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RESEARCH ARTICLE

Research on the electrical effect of ferromagnetic material on the coil

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Abstract

Applying an electric current to the coils causes a magnetic field around them. The self-induction electromotive force in this magnetic field depends on time, coil current, and the number of turns. This magnetic field can magnetize ferromagnetic materials such as iron, cobalt, and nickel. In the study, different values of Alternating and Direct current were applied to the coil wound on the square-shaped carcass under core and coreless conditions. Obtained values are interpreted with tables and graphics. In the application made by placing the silicon core in the coil under varying values, it was observed that the values obtained in the core and coreless cases were the same. In alternating current measurements, it was determined that the electrical current values obtained under both conditions were different. In this study, the effect of the core on the coil has been demonstrated experimentally in the electrical system.

1. Introduction

The increasing world population and rapid technological developments are increasing the demand for electrical energy [1]. In electrical systems, circuit elements such as coils, resistors, and capacitors are fundamental and need to be understood [2]. Coil and core structures are used in the system of electric motors and generators and transformers used in energy transmission distribution [3]. While conductors such as copper, aluminum, and silver are used in the construction of the coils, ferromagnetic materials such as silicon, cobalt, and soft iron are used in constructing the core [4]. Ferromagnetic materials are substances that can be magnetized in the same direction as the magnetic field lines of that magnet while in the magnetic field of any magnet. The object that magnetizes them and becomes very well magnetized when they remain in the magnetic field attracts ferromagnetic materials. When ferrimagnets are heated, they lose their magnetic property at a temperature called the Curie point and turn into a completely normal substance. The Curie point of pure iron is 770°C [5]. A ferrous substance above this temperature can neither be a magnet nor be attracted by a magnetic field. The change in Curie point is due to the loss of the ability of the atomic magnets to orient in a parallel direction. It is known that a magnetic field occurs around a current-carrying conductor [6]. If this conductor is turned into a coil, the magnetic field around the coil becomes stronger [7]. The behavior of a coil changes according to the core and coreless situations, and the magnetic reluctance resistances change. In the study, the effect of a magnetic iron core with a silicon sheet on the coil has been worked.

2. Material and Method

It is known that a magnetic field occurs around a current-carrying conductor. If this conductor is turned into a coil, the magnetic field around the coil becomes stronger. Thus, the coil is in the changing magnetic field environment created by the change of current passing through it. That is, since the coil is in the variable magnetic field created by itself, an electromagnetic induction force (emf) occurs in the coil [8]. This emf induced by the coil staying in the magnetic field created by itself is called "self-induction emf" [9]. Self-induction emf is different from the induction event. Because in the case of induction, the emf is generated by an external field. In self-induction, the coil creates the magnetic field, depending on the current flowing through the coil and its number of turns.

2.1. Self-Induction Coefficient and Its Calculation

The self-induction emf opposes the change in the magnetic lines of force that generates itself according to Lenz's law. Thus, the ability of the coil to resist any change in current flowing through the coil is called the coil's "self-inductance." In short, it is called the inductance of the coil. The unit denoted by the letter L is Henri.

If 1 amp per second change and 1-volt emf is induced in a coil, the inductance of the coil is 1 Henri. The inductance of a coil depends on the change in current flowing through the coil, provided the number of turns of the coil remains constant. L is coil inductance (Henry, N is coil number of turns, $\Delta\emptyset$ changes in a magnetic field (weber), Δ and i change in current (Amps).

$$L = N\frac{\Delta\emptyset}{\Delta i} \tag{1}$$

If we want to calculate the inductance of a coil taking into account the reluctance, we can use the following (2).

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

Rm is Reluctance (Magnetic resistance) (1/Henri), and the Induction of a coil changes with its size. Ferromagnetic materials are widely used to increase the coil's inductance [6]. The expression of inductance depending on the permeability of the environment is given in (3).

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$$L = \frac{N^2 \cdot \mu \cdot S}{l} \quad (3)$$

Where μ is the permeability of the environment (Henri/meter), S is the Cross section of the coil core (m^2), and l is coil length (meter).

