductance

Theoretical background

Inductance opposes a change in current. It is a property of an electrical conductor. A raise in current causes the magnetic flux to be stored in the field. This reduces the current and there is a voltage drop. A fall in current causes the magnetic flux to be released and supplies current to the system, causing a rise in the voltage. The inductance can be defined by the Faraday's law:
$\mathcal{E} = -L\frac{\Delta I}{\Delta t}$
where:
$\mathcal{E}$: is the electromagnetic force or the magnetic flux

L: is the inductance
I: is the current
t: is time

The magnetic flux density inside the solenoid is to be considered constant. As it was already shown in this report, it is given by the equation: $\Phi = \mu_0 \frac{NIA}{l}$
where:
A: is the area of the cross-section
It comes from the magnetic field equation:
$B = \mu_0 \frac{NI}{l}$
Combining the magnetic flux with the inductance: $L = \frac{N\Phi}{I}$
$L = \mu_0 \frac{N^2 A}{l}$
As it can be seen, the inductance of a solenoid is dependent of the current.

the current in the circuit is described by

$$I(t) = \frac{\mathcal{E}_0}{R}\left(1 - e^{-t\frac{R}{L}}\right) \tag{4}$$

where:
$\mathcal{E}_0$ is the EMF provided by the power source
R: is the resistance in the circuit
L: is the inductance of the coil
t: is time

Methods

In this part, a circuit was as shown in fig 23. A Hall probe was used to measure the magnetic field inside the solenoid. A voltmeter was used in order to measure the voltage across the resistor.

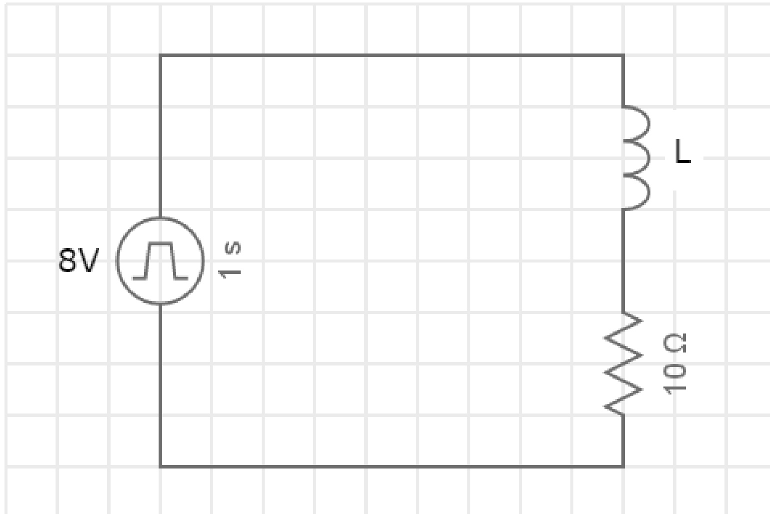

Figure 23: part 3 a circuit

In this part of the experiment, the goal was to show the behavior of the current through the solenoid and the magnetic field inside it as a function of the voltage. In order to do it, the Hall probe was placed in the middle of the solenoid. A voltmeter was connected to the resistor. the whole circuit was connected to a $8V$ alternate current (AC) supply. The wave shape was set to square.

Results

The first graph shows the voltage as a function of time and was fitted using the expression $a \cdot e^{(-bx)} + c$.

