Optimization of Magnetic Coil Construction Using Genetic Algorithm Method

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Abstract. In this article, we discuss coil construction that has the right combination of the number of layers and the number of turns per layer. This combination produces a large electromagnetic force with a physical form that is not too large. A magnetic coil can be used as an electromagnetic ejection. The modification of coil construction is done by using the genetic algorithm method. Experiments were carried out using a population of 100 chromosomes and encoded in 8 bits. Then the resulting programming results are calibrated using the FEMM application to obtain a magnetic force profile. The simulation is carried out with a coil forming wire using the #AWG 10 standard which has a length of 3 meter. The results showed that the optimal force was achieved with a coil construction that had 27 layers (nL) and each layer had 38 turns (TPL).

1. Introduction

Electromagnet coil is a type of magnet which consists of a wire wrapped into a coil which is energized by an electric current[1][2]. The current through the wire produces a magnetic field that is concentrated in the center hole of the coil[3][4][5][6]. The magnetic field disappears when the current is turned off. The amount of field depends on the combination of the number of layers, the number of turns per layer on the coil, and the current that is injected into the coil[7][8][9].

The magnetic field of a coil has characteristics that produce a magnetic force profile. The force along the coil is influenced by the magnitude of the magnetic field and the length of the current injected into the coil. To get the magnetic field as needed, a coil construction design is needed[10]. The optimization of coil construction can use several methods, including using genetic algorithm methods[11][12][13][14][15]. This method is used to determine the number of layers and the number of coil turns to obtain the optimal magnetic field and force on an electromagnet coil.

2. Research Method

The wire used as an experiment to form an electromagnet coil has a maximum length of 2 meters with the standard #AWG 10. Coil construction is a coil of wire that has a certain number of layers and a certain number of turns per layer. The electromagnetic force is the force generated by the coil when an electric current is applied. The design of input and output from the Genetic Algorithm program is shown in the block diagram in Figure 1.
In designing the electromagnet coil, several important parameters are used, including the diameter of the AWG #10 standard copper wire, current, voltage, and the inner diameter of the coil shown in Table 1.

| No | Parameters      | Value     |
|----|----------------|-----------|
| 1  | Wire diameter  | 2.588 mm  |
| 2  | Wire length    | 3 m       |
| 3  | Inner Coil     | 12 mm     |
| 4  | Voltage        | 12 Volt DC|
| 5  | Current        | 1 A       |

The outer radius of the coil is calculated using Equation 1.

\[ r_{out} = r_{in} + 2.n.D_k \]  

(1)

The number of turns per layer \( T_{PL} \) can be calculated with \( N \) is the number of turns in the coil using equation 2.

\[ T_{PL} = \frac{N}{n} \]  

(2)

The Genetic Algorithm was chosen to obtain the value of the number of layers and the number of turns per layer to obtain the maximum magnetic field provided that the length of the wire is determined with \( P_{kn} \) is wire length layer \( n \) and \( D_{L1} \) is coil diameter at layer 1 according to the Equation 3.

\[ P_{kn} = \pi.T_{PL}.(n.D_{L1} + (n^2 - n).D_k) \]

(3)
Calculation of the energy generated by the coil with the length of the wire which has an inductance (L) in Henry units and current flows in ampere (A) using Equation 4.

$$E = \frac{1}{2} L I^2$$

(4)

3. Result and Analysis

To validate the electromagnetic coil design, the Finite Element Method Magnetics (FEMM) is used as a reference for the 1000 coil specifications with an object in the form of a spherical iron placed in the solenoid. The object is moved across the inside of the coil from one end to the other. The coil is energized by 1 ampere of voltage 12 volts DC shown in Figure 3.

![Fig. 3. Magnetic field with respect to coil length using FEMM.](image)

The objective function in the optimization process is carried out by placing an object in the form of an iron ball which has a diameter of 11 mm with a distance of 10 mm from the end of the coil which is coded into the binary number 2x8 bits. The simulation calculation results from the smallest number of layers to the largest number of layers produce the force profile shown in Figure 4. This figure is a graph of the number of layers (nLayer) against the maximum force. Meanwhile, the number of layers affects the number of turns per layer, because the length of the wire is fixed.

![Fig. 4. Coil optimization](image)
The optimal coil design for copper wire with a length of 3 meters produces 27 layers and 38 turns. The construction has a magnetic field profile concerning position (coil length) is shown in Figure 5. In this figure, a comparison of the magnetic field profile for the number of layers 26 produces 41 turns per layer, and the number of layers 28 which produces turns per layer is 36. The simulation results show that the number of layers 27 has the greatest magnetic field shown in the green graph.

The force profile at each position (along with the coil) is shown in the comparison of the force profile for \( n_L = 26 \) with \( T_{PL} = 41 \), \( n_L = 27 \) with \( T_{PL} = 38 \) and \( n_L = 28 \) with \( T_{PL} = 36 \). The simulation results show that \( n_L = 27 \) has the greatest force as shown in the graph with green. Different magnetic field values, of course, have different force values, so to design a solenoid coil it is necessary to consider the combination of the number of layers \( (n_L) \) and the number of turns per layer \( (T_{PL}) \) accordingly to have a maximum force. The force profile is shown in Figure 5.

**Fig. 4.** Coil optimization

![Coil optimization graph](image)

**Fig. 5.** Electromagnetic force

![Electromagnetic force graph](image)

4. Conclusion

In this study, copper wire with AWG # 10 standard was used as a coil making material which has a length of 3 meters. The simulation results show that to get an optimal electromagnetic coil a good design is needed to determine a large number of layers \( (n_L) \) and the small number of turns per layer \( (T_{PL}) \), because the number of turns per layer \( (T_{PL}) \) is large but has several layers \( (n_L) \) small or otherwise does not necessarily have an optimal magnetic field or force so that the appropriate combination is needed. The results of the experiment (simulation) produce that the maximum force is achieved in the coil construction which has 27 layers \( (n_L) \) and 36 turns per layer \( (T_{PL}) \) efficient.

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