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Sensitivity Testing of Simple Metal Detection System on Coil Dimension Change and Measurement Distance

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A M Bangun, E Yuliza and R Ekawita*

Department of Physics, Faculty of Mathematics and Natural Science, University of Bengkulu Jalan WR Supratman, Bengkulu, 38122, Indonesia.

***E-mail:** rekawita@unib.ac.id

Abstract
Metal residues in soils of shallow depth can be detected with a simple detector tool. Development is carried out using several equipment tests. This study aims to design a simple metal detection system with a test of coil diameter, copper diameter, and coil windings to determine its effect on the detection distance of a simple metal detection system. The simple metal detection system in this study used the pulse induction (PI) method which used one coil as a transmitter as well as a receiver. Copper used 4 types of sizes. For one size of copper, 3 variations in the number of windings and 5 variations in the diameter of the coil are made. The test results show that the diameter of the coil affects the detection distance of a simple metal detection system, the larger the diameter of the coil, the farther the detection distance is for medium-sized and large-sized metals while for small-sized metals, the detection distance is lower. The copper diameter affects the detection distance of a simple metal detection system, the larger the copper diameter, the farther the detection distance, and vice versa the smaller the copper diameter, the lower the detection distance. The number of windings affects the detection distance of a simple metal detection system, the more the number of windings, the farther the detection distance while the fewer the number of windings, the closer the detection distance.

Keywords: Diameter, Sensitivity, Simple Metal Detector, Winding

1. Introduction

These advances in modern technology encourage us to use it with the aim of simplifying work while increasing efficiency and quality [1]. Many modern tools are produced to achieve such goals. Many of the modern tools that have been produced use metal as the base material [2]. Even from ancient times, the practice of using metals has been carried out [3]. Metals are naturally formed mineral elements. The metal has a very high tensile strength, a high electrical conductivity, and is easy to form [4]. Metals have been widely used by humans in various fields, for example in the industrial field, industries such as factories produce a lot of waste containing metals that can damage soil nutrients [5]. The use of basic materials or sufficiently high metal waste is directly proportional to the metal residues present in the environment. A lot of metal is deposited in the soil because it is removed and left for a long time. Metal residues deposited in the soil can pollute the soil and water [6]. The presence of metals in the soil needs to be reduced so as not to pollute nutrients in the soil, a simple metal detector is certainly needed in this case. Based on the conditions described above in the development of existing equipment, this study made a simple metal detection system with tests of coil diameter, copper diameter, and a number of coil windings with detection distance.

A metal detection device is a tool that can detect the presence of metal above and below ground level at a certain distance. Metal detectors are very useful and are often used by security personnel in public places to ensure that everyone who will enter a certain area is free from dangerous objects such as sharp weapons, pistols, bombs, or other prohibited objects to be carried [7]. Metal detectors work according to the electromagnetic principle by making a coil that is flowed by a current so that it creates a magnetic field that can attract metal [8]. There are several technologies in the development of metal detection devices, namely Beat Frequency Oscillator (BFO), Very Low Frequency (VLF), and Pulse

Induction (PI). The most basic technology of metal detection is BFO where this technology uses two types of coils. The large coil is in the detector head while the small coil is located in the control box.

Each coil is connected to an oscillator that produces thousands of pulses per second. This pulse frequency has a slight offset between the two coils. The pulses passing through each coil will produce radio waves. A small receiver in the control box picks up radio waves and creates a series of audible tones (beats) based on frequency differences. If the coil on the search head passes through a metal, the magnetic field caused by the current flowing through the coil creates a magnetic field around the object. The object's magnetic field interferes with the frequency of radio waves generated by the coil of the detector head. As a frequency that deviates from the frequency of the coil in the control box, an audible tap changes the duration and pitch. The next technology is VLF, where this technology uses two coils located next to each other in the detector head. The first coil serves to signal and the other coil serves to receive a signal if the presence of metal is detected [9]. The way VLF technology works is that in the transmitter circuit there is an oscillator that flows into the transmitter coil. When electricity flows through the transmitter coil, it creates a magnetic field. Such magnetic fields penetrate objects. The magnetic field creates a flow of electric current inside a metal object. This flowing electric current creates another magnetic field around the object.