2.2. Experimental Setup

Experimental setup, 250 spiral 0.8 mm varnished insulated copper wire coil on a square carcass (the maximum current value of the coil is 1.5 A and the measured ohmic resistance is 1.8 Ω), iron core obtained by pressing from siliceous sheets, The magnetic induction density of the sheets forming the iron core is 12000 Gauss. Adjustable autotransformer (variac), AC consists of a bridge diode for /DC conversion and a capacitor for filter operation. The experimental setup is shown in Figure 1; the experimental study is carried out by measuring the electrical values of the coils in different voltage stages under DC and AC, the variation of the distance between the coils, and the cored and coreless conditions. The dimensions of the core and the reel of the coil are given in Figure 2.

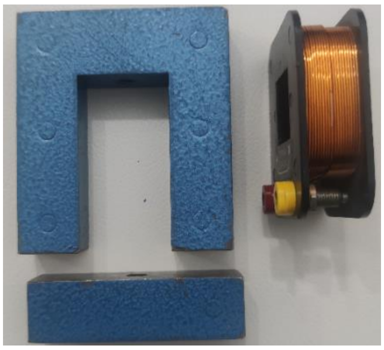

Figure 1. Ferromagnetic core and coil

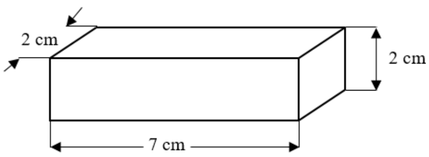

Figure 2. Measurement of core

2.3. Working with Magnetic Core and without Core in DC

When DC voltage is applied to a coreless coil (air core), a DC flows through the coil, and a constant magnetic field is formed around the coil. Since the coil itself is interrupted by a constant magnetic field, no self-induction voltage (opposite emf) is induced in the coil. The only factor limiting the current opposing the DC in the coil is the ohmic resistance of the coil. So I=U/R.

The circuit diagram of the DC-applied coreless coil is given in Figure 3. There is no core here, and a capacitor is used for the filter.

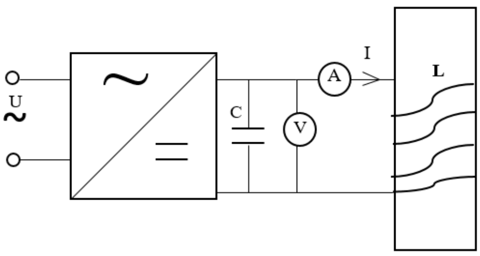

Figure 3. Coil working in DC without core

The circuit diagram of the DC-applied core coil is given in Figure 3. It is converted to AC/DC with a rectifier circuit.

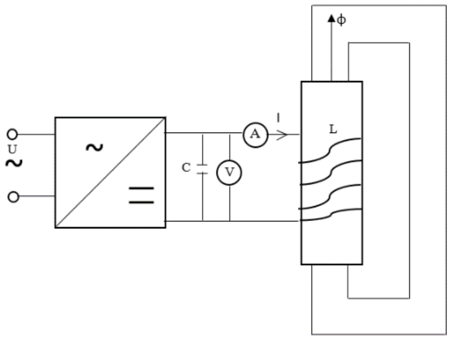

Figure 4. Operation of the coil as a core in DC

The table and curve showing the change of the current drawn by the DC applied ferromagnetic core and coreless coil according to the applied voltage are as follows.

Table 1. U,I are measured in DC with core and without core

U(V)	I(A)
0.5	0.33
1	0.66
1.5	0.99
2	1.3
2.5	1.6

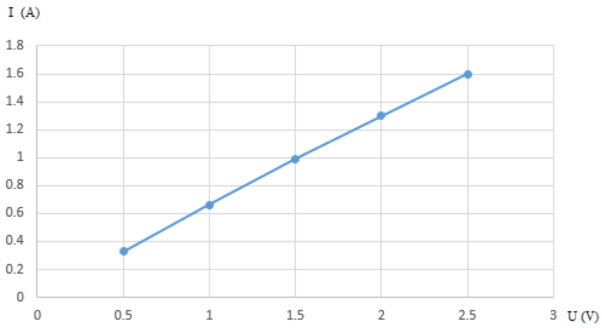

Figure 5. Current - Voltage curve with core and coreless in DC

μ0 is the permeability of the air and μr is the magnetic permeability of the material. When DC is applied to a coil with a ferromagnetic core, since the magnetic permeability of the ferromagnetic core is high (its magnetic resistance is low), increasing μr according to the following formula significantly reduces the magnetic resistance Rm.

