The International Journal of Energy & Engineering Sciences, 2022, 7 (2) 99-112
ISSN: 2602-294X - Gaziantep University

INVESTIGATION OF THE CHANGE INDUCTANCE OF A COIL AS AIR-IRON-SILICON STEEL AND ALUMINUM CORES

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ABSTRACT

Coils are one of the primary circuit elements of electrical and electronic systems, and their difficulty against the electric current has been known as inductance. So, inductance is a measure of the coils resisting current flow and is the energy storage capacity of the coils. Inductance; It depends on factors such as the number of turns of the coil, the wire cross-section and diameter, the type of core, and the frequency. In the study, the inductance effect of the body to the coil wound on the square carcass; has been experimentally investigated for air, silicon steel, iron, and aluminum environment. In the results obtained, it has been seen that the permeability of the magnetic core material and the effect of the fukolt brake for aluminum are essential. The interpretation has been made by examining the impact of inductance in changing alternating voltage values in the core environment.

Keywords: Coil, Inductance, Fukolt Brake, Magnetic Permeability, Core

1. INTRODUCTION

The concept of coil and inductance is considered an essential parameter in transformers, power transmission lines, electric motors, and electrical systems [1]. One of the main components of power electronics circuits is inductance [2]. The coil presents a relatively great difficulty at the first moment when the circuit is energized against the direct current (DC) [3]. However, after a short time, this difficulty becomes just the resistance of the wire [4]. The situation is different when alternating current (AC) is applied to the ends of a coil. The coil in AC; creates a magnetic field whose direction and strength are constantly changing at its ends [5].

When DC is applied to the coil, the ohmic resistance of the coil (R) opposes the flowing current, while when AC is applied to the same coil, the resistance to the AC will be more significant [6]. This resistance of the coil in AC is expressed by (X_L) and is known as inductive resistance or inductive reactance [7]. One of the other factors affecting the inductance is the core on which the coil is wound [8]. If the core's magnetic permeability increases, the coil's magnetic field intensity will increase, and the inductance will also increase [9]. The number of magnetic field lines formed on a coil wound on a soft iron core is higher than the number of magnetic field lines formed on a coil that does not use any material as a core; that is, the air is the core [10]. Fuco (Eddy) currents or eddy currents create a braking effect on metal moving in a magnetic field. For example, when an aluminum plate pendulum enters the magnetic field while an electromagnet is operating, the strong current caused by the induction voltage creates a braking effect [11]. The study experimentally investigated the change of the inductance effect of air, iron, silicon steel, and aluminum cores on the coil under AC.

2. MATERIALS AND METHOD

2.1. Inductance

The difficulty that the coils put on the current flow is called inductance, and while the coils prevent the current from flowing, they also induce an electromagnetic fields (EMF) in the opposite direction on themselves [12]. If the voltage source is bypassed and the circuit is created with only the coil and resistors, it will have a current due to the induced voltage on the coil. This current flows through the resistor and turns into heat. For this reason, coils are called current storage elements. Inductance is also defined as the capacity to store energy or induce EMF on the coil. The unit of inductance is Henry, denoted by the letter "H" for short. Figure 1 shows a coil.

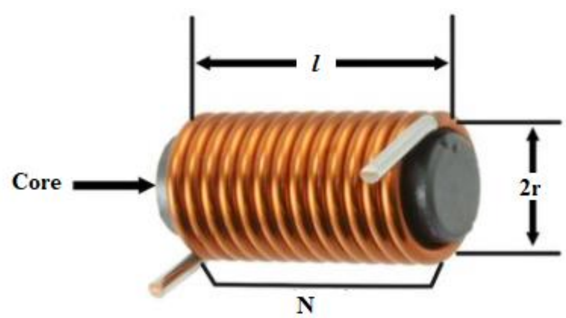

Figure 1. Coil

The inductance (L) formula of the coil is given in equation (1), where N is the number of turns, l is the core length of the coil (m), the magnetic permeability of the core (H/m), A is the core cross-section area (πr^2, m^2).

$$L = \frac{\mu N^2 A}{l} \quad (H) \qquad (1)$$

The inductive reactance (X_L) of the coil is found by equation (2), where f is frequency (Hz).

$$X_L = 2\pi f L \quad (\Omega) \qquad (2)$$

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The digital LCR meter shown in Figure 2 was used for inductance measurement. The measuring range is 2mH/20mH/200mH/2H/20H and the Best Accuracy value is ±(2%+8).

