A measurement low magnetic field at copper plate electromagnet

S Wardoyo1, M Djamal2,* and M Budiman2

1Physics Department, University of Cenderawasih, Jayapura, Kamwolker Street, Indonesia
2Physics Department, Bandung Institute of Technology, Bandung, Ganesha 10 Street, Indonesia

*mitra@fi.itb.ac.id

Abstract. Discovery of electromagnets has had a great influence on the development of science and technology, which due to the nature of the magnetism that can be arranged so that it can provide practical benefits including electric motors, relays, power generators, and automatic door switches. In this research, an electromagnet the form of copper plate with hole in the middle for iron core. Each plate has an insulator that separates between each plate which is arranged in threads to form a helical coil of copper plate. Value obtained from design electromagnets using copper is 0 to 8 mT, with measurement using Gaussmeter as a reference in the development of sensors using giant magnetoresistance. The implications and application from this research is portable and concise high field in the form of copper plate models. In the future it potential application on biomedical and engineering.

1. Introduction
Electromagnet is a unique combination between an iron core and a coil of wire that is powered by an electric current. A physics principle that is the basis of every science and technology research. The development of copper plate type electromagnets by Francis Bitter has laid the foundation for a new development for high magnetic fields. The combined conductor and insulator plates formed like helical geometry produce a magnetic field behavior that is far from the wire type geometry model, so that when viewed from this invention it has the potential to open new gates for the most recent research,[1][4][5]. In this study, a preliminary study was conducted to design the simplest type of electromagnet plates by adopting the results of previous studies.

Recent studies have found high magnetic fields above 40 Tesla. With the most complex design in infrastructure supporting high-field electromagnets including the cooling process of the conductor plates used, [7][11][12], Another benefit of applying other sophisticated research is in the development of optical technology, [2]. Research and development carried out by HFML on bitter type electromagnets is not only for the sake of science but also the engineering sciences carried out by other institutions that want collaboration, [6][8][9][10]. High level research in the field of quantum mechanics can also be experimented with using high magnetic field technology, which is why the benefits of this electromagnet are so great, [8]. If we look at the basic prototype model, then this type of electromagnet has a fixed and large base, this is because of the complexity of the supporting components. For this reason, this research designed a Bitter-type electromagnet that is compact in size
but with a limitation in the early stages of design that is more focused on the mechanism and working principle of producing magnetic fields.

![Image](image-url)

**Figure 1.** Institutions that conduct research on plate type electromagnets.

Electromagnet has become the core of every technological development starting from, not escape from the use of electromagnets. One application of the magnetic field in the medical purpose is MRI, but it is also experimental and implementation on energy physics. The main objective of this research is to produce a plate type electromagnetic form that can be used commercially, is simple, low cost and can be applied to schools and campuses.

In its progress, research and development of electromagnets has had a major impact on various discoveries in the fields of engineering and science. As shown in Figure 1, institutions that conduct research on plate type electromagnets with targets to be achieved in the future.

![Image](image-url)

**Figure 2.** Geometry factors for electromagnetic design optimization.

Figure 2 is a cross section of copper plate type electromagnet geometry. The combination of the outer and inner radius is called the alpha value, while for the height is a beta value. The combination is important to get the optimal plate design. This combination of physics and mathematics is a form that reflects the value produced by the middle plane of the electromagnetic solenoid geometry of plate diameter and combination in height.

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

**Equation (1)**

Fabry factor in equation (1) important in the process of producing an electromagnetic design, this is because geometry has a substantive and structural role in the process of producing a magnetic field \( B \) from the equation. Besides the combination of the number of plates arranged helically will affect the amount of magnetic field produced and is proportional to the amount of electric current,
\[ B_0 = \sqrt{\frac{\mu_0 W_m}{a_1^3}} G \]  

Equation (2) is a magnetic field value related to the geometrical value in the form of magnetic height and also the diameter of the copper plate, variable \( B_0 \) is the value of the magnetic field in the solenoid core, and the magnitude of the magnetic energy \( W_m \). From the above equation it can be concluded that the diameter factor has a very large role in producing magnetic fields.

