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Model for determining the magnetic permeability of a neodymium magnet

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Abstract: A laboratory educational experiment is presented to determine the characteristics of an oscillating circle under the influence of a neodymium magnet $Nd_2Fe_{14}B$ .The oscillating circuit is composed of a coil with an inductance of 10.14 H and a capacitance of 1 μF .A transformer is used to convert the alternating voltage from the 220V electrical network into 6V and a frequency of 50Hz. The indicated methodology can be widely used for developing seminar and laboratory exercises in physics.

Keywords: Magnetic field influence on LC circuit, magnetic permeability.

1. Introduction

In modern electrical engineering, oscillatory circuits are widely used for signal generation and filtering. These circuits are sensitive to external electromagnetic influences. The influence of magnetic fields on oscillating circuits is important in the design and optimization of radios and other electronic systems [4-6]. For example, in radio receivers, it is necessary to minimize external magnetic influences to ensure stable operation and frequency accuracy. Different design models, questions arise such as: Using magnetic fields for control and modulation of signals. Measuring magnetic inductance under different conditions. Similar analyses are presented in work [2-3]. Determination of the magnetic force in a permanent magnet discussed in work [7] is a factor for increasing the magnetic flux. Functional dependencies between, magnetic induction and current magnitude, inductance and specific permeability, specific permeability and magnetic

induction, inductance and direct electric current are considered. The magnetic permeability μ of a given body can be determined by its ability to change the magnitude of the magnetic induction-B and the intensity H of an adjacent magnetic field. The ability of a material to be magnetized refers to its permeability under the influence of an external magnetic field to form magnetic domains. Previous studies of magnetic permeability include Hall sensor, toroidal method presented in [1]. This allows for the classification of the material as having diamagnetic, paramagnetic or ferromagnetic properties. The purpose of this report is to consider the influence of a neodymium magnet on the electric

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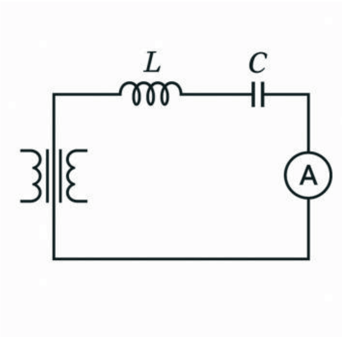
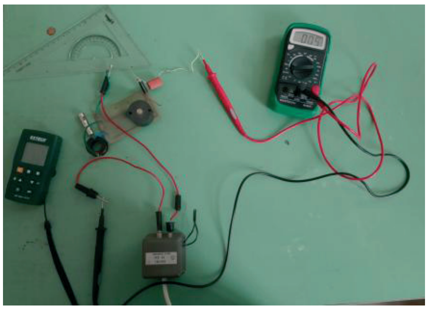
current, magnetic permeability and magnetic induction and inductance in the oscillating circuit.

2. Materials and Methods

To consider the magnetic permeability of ferromagnetic materials, it is convenient to use an oscillating circuit. The oscillating circuit is an electrical circuit consisting of an inductive element coil and a capacitor, which form an oscillating system. Fig. 1a shows a diagram of a series-connected oscillating circuit. The oscillating circuit includes a transformer with an input alternating power supply of 220 V and an output 6 V, and a frequency of 50 Hz, a coil with a radius of R=0.0175 m and a capacitor with a capacity of 1 μF. As can be seen from Fig. 1b In the presence of an external magnetic field, especially from a strong permanent magnet such as neodymium ($Nd_2Fe_{14}B$), the characteristics of this system change. Changes in oscillation frequency, amplitude, and waveform are expected.



(**a**)



(**b**)

Figure 1. Flickering circuit diagram

After substituting the frequency and capacitance in formula (1), for the inductance of (2) we get L= 10,13H .

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$L = \frac{1}{(2\pi.f)^2.C} \tag{2}$$

If we introduce a permanent magnet $Nd_2Fe_{14}B$ to an oscillating circuit (LC circuit). A permanent magnet creates a static magnetic field. It is leads to a change in the distribution of magnetic flux-Φ, around the oscillating circle. It is expected that a slight change in the effective magnetic permeability-μ_r will be observed .Using an ammeter and a Tesla-meter we determine the magnitude of the electric current and the magnetic induction The magnetic induction measured with the teslameter is 0,5μT The measurements carried out for the electric current correspond to a harmonic sinusoidal dependence shown in Fig. 2.

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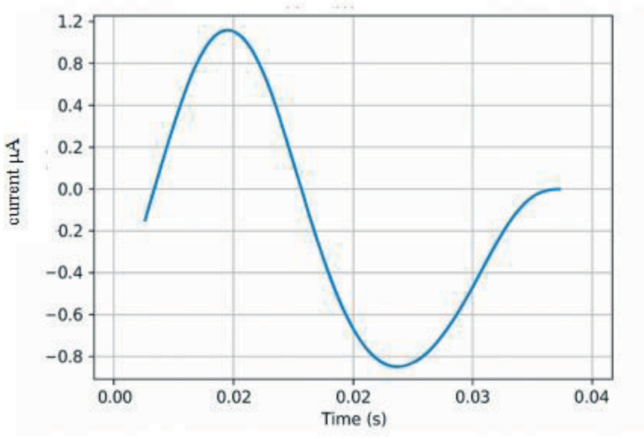

Figure 2. Sinusoidal alternating current

The dependence that describes the harmonic oscillation is represented by (3):

$$I(t) = I_{aver.} + I_0.\sin(2\pi f + \varphi_0) \tag{3}$$

where:I_{aver} -average current value ,I_0 - amplitude of the sinusoidal oscillation .f -frequency of oscillations Hz.φ -initial phase, no phase shift is observed, φ=0,t-time[s].Formula (3) gives the current at any moment in time, which varies periodically between +1.2 A and –0.8 A. Substituting the values, we get:

$$I_{aver} = \frac{1{,}2 - 0{,}8}{2} = 0{,}2A \tag{4}$$

$$I_0 = \frac{1{,}2 + 0{,}8}{2} = 1{,}0A \tag{5}$$

$$I(t) = 0{,}2 + 1{,}0.\sin(2\pi.50.t) \tag{6}$$

The magnetic induction B without the influence of the neodymium magnet is 0,47μT.