Figure 2. LCR meter

2.2. Experimental Setup

In the experimental setup, a coil with a 21.7-ohm ohmic resistance and a maximum current of 0.8 A was used, which was wound with 1000 turns of insulated copper wire on a square carcass. By pressing the silicon core from silicon sheets, aluminum and iron cores were obtained as one piece. The experimental study measured the electrical output of the coils at different voltage levels under AC, coreless, and core conditions. Core, coil, and reel dimensions are shown in Figure 3.

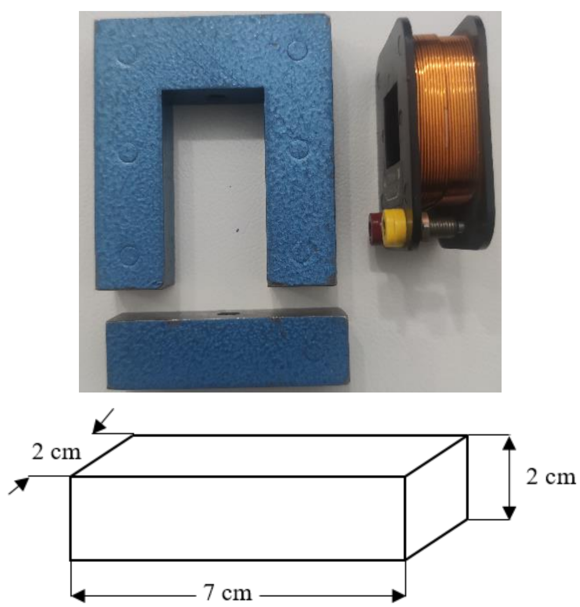

Figure 3. Core, coil and reel dimensions

2.3. Coil operation under coreless AC

If there is no change in current, we cannot talk about inductance in a coil circuit, the inductance of a coil can be expressed by (3) or (4).

$$L = \frac{\emptyset N}{I} \tag{3}$$

L is the inductance of the coil (Henry), ∅ is the magnetic flux (weber), N is the number of turns, and I is the current passing through the coil (A).

$$L = \frac{N^2}{R_m} \tag{4}$$

R_m (1/H) indicates magnetic resistance or magnetic reluctance, that is, the difficulty shown against electric lines of force.

Since the magnetic resistance of the air is high in the case of the air core, according to the formula (5), and in the magnetic circuit according to ohm's law formula, since the magnetic resistance is very high, the magnetic flux is weak, therefore the inductance is small.

$$\emptyset = \frac{\Phi}{R_m} = \frac{NI}{R_m} \tag{5}$$

Figure 4 shows the measurement of the inductance of the Coreless coil with an LCR (Henry-Farad-Ohm) meter. The value from the LCR meter is instantaneous. The LCR-meter does not detect the decrease in the change in flux and the decrease in the self-induction voltage by the saturation of the core with the increase of current in the iron core and silicon steel.