Then the magnetic field will be received through the receiving coil moving upwards. The magnetic field creates a flow of electricity around the transmitting coil and rises to the receiver's coil. The last technology of metal detection is the Pulse Induction (PI) type, using one coil that is used as a receiver as well as a transmitter. This technology transmits powerful, short bursts (pulses) of current through the wire coil. The pulse series generates a short magnetic field. When the pulse ends, the magnetic field reverses polarity and collapses very suddenly resulting in a spike. This spike lasts a few microseconds and causes another current to run through the coil. This current is called a very short pulse reflection, lasting only about 30 microseconds. Other pulses are then sent and processed repeatedly [10]. The receiver coil on Pulse Induction (PI) technology is connected to the control box to receive and process electronic signals. The coil is inside the coil housing which is usually simply called the "coil", and all the electronics are inside the electronic housing attached to the coil through the electrical wiring and are commonly called the "control box" [11]. A coil is a passive electronic component consisting of an arrangement of wire windings that form coil. The coil can basically generate a magnetic field if it is electrified. The magnetic field generated can cause energy in a relatively short time [12].

Working Principle of Coils

If a coil is electrified, according to the basic electromagnetic principle, a magnetic field will appear around the coil. According to Faraday's law, the induction voltage in a coil will be generated when there is a change in magnetic flux in the coil. The coils used are circular with an air core. Such coils are commonly used in instrument transformers and other electronic devices.

Inductance on the coil can be written mathematically:

$$L = N\frac{\Phi}{I} \quad (1)$$

where L is the inductance (H), N is the many windings, Φ is the magnetic flux (Wb) and I is the strong electric current.

Magnetic flux is the density of a magnetic field that can be expressed equation (2).

$$\Phi = B.A \quad (2)$$

Where Φ is the magnetic flux (Wb), B is the magnetic field strength (T), and A is the cross-sectional area (m^2).

So that the inductance of a coil or coil can be simplified into equation (3).

$$L = N\frac{B.A}{I} \quad (3)$$

The strength of the magnetic field on a circular wire can be expressed by equation (4).

$$B = \mu \circ \frac{I}{2a} \qquad (4)$$

Where N is a lot of winding, I am the strong of the electric current, l is the length of the winding and μ is the permeability of the material [13].

Then the coil inductance equation in general can be written to:

$$L = N \frac{\mu.N.I}{l.I} A \qquad (5)$$

$$L = \mu \frac{N.A}{l} \qquad (6)$$

Where L is the inductance of the inductor (H), μ is the permeability of the material, N is the number of windings, A is the cross-sectional area (m^2) and l is the length of the winding (m) [14].

Research designing metal detection systems with microcontrollers has been carried out by several previous researchers, namely [15] and [16]. De Lama, et al, 2016 used a coil with a coil diameter of 4 cm, a copper diameter of 0.26 mm and a total of coil windings of 40 windings [15] and Pratmanto et al. using conductivity sensors as metal detection coils [16]. Of the two studies, there were no variations in copper diameter, coil diameter and number of windings on the coil. Even though these variations can affect the detection distance and sensitivity of a metal detection system. Therefore, this study aims to test variations in coil diameter, copper diameter and number of coil windings against the detection distance of the metal detection system designed to build.

2. Method

The methods used in this study are design and test methods. The first stage carried out is the design of the control box. In the design of the control box, there are components that must be prepared and assembled according to Figure 2. A series of control boxes are assembled on the PCB. Before the components are assembled, previously checking the specifications of the components so that the control box built can function properly.

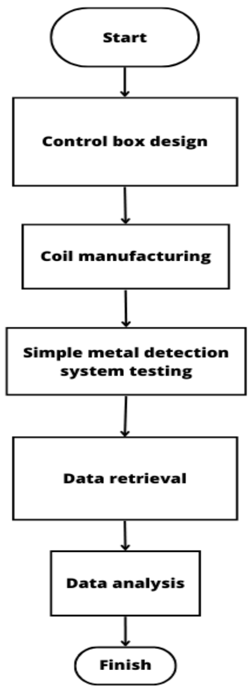

Figure 1. Flow chart.

