optimization of coil

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PART A. APPLED AND NATURAL SCIENCES

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OPTIMIZATION OF COIL PARAMETERS AS A CANDIDATE OF TEMPERATURE SENSOR DEVICE BASED ON MAGNETIC SUSCEPTIBILITY

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ABSTRACT

The research on the optimization of coil parameters and its potential to be used as candidates of a low temperature sensor device based on magnetic susceptibility has been done. The coil parameters varied consist of wire diameter and number of windings. Several coils from copper wire were used as sample. Diameter of wire was varied from 0.10 to 0.20 mm, and the number of windings was varied from 3600 to 12000. Water vapor was used as a medium which has temperature may be set from -10°C to 60°C. An analysis using linear regression is being used to determine the best available sample to be used as a temperature sensor at the temperature range pointed data (χ_{m_i}, T_i). The degrees of linearity (R^2) and resolution of curve can be examined from the equation. The results showed that all samples have susceptibility that responsive to the change of temperature. Almost all of the samples showed a linear relationship between susceptibility and temperature. This is showed by the value of determination index that over of 0.95. A coil with diameter of 0.10 mm and number of windings 12,000 has the highest level of linearity i.e. R^2 = 0.98 according to the equation $T = -175.4\,\chi_m + 71.1$ (where T is temperature and χ_m is susceptibility of medium), and has the resolution of 5.7 gauss / °C. With this result, this coil has the potential to be used as a low temperature sensor device.

Key words: Coil, wire, windings, temperature sensor, magnetic susceptibility

1. INTRODUCTION

The sensors based on induction field known as inductive sensors have several advantages compared with others, that do not require a contact with the measured object, have a simple structure, very sensitive, and can be operated by using the remote control allowing it to be automatically monitored [1,2]. Currently, induction sensors have been used in various fields, such as in the fields of irrigation pipes to detect the leaks in underground [1], to monitor the acoustic system [3], and to identify the slope and the shift of an object [2].

On induced sensor, the changes in temperature can be identified by the quantity of magnetic susceptibility. Similarly, the temperature can also be identified through the current changes, magnetic fields, mechanical stress, concentration of the gas in the chamber, and other parameters.

Among the researchers regarding the temperature sensor, Tanaka *et al.* concentrate on the development of the coil material by using Fe-Si as a low temperature sensor material between -10 ° C to 70 °C [5]. Moreover, an inductor made of alloy when processed by heating and then quenching is very suitable if it is being used as a temperature sensor, placed in a vibrating chamber containing a wide frequency vibrating oscillators from low to high. In that situation the sensor is still able to measure temperatures accurately without any disturbance from the oscillation frequency. Now, it temperature sensor has been eventually transformed into a thermometer and it has been fabricated [6].

There is also a researcher focusing on the design of the coil from a single to dual coils which have a given core inside. This sensor is known as flux gate sensor. Flux gate sensor can be used to sensitively identify temperature-based permeability [7,8]. Brito *et al.* used the Ni-Zn ferrite sintered at various temperatures from 1200 °C - 1400 °C as core of solenoid [4]. It is very easy to use these sensors that can be installed in a complicated space such as in the piston chamber [9].

Water is a diamagnetic material with susceptibility of -0.91. If the water is heated it will turn into steam so its susceptibility will be increase and its magnetic properties change from diamagnetic to become paramagnetic [10,11,12,13]. The dependence of susceptibility on the temperature of water is caused due to the influence of oxygen in the water bond. Diamagnetic material has a negative susceptibility; whereas paramagnetic materials have a small positive susceptibility. The dependence of susceptibility on the temperature allows make the temperature sensor devices based on magnetic susceptibility. Coil is an instrument that can be used to capture the response of magnetic properties of the medium in magnetic induction expression.

This research was conducted to optimize the coil parameters included the diameter of wire and the number of windings which have the potential to be used as a temperature sensor device based on magnetic susceptibility. Water vapor with varied temperatures ranging from -10 °C to 60 °C is being used as a medium in the coil.