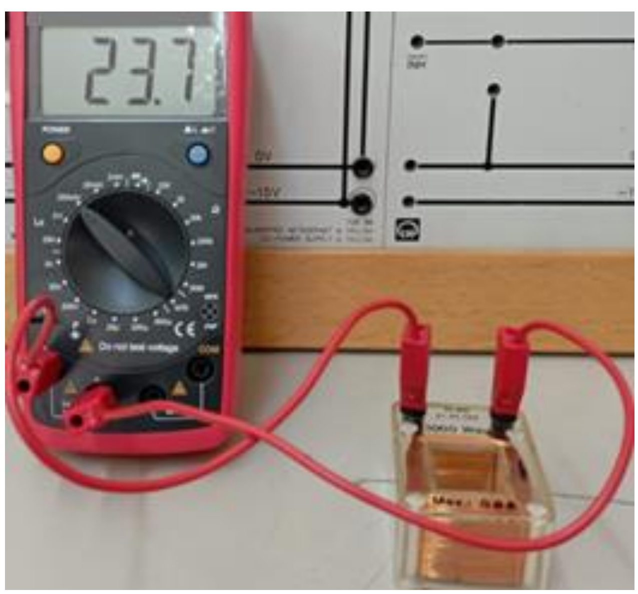

Figure 4. Measurement of the inductance of the coreless coil with an LCR meter

In Figure 5, the connection diagram for the operation of the coreless (air core) coil is given. It is applied to the variable AC coil through the autotransformer at the input.

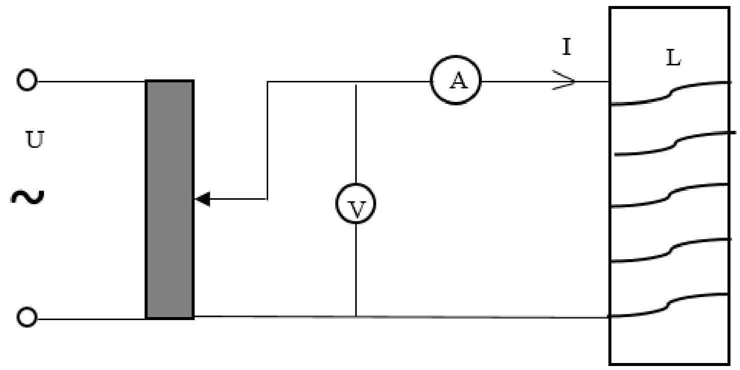

Figure 5. Measurement of the current passing through the coreless coil

In the coreless operation of the coil, the impedance (Z) of the coil is calculated in Formula 6 according to the current drawn by the coil.

$$Z = \frac{U}{I} = \frac{6.83}{0.3} = 22.76\ \Omega \qquad (6)$$

Since the ohmic resistance of the coil is known, its inductive reactance (X_L) is calculated by eq.(7).

$$X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(22.76^2 - 21.7^2)} = 6.86\Omega \qquad (7)$$

The inductance of the coil is found by the Formula 8, with a frequency of 50 Hz.

$$L = \frac{X_L}{2\pi f} = \frac{6.86}{314} = 21.84\ mH \qquad (8)$$

The inductance values and the current drawn values according to the AC applied in the coreless, that is, the air core operation of the coil are given in Table I.

Table I. Current and inductance values from the Coreless Operation of the Coil

U (V)	I (A)	X_L(Ω)	L (mH)	R(ohm)
6.88	0.3	6.86	21.84	21.70
11.40	0.5	6.99	22.26	21.70
13.83	0.6	7.77	24.74	21.70
18.68	0.8	8.62	27.45	21.70
21.10	0.9	8.86	28.21	21.70

The inductance change according to the current drawn by the coil from the Coreless Operation of the coil is seen in Figure 6.