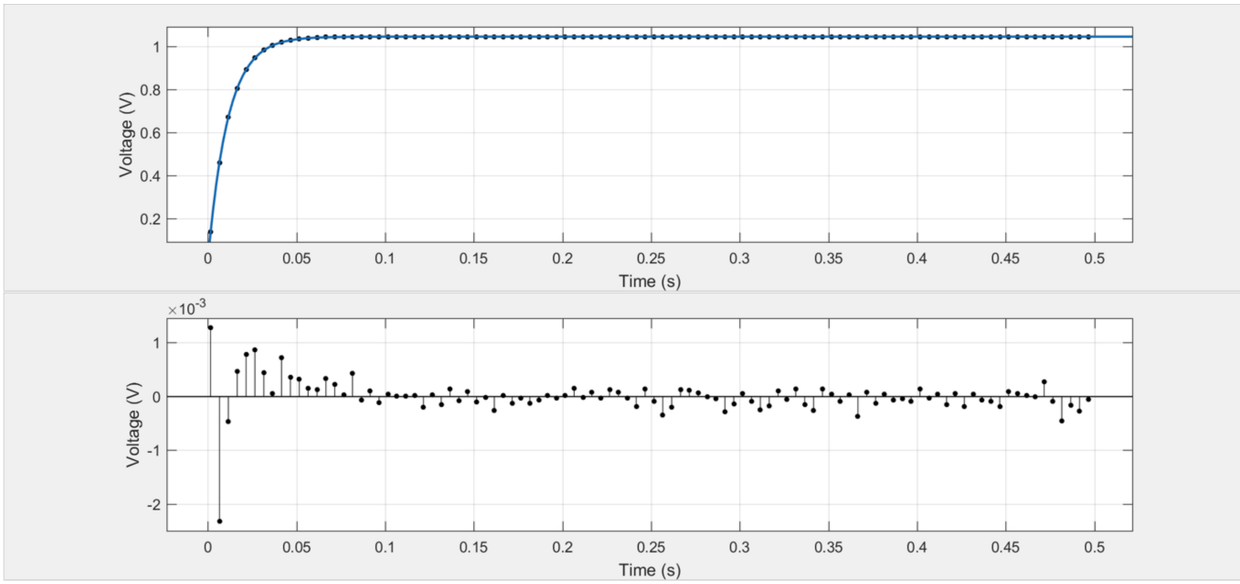

Figure 24: voltage over the resistor in fig 23 as a function of time

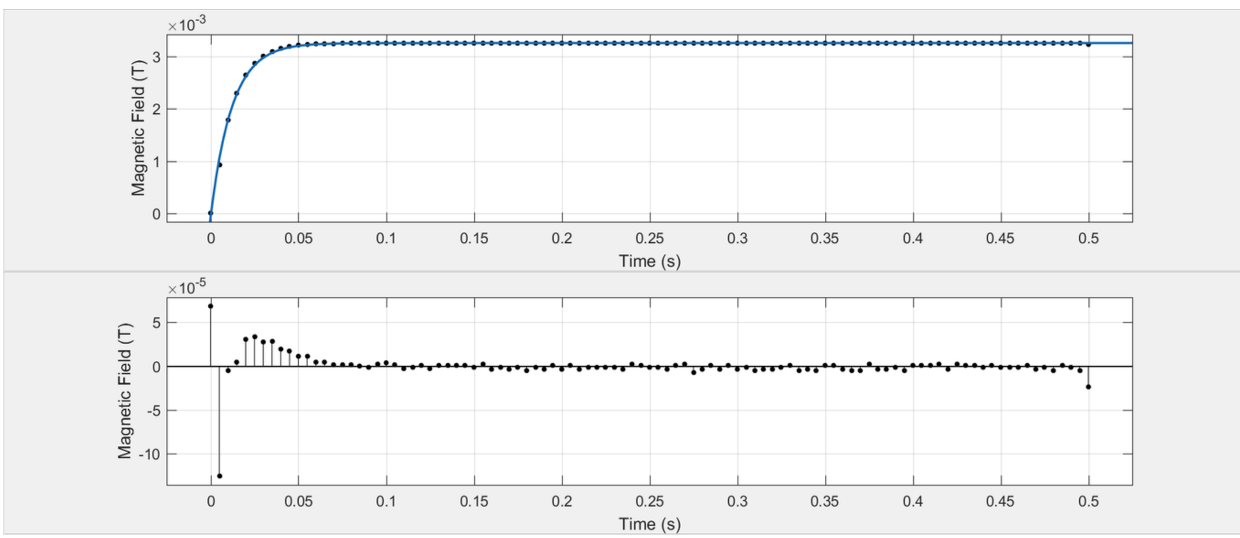

Figure 25: magnetic field in the coil in fig 23 as a function of time

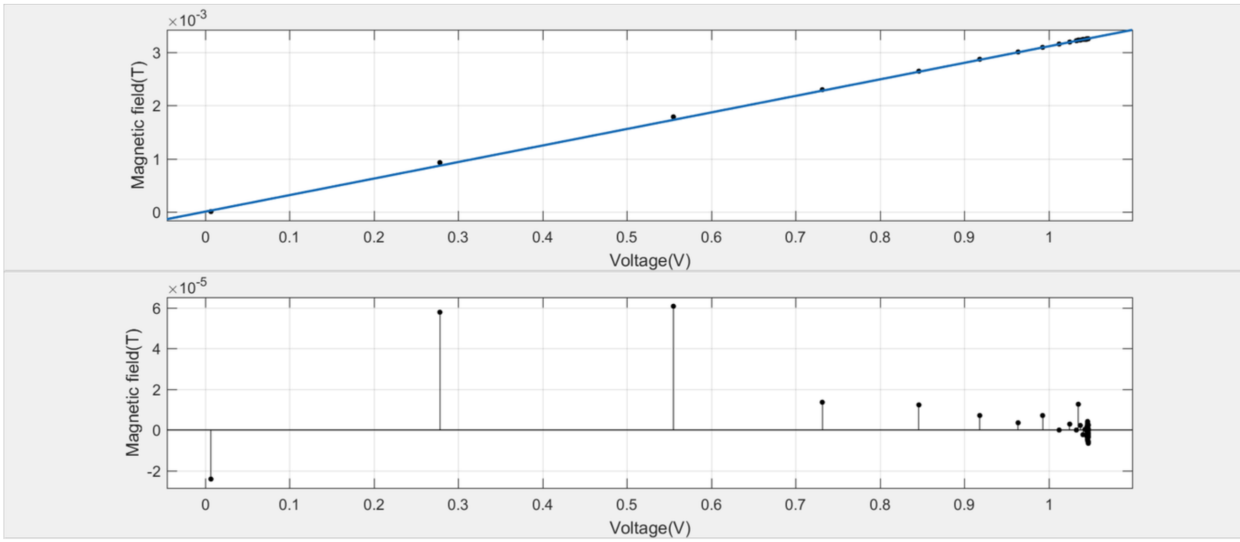

Figure 26: This is a caption

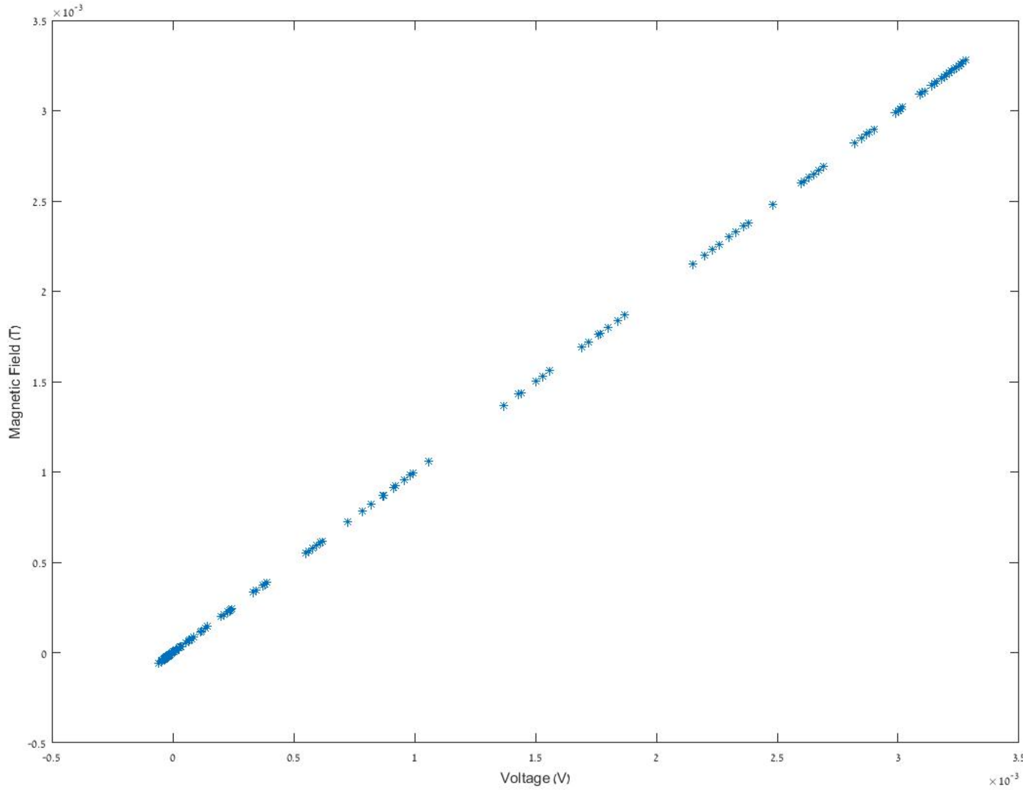

Figure 27: The magnetic field as a function of the voltage

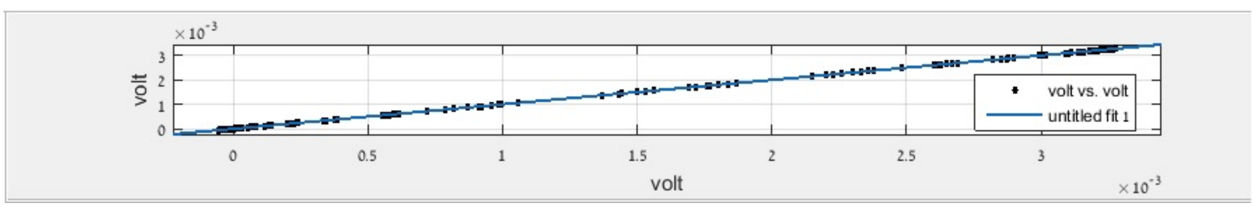

Figure 28: Fitting plot

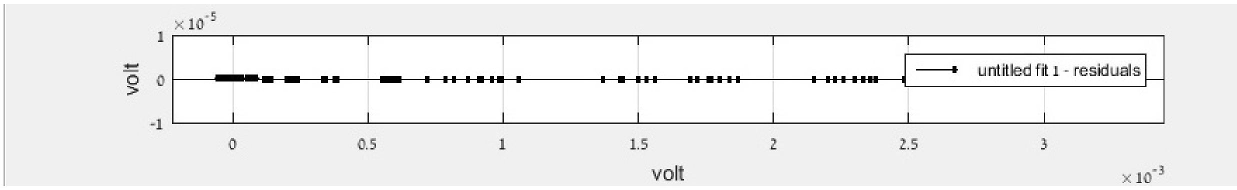

Figure 29: Residual plot

Conclusions

It can be understood from the graph that the dependence of the magnetic field and the voltage is linear. our fit predicts $\frac{R}{L} = 88.77\frac{\Omega}{H} \pm 0.08\frac{\Omega}{H}$ the resistance of the coil is 60Ω and the and the resistance of the resistor is 10Ω using the data the coil inductance was calculated to be $1.27H$ the inductance for a $3400\ turn\ 10\ cm$ coil with a radius of $5\ cm$ is $1.25H$

