

Lab 3: Self- and Mutual Inductance

Goal

The investigation of how changing magnetic fields can give rise to self- and mutual Inductance.

Objectives

1. Explain how changing current in a coil generates the phenomenon known as self-inductance.
2. Determine the value of the self and mutual inductance and its dependence on the coil geometry.
3. Determine the frequency response of the induced emf on a coil.

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report.
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

Introduction to Concepts

A coil carrying current, $I(t)$ induces emf across a second coil,

$$V_{emf}(t) = -M \frac{d}{dt} I(t) \quad (1)$$

Where M is the mutual inductance, $I(t)$ is the current flowing in the primary coil and $V_{emf}(t)$ is the induced emf on the secondary coil. The mutual inductance of the secondary coil due to a time varying current flowing in the primary coil,

$$M = \mu_o \frac{N_1 N_2 A}{2R} \quad (2)$$

Where N_1 is no. of turns in the primary coil, N_2 is the no. of turns in the secondary coil, μ_o is the magnetic permeability of the free space and A is the cross sectional area of the secondary coil normal to the magnetic field.

If a voltage $V(t) = V_o \sin(\omega t)$ is applied to the primary coil, the current flowing in the coil,

$$I(t) = I(\omega) \sin(\omega t + \phi) \quad (3)$$

Where $\omega = 2\pi f$ is the frequency of the voltage, ϕ is a phase-shift in the current with respect to the voltage, and the $I(\omega)$ is the frequency dependent amplitude of the current, $I(t)$

$$I(\omega) = \frac{I_o}{\sqrt{1 + \omega^2 L^2 / R_o^2}} \quad (4)$$

Where $I_o = V_o / R_o$, R_o is the resistance of the coil and L is the self-inductance of the primary coil. The current in the primary coil depends on the frequency of the alternating current driving the primary coil. Therefore, the induced emf depends on the frequency of the alternating current driving the primary coil. The emf in the secondary coil,

$$V_{emf}(t) = -M \cdot (I(\omega)\omega) \cos(\omega t + \phi) \quad (5)$$

Preliminary Lab Questions

1. Find an equations for self-inductance of the primary coil (discussed this in the previous lecture class)?
2. Find the amplitude of the emf as $L.\omega \ll R$?
3. Find the amplitude of the emf as $L.\omega \gg R$?

Equipment and Parts

1. Multimeter
2. RLC meter
3. A 200 turns current primary coil (radius of 10.5 cm)
4. A 200 turns current coil (small size) to detect electromagnetic induction (secondary coil)
5. Power amplifier II as a power source (do not exceed the specified limiting current of 1A).
6. PASCO voltage probe
7. Science workshop interface
8. A Laptop.

Procedure

Setup PASCO Software Suite

- Connect the **voltage probe** to Science workshop interface
- Connect the Power amplifier II as a power source to Science workshop interface
- Connect the USB cable from Science workshop interface to the laptop
- Open the PASCO software suite in the laptop
- Add the voltage probe to current work environment
- Add a measurement tab to PASCO software suite work environment to record voltage reading in to a table and a graph
- Make sure to set the readout gain to $1\times$ for voltage and current output of the power amplifier.
- Use “scientific notation” to record numbers by clicking the “Settings” button in the data table.
- Set the sampling rate to 4 kHz
- Click “Record” button in the PASCO software suite

Frequency Dependant Mutual Inductance

- Using the RLC meter measure the self-inductance and resistance of the primary (Coil1) and secondary (Coil2) coils
- Calculate the self-inductance of the primary coil using the equation you derived at **Preliminary Lab Questions F**
- Discuss the agreement or disagreement of your results
- Calculate the mutual-inductance of the secondary coil using the equation 2 F
- Calculate the voltage required to generate a $I \sim 1\text{ A}$ in the Coil1, **The power amplifier can only support up to $I \sim 1\text{ A}$** F
- This value will be the amplitude of the “AC” sinusoidal signal that will be used in the experiments.
- Measure the average diameter of the Coil1 (R_1) F
- Measure the length and height of the Coil2 to calculate the normal surface area F
- Connect the **Power Amplifier II** to Science workshop interface
- in the PASCO suit, Add the Power Amplifier II to current work environment

- Click on the “Signal Generator” button at the left
- Set “AC” sinusoidal signal with amplitude calculated in the above step and frequency to 5 Hz .
- **If the “Red” indicator blinks in the Power Amplifier II, reduce the amplitude by few tenths of volts**
- Turn “On” the signal generator
- Using the multimeter measure the RMS output voltage at the “Red” and “Black” terminals of the Power amplifier II to verify output is approximately what you set in the PASCO suit
- Connect the Power amplifier II to the current carrying coil (Coil1)
- Place the secondary coil (Coil2) at the center of the Coil1 (see Figure 1)
- Connect the two terminals of the voltage probe into the Coil2
- Set the sampling rate to 4 kHz
- Record the current in the Coil1 and induced voltage in the Coil2 into a dataset and to graphs to show time variation. You can select current and voltage output for the Power amplifier.
- Tabulate your results (current on Coil1 and induce voltage on Coil2) to show data at least for 1-2 seconds F
- **Verify using the graphs that the frequency is 5 Hz**
- **Verify using the graphs that the current on the coil is correct based on the equation 4**
- **Verify using the graphs that the emf on the Coil2 is correct based on the equation 5**
- Save the data for current on Coil1 vs. time and induce voltage on Coil2 vs. time
- Measure the average amplitude of the current on Coil1, $I(\omega)$ and induce voltage on Coil2, $V_{emf}(t)$
- Record data in a table as shown in Table 1
- Increase the frequency to 10 Hz .
- Tabulate your results (current on Coil1 and induce voltage on Coil2) to show data at least for 1-2 seconds F
- **Verify using the graphs that the frequency is 10 Hz**

Table 1: Sample Data Table. The average $V_{emf}(t)$ is based on the positive and negative values

Frequency (Hz)	Average $V_{emf}(t)$ (V)	$I(\omega)$
5		
10		
15		
20		

- **Verify using the graphs that the current on the coil is correct based on the equation 4**
- **Verify using the graphs that the emf on the Coil2 is correct based on the equation 5**
- Save the data for current on Coil1 vs. time and induce voltage on Coil2 vs. time F
- Measure the average amplitude of the current on Coil1 and induce voltage on Coil2
- Record data in a table as shown in Table 1 F
- Repeat up to 100 Hz in steps 10 Hz
- Repeat from 100 Hz to 500 Hz in steps 100 Hz
- Plot the amplitude $I(\omega)$ of the primary coil vs. frequency F
- Overlay equation 4 in the same plot F
- Calculate percent error of the measured $I(\omega)$ with respect to equation 4 F
- Plot amplitude V_{emf} vs. frequency F
- Overlay equation 5 in the same plot F
- Calculate percent error for the results; Plot the percent different vs the frequency F
- Estimate the frequency at which the amplitude V_{emf} starting to saturate F
- Calculate the amplitude V_{emf} as $L\omega \gg R$ using F equation 5
- Discuss the agreement or disagreement of the amplitude V_{emf} as $L\omega \gg R$ with maximum amplitude V_{emf} obtained from the experiment
- Using the region where V_{emf} changed linearly estimate the mutual-inductance of the secondary coil using a linear fit applied to the dataset F
- Discuss the agreement or disagreement of your results