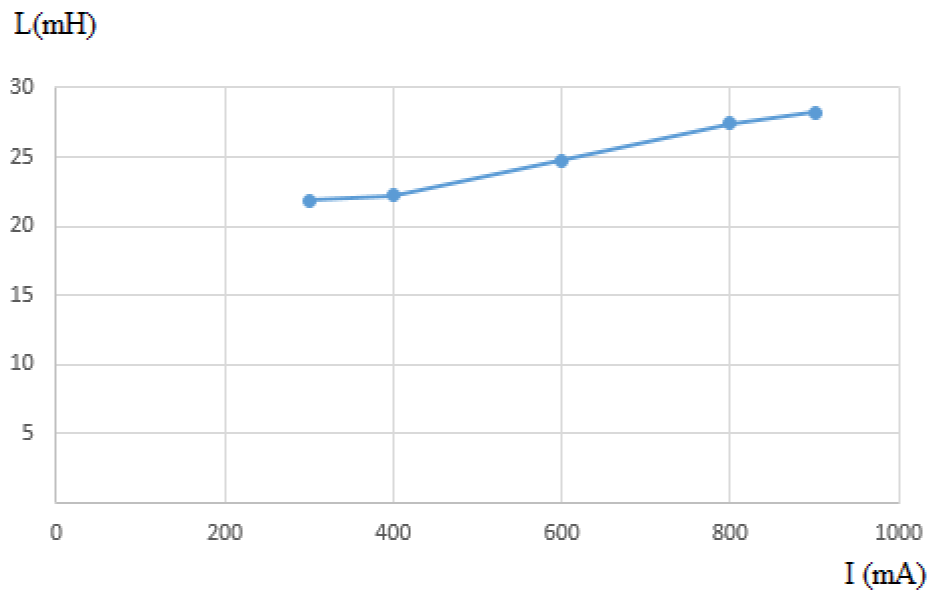

Figure 6. Inductance change in Coreless Coil Operation

As the voltage applied to the circuit in the air core coil increases, the current and magnetic flux increase according to Ohm's law, and therefore the inductance increases.

2.4. Working under AC as the core of the coil

In the operation of the coil as a core, silicon steel, iron, and aluminum were used separately as core materials. The current drawn by the coil was measured and calculations were made by applying AC at different values to each core with an autotransformer. The connection diagram used in the core operation of the coil is shown in Figure 7.

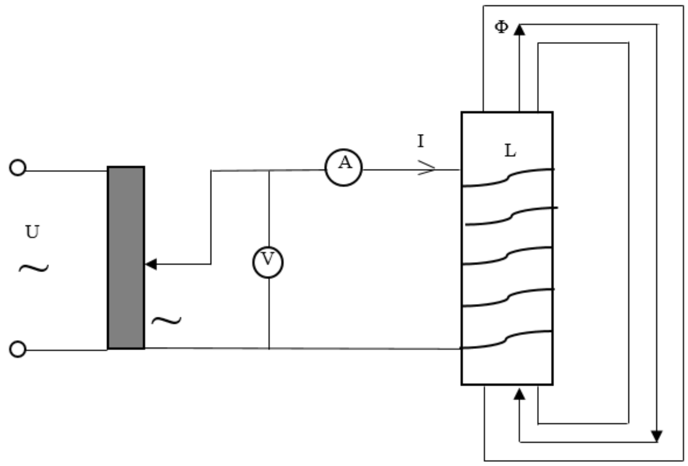

Figure 7. Working of the coil with the core

2.4.1 Coil Operation in Iron Core Environment

Figure 8 shows the measurement of the inductance of the iron core coil with an LCR meter. The value from the LCR meter is instantaneous. The LCR-meter does not detect the decrease in the change in flux and the decrease in the self-induction voltage by the saturation of the core with the increase of current in the iron core and silicon steel.

