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Development of Alternating Current Transmitter of Detection System for Magnetic Material in Soil Subsurface

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Abstract. Generally, detection system for magnetic material in soil subsurface using electromagnetic induction method consists of two parts, they are transmitter and receiver unit. A transmitter must be able to produce a continuous and stable AC current at a certain frequency, meanwhile receiver should be able to catch the secondary magnetic field of magnetic material in soil subsurface. The aim of this study was to develop a new AC current transmitter of detection system for the magnetic material in soil subsurface. This paper will describe the results of the development of AC current transmitter systems, distance characterization of the sensor detection toward horizontal solenoid positions, and characterization of magnetic material in the soil subsurface. It has successfully made the AC current transmitter system, composed of a sinusoidal signal generator, power amplifier, and a source of AC magnetic field. The output of the generator has a frequency varies: 1 kHz, 2 kHz, 5 kHz, and 10 kHz. We found that the AC current transmitter that has been developed able to work properly up to a frequency of 10 kHz.

Keywords: electromagnetic induction**,** fluxgate, magnetic material, soil subsurface
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INTRODUCTION

A magnetic material detection system is needed to determine the content of pollutants, such as the magnetic material in soil subsurface. The detection system was developed using electromagnetic induction method [2]. Electromagnetic induction method is one of the non-destructive surface geophysical techniques used to measure the conductivity of the soil subsurface, rock, and groundwater. This method has been developed since the 1920s to detect conductive metal deposits based on rock resistivity contrasts. Some important properties of the EM method are a high sensitivity to subsurface resistivity contrast, high lateral resolution, penetration ability is quite varied depending on the frequency of the signal being used, and the data acquisition are easy to perform. In addition, the EM induction system has been proven to be very effective in detecting metallic and magnetic materials in soil subsurface [3].

One of the important issues in the development of detection systems of magnetic material in the soil subsurface using EM induction method is an alternating current transmitter to supply current on solenoid as source of AC magnetic field. In this paper be presented experimental results on the development of alternating current transmitter for a detection system of magnetic material in soil subsurface.

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EXPERIMENTAL

The transmitter is a device generating a primary magnetic field source that used to induce a magnetic material. Therefore, a transmitter must be capable of generating a stable of alternating current signal controlled. A current transmitter system that was developed in this study consists of a series of sinusoidal signal generator, power amplifier, and a solenoid. The circuit of sinusoidal signal generator is made using IC XR2206. Oscillation frequency (f_o) is obtained by adjusting the potentiometer (R) on pin 7 and the capacitor (C) are connected to pin 5 and 6 of the IC XR2206. The oscillation frequency is calculated using the equation:

$$f_o = \frac{1}{RC} \; Hz \tag{1}$$

The output of the signal generator circuit is connected to Band pass filter that has a pole frequency of filter are 50 Hz and 72 kHz. Pole frequency below 50 Hz is used for filtering the AC voltage of the PLN, while frequencies above 72 kHz to limit the operating frequency range of the signal generator. In order to output signal of the generator is stronger, we used the power amplifier.

Meanwhile the power amplifier used is the type of OCL (output capacitor-less) where the output of the power amplifier is connected directly to the load without additional capacitors and transformers. Source voltage required by the power amplifier circuit is ± 42 Volts. The output of the power amplifier is then connected to the load and solenoid. The load circuit consists of some resistor 100W than connected in series, with the total resistance of 3.67 Ohm. While the electric current flow in the solenoid is used for generating a magnetic field.

Two types of solenoid that has been made; there are ferrite-core solenoid and air-core solenoid. Measurements of inductance and resistance of solenoid performed using GW *Instek* LCR meter 829 series at frequencies of 1 kHz and 10 kHz. Detection of primary magnetic field of the solenoid and secondary magnetic field of the material was used fluxgate sensors that have high sensitivity as shown in Table 1.

TABLE 1. Fluxgate Sensor

Sensor	Sensitivity (nT/mV)	Relative error (%)
Sensor 1	1.32	0.124
Sensor 2	1.14	1.805
Sensor 3	1.23	1.682

RESULT AND DISCUSSION

It has made a signal generator where the output voltage at a frequency of 1 kHz, 2 kHz, 5 kHz, 10 kHz, and the the output of the power amplifier are shown in Figure 1. It appears that the signal generator functioning properly up to a frequency of 10 kHz, meanwhile the band pass filter circuit mounted on the output of the signal generator capable of filtering the frequency of undesired signal.