**Figure 3.** Magnetic field values are produced by the combination of the number of plates and the source of electric current, [14].

From previous studies, [14], seen in Figure 3, applications from copper plate type electromagnets have been obtained, which make multiple magnet fields using an electric current, the mechanism of which is a switch system applied to plate partitions with varying amounts of adjusted.

2. Materials and Method
Copper plate based electromagnet theory is a mathematical parameter that is the geometry of height and diameter on which the physical equation is based. It also becomes a handle in making prototypes from the initial design, used design and using software. Analysis of the dimensions and geometry of the copper plates were used as design parameters. Optimization, design, process analysis of copper plate electromagnet structure and physical structure design are carried out using finite element analysis software, [13][14]. Figure 4a shows the design results which are then used in the process of printing plates through laser cutting on copper sheets with a thickness of 0.3mm. the results are shown in Figure 4b.

**Figure 4.** (a) plate design using ANSYS, (b) the results of laser cutting on copper plates.

With a radius of \( a_1 = 5 \)mm, as in previous research results, [14], it can be found that the optimal results must be close to 2 mm to get the best results, according to the Fabry Factor simulation. But in this early stage of research, it is hoped that an ideal model can be obtained that can describe the phenomenon of copper plate type electromagnets.
2.1. Measurement of the Magnetic Field on Copper Plate Type Electromagnets

The electromagnet used in this experiment is a copper plate type, with the number of plates arranged helically as 30 pieces, which if translated as 30 turns of solenoid. Physically the main parameters in building copper plates include magnetic field strength, \( H \) (A/m), flux magnet density, \( B \) (Tesla), and flux magnet, \( \Phi \) (Wb), \([2][3]\). Simulation and design using ANSYS 19 academic version, \([15][16]\).

![Figure 5. Measurement of magnetic fields using Gaussmeter.](image)

By using variations in the electric current source of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5 amperes, from the GW Instek brand Power Supply device, to produce varying magnetic fields, with an electric potential of 4.5 volts. Testing prototypes with low currents and electrical potential is intended to get the lowest limit of the ability of the prototype to produce a magnetic field, besides the safety factor is the main reason. As shown in Figure 5, using the WT10 series gaussmeter from Weite Technology manufacturing, with the smallest standard value of 0.1 mili Tesla to the largest of 2 Tesla.

2.2. Testing of GMR Sensors on Copper Plate Type Electromagnets

Experiments carried out to test copper plate type electromagnets using GMR-based magnetic sensors, the sensor response of changes in the magnetic field on the prototype. The purpose of this method is to ensure that the linearity of the magnetic field changes to the effect of the Giant Magnetoresistance of the sensor.

![Figure 6. Set up a magnetic sensor based on Giant magnetoresistance.](image)

In Figure 6, the sensor position adjustment uses a plastic caliper, by adjusting the horizontal distance of the \( r_{\text{GMR}} \) and vertical \( h_{\text{GMR}} \) from the center of the iron core on a copper plate type electromagnet. Horizontal spacing is done in the range of 10 to 30mm and vertical ranges of 3, 5 and 7mm.

3. Results and Discussion

The measurement results obtained that the copper plate type electromagnet prototype is able to work well. Gaussmeter is used to detect magnet phenomena generated meanwhile GMR sensor serves to determine the output in each magnetic field change.

Plate-type electromagnets are able to work well with the lowest magnetic field produced by 2 mT on the 10th plate, while the highest is 8.5 mT on the 30th plate. Based on the data, it appears that the
The addition of a magnetic field is very linear with the addition of an electric current to the power supply, which means that the electromagnet works consistently and is not volatile. Physically it means that the electric current is able to flow well, even though the solenoid is in the form of copper plate partitions.

3.1. Magnetic field measurement results
Mapping and magnetic field graphs are shown in Figure 7, the red mapping shows the highest magnetic field of 8.5 mT and the color of purple to blue is the lowest mapping of 2 mT.