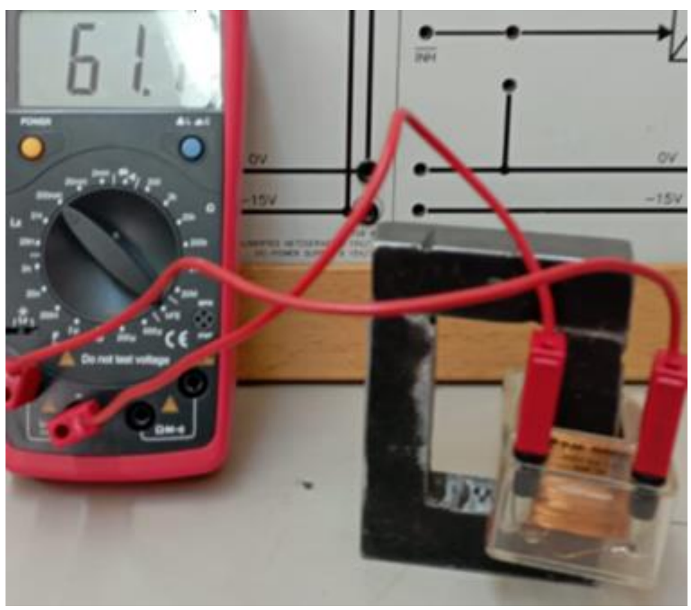

Figure 8. Measuring the inductance of the iron core coil with an LCR meter

In the coil's iron core operation, the coil's impedance (Z) according to the current drawn by the coil is calculated in equation 9.

$$Z = \frac{U}{I} = \frac{30.05}{0.3} = 101.66\ \Omega \qquad (9)$$

The DC ohmic resistance of the coil, as is known, the AC ohmic resistance is calculated with the Equation 10,

R_{AC} =1,2.R_{DC} = 21,7.1,3=28,21 Ω (10)

Its inductive reactance (XL) is calculated by eq. 11.

$$X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(101.66^2 - 28.21^2)} = 97.66\ \ \Omega \qquad (11)$$

The inductance of the coil is found by eq. 12, with a frequency of 50 Hz.

$$L = \frac{X_L}{2\pi f} = \frac{97.66}{314} = 311.01\ mH \qquad (12)$$

The inductance values and the current drawn values according to the AC applied in the iron core operation of the coil is given in Table 2.

Table II. Current and inductance values taken from the Iron Core Study of the Coil

U (V)	I (A)	X_L (Ω)	L (mH)
30.5	0.3	97.66	311.01
39.1	0.4	93.59	298.05
47.1	0.5	89.87	286.21
54.6	0.6	86.51	275.50
68.6	0.8	80.97	257.86
75.5	0.9	78.99	251.56

In the case of an iron core, the inductance change according to the current drawn by the coil is seen in Figure 9.

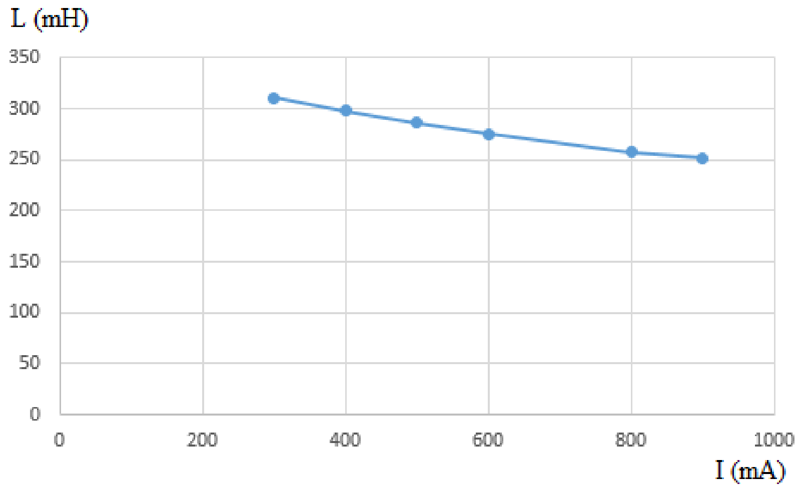

Figure 9. Inductance change in the iron core case

In the case of an iron core, as the voltage applied to the circuit increases, the current increases, so the magnetic flux increases, but it is seen that the inductance decreases. The reason for this is that the iron core is saturated and the change in magnetic flux decreases, accordingly the self-induction electromotive force induced in the coil decreases and therefore the self-induction coefficient (Inductance) decreases.

2.4.1 Operation of the Coil in Silicon Steel Core Environment

Figure 10 shows the measurement of the inductance of the Silicon core coil with an LCR meter. The value from the LCR meter is instantaneous. The LCR-meter does not detect the decrease in the change in flux and the decrease in the self-induction voltage by the saturation of the core with the increase of current in the iron core and silicon steel.