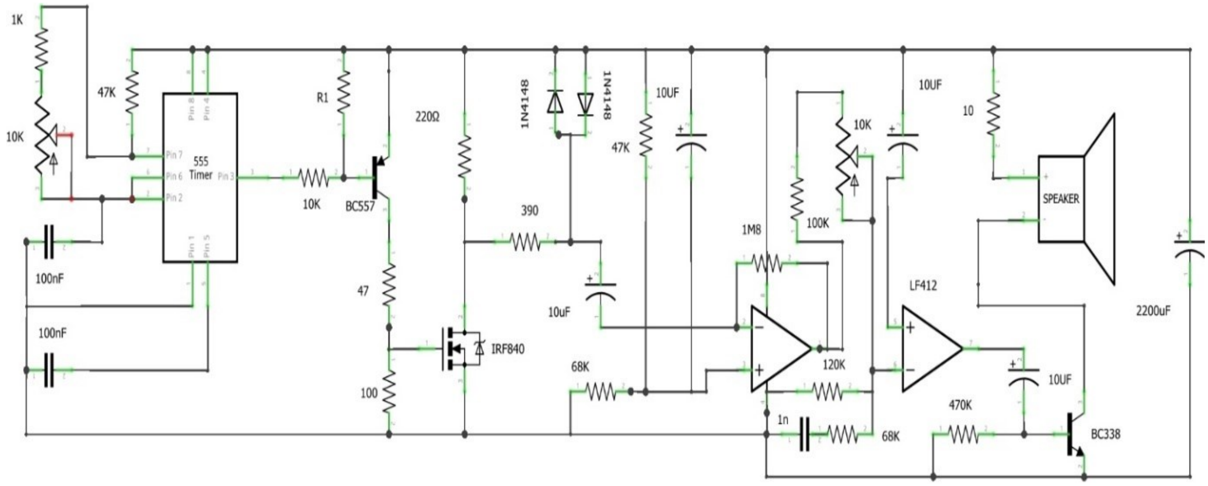

Figure 2. Control box component family.

Broadly speaking, a simple metal detection system works as follows. The magnetic field generated by the coil interacts with the metal and sends a pulse back to the brain of the circuit, which is part of the control box (Figure 2). The NE555 *IC* acts as a square wave generator that generates frequencies. Mosfet (IRF840) serves to amplify the signal from IC NE555. When the coil passes through the metal, the resulting magnetic field will be disturbed and trigger the voltage on the gate leg of the mosfet so that the voltage from the source leg flows into the drain. Mosfet uses heatsinks and mini fans as coolers because when this metal detection system operates the mosfet temperature will increase, if the mosfet temperature increases then the sensitivity distance of the metal detection system or its performance will decrease. The signal from the mosfet is enough to be heard by the human sense of hearing when it is ejected through the output (buzzer). However, the circuit is equipped with an audio amplifier (LF412) so that the signal from the mosfet leg is amplified so that the response to the presence of metal is easy to hear. In the series of control boxes (Figure 2), there are two resistor variables. The first variable resistor serves to raise or decrease the frequency of the NE555 IC. The frequency range on the Ne555 *IC* is 185–275 Hz.

