The transformation of equation of the characteristic curves to widen the working area of the hall effect sensor

To cite this article: D Darmawan et al 2017 J. Phys.: Conf. Ser. 853 012018

View the article online for updates and enhancements.
The transformation of equation of the characteristic curves to widen the working area of the hall effect sensor

D Darmawan*, F Rahmawati, Suprayogi and A Suhendi
Engineering Physics, Telkom University, Bandung, Indonesia.

*Corresponding email address: dudiddw@telkomuniversity.ac.id

Abstract. The ability of a measuring instrument is determined by the characteristics of the sensor used. One of the important characteristics of a sensor is its area of work. The working area of a sensor is determined by a linear relationship between the physical quantities to be measured with the actual measured physical quantity. A narrow sensor working area will limit the use of the instruments. Transformation equation of sensor characteristic curve is expected to widen the working area of this sensor. In this study, the magnitude of a magnetic field is used as an example of the physical quantity to be measured. Hall Effect sensors are used as sensing elements and the transformation equation performed on the sensor characteristic curve. Hall Effect sensor which is used as the object of widening the area of work is UGN3503UA while the reference sensor is A1302UA. The result of this equation transformation is embedded inside a micro-controller. The interpolation value of the magnetic field, as the result of the characteristic curve transformation, which compared to the actual value of the magnetic field provides an average relative error of measurement results of 3.83 %.

1. Introduction
In recent years, the measurement of the magnetic field has become an important concern in the industrial world [1] [2]. One of the sensors used to detect magnetic fields is Hall Effect sensor.

Hall Effect sensors is mostly used because it provides lossless and isolated current-sensing solution, by sensing the current without dissipating the power that passive resistors do [3]. Their low maintenance, robust design and sealed Hall Effect devices are immune to vibration, dust and water [4].

Hall Effect sensors work based on the concept of Lorenz which posed the charged particles under the influence of magnetic fields [3]. Linear relationship between the electric potential generated by the magnetic field on charged particles, which polarized the particles, is used as the basic concept of measuring the magnetic field [4]. Interval linearity which is the characteristic of each sensor is referred to as the working area of the sensor. The working area of the sensor is one of the problem of the measurement devices.

The Hall Effect sensors used in this study are UGN3503UA and A1302UA. Both magnetic sensors are only a sample of sensors to implement the results of widening the working area of the sensor. Two magnetic sensors used in a Hall Effect sensor which have different work area. One sensor, which has a
wider working range, is used as a reference. Meanwhile, the other sensor, which have a more narrow working area, is used as an object sensor that will be widened. Sensor UGN3503UA is one of the Hall Effect sensors that is widely used and easily available in the market at a price that is not too expensive. The test results of this sensor in a previous study [5] found that the electrical potential linear response obtained in the magnetic field are given below 900 Gauss.

Meanwhile, in another study [6], A1302UA sensor can provide a linear response to electrical potential to the provision of a magnetic field of 1800 Gauss. Therefore, the sensor UGN3503UA has a work area that is narrower than A1302UA sensor.

Based on the data acquired from the results of these studies, we can make measurements from a magnetic field with a value greater than 900 Gauss using UGN3503UA sensor. Through this idea, the sensor UGN3503UA, with a narrow working area, can be used to measure the magnitude of the magnetic field that is greater than the maximum limit of the linear sensor. To be able to do that, the sensor characteristic curve equation UGN3503UA needs to transform to the sensor characteristic curve equation A1302UA. The equation of this transformation is then used to interpolate the value of the magnetic field of the electric potential measurements by sensors UGN3503UA. Through this process, the working range of the sensor UGN3503UA will be wider so that it can be used to measure the magnetic field to the maximum extent of A1302UA sensor. Equations transformation and interpolation step are then translated into the program and can be implemented into the microcontroller.

2. Research method
The study begins by characterizing the source of the magnetic field that will be used, namely neodymium magnet rods. This step is done by measuring the magnitude of the magnetic field as a function of distance. The magnitude of the magnetic field as a function of distance measurement produces a characterization curve. This curve is then used to calibrate and validate the results of the determination of the value of the magnetic field by the sensor under test.

The next stage is to characterize the second Hall Effect sensor. Through the characteristic curve of each sensor, the working area of the sensor and the characteristic equation can be determined. After the equation of each characteristic curve is obtained, then the transformation equation of the sensor characteristic curves is done. Transformation is done from the sensor with a narrow working area to the reference sensor characteristic curve which has a wider working range. Overview of the characteristic curve and the working area of each sensor are shown in Figure 1.