$$R_m = \frac{L_o}{\mu_o \cdot \mu_r} \quad (4)$$

According to the expression below, the magnetic flux formed around the coil increases to a great extent.

$$\emptyset = \frac{\theta}{R_m} = \frac{N.I}{R_m} \quad (5)$$

The magnetic flux increasing around the coil is still a constant magnetic flux, the self-induction voltage (opposite emf) is not induced in the coil and the current drawn by the coil is I=U/R.

As a result, when DC is applied to the coil, the current that the coil will draw in the core and the coreless condition is the same, and the relationship between voltage and current is linear. As the voltage increases, the current increases at the same rate. However, the coil's magnetic field dramatically increases in the cored case.

2.4. Working of the coreless coil in AC

If AC is applied to a coreless (air core) coil, an AC flows through the coil, and a variable magnetic field is created around the coil. When the coil windings are interrupted by this variable magnetic field, self-induction voltage (opposite emf) is induced in the coil windings. The formula finds the coil current, where Z is the coil's impedance in ohms.

$$I = \frac{U}{Z} \tag{6}$$

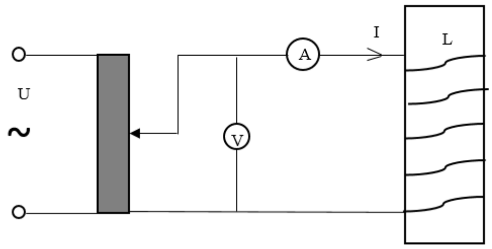

Figure 6. Operation of the coil in coreless AC

The number of magnetic field lines formed on a coil without material as a core, that is, with air as a core, is less than in ferromagnetic materials.

The table and curve showing the variation of the current drawn by a coreless (air core) coil in AC according to the voltage are as follows.

Table 2. U, I are measured in coreless AC

U(V)	I(A)
0.3	0.257
0.8	0.56
1.2	0.77
1.5	0.94
2	1.22
2.55	1.5

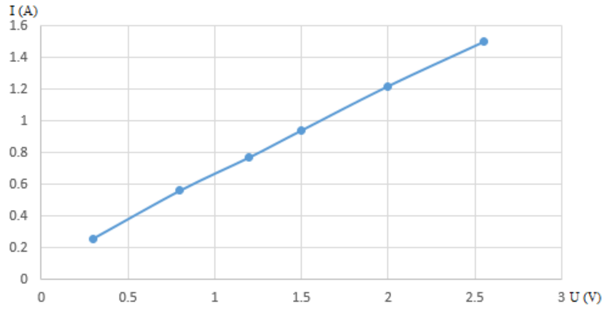

Figure 7. Current-Voltage curve of the coil under AC in coreless condition

Since the magnetic permeability is high (the magnetic resistance is low) when AC is applied to a coil with a ferromagnetic core, increasing μr according to eq.(6) will significantly reduce the magnetic resistance Rm.

$$R_m = \frac{L_o}{\mu_o.\mu_r} \tag{6}$$

According to the formula below, the magnetic flux formed around the coil increases to a great extent.

$$\emptyset = \frac{\theta}{R_m} = \frac{N.I}{R_m} \tag{7}$$

Increasing magnetic flux around the coil greatly increases the self-induction voltage (opposite emf) in the coil compared to the coreless situation, and according to the formula below, decreasing the magnetic resistance Rm in the case of ferromagnetic core greatly increases the inductance.

$$L = \frac{N^2}{R_m} \tag{8}$$

Increasing the inductance causes a high increase in the X_L value according to the following eq. (9),

$$X_L = wL = 2\pi f \tag{9}$$

According to the formula below, the impedance of the coil increases, and according to the expression I=U/Z, the current drawn by the coil decreases greatly.

$$Z = \sqrt{(R^2 + {X_L}^2)} \tag{10}$$

2.5. Working of Coil with Core in AC

The AC circuit of a coil with a ferromagnetic core is given in Figure 8.