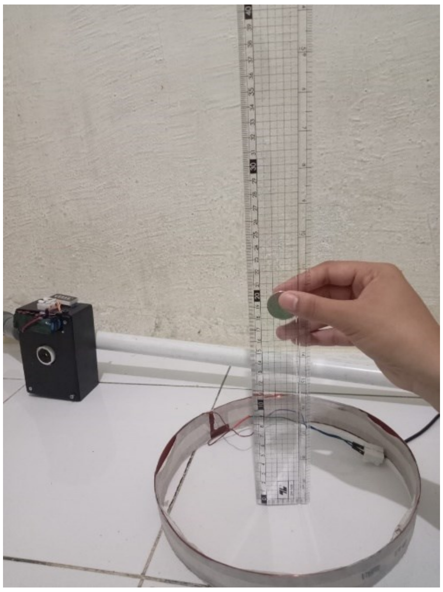

Figure 3. Test Metal Detector System

The lower the frequency, the sensitivity distance of the simple metal detection system the more sensitive but as a consequence the mosfet temperature the faster it heats up otherwise the higher the frequency then the sensitivity distance of the simple metal detection system decreases further but the mosfet temperature remains low. The second resistor variable serves to increase the distance or lower the sensitivity distance of a simple metal detection system. In this study, the frequency used was a minimum of 185 Hz to get maximum results.

The next stage is the manufacture of the coil. Coils with various sizes of coil diameters, copper diameters, and the number of coil windings are prepared for entering the testing and data collection stages. The diameter of copper used in this simple metal detection system is 4 variations, namely 0.2 mm, 0.5 mm, 0.8 mm, and 1 mm. Tests were carried out for one type of copper diameter made with 3 variations in the number of windings and 5 variations in the diameter of the coil. Each variation was tested for response to metals with various distances.

After the manufacture of the coil is completed, the next step is the testing of a simple metal detection system. The test is carried out by turning on the metal detection system and using one type of coil that has been made then tested to detect a metal as shown in Figure 3 Testing is carried out to find out the simple metal detection system that is made to work if a simple metal detection system is working, the next step is data retrieval. Data retrieval is carried out by measuring the detection distance of a simple metal detection system when detecting the presence of a metal. The metal samples used are metal 1 (small-sized metal), metal 2 (medium-sized metal), and metal 3 (large-sized metal). Measurements are made using a ruler. The distance measured is when the metal under test is approached by the coil and the metal detection system makes a sound indicating the detection of the presence of a metal. Each coil test uses all three metals to be tested.

The data obtained were analyzed using Microsoft Excel in the form of a graph of the detection distance of the metal detector against the diameter of the coil and the number of coil windings using 4 types of copper diameters. The simple metal detection system built can only detect iron, aluminum, copper, lead, and zinc-type metals. This metal detector cannot detect precious metal types.

3. Results and Discussion

The size of the copper diameter used as a coil in this study was 0.2 mm, 0.5 mm, 0.8 mm and 1 mm. Each of them varied the number of windings on the coil and the diameter of the copper. For one type of copper diameter, coils are made with various diameter sizes, namely 15cm, 17.5cm, 20cm, 22.5cm, and 25cm and various numbers of windings, namely 20, 30, and 40.

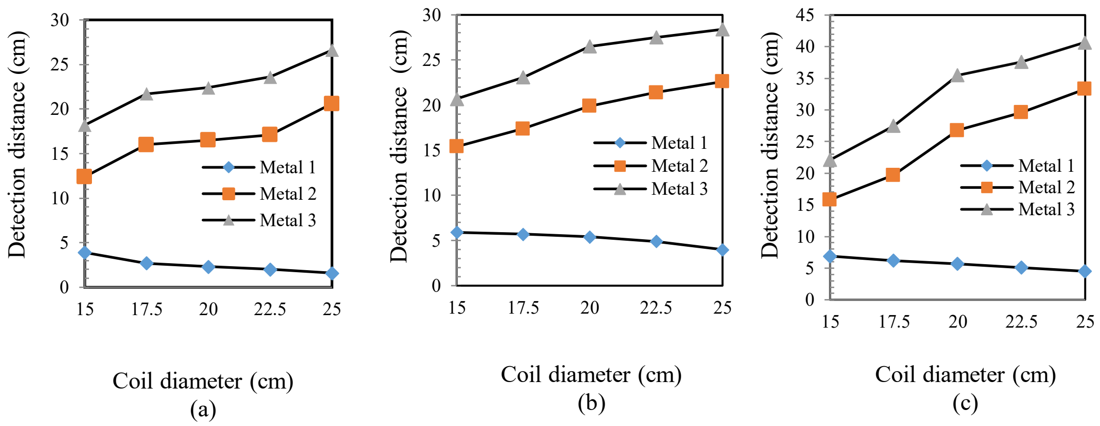

Figure 4. Detection distance uses a copper diameter of 0.2mm with the number of windings (a) 20, (b) 30, and (c) 40.