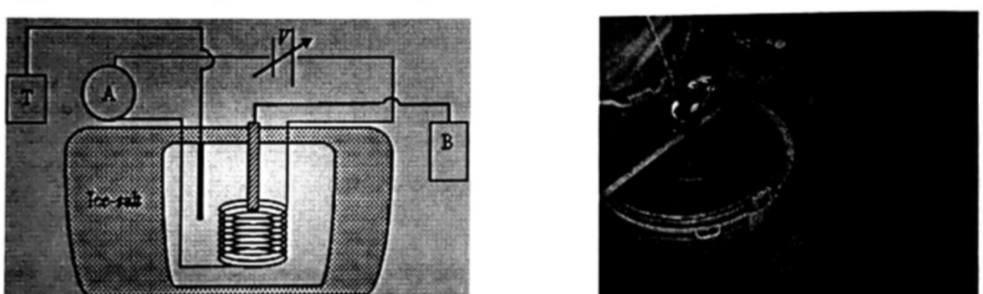
2. MATERIALS AND METHODS

Experiment procedure

The experiment was conducted with the following step. The coil was prepared from copper with diameter of 0.1 mm, 0.15 mm, and 2.0 mm and number of windings was varied of 3600, 6000, and 12000. The length of the coil was 0,035 m (as shown in Fig. 1). The coils were inserted inside the beaker glass (brand Iwaki TE-32 Pyrex) with the two ends were connected to the power supply (brand Super Anzon model SS500) that set at 12 volt.

***Fig. 1.** Some coils with various diameters from 0.10 mm to 0.20 mm and the number of windings from 3600 to 12000.*

The temperature of air was prepared on -10°C, which was done by cooling the surrounding medium with salted ice. The temperature measurement of the medium was done by using digitally thermocouple brand Winner M-890 °C; meanwhile, the current measurement was done using multimeter brand Sunwa type YX-830 B. The induced magnetic field is measured using gauss meter brand Hirst type GM 04. A heater was used to rise the medium temperature until 60°C. The temperature, current, and the magnetic field were simultaneously observed during the experiment. The schematic diagram of the equipment used in the experiment is shown in Fig. 2.



(a) (b)

***Fig. 2.** (a) Scheme diagram to determine the relationship between the magnetic susceptibility to the temperature. At the picture: A ammeter, V voltmeter, T thermometer, and B gaussmeter. (b) Photograph of equipment used in the experiment.*

Procedure for Data analysis

Curves based on the data set of temperature and suceptibility (T_i, χ_{mi}) on each coil variation were plotted according to the linear regression $y = ax + b$, where y is χ_m and x is T. The strong of relationship between the two variables are determined by degrees of linearity (R^2) and resolution of sensor was obtained from the slope of the graph. The coil which has the largest slope and the R^2 tend to 1 is the most feasible to be used as a temperature sensor. Furthermore, the phases of the medium inside the coil whether it is paramagnetic or diamagnetic were also determined from the curve. Materials with negative susceptibility are considered as a diamagnetic material and are not feasible to be used as a temperature sensor by considering that the susceptibility of diamagnetic material almost unaffected by the changes of temperature.

3. RESULTS AND DISCUSSION

Fig. 3, 4, and 5 show how wire diameter and number of windings in the sensor affected the susceptibility of the medium. All coils reveal the linear relationships between susceptibilities and temperature ranging from -10°C to 60°C with determination index mostly above 95%. On the other hand, almost all of the media inside the coils are in paramagnetic phase, and only a few are in diamagnetic phase.

A coil with diameter of 0.10 mm, as a curve shown in Fig. 3 with the number of winding 3600 and 6000 shows a diamagnetic properties; whereas with the number of windings 12000 shows paramagnetic properties. Equations associated with the linear relationship between temperature and susceptility and determination index are shown in Table 1. The coil with the number of windings 12000 have the highest resolution that is 0.0057/°C, and have the strong relationship between temperature and susceptibility with the R^2 of 0.980.

