MATEC Web of Conferences **218**, 02001 (2018) https://doi.org/10.1051/matecconf/201821802001
ICIEE 2018

Design of a Sensor Coil for Electromagnetic Induction Tomography

Dita Ayu Banjarnahor[1], *Rohmadi* Rohmadi[2,*] *Amir Rudin*[2], *Imamul* Muttakin[3], and *Warsito P.* Taruno[2]

[1]Department of Engineering Physics, Institut Teknologi Bandung, Bandung, Indonesia
[2]CTECH Labs Edwar Technology, Tangerang, Indonesia
[3]Engineering Tomography Laboratory, University of Bath, Claverton Down, BA2 7AY, UK

Abstract. Electromagnetic tomography method works by utilizing magnetic field induced by coils that are given an electric current. An object with certain conductivity property interferes the magnetic field which will be sensed by the sensor in the form of voltage difference. Experiment using iron as an object has been conducted. In addition, parameters given are distance between transmitter and receiver coil, and frequency of transmitter signal. The result shows that conductive material gives significant voltage difference, which ranges between 0 – 0.072 V. The optimal transmitter-receiver coil distance is the shortest, while the optimal transmitter signal frequency is at 5MHz and 9MHz. Based on the optimum parameters gained, multi-channel magnetic induction tomography (MIT) sensor is designed. It contains four transmitter coils and four receiver coils. They are arranged in circle, which each transmitter and receiver pairs are in opposite location. The sensor proved to be able to sense voltage difference induced by an object. Samples of imaging are also successfully provided accordingly.

1 Introduction

Magnetic Induction Tomography (MIT) is a relatively new non-contact imaging modality which is used for imaging the internal distribution of the passive electromagnetic properties (conductivity, permittivity, and permeability) of an object by measuring the mutual inductances between pairs of coils placed around its periphery [1].

Since this technique uses magnetic field, it has non-invasive feature and therefore can be applied in many fields, like biomedical application. There has been considerable interest shown over the past decade in the MIT imaging technique and its application to various problems. If there is a contrast or change in dielectric properties of the object of interest, MIT may potentially be used as an imaging tool [2]. MIT can be used for industrial process such as metal production and coating inspection [3].

Maxwell's equation states that the electric voltage applied to a closed path is proportional to the rate of change in the magnetic flux enclosing the closed path [4]. It is also stated that the induced magnetic field around a closed path is proportional to the rate of

* Corresponding author: rohmadi@c-techlabs.com

change in the electric field enclosing the path. In practice, this means that a magnetic field can be created by passing an electric current to a closed path in the form of a wire coil. In addition, an electric field can also be created by exciting the magnetic field to the wire coil. The electromagnetic tomography works by utilizing this principle.

2 Induction Coil Sensor

Sensors will be specifically used for imaging of metal objects. Metal in general has a relatively high conductivity. Based on the need to measure the voltage difference, an MIT sensor will be designed with specific number of coils, number of turns, diameters, shapes, and configurations. The selected design is coils having radius of 21 mm with each 50 number of turns, wire with 0.8 mm diameter, and with four transmitter and receiver coils respectively [5]. This selection is done by considering the optimal diameter of the sensor. The measured voltage will be greater in value when the distance between the transmitter and receiver coils is getting smaller. The object tested on the test itself is a thin beam iron with a width of 10 cm. Thus, the total diameter of the entire sensor of 11 cm is chosen, the maximum number of sensors that meet is eight.

The following Fig. 1 shows a sketch of the sensor configuration.