![Figure 1](image)

Figure 1. An overview of the sensor characteristic curve

Figure 1 shows the different working areas of both sensors. Both sensors provide a voltage output that is proportional to the magnetic field strength, the greater the magnetic field is given, the greater the output voltage measured by the sensor. Sensor 1 has a working range narrower than sensor 2.
Thus, the transformation of the characteristic curve equation will be conducted from sensor 1 to sensor 2. Through this transformation equations, interpolation value of the magnetic field may be based on electric potential value measured by sensor 1. It is expected that the sensor 1 will behave the same as sensor 2. Flowchart of research conducted seen in Figure 2.

\[ \text{Figure 2. Flowchart of research} \]

3. Results and analysis

3.1. Characteristic of magnetic field source

To test the Hall Effect sensor, a source of magnetic field measured and calibrated needed. Sources of magnetic fields have two important characteristics which are the flux density and polarity. To obtain the characteristics of the source of the magnetic field, neodymium magnet is used in this study. Specifications bar magnets used is 2 cm long, 1 cm wide and 0.5 cm high. Results of measurement of magnetic field strength showed a function of distance measurement, using teslameter 7010 models that have been calibrated, shown in Figure 3.

\[ \text{Figure 3. The characteristic curves of the magnetic field source rod neodymium} \]

Figure 3 shows that the maximum magnetic field generated by the magnet rod is achieved at 3000 gauss neodymium magnet at the position approaching the probe teslameter (position 0 cm). Meanwhile, if the position is eliminated, the amount of neodymium magnet magnetic field decreases
and reaches a value close to 0 gauss at a distance of about 8 cm. However, the linear relationship between the magnitude of the magnetic field and the distance measurement can be achieved between 0 cm and 2 cm. Therefore, the validation of Hall Effect sensors using neodymium magnet rods will only be done in the measurement range below 2 cm.

3.2. **Characteristic of hall effect sensor**

In the same way, to ensure the measuring area to be used, the characterization of the Hall Effect sensor needs to be done. Measurement of magnetic field strength neodymium rod do the same using both UGN3503UA hall Effect sensor and A1302UA, as shown in Figure 4. The measurement results of the second voltage sensor bar magnet distance changes were obtained as shown in Figure 5.

![Figure 4. Measurement of the magnetic field](image)

![Figure 5. Graph comparison voltage output sensor test results 1 (UGN3503UA) and sensor 2 (A1302UA) with neodymium magnet rods against distance measurement](image)

The output of the two sensors, in Figure 5, shows that the sensor responds to changes in the magnetic field is also given linearly at a distance of less than 2 cm.

Furthermore, by using a measuring instrument that has been calibrated (Teslameter 7010), the measurement of magnetic field strength on every point distance measurement between 0 and 2 cm is done. Results of measurement of magnetic field strength by teslameter and the electric potential arising from the Hall Effect sensor by a multi meter plotted become characteristic curve, as shown in Figure 6.
Figure 6. The second characteristic curves of sensors with neodymium magnet rods source

The relationship between the values of the magnetic field sensor output voltage 1 did not produce a linear curve entirely. For sensor 1, the curve is linear only in the range of 0 to 900 gauss. If the magnetic field exceeds 900 gauss is given then the sensor experience saturation. Similarly, in the second sensor, the resulting curve only produces a linear curve until approximately 1400 gauss. From the measurement data, sensor 1 can be targeted widening of the work area. Through this process, the sensor 1 is expected to work on the areas of work as well as sensor 2.

3.3. The equation of characteristic curve of hall effect sensor

At this stage, the characteristic curve equation will be determined by the method of interpolation. Equation characteristic curve for each sensor is broken down into two intervals in the range 0-900 gauss and 900-1400 gauss. Sampling and interpolation curves to measure data at the sensor characteristic curve 1 (UGN3503UA), within the range of 0-900 gauss, obtained as shown in Figure 7. Meanwhile, the equation interpolation on the curve characteristic of the sensor 2 (A1302UA), in the same range, is obtained as shown in Figure 8.