Figure 10. Measuring the inductance of the silicon steel core coil with an LCR-meter

The impedance (Z) of the coil according to the current drawn by the coil in the study of the silicon core of the coil was calculated in eq.13.

$$Z = \frac{U}{I} = \frac{134.6}{0.3} = 448.66\ \Omega \quad (13)$$

Since the DC ohmic resistance of the coil is known, AC ohmic resistance is calculated by eq. (14),

R_{AC} =1,2.R_{DC}= 21,7.1,3=28,21 Ω
(14)

Its inductive reactance (X_L) is calculated by eq.15.

$$X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(448.66^2 - 28.21^2)} = 447.77\ \Omega \quad (15)$$

The inductance of the coil is found by the eq.(16), with a frequency of 50 Hz.

$$L = \frac{X_L}{2\pi f} = \frac{447.77}{314} = 1.42\ H \quad (16)$$

The inductance values and the current drawn values according to the AC applied in the operation of the silicon core of the coil is given in Table 3.

Table III. Current and inductance values taken from the Coil's Silicon Core experiment

U (V)	I (A)	X_L (Ω)	L (mH)
134.6	0.3	447.77	1420
145.7	0.4	363.15	1150
154.5	0.5	307.70	970
161.2	0.6	267.17	850
171.9	0.8	213.01	670
176.5	0.9	194.07	610

In the case of silicon steel core, the inductance change according to the current drawn by the coil is seen in Figure 11.

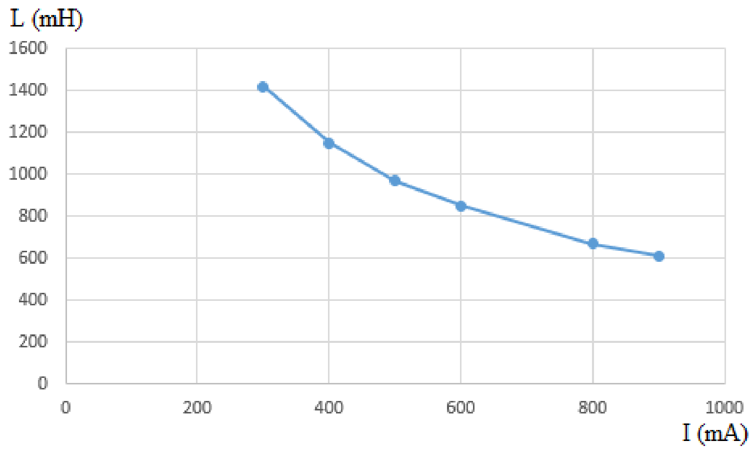

Figure 11. Inductance change in iron core case

Since the magnetic permeability of the silicon steel core is much higher than that of the solid iron core, the silicon steel core becomes saturated at a smaller current value than the iron core, the magnetic flux change decreases, and therefore the inductance decreases.

2.4.1 Coil Operation in Aluminum Core Environment

Figure 12 shows the measurement of the inductance of the aluminum core coil with an LCR meter. The value from the LCR meter is instantaneous.

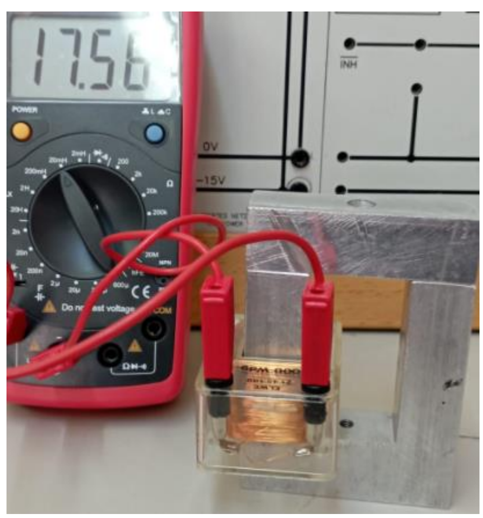

Figure 12. Measurement of the inductance of the aluminum core coil with an LCR meter