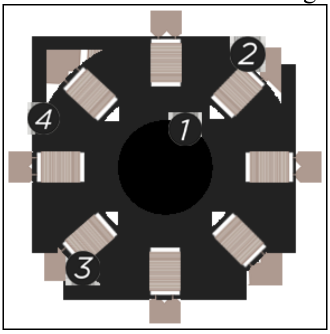

Fig. 1. The Coil Sensor Configuration in Top View

It has specification of 0.8 mm coil wire as long as (8 x 50 x 2 x π x 21) mm = 52.800 mm or approximately 55 m; and cylinder pipe for coil winding with 21 mm radius. The total height is estimated (8 x 6) cm = 48 cm. Transmitter and receiver buffer with area of (π x (5.5 + 6)2) cm^2 = 415.3 cm^2. In **Fig**. 1, the notation 1, 2, 3, 4 each shows the object, transmitter coil, receiver coil, and coil sensor buffer respectively. The transmitter and receiver coil is arranged to be face to face (opposite).

Basically, the magnetic induction tomography (MIT) sensor consists of at least a pair of transmitting and receiving sensors, both of which are coils. The transmitter coil is connected to a power source that provides an electrical signal. In accordance with Maxwell's equations, the receiving coil will detect the magnetic field and convert it into an electric field, which can be measured in voltage and phase quantities. The existence of an object with a certain conductivity between the transmitter and the receiver coil will affect the excited magnetic field so that the measured voltage on the receiver coil will differ in magnitude before and after being given the object. This measured voltage difference is used to then determine the image of the object. The transfer function of the receiver coil sensor is expressed by the following equation which is a derivative of the Maxwell-Faraday equation [6].

$$V = -n \cdot \frac{d\emptyset}{dt} = -n \cdot A \cdot \frac{dB}{dt} = -\mu_0 \cdot n \cdot A \cdot \frac{dH}{dt} \quad (1)$$

$V =$ voltage
$n =$ number of coil
$\mu_0 =$ magnetic vacuum conductivity
$A =$ coil surface area
$H =$ magnetic field intensity

To produce high image resolution, a sufficient number of measurements are required to map all output voltages excited by each part of the object. Increasing the number of measurements can be made by increasing the number of coils or by moving the transmitter coil and/ or the receiver and/ or the object [6].

3 Characterization

A characterization is conducted related to the design. Parameters being tested for determining an optimal sensor design are transmitter-receiver distance, and frequency of transmitter signal. Initially, a single pair of transmitting and receiving sensor is used, with variations in distance ranged from 3cm - 11cm, and signal frequency variation in ranges: 10,000Hz – 100,000Hz, 100,000Hz - 1,000,000Hz, and 1,000,000Hz - 10,000,000Hz. The test is performed in accordance with the experimental diagram in Fig. 2 below.

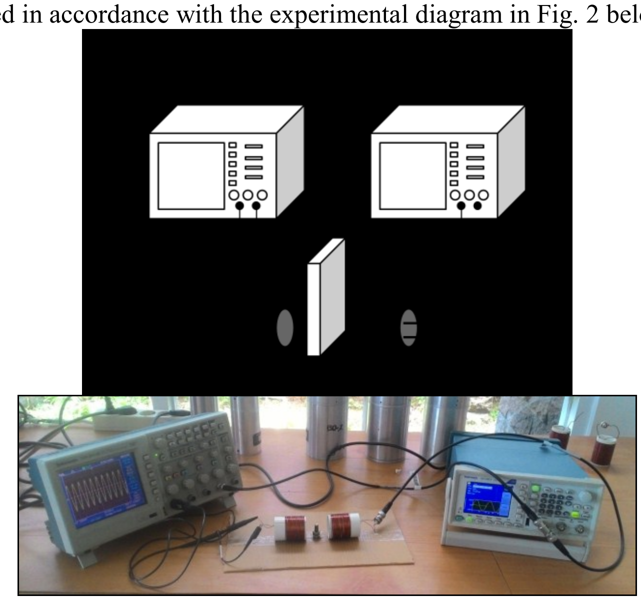

Fig. 2. Characterization Diagram and Experiment Setup

For each variation of these parameters, the optimum condition is indicated by the largest voltage difference measured before and after the magnetic field is disturbed by the object. In graphical representation, the measurement results are shown as follows.