Figure 4 shows the relationship of the detection distance to the coil diameter with the number of coil windings of 20 windings (a), 30 windings (b) and 40 windings (c) using a copper diameter of 0.2 mm. The detection distance increases when the diameter of the coil is enlarged or the number of coil windings increases according to the inductance formula in Equation (6), this happens in metal tests 2 and 3. The inductance value is directly proportional to the number of windings and the cross-sectional area of the coil according to research conducted by Hidayat et al, 2020 [17] while the detection distance for metal 1 decreases when the diameter gets larger because metal 1 is small and according to Equation (3), the larger the diameter of the coil, the smaller the magnetic field at the center of the coil but the detection distance against metal 1 increases when the number of windings is more because the magnetic field is proportional to the number of coil windings.

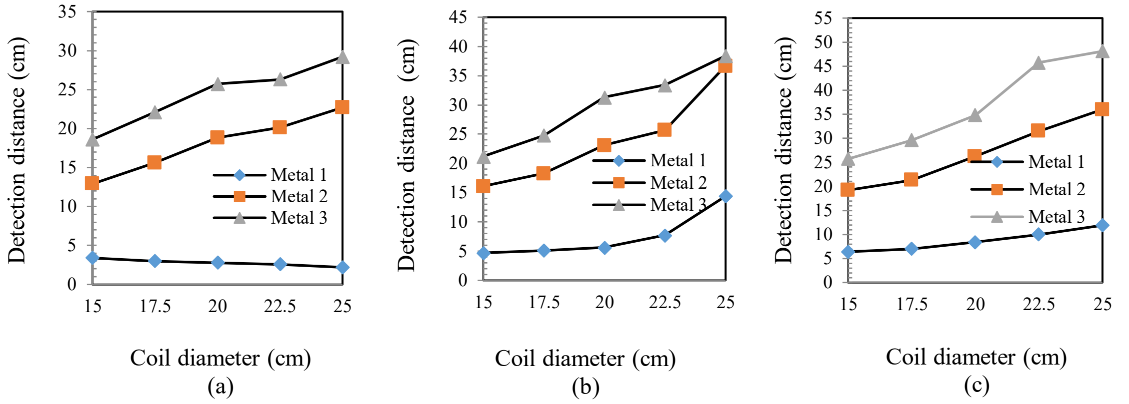

Figure 5. Detection distance uses a copper diameter of 0.5mm with the number of windings (a) 20, (b) 30 and (c) 40.

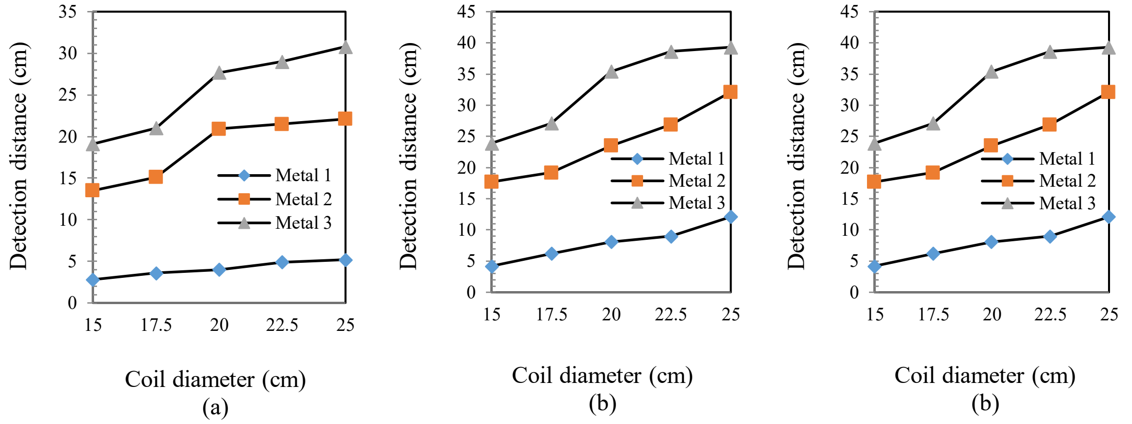

Figure 6. Detection distance uses a copper diameter of 0.8mm with the number of windings (a) 20, (b) 30, and (c) 40.