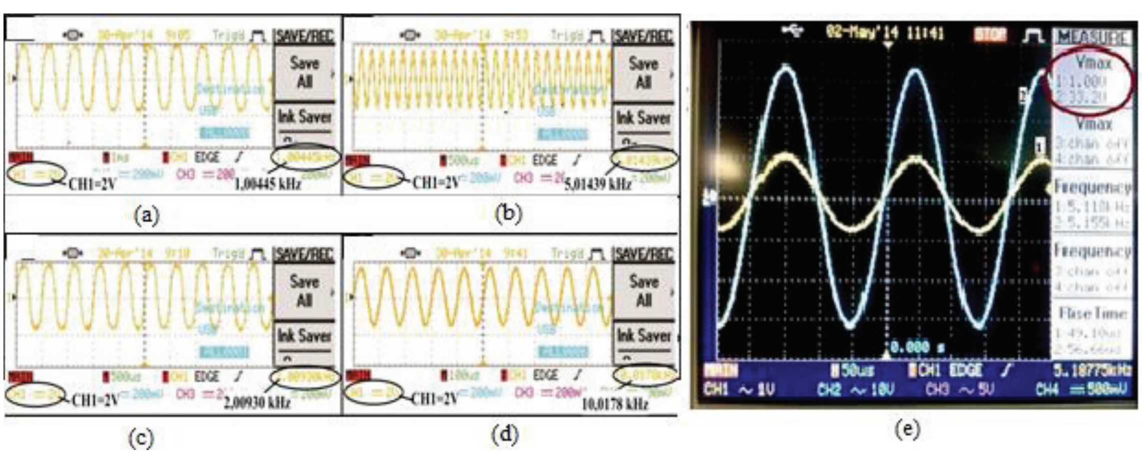

FIGURE 1. The output voltage of the generator signal at frequencies of: (a) 1 kHz, (b) 2 kHz, (c) 5 kHz, and (d) 10 kHz. (e) The output voltage signal generator (1) and the output of the power amplifier (2) at a frequency of 5.18775 kHz.

The output of sinusoidal signal generator is amplified by the power amplifier 600 watts which gains 33.2 times. Based on Figure 1(e) there is no phase shift between the input voltage and the output voltage of the power amplifier, but there is a difference between the input and output frequencies. The frequency difference between the input signal (1) and the output signal (2) arise due to differences the sampling time between the input signal (1) and the output signal (2).

The output signal from the power amplifier is then connected to the load circuit and solenoid. The solenoid is used as a source of AC magnetic field, i.e. solenoid A and solenoid C, where A has an air core solenoid and consists of 4x130 turns of wire, whiles the C solenoid with a ferrite core and consists of 130 turns of wire. Both of solenoids have an inductance of 2.926 mH and 2.06 mH, respectively, at a frequency of 10 kHz.

Distance Characterization of the Sensor Detection

Measurement scheme of distance characterization of the sensor 1, 2, and 3 toward solenoid's position is shown in Figure 2(a). The position of the head of sensor 1 is facing the solenoid, in the z axis direction. To determine the distribution of the magnetic field around the solenoid, the position of sensor (x, y, z) was changed toward the solenoid, then the intensity of the magnetic field recorded as data. The results of sensor characterization by changing the position of y on x and z fixed, shown in Figure 2(b). In Figure 2(b) appears that the shape of the output curve of sensors 1, 2, and 3 are different, according to the direction of the field that is detected by each sensor. Sensor 1 detects field parallel to the solenoid, the farther the location of point P on the axis of the solenoid, the field is captured by the sensor 1 will be smaller so as to change the distance of y, then the curve of the magnetic field is in the Gaussian form. Otherwise the sensor 2 captures magnetic field in the direction of the y-axis. The minimum magnetic intensity in the direction of y-axis obtained when P is at y = 0, but there is a shift of this intensity B = 0 at y = 2 cm because the element of sensor-2 located at a distance of 2 cm from the sensor reference point. Meanwhile the sensor 3 detects the vertical field with the maximum intensity of the detected magnetic field is 0.34 μT. Matching the shape of the curve on the measurement results with theoretical calculations performed using the approach of Biot-Savart law (solid line in Figure 2(b)).

Magnetic field intensity at any point due to the solenoid has been written in the equation (2), (3) and (4):

$$\boldsymbol{B}_{x'} = \frac{3IA\rho z\mu \ \cos\ \phi}{4\pi\left(\rho^2 + z^2\right)^{5/2}} \tag{2}$$

$$\boldsymbol{B}_{y'} = \frac{3IA\rho z\mu \ \sin\ \phi}{4\pi\left(\rho^2 + z^2\right)^{5/2}} \tag{3}$$

$$\boldsymbol{B}_{z'} = \frac{\mu IA\left(2z^2 - \rho^2\right)}{4\pi\left(\rho^2 + z^2\right)^{5/2}}\hat{z} \tag{4}$$

Based on the equation (2), (3), and (4) obtained a model to approach the results of measurements that have been carried out as shown in Figure 5. The form of the curve in Figure 5 is accordance with the results that have been obtained by other researcher [4, 5, 6].