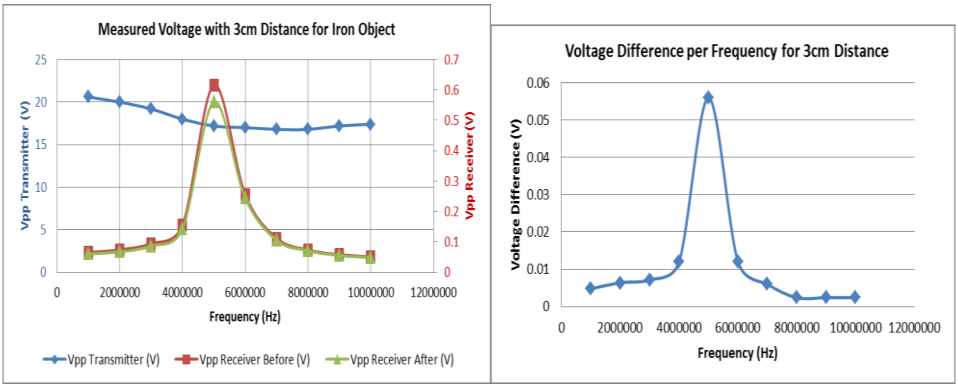

Fig. 3. Measured Voltage and Voltage Difference with 3cm Distance

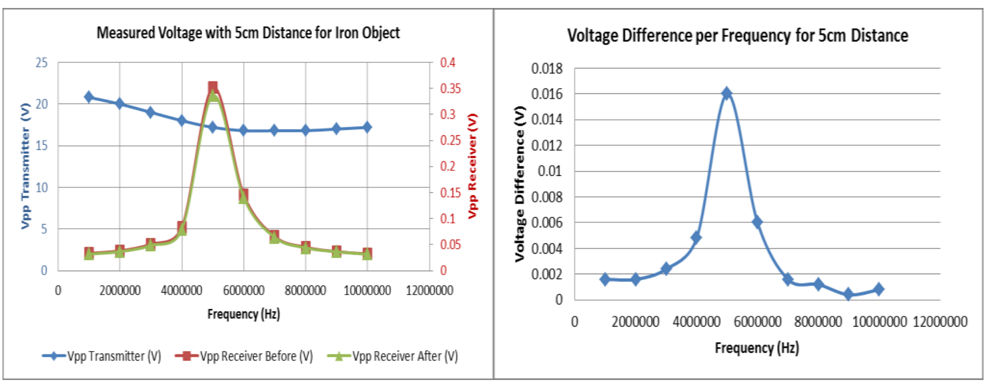

Fig. 4. Measured Voltage and Voltage Difference with 5cm Distance

Based on the tests, it is found that the measured voltage difference will be greater if the distance transmitter - receiver is getting closer. For frequency parameters, 4MHz and 5MHz values show significant voltage differences compared to other frequencies. Thus, the inductance sensor of this coil will be designed to have the closest distance between the transmitter coil and its receiver; while excitation signal is set at frequency range of 4MHz - 10MHz, and is used for imaging metal objects.

4 Experiment Results

Sensor and its testing are made according to the optimum parameters that have been obtained. Figure 5 shows multi-channel sensors measurement setup according to the design.

Fig. 5. Multi-Channel MIT Sensor Experiment Setup

There are eight coils with four transmitters and four receivers. Each transmitter coil is arranged in opposite with the receiving coil. The following test results show the measured voltages for the iron object for all four pairs of coil sensors.