![Figure 7. The results of measurements on copper plate type electromagnets.](image)

With the smallest accuracy value of 0.1 mT, the graph shows linear and consistent results based on the increase in the electric current source. This is important if plate type electromagnets are to be applied commercially. Apart from the simple prototype design and light weight. From the measurement results with gaussmeter, the results obtained will be proportional to the GMR sensor output which is also ideally linear.

3.2. GMR magnetic sensor output
Measurement variations based on horizontal distance of $r_{GMR}$ and vertical $h_{GMR}$, shown in Figure 8, the horizontal measurement range from 10 to 30mm, with a vertical distance of 3mm, the sensor output mapping is not too linear, shown in Figure 8a.

![Figure 8. $r_{GMR}$ and $h_{GMR}$ position variations on GMR sensors, (a) 3mm, (b) 5mm and (c) 7mm](image)

When compared with the data in figures 8b and 8c, the linearity of the sensor output results is at a vertical distance of 5mm.

3.3. Output Sensor Results
The results experiment and measurement by copper plate type electromagnet prototypes using GMR sensors that are consistently linear, as in Figure 9, it appears that linearity is needed in the development of magnetic sensors.
In addition, the development of plate type electromagnets that consistently produce magnetic fields is very useful to be developed as a magnetizer for commercial purposes. With the GMR-based magnetic sensor, a very small magnetic field can be detected.

4. Conclusion
Experimental results which prove the advantages of plate type electromagnets compared to copper wire types are easy to add or subtract the number of turns.

From the results of measurements using Gaussmeter, it was found that the magnitude of the magnetic field measured from 0 to 8 mT with the use of 10 to 30 copper plates (30 coil turns). The electric current source used is 0.5 to 4.5 amperes with a potential difference of 4.5 volts. Research on measuring weak magnetic fields on copper plate type electromagnets has been successfully carried out. Minimum magnetic field measurements of 2 mT, while a maximum of 8.5 mT. With variations in electric current 1 to 4.5 amperes with a potential difference of 4.5 volts. Testing of magnetic sensors based on Giant Magnetoresistance (GMR) using a magnetic field of 8.5 mT, the sensor managed to detect the magnitude of the magnetic field with a linear sensor output, in the range of \( r_{GMR} = 10 \text{ mm} \) to 30 mm and height of \( h_{GMR} = 5 \text{ mm} \) in 8.5 mT magnetic field it generates linear data for the sensor.

5. Acknowledgement
Author would like thanks to DIKTI, for the Doctor Dissertation Research Grant (PDD), also the Bandung Institute of Technology, through the Physics Doctoral Program which has accepted the author as a student, and the Cenderawasih University where the author Institution.

References
[1] A reference to the optimization of copper plate type electromagnets.
Bates, E.M., Birmingham W.J. and Talamas, C.R., “Design Optimization of Nested Bitter Magnets”, IEEE Trans. On Magnetics, 53(3), pp. 1-8, 2017.

[2] A reference to the development of advanced electromagnets.
Bird, M.D., Dixon, I.R. and Toth, J., “Design of the Next Generation of Florida-Bitter Magnets at the NHMFL”, IEEE Trans. On Applied Superconductivity, 14(2), pp. 1253-1254, 2004.

[3] A reference about permanent magnet.
Furlani, E.P., “Permanent Magnet and Electromechanical Devices”, Academic Press, 1-3, 2001.

[4] A reference high magnetic field electromagnet.
Kolm, H.H., “Advances in the Generation and use of Very High Continuous Magnetic Fields”, Nature, 192, pp. 299-300, 1961.
[5] A reference geometry equation for plate type of electromagnet. 
Kratz, R. and Wyder, P., “Principles of Pulsed Magnet Design”, Springer-Verlag, I-53, 2002.