Part IV

Mutual Induction

Theoretical background

Methods

Results

Conclusions

Part V

Ferromagnetism

Theoretical background

Certain materials such as iron, cobalt, and nickel, form permanent magnets. This characteristics is known as ferromagnetism. It is the strongest type of magnetism. At atomic level, these materials exhibit a long-range ordering capacity. It causes the unpaired electron spins to line up parallel with each other in a certain region, which is called domain. Within this region, the magnetic field is intense. A small external magnetic field can cause the magnetic region to line up with each other. The material then will be magnetizes. The main magnetic field will increase. Ferromagnets tend to stay magnetized after being subject to an external magnetic field. Ferromagnetism is dependent on the temperature of the material. And for different materials there are different maximum temperatures for which the ferromagnetic property disappears.

Methods

In this part of the experiment, the goal was to show the magnetic field formed by a metal bar in comparison to the external magnetic field. A metal bar was placed in the center of the 3400 turns solenoid. The magnetic field probe was placed on the edge of the metal bar and the magnetic field was measured. the solenoid was connected the voltage source. The magnetic field was measured on the edge of the metal bar as a function of the current. The current varied from $0A$ to $0.2A$.. Measurements were taken. And then the scale of the current was reverted and other measurements were taken. The solenoid was then disconnected. The magnetic field was measured again at the edge of the metal bar.