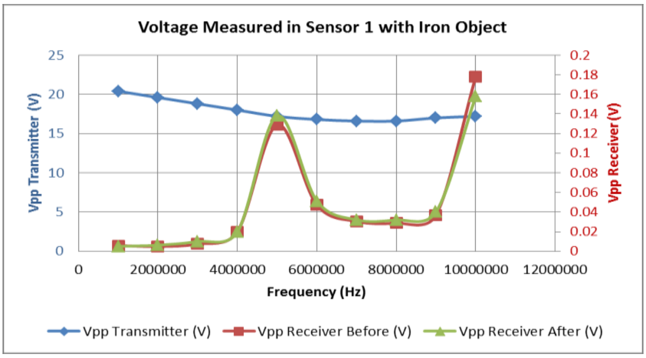

Fig. 6. Voltage Measured using Sensor 1

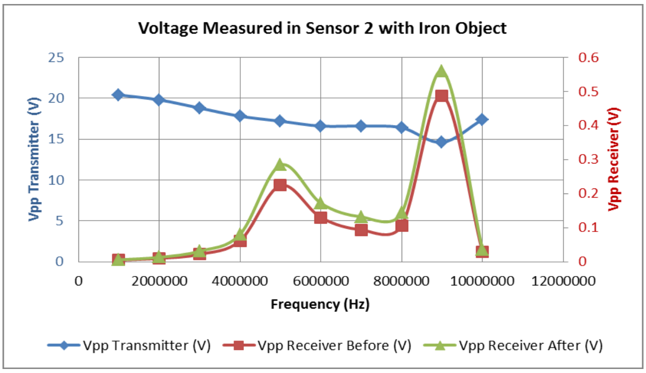

Fig. 7. Voltage Measured for using Sensor 2

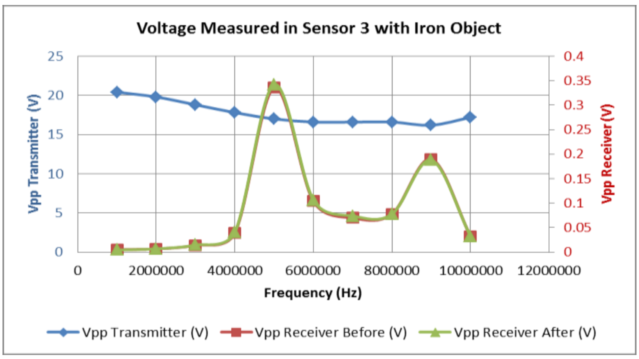

Fig. 8. Voltage Measured using Sensor 3

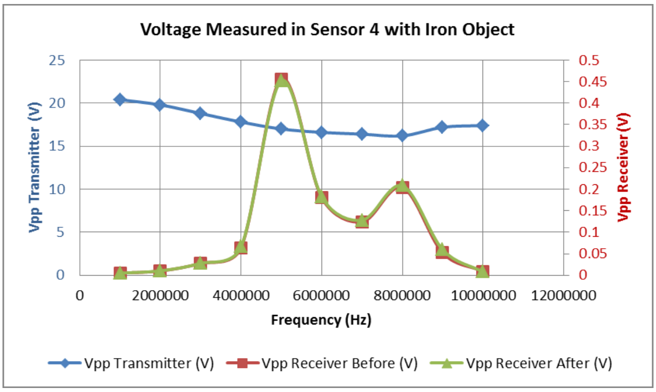

Fig. 9. Voltage Measured using Sensor 4

Based on the measurement results, it can be seen that in general, frequencies that give the most significant voltage difference are 5 MHz and 9 MHz. These two frequencies are then referred to as resonance operating frequencies, where the greatest voltage difference before and after the magnetic field is disturbed by the object occur. Multi-frequency sensor implementation could be beneficial in precision medical use [8].

The date is verified from Bath 8-MIT system used for frequency spectroscopy imaging [9]. Metallic object was placed inside sensing area of similarly constructed coil (with different number of turns) and swept by ac-signal at frequency of interest. Amplitude mode measurements were taken and reconstructed using back-projection algorithm [10] as shown in Fig. 10.