The presence of a magnetic material

The effect of the presence of magnetic material around the source of AC magnetic field is investigated by placing a magnetic material (ferrite 1 and ferrite 2) in soil subsurface, as follow the procedure in Figure 2 (c). A ferrite cylinder with a diameter of 2 cm with a length of 3 cm (ferrite 1) placed at the position x = 10 cm and y = -2 cm with a depth of 5 cm in the soil subsurface. In this research, the characterization of the field on the soil surface using the distance between the solenoid (Tx) and sensors (Rx) is constant, of 20 cm. Then Tx-Rx is moved simultaneously along the plane (x, y) so that the field distribution on the surface of the soil can be measured. To study the response of the sensor to the difference size of material, also conducted measurements using ferrite with a diameter of 4 cm and a length of 3 cm (ferrite 2). Results of measurements of the magnetic field intensity by the fluxgate sensor is shown in Figure 2 (d), 2 (e) and 2 (f).

Sensor 1 which measures the magnetic field parallel to the source has not changed the shape of the curve, but the amplitude of the sensor output increases, as shown in Figure 2 (d). Because the primary magnetic field of the solenoid is quite dominant than the secondary field of magnetic materials. The results of the characterization of the sensor 2 to the presence of a magnetic material in the soil subsurface are shown in Figure 2 (e). Ferrite rods twice detected by the sensor 2. It appears that the lowest point at position b (x = 10 cm and y = - 2 cm), and the highest point at a position (x = 10 cm and y = -8 cm). Finally, characterization of the sensor-3 on the presence of magnetic material in the soil subsurface is shown in Figure 10 (d). Ferrite rods were placed at position x = 10 cm and y = -2 cm, once detected by the sensor-3. It appears that the lowest point at position x = 10 cm, y = -2 cm.

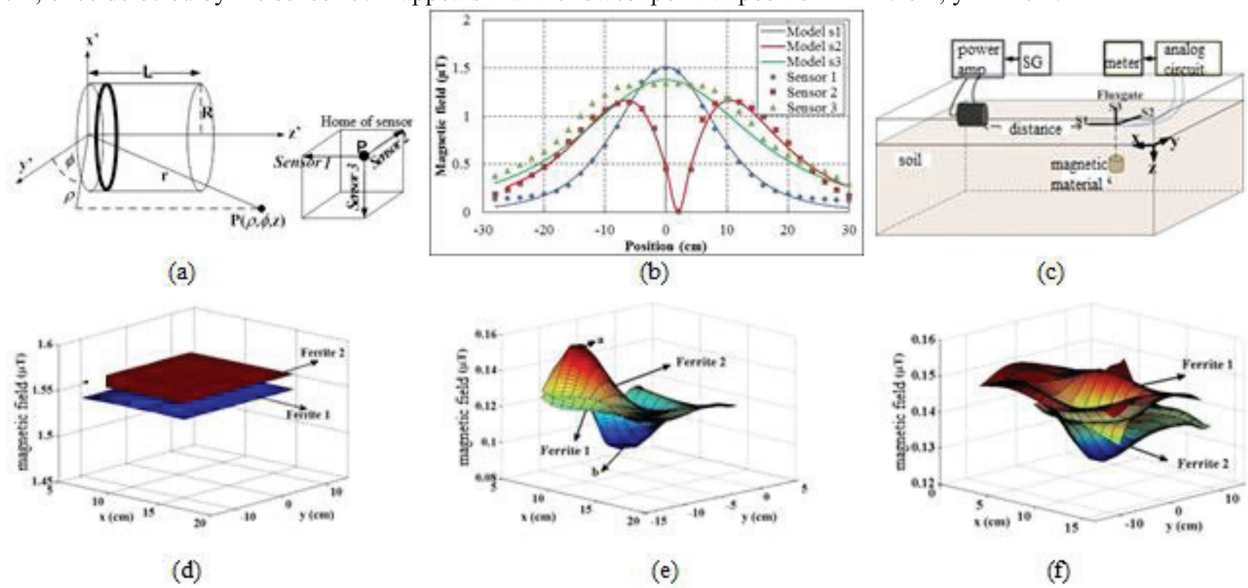

FIGURE 2.(a) Measurement scheme with a fixed position x and z, y position change. (b) Characterization results of the output sensor 1, sensor 2 and sensor 3 to change the y-position. (c). Data collection scheme with ferrite objects 1 and 2 are in the soil, solenoid position is horizontal (north-south). Output curve of (b) sensor 1, (c) sensor 2, and (d) sensor 3.

CONCLUSIONS

We have developed an alternating current transmitter of detection system for magnetic material in soil subsurface. This alternating current generating a primary magnetic field source that used to induce a magnetic material in soil subsurface. The frequency of the magnetic field can be varied within 1 kHz, 2 kHz, 5 kHz, and 10 kHz. Transmitter AC that has been developed is capable to use for detection system of magnetic material in soil subsurface.

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