In this case, I=1.2 A can be used to calculate the maximum magnetic energy in the coil. After substituting in (7) we get W = 7,3J

$$W = \frac{1}{2}CU^2 = \frac{1}{2}LI^2 \tag{7}$$

We apply an external magnetic field from a neodymium magnet with a force of 49 N , the diameter of the magnet: 0.01 m and a length of 0.1 m as the magnet is placed on the coil .We use a relationship (8) , [7-8]where if a force F acts on a surface with area A due to magnetic pressure - p_B.

$$F = p_B.A = \frac{B_1^2}{2\mu_0}.A \tag{8}$$

The main dependencies that determine the magnetic permeability are: Circulation of the magnetic field-H intensity along a closed loop and magnitude of magnetic induction-B. To test the magnetic permeability, we place the neodymium magnet on the coil.

We calculate the magnetic permeability by:

$$\mu_r = \frac{B}{H} \tag{9}$$

$$\oint Hdl = I \tag{10}$$

$$\mu_r = \frac{B}{I} = 0{,}4H / m \tag{11}$$

The inductance L of a coreless coil is(12),[7] .When a magnet is added to the coil, it partially changes the magnetic permeabiliti μ_f .This leads to a change in the inductance in the coil.

$$L = \frac{\mu_0.\mu_r.N^2 A}{l} \tag{12}$$

$$\frac{L}{L_0} = \frac{\mu_f}{\mu_0} \tag{10}$$

This leads to a change in the frequency and amplitude of the harmonic curve. A smaller electric current is observed. Measurements conducted using an ammeter show a lower current magnitude I2=0,9μA. The graph of the current through the capacitor as a function of time for an LC circuit is shown in Fig. 3.

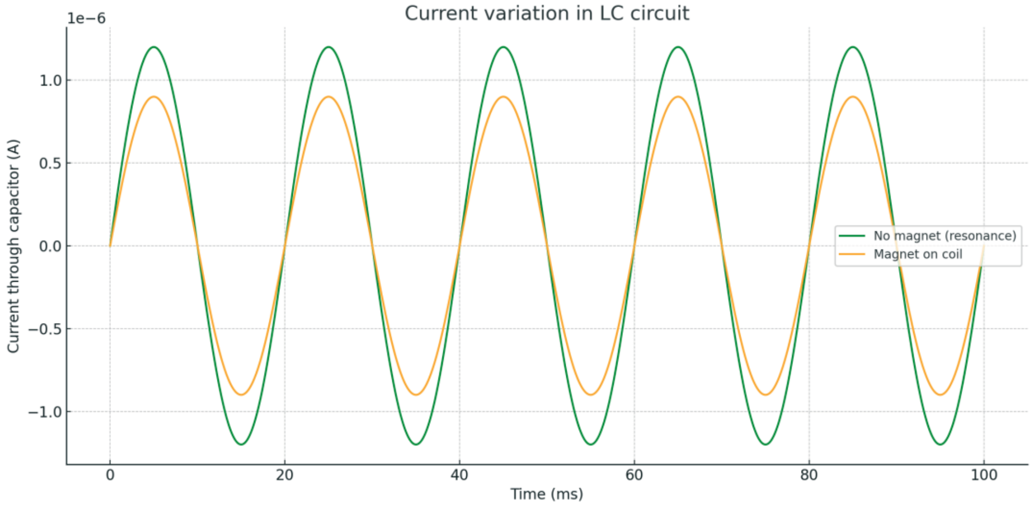

Figure 3. The current through the capacitor as a function of time for an LC

We apply an external magnetic field from a neodymium magnet. The green line shows the current at resonance (without magnet), amplitude ±1.2 μA. The orange line shows the current with a magnet added to the coil, amplitude ±0.9 μA.

3. Results

The permanent magnet does not induce current by itself, but by increasing the inductance it changes the natural frequency of the oscillating circuit. This leads to a change in resonance with the input power supply 50 Hz .It reduces the amplitude and, accordingly, the magnitude of the electric current.

4. Discussion and Conclusions

The coil used is without a ferromagnetic core. The measurements conducted with a teslameter and an ammeter show that before placing the magnet on the coil, a higher electric current and a lower magnetic induction are observed. After placing the magnet on the coil, a lower current is recorded. The change in magnetic induction can theoretically be calculated .If B changes due to the approach of the magnet, and L, C are constants. For two consecutive measurements we can write the following proportion:

$$n = \frac{I_1}{I_2} = \frac{B_1}{B} \quad (11)$$

After substituting the obtained values for the electric current and magnetic induction, the effect of the neodymium magnet on the magnetic induction is:

$$n = \frac{0,9\mu A}{0,8\mu A} = 1,33 \quad (12)$$

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