Results

For the first part of this section, twelve measurements were taken. With the data acquired the following graphs could be plotted:

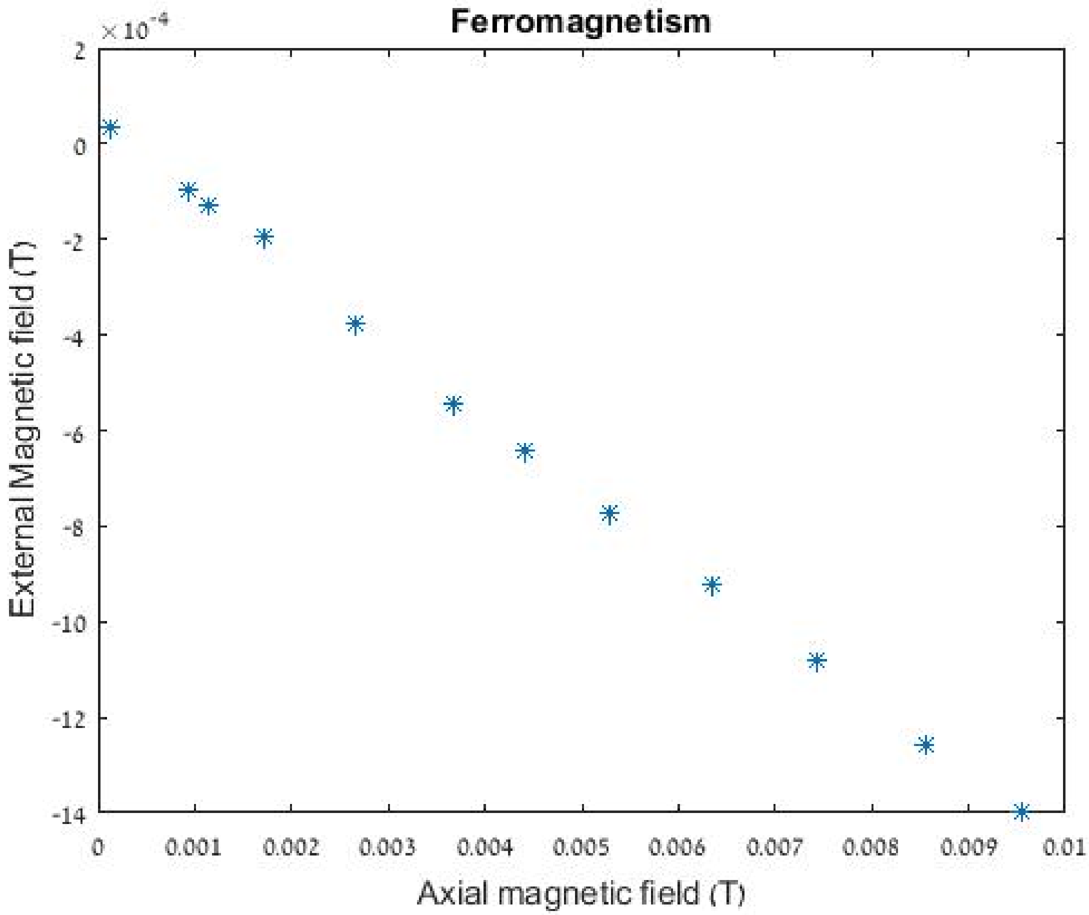

Figure 30: Magnetic field on the edge of the metal bar in comparison with the external magnetic field

Using the curve fitting tool of the Matlab software, the data was fit to a linear graph. The fitting is shown below:

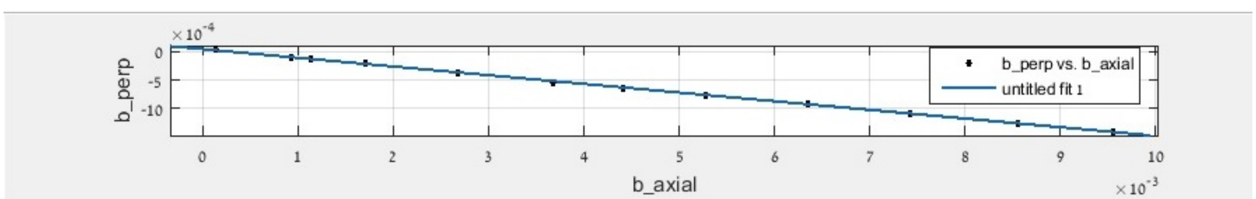

Figure 31: Fitting plot

The residual plot is:

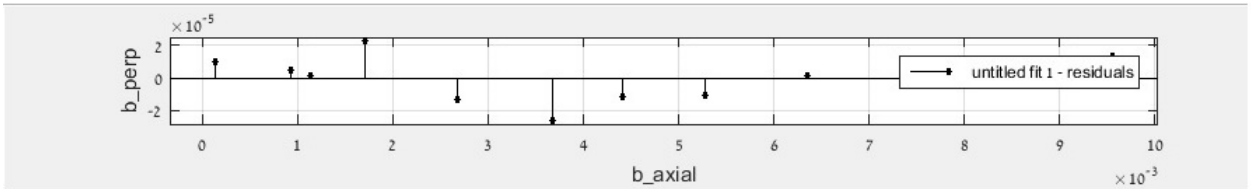

Figure 32: Residual plot

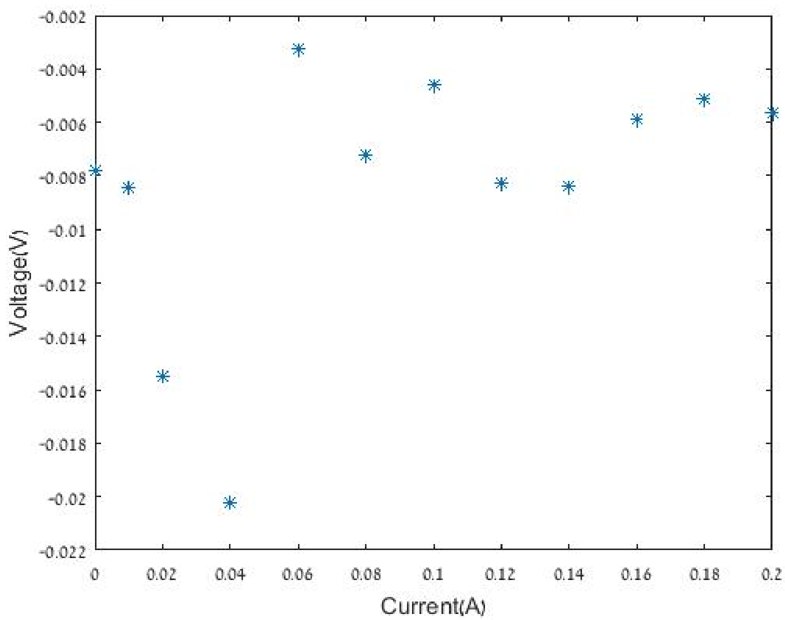

Figure 33: Voltage as function of the current

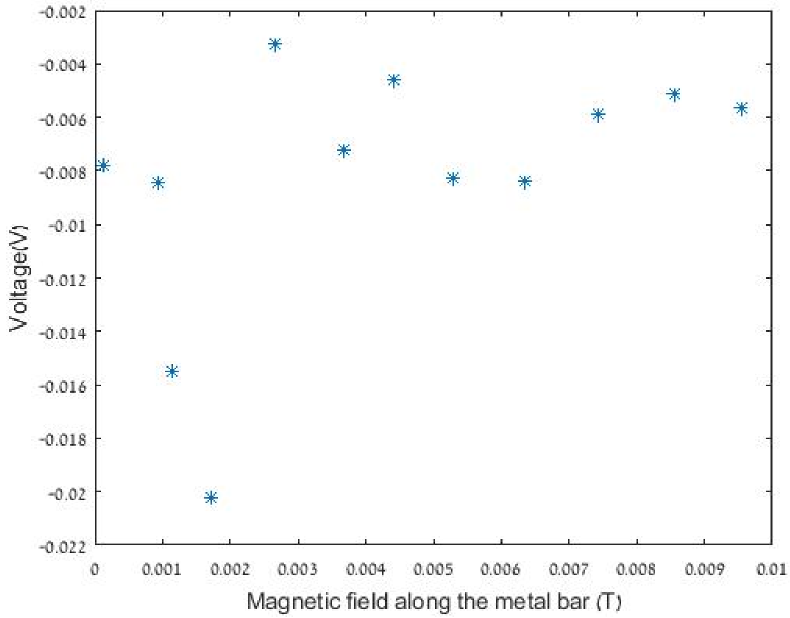

Figure 34: T

Conclusions

It can be understood from the graph that the dependence between the magnetic field on the edge of the metal bar and the external magnetic field is linear. In an interesting phenomenon, the current and the magnetic field behave in a similar way in function of the voltage.