Design Multi Field Electromagnet Based on Copper Plate with Single Electric Current

Sony Wardoyo¹², Mitra Djamal¹, Maman Budiman¹, Kian Ming³

1) Bandung Institute of Technology, Indonesia
2) University of Cenderawasih, Indonesia
3) Parahyangan Catholic University, Indonesia

Email: sonywardoyo@students.itb.ac.id, mitra@fi.itb.ac.id

Abstract. The magnetic fields produced by an electromagnet depends on the amount of current and voltage. A single current source can produce multi-field magnetic fields, the position of the solenoid connected to the electric current source, where there are multi connectors that can be switched based on the composition of the helical coil and from the data obtained that this can proved. This research was carried out in a helical and design of copper plates forming solenoid windings, each part of the partition plate numbered 10, 15, 20, and 30 connected to electric currents of 1.5, 3, and 4.5 Ampere and the switch functioned to flow electric current to the partition based on the number of electromagnet plates. The experimental results obtained that the number of plates can produce multi magnetic field with a single current source with a range 0 to 8 mT which is measured using Gaussmeter. The benefits of this research will have impact on physical and engineering research related to the use of electromagnets that are portable and concise but with a single electric current source with multi magnetic fields, besides the next research has the potential to be developed in order to produce high magnetic fields.

Keywords: electromagnet, field, current, plate, copper.

1. Introduction

The development of copper plate type electromagnets was first developed by Francis Bitter at MIT, in 1936, so it was called the ‘Bitter’ type electromagnet or resistive magnet. The magnet developed is a helical-shaped coil formed by a stack of copper plates designed in the form of discs, combined with a separator sheet between plates, an insulator and integrated with a cooling system using water to avoid heat generated from large electric currents, [1][4]. When compared to conventional electromagnets that use wire coils, copper plate-based electromagnets are relatively easier to modify, because they are easily added or reduced by the number of turns in this case copper plates because they are ideal in the development of electromagnets compared to other metal materials such as gold, silver and aluminum, [5].

Achievements by the NHMFL magnetic research institute in the US were able to produce 41.5 Tesla Bitter electromagnets with cooling systems, [7][11], in addition experiment magnet technologies in optics, [2]. The Radboud University HFML magnetic field research institute in Nijmegen also has a plate type electromagnet with a DC current source that is used for research services in the field of high magnets, with some research that has been done in the field of engineering science, [6][8][9][10].
Several studies have been carried out using plate type electromagnets including quantum physics research, [8][12]. The problem is that copper plate-based electromagnets that have been developed are not portable and are also not designed to produce multi magnetic fields. By referring to the research carried out by NHMFL and HFML, in this study the initial design of a portable type plate electromagnet prototype was able to produce multi magnetic fields with a single DC electric current source.

\[ \frac{a_2}{a_1} \]

Figure 1. Geometry factor on electromagnet design, [5]

1.1. Alpha Value
The Alpha value is related to the diameter ratio of a solenoid, in Figure 1, the form of the equation is

\[ \alpha = \frac{a_2}{a_1} \] (1)

1.2. Beta Value
Beta values are closely related to the value of the ratio between the height of the solenoid and the inner radius of the electromagnet, where the geometric equation is

\[ \beta = \frac{h}{2a_1} \] (2)

1.3. Fabry Factor
In equations (1) and (2) are substituted in equation (3) which is called the Fabry factor equation, is an expression to produce the central plane of the solenoid as a function of the geometry dimension, as a function of the value \( \alpha \) and \( \beta \),[5].

\[ G = \frac{1}{\sqrt{4\pi \beta \ln \alpha}} \ln \frac{\alpha(\beta + \sqrt{1 + \beta^2})}{\beta + \sqrt{\alpha^2 + \beta^2}} \] (3)

1.4. Magnetic Field
Fabry factors have dimensionless values that are closely related to the design of an electromagnet. This becomes a reference in the aspect of theoretical studies regarding the prediction of the magnitude of the magnetic field \( B \) produced from the design that has been designed, the form of its physical equation,

\[ B_0 = \frac{\mu_0 n m}{a_1^3} \] (4)
Equation (4) is a large magnetic field associated with geometry factors, where $B_0$ is the magnitude of the magnetic field in the middle of the solenoid, $W_m$ is magnetic field energy. So that a large factor in the solenoid inner, outer and high radius plays a role in the magnitude of the magnetic field produced.

2. Materials and Method

The basic principle of plate-based electromagnets is that there are geometric factors underlying their physical equations. This factor is the basis for the design and development of electromagnets, as in Figure 2a, the results of the design using the academic version of ANSYS, [13][14], which has been tested for plate structure simulation. In Figure 2b the process of assembling copper plates and insulators is part of a helical coil, in which the position of the insulator is sheared 90° below the copper plate, so that when arranged with other plates it will form a helix. The platform as shown in Figure 2c, is a framework or chassis that unites all the helical plate components into electromagnets, [15].

![Image](a) ![Image](b) ![Image](c)

**Figure 2.** The design process to copper plate based electromagnetic assembly, (a) Design and simulation using the academic version of ANSYS 19.2 software, (b) Copper plates and insulators in 1 coil, (c) Copper plate based electromagnetic circuits, [15].