For coils made of wire with diameter of 0.15 mm have susceptibility as shown in Fig. 4 and equations associated with it are shown in Table 1. Two coils with number of windings 3600 and 6000 appeared to have the most linear relationship between temperature and magnetic susceptibility. This high level of linearity is indicated by the determination index above 95%. Meanwhile, the coil with 12000 windings showed the less linear relationship, which has the determination index of about 92%. The medium in the coils 6000 and 12000 windings has paramagnetic properties in temperature range from -10

°C to 60 °C, while in the 3600 windings exist in two phases that are diamagnetic for temperatures between -10 °C to 24 °C and paramagnetic for temperature between 24 °C to 60 °C.

The coil with 3600 windings has the highest resolution of 0.0018 / ° C, and then followed by the 6000 and 12000 windings. Both have the resolution of 0.0001/°C. However, according to the level of linearity, coil 6000 windings is the most linear with R^2 = 0.98 which is higher compared to the other coils. Another consideration for a coil with 6000 windings in temperature ranging from -10°C to 60 °C is paramagnetic phases, while the coil with 3600 windings exists in two phases i.e. paramagnetic and diamagnetic.

Fig. 5 shows the curve of magnetic susceptibility for coil with wire diameter of 0.20 mm and various numbers of windings from 3600 to 12000. All of samples revealed its response to the temperature of medium. Unfortunately, the susceptibility fluctuates about the straight of linear regression of magnetic susceptibility and temperature. On another hand, the medium is inside the coil consist of two phases namely diamagnetic and paramagnetic. Therefore, the wire with diameter of 0.2 mm is less feasible to be used as a temperature sensor.

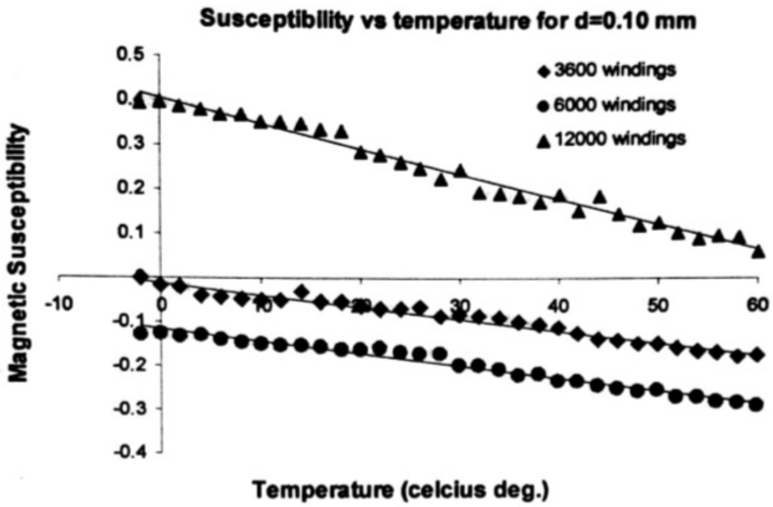


Fig. 3. *The relationship between magnetic susceptibility and temperature of the medium for the coil wire with a diameter of 0.10 mm.*

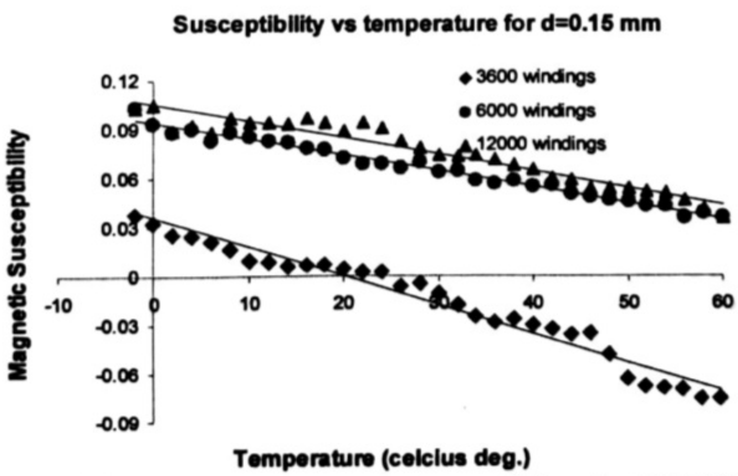


Fig. 4. *The relationship between the magnetic susceptibility and temperature of the medium for the coil wire with diameter of 0.15 mm.*