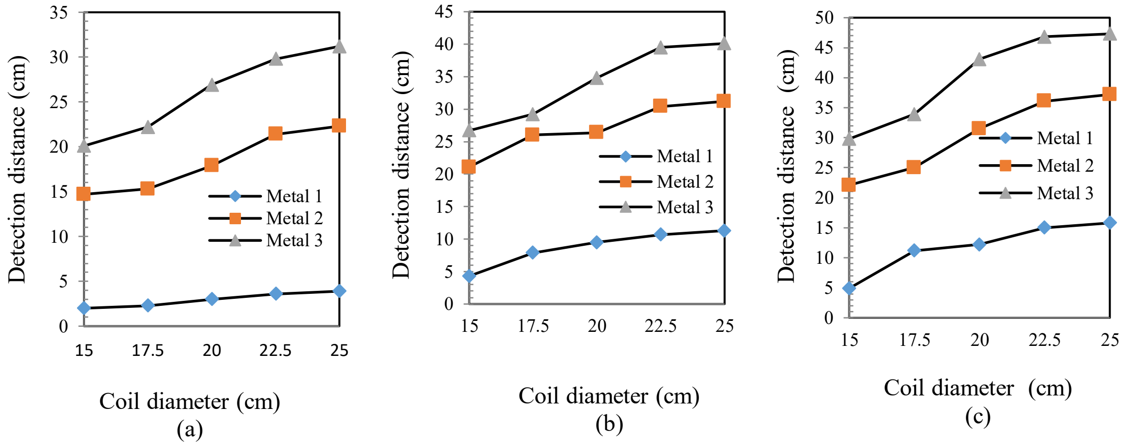

Figure 7. Detection distance uses a copper diameter of 1mm with the number of windings (a) 20, (b) 30 and (c) 40.

Figures 5, 6 and 7 show the relationship of the detection distance with the diameter of the coil and the number of windings i.e. (a) 20 windings, 30 windings (b) and 40 windings (c) using diameters of 0,5 mm, 0.8 mm and 1 mm. The detection distance against metal 1, metal 2 and metal increases by 3 as the number of windings gets more and the diameter of the coil gets larger according to research conducted by Kim et al, 2014 [18] shows that the more the number of windings, the greater the inductance value.

The greater the inductance value of a coil, the better the sensitivity of the metal detection system [19]. The detection distance at 1 mm copper diameter is greater than the copper diameter of 0.8 mm and the detection distance of copper with a diameter of 0.8 mm is better than copper with a diameter of 1 mm according to research conducted by Susilo et al, 2021 [20] indicates that the larger the copper diameter of a coil, the smaller the resistance of the coil.

4. Conclusion

The test results of the number of coil windings to the sensitivity distance of the metal detection system show that the greater the number of windings, the better the sensitivity distance of the metal detection system. The results of the coil diameter test show that the larger the coil diameter, the better the sensitivity distance except using a copper diameter of 0.2 mm to detect small metals. The copper diameter test results show that the larger the copper diameter the better the detection distance of the metal detection system. The most effective copper diameter for the coil of the metal detection system built is copper with a diameter of 0.5 mm with a total winding of 40 windings and a 25 cm coil diameter, a copper detection distance of 0.8 mm, and 1 mm in diameter is indeed better than copper with a diameter of 0.5 mm, but copper with a diameter of 0.8 and 1 mm makes the *mosfet* heat up quickly so that it cannot be used for a long time.

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