The electromagnetic platform or chassis uses aluminum material, with insulators using heat-resistant Teflon paper with a thickness of 0.1mm. While on the conductor plate used for coil plates, using copper with a thickness of 0.3mm with an inner diameter of 20mm and an outer diameter of 50mm, which is printed and cutting using a laser of 30 plates. This amount is equivalent or equivalent to 30 solenoid turns. There are 4 small holes which are divided into the same position, functioning as a place to adjust the position of the conductor plates and insulators made of heat-resistant Teflon paper, arranged into a helical coil. The mechanism of action of a multi-magnetic copper plate based electromagnet is a variety of connecting cables that are placed on the part of the plate partition, whose experimental data has been taken.

In Figure 3 is an experimental design of magnetic field measurements on a copper plate-based portable plate type electromagnet prototype, which has been integrated with a DC electric current source and Gaussmeter measuring instrument. The switch system plays a role in the system of transferring the number of plates in this case “reduction” and “addition” electrically. This mechanism will have the effect of a multi-magnetic field, even though the electromagnet is supplied with a constant electric current. The simple analogy is with the gear shift system in car vehicles, high gear to increase speed and low to reduce speed.

The electromagnetic testing process and retrieval of experimental data using multimeter instruments and measuring instruments, manufacture, SANWA, cd800A series, are used to check and test between plates to stay connected to one another. Measurements made by large magnetic fields using Gaussmeter, manufacture WEITE, WT10A series with a range of 0-2 Tesla, where measurements are made from plates to 10, 15, 20, 25 and 30, 4.5 volt DC current voltage sources, manufacture GW Instek, series GPS-1850D, with an electric current variation of 0.5 to 4.5 Ampere. Impulse magnetizing fixtures typically consist of a coil wound on a nonmagnetic support structure that platform and houses of electromagnet, [3].
Electromagnets that use copper wire as a solenoid coil, it is difficult to apply a mechanism like this, this is because the winding of the wire overlap each other up and towards the outside of the radius. In contrast to the type of plate, the addition of the number of turns is in line with the iron core and the magnetic field.

3. Results and Discussion
The results of this study are simulation and physical in building portable electromagnets based on copper plates, based on the research method obtained $\alpha$ and $\beta$ values. In Figure 4a is a graph simulation for alpha values based on copper plate geometry, this value means that the size of the inner diameter is very influential on the magnitude of the magnetic field produced by the electromagnet, while in Figure 4b which is a significant beta value the number of plates is also high electromagnets have a role in the magnetic field produced in accordance with the physical meaning in equations (1) and (2).

The values of $\alpha$ and $\beta$ greatly influence the Fabry factor as shown in Figure 5, the simulation results for the relationship between Fabry factors and the radius in the copper plate. In plate prototype $a_1 = 10$ mm the value of Fabry factor is not equal to the ideal $a_1$ value which is between 3 and 5 mm, which means that in the next study a value of $<10$ mm will be carried out. This copper plate-based electromagnetic prototype is the initial stage of this research, which focuses on theoretical, simulation and experimental testing and is the initial foundation for the design and design of the next prototype.
Figure 5. Relation Fabry factor and inner radius from copper plate.

The experimental results of measuring the magnitude of a magnetic field on a portable electromagnetic prototype of a copper plate type, seen in Figure 6, magnetic field mapping shows approximately there are 6 color spectrum that represent the magnetic field of each plate with variations in electric current from 0.5 to 4.5 amperes. The lowest magnetic field range is detected 0.1 mT on the 10th plate with a 0.5 ampere electric current and the highest 8 mT on the 30th plate with a 4.5 ampere electric current.

Figure 6. Mapping and experiment of magnetic field.

The switch system is applied to the 10th, 15th, 20th, 25th and 30th plates. In Figure 7, the results of magnetic field measurements based on plate division and also a single electric current which are 1.5, 3.0 and 4.5 amperes respectively implemented by electromagnets. The first graph on the 1.5 ampere electric current source shows an increase in the magnetic field 0.1 to 0.2 mT when the electromagnets are switched from 10 to 30 plates. Then for a 3 Ampere electric current, an increase of up to 5 mT and 8 mT for a 4.5 Ampere current source.
Figure 7. Multi-field electromagnet with single electric current

The experimental results prove that the switch system has a role in a multi-magnetic field system with a single electric current source, which if developed further can provide benefits in engineering, as well as in physics experiments related to magnetic fields. Of course this research still lacks, because the magnetic field produced is still in the mT range, electromagnet geometry factor, construction, material, voltage and electric current greatly influences the magnitude of the magnetic field on the plate-based electromagnet which will continue to be used for subsequent developments.

4. Conclusion
The design and copper plate-based electromagnetic experiments have been carried out successfully and copper plate-based electromagnets can be utilized to produce many magnetic fields, with a fixed source of electric current and a switch system in each electromagnetic plate partition. Theories and experiments also prove that the alpha and beta values integrated in the Fabry factor have a large influence on the creation of large magnetic fields, this is because it is related to the diameter, number of turns and height of the solenoid. In addition to the electromagnetic design based on copper plates, it is easy to add and reduce the number of plates in this case solenoid windings compared to electromagnets, but this study still has a disadvantage, namely the magnitude of the magnetic field has not reached the Tesla order, so the next stage of research will focus on increasing large magnetic field on a portable copper plate-based electromagnet.

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