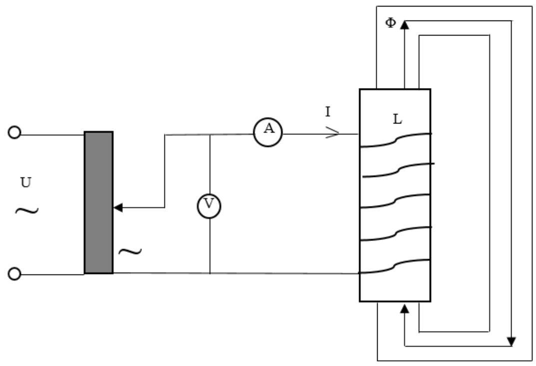

Figure 8. Circuit of the coil with a core in AC

The table and curve showing the change of current according to the given voltage are as follows:

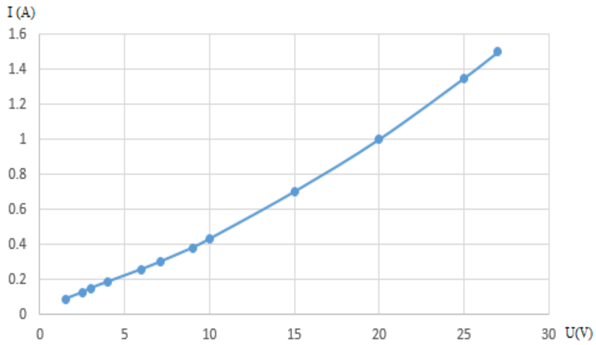

Figure 9. Current-Voltage change of the coil with a core in AC

Table 3. Currents drawn in AC

U(V)	I(A)
1.5	0.086
2.5	0.125
3	0.148
4	0.185
6	0.257
7.1	0.3
9	0.38
10	0.43
15	0.7
20	1
25	1.35
27	1.5

According to the result, when AC is applied to the coil, self-induction voltage is induced in the coil in the coreless and cored condition. However, in the cored case, the increasing variable magnetic field around the coil significantly increases the self-induction voltage induced in the coil, and the current drawn by the coil is reduced considerably compared to the coreless case.

3. Conclusion

Whether alternating or direct current is applied to a coil with a ferromagnetic core, the magnetic reluctance value decreases compared to the coreless case. Therefore, the permeability and the number of lines of force (magnetic flux) occurring around the coil increase considerably compared to the coreless situation. When DC is applied to the magnetic core coil, there is no change in the current drawn by the coil compared to the coreless case. Because when DC is supplied to the coil, the inductance of the coil is zero. In the cored state, the magnetic flux increases. However, the inductance is zero since the magnetic field around the coil is still a constant magnetic field. In other words, the coil draws the same current in both cases in DC, whether with or without a core. The only reason limiting the current here is the resistance of the coil.

However, when AC is applied to the core coil, magnetic permeability and then magnetic flux and inductance of the coil increase with the decrease of magnetic reluctance. Because the magnetic field around the coil in AC is variable, as the inductance of the coil increases, its reactance, and hence its impedance increases, and the current drawn by the coil decreases considerably compared to the coreless case.

For this reason, if DC of the same value is supplied to a relay or contactor operating with AC, the coil will not have inductance. The only factor that resists the current will be the ohmic resistance of the coil, so the relay or contactor coil will draw quite a lot of current compared to the operating situation in AC. Likewise, if the exact value of AC is supplied to a relay or contactor operating with a particular DC, the impedance will occur due to inductive reactance. Since the impedance is too large compared to the ohmic resistance of the coil, the relay or contactor will draw a tiny current. Therefore the relay and contactor will not be able to remove the pallet, and the contacts will not be able to change position. In this study, the effect of air and ferromagnetic material on the coil has been investigated. Experimental investigation of the magnetic effects of different materials is aimed at future studies.

Author contributions

Mehmet Ali Özçelik: Supervision, Writing - review & editing,Validation

Ahmet Aycan: Conceptualization, Methodology, Resources, Writing - original draft, Validation, Visualization

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