In the aluminum core experiment of the coil, the impedance (Z) of the coil according to the current drawn by the coil was calculated in the equation (17).

$$Z = \frac{U}{I} = \frac{9.84}{0.4} = 24.66\,\Omega \tag{17}$$

Its inductive reactance (X_L) is calculated by eq.18.

$$X_L = \sqrt{(Z^2 - R^2)} = \sqrt{(24.66^2 - 21.77^2)} = 11.58\ \Omega \tag{18}$$

The inductance of the coil is found by the equation (19), with a frequency of 50 Hz.

$$L = \frac{X_L}{2\pi f} = \frac{11.58}{314} = 36.87\ mH \tag{19}$$

Table IV. Current and inductance values taken from the Aluminum Core Study of the Coil

U (V)	I (A)	X_L (Ω)	L (mH)
9.84	0.4	11.58	36.87
12.3	0.5	11.58	36.87
14.8	0.6	11.71	37.29
20	0.8	12.41	39.52
22.7	0.9	12.85	40.92

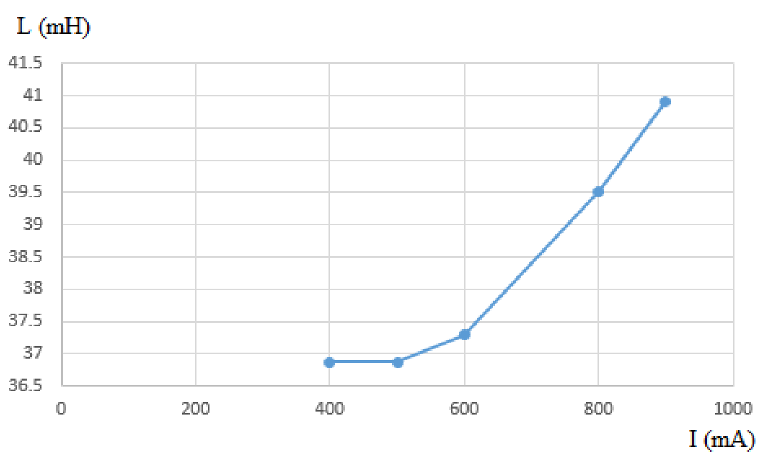

Figure 13. Inductance change in the aluminum core case

It has been previously stated that in the case of an aluminum core, the inductance decreases compared to the air core due to the effect of the fukolt brake. In the case of an aluminum core, the current increases depending on the voltage, and the inductance increases due to the magnetic flux.

CONCLUSIONS

The coils show as much difficulty against DC as the resistance of the wire (R), while in AC, it increases with frequency. The coil resists the DC at first. Therefore, when DC is applied to the coil, the coil is insulating first and then conducting. When AC is applied to the coil, it shows resistance because the direction of the current is constantly changing. Coils briefly show little difficulty (convenience) with DC and little difficulty with AC; that is, it passes direct current and resists alternating current.

In the study, as the voltage applied to the circuit increases in the air core coil, the current and magnetic flux increase according to Ohm's law, and therefore the inductance increases. As the voltage applied to the circuit increases while the iron is in the core state, the current increases, so the magnetic flux increases, but it is seen that the inductance decreases.

This is because the iron core saturates, and the change in magnetic flux decreases; accordingly, the self-induction Electromotive force induced in the coil decreases, and therefore the self-induction coefficient decreases.

Since the magnetic permeability of the silicon steel core is much higher than that of the solid iron core, the silicon steel core saturates at a smaller current value than the iron core, and the magnetic flux change decreases, so the inductance is reduced. In the case of the aluminum core, it is observed that the inductance decreases compared to the point of the air core, and this has the effect of a fukolt brake.

In the case of aluminum core, current increases due to voltage, and inductance increases due to magnetic flux. As it is known, aluminum permeability is much less than the iron core and silicon steel core. In future studies, the core effect will be examined using different materials.

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