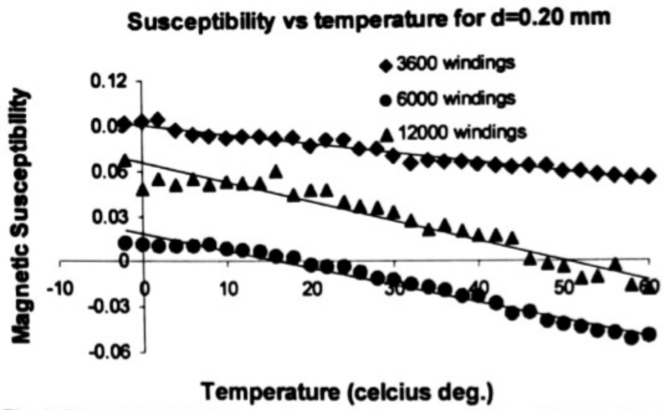


Fig. 5. The relationship between the magnetic susceptibility and temperature of the medium for the coil wire with diameter of 0.20 mm.

Recapitulation the data fitting equation χ_m vs T

The recapitulation of the data fitting equations between the magnetic susceptibility and temperature is shown in Table 1.

Table 1. The relationship between the magnetic susceptibility and temperature of the medium for the coils with varied diameter and number of windings

No	Diameter of wire (mm)	Number of windings	Equation	Determination Index	Phase type
1	0.10	3600	$y = -0.0027x - 0.012$	$R^2 = 0.9661$	Diamagnetic
		6000	$y = -0.0028x - 0.117$	$R^2 = 0.9683$	Diamagnetic
		12000	$y = -0.0057x + 0.405$	$R^2 = 0.9801$	Paramagnetic
2	0.15	3600	$y = -0.0018x + 0.0357$	$R^2 = 0.9635$	Dia-para
		6000	$y = -0.001x + 0.094$	$R^2 = 0.9827$	Paramagnetic
		12000	$y = -0.001x + 0.1052$	$R^2 = 0.922$	Paramagnetic
3	0.20	3600	$y = -0.0006x + 0.0907$	$R^2 = 0.9635$	Paramagnetic
		6000	$y = - 0.0011x + 0.0183$	$R^2 = 0.9707$	Dia-para
		12000	$y = -0.0013x + 0.0657$	$R^2 = 0.9265$	paramagnetic

From Table 1, it appears that the coil with 0.10 mm diameter and 12000 windings which has the equation:

$$y = -0.0057x + 0.405 \quad (1)$$

is the best temperature sensor compared to the other two coils. The sensor has the highest sensitivity that is 5.7 /°C and has a strong relationship between the two variables that is $R^2 = 0.9801$. If the expression of equation (1) is reversed into the equation that relates x to y, we have

$$x = -175.4y + 71.1 \quad (2)$$

In the susceptibility and temperature expression, we get

$$T = -175.4\chi_m + 71.1 \quad (3)$$

With the eq. (3), the temperature can be determined on each of magnetic susceptibility changes.

4. CONCLUSIONS

From the discussion above, we can conclude that:

1. All coils with diameter of 0.10 - 0.20 mm with the number of windings from 3600 to 12000 can affected the susceptibility of medium on each of temperature changes.
2. A coil with wire diameter of 1.0 mm and 12000 windings is the most appropriate coil to be used as a candidate of temperature sensor device based on magnetic susceptibility due to the sensitivity and linearity

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