[6] A reference to the benefits of plate type electromagnets in science research. 
Motokawa, M., Awaji, S., Miura, S., Hamai, H., Mogi, I. and Watanabe, K., “Construction of Large Scale Bitter Magnet and its Application to Crystal Growth in Levitating Water”, IEEE Trans. On Applied Superconductivity, 10(1), pp. 905-906, 2000.

[7] A reference to the development of 45 Tesla electromagnets. 
Ouden, A., Wulffers, C.A., Hussey, N.E., Laureijs, G., Wijnen, F.J.P., Wulterkens, G.F.A.J., Bird, M.D., Dixon, I.R. and Perenboom, J.A.A., “Progress in the Development of the HFML 45 T Hybrid Magnet”, IEEE Trans. On Applied Superconductivity, 26(4), pp. 1-3, 2016.

[8] A reference to the benefits of high-field electromagnets in laser spectrometer applications. 
Ozerov, M., Bernäth, B., Kamenskyi, D., Meer, A.F.G., Christianen, P.C.M., Engelkamp, H. and Maan, J.C., “A THz Spectrometer Combining the Free Electron Laser FLARE with 33 T Magnetics Fields”, Applied Physics Letter, 110(094106), pp. 2-5, 2017.

[9] A reference of development plate type of electromagnet. 
Perenboom, J.A.A.J., Maan, J.C., Breukelen, M.R., Wiegars, S.A.J., Ouden, A., Wulffers, C.A., Zande, W.J., Jongma, R.T., Meer, A.F.G. and Redlich, B., “Developments at the High Field Magnet Laboratory in Nijmegen”, Journal of Low Temperature Physics, 170, pp. 520-522, 2012.

[10] A reference about experiment used electromagnet. 
Sabulsky, D.O., Parker, C.V., Gemelke, N.D. and Chin, C., “Efficient Continuous-Duty Bitter-Type Electromagnets for Cold Atom Experiments”, Review of Scientific Instruments, 84(104706), pp. 1-5, 2013.

[11] A reference about electromagnet construction. 
Toth, J. and Bole, S.T., “Design, Construction, and First Testing of a 41.5 T All-Resistive Magnet at the NHMFL in Tallahase”, IEEE Trans. On Applied Superconductivity, 28(3), pp. 1-4, 2018.

[12] A reference to the benefits of plate type electromagnets in scientific research. 
Wang, Z., Wu, J., Yang, W., Bera, A.K., Kamensky, D., Islam, A.T.M.N., Xu, S., Law, J.M., Lake, B., Wu, C. and Loidl, A., “Experimental Observation of Bethe Strings”, Nature, 554, pp. 221-222, 2018.

[13] A reference to measuring magnetic fields on plate-type electromagnet prototypes. 
Wardoyo, S., Djamal, M., and Budiman, M., “Design and Development Portable Eelctromagnet Based on Copper Plate”, 8th National Physics Conference, UNJ, Jakarta, pp.1-5, 2019.

[14] A reference application for copper plate type electromagnets that produce multi magnetic fields. 
Wardoyo, S., Djamal, M., Budiman, M., and Ming, K., “Design Multi Field Electromagnet Based on Copper Plate with Single Electric Current”, ICAPMA, pp.1-6, 2019.

[15] A reference to the design and simulation of copper plates on electromagnets. 
Wiegars, S.A.J., Rook, J., Ouden, A., Perenboom, J.A.A.J. and Maan, J.C., “Design and Construction of a 38 T Resistive Magnet at the Nijmegen High Field Magnet Laboratory”, IEEE Trans. On Applied Superconductivity, 22(3), pp. 2-3, 2012.

[16] A reference to the design and simulation of copper plates in electromagnets. 
Wijnen, F.J.P., Wiegars, S.A.J., Velsen, J.M.H., Rook, J., Ouden, A., Perenboom, J.A.A.J. and Hussey, N.E., “Construction and Performance of a 38-T Resistive Magnet at the Nijmegen High Field Magnet Laboratory”, IEEE Trans. On Applied Superconductivity, 26(4), pp. 1-2, 2016.