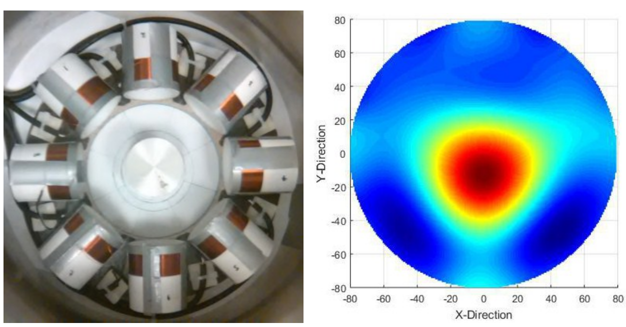

Fig 10. Reconstruction of the Object

Generally, the presence of conductive object can be distinguished, although the image is rough due to simplification in reconstruction. Further analysis of imaging requires more considerations toward physical simulation and algorithm, and is beyond the scope of this work.

5 Discussion and Conclusions

An induction coil sensor with four transmitter and four receiver coils has been constructed. The main goal is to detect the voltage difference in the presence of metal object. Made of 50 turns, 4.2 cm diameter coil, and 0.8 mm wire diameter, arranged in circle and the transmitter and receiver pair is face to face, the sensor is proved to be able to sense the voltage difference, with the most significant value captured at 5MHz and 9MHz frequency. Multi-channel measurement performance has been tested and offers adequate merits for electromagnetic tomography on conductive material.

For higher sensitivity, conductor shield can be attached to separate the transmitter and receiver coils electronically without disturbing the excited magnetic field. The arrangement of coils also influential. By arranging the transmitter and receiver coils asymmetrically, the number of measurements can be increased to improve image resolution. Additionally, the preparation of each coil as an array will allow the excitation of magnetic field of one of the transmitter coils to be captured by the receiver coil as an array as well.

Reference

1. H Griffiths, "Magnetic induction tomography," in *Electrical Impedance Tomography - Methods, History and Applications.*, D S Holder, Ed.: IOP Publishing, 2005, ch. 8, pp. 213-38.
2. M Soleimani, Image and Shape Reconstruction Methods in Magnetic Induction and Electrical Impedance Tomography, PhD Thesis.: The University of Manchester, 2005.
3. Wuliang Yin et al "The Design of a FPGA-based Digital Magnetic Induction Tomography (MIT) System for Metallic Object Imaging," Instrumentation and Measurement Technology Conference, ©2010IEEE doi: 10.1109/IMTC.2010.5488275
4. J. Clerk Maxwell, *A Treatise on Electricity and Magnetism*, Oxford: Clarendon, 1892, pp.68-73.
5. H. Yu Wei, M. Soleimani, "Magnetic Induction Tomography System for Prospective Industrial Processing Applications," Chin. J. Chem. Eng., vol. 20. 2012
6. S. Tumanski, "Induction coil sensors a review," Meas. Sci. Technol., 2007.
7. C. Hannelore Igney, R. Pinter, O. Such, "Magnetic Induction Tomography System and Method," US Patent US8125220B2. 2012.
8. I. Muttakin, S.-Y. Yeap, M. M. Mansor, M. H. M. Fathil, I. Ibrahim, I. Ariffin, C. Omar, and E. Supriyanto, "Low cost design of precision medical ultrasound power measurement system," International Journal of Circuits, Systems and Signal Processing, vol. 5, no. 6, pp. 672-682, 2011.
9. L. Ma, M. Soleimani, "Magnetic Induction Spectroscopy for Permeability Imaging," Sci. Rep., vol. 8, no. 1, p. 7025, 2018.
10. H. Herdian, I. Muttakin, A. Saputra, A. Yusuf, W. Widada, W. P. Taruno, "Hardware implementation of linear back-projection algorithm for capacitance tomography", 2015 4th International Conference in Instrumentation Communications Information Technology and Biomedical Engineering (ICICI-BME), pp. 124-129, 2015.