Figure 7. Sampling data and interpolated curves characteristic of the sensor 1 in the range of 0 to 900 gauss
From Figure 7 and 8, it can be obtained that equation characteristic curve for sensor 1 and sensor 2 is

\[ B (V_1) = 548.87V_1 - 1382.6 \]  \hspace{1cm} (1)
\[ B (V_2) = 1077V_2 - 2653.3 \]  \hspace{1cm} (2)

With

- \( B \) is a large magnetic field (gauss)
- \( V_1 \) output voltage (volts) sensor 1
- \( V_2 \) output voltage (volts) sensor 2

As for the magnetic field ranges between 900 to 1400 gauss, the characteristic curve is obtained as Figure 9 and 10.
Equation characteristic curve for the range 900 to 1400 gauss is

\[
B (V_1) = 12920 V_1^2 - 10409 V_1 + 210448
\]  
(3)

\[
B (V_2) = 1053 V_2 - 2581.1
\]  
(4)

3.4. The transformation of characteristic curve equation

Transformation equation is done in two ranges. For the range of 0 to 900 gauss, because the magnetic field measured by the sensor is the same value of the magnetic field, the value of equation (1) will be equal to the value of equation (2).

\[
B (V_1) = B (V_2)
\]  
(5)

Completion of the equation (5) yields as a function of V1 V2, such as the equation (6)

\[
V (V_1) = \frac{548.87 V_1 - 1270.7}{1077}
\]  
(6)

Equation (4) is the transformation equations to get the same voltage as the voltage sensor 2. Then equation (6) is substituted into the equation (2) and will generate the equation (7).

\[
B (V_1) = 1077(\frac{548.87 V_1 - 1270.7}{1077}) - 2653.3
\]  
(7)

Equation (7) indicates a value approach magnetic field measured by the sensor 2 will be based on the value of the voltage that is read by the sensor 1 measuring range 0-900 gauss. Equation (7) is the result of the transformation equation thus replacing the equation (1).

Just like the range of zero to 900 gauss, the determination of the equation range from 900 to 1400 gauss is done by substituting the equation (3) and (4) to the equation (5). This result in a voltage transformation equations equation (8).

\[
V_2(V_1) = \frac{102920 V_1^2 - 104091 V_1 + 2130291}{1053.9}
\]  
(8)
While equation to interpolate the value of the magnetic field is obtained by substituting the equation (8) into the equation (4). The result is obtained as equation (9).

\[ B(V_1) = 1053.9 \left( \frac{102920 V_1^2 - 104091 V_1 + 2130291}{1053.9} \right) - 2581.1 \]  

(9)

Equation (9) indicates a value approach magnetic field measured by the sensor 2 will be based on the value of the voltage that is read by the sensor 1 on the measurement range 900-1400 gauss. Equation (9) is the result of the transformation equation thus replacing the equation (3).

3.5. Validation of the transformation results

In this section, the testing is done by moving closer and away from the source of the Hall Effect sensors magnetic field. Sources of magnetic fields used are neodymium magnet rods with characteristics as in part A. By varying the distance between the permanent magnet rods with a layout position of a Hall Effect sensor, the test results for the magnetic field ranges from 0 to 900 gauss is as shown in Table 1. As for the range of 900 gauss to 1400 is as shown in Table 2. In Table 1, the validation is done by comparing the results of the transformation equation is \( B(V_1) \) (equation (7)) to the value of the magnetic field measured on a Hall Effect sensor reference in that equation (2). Whereas in Table 2, the validation is done by comparing the results of the transformation equation is \( B(V_1) \) (equation (9)) to the value of the magnetic field measured on a Hall Effect sensor reference in that equation (4).

| Table 1. Results of Testing Transformation sensor 1 to sensor 2 range 0-900 Gauss |
|-------------------------------------------------|---------------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| distance | V1 | V2 | V2 (V1) | B (V1) | B (V2) | Error |
| (cm) | (Volt) | (Volt) | (Volt) | (Gauss) | (Gauss) |  |
| 0.7 | 3.83 | 3.11 | 3.23 | 881.60 | 855.62 | 2.95 |
| 0.8 | 3.56 | 2.99 | 3.11 | 703.72 | 694.48 | 1.31 |
| 0.9 | 3.37 | 2.90 | 3.01 | 577.13 | 569.26 | 1.36 |
| 1 | 3.23 | 2.84 | 2.93 | 486.60 | 454.58 | 6.58 |
| 1.1 | 3.13 | 2.78 | 2.87 | 394.88 | 400.61 | 1.45 |
| 1.2 | 3.04 | 2.73 | 2.82 | 335.20 | 350.91 | 4.69 |
| 1.3 | 2.96 | 2.68 | 2.77 | 287.82 | 330.50 | 14.83 |
| 1.4 | 2.90 | 2.65 | 2.74 | 257.98 | 288.37 | 11.78 |
| 1.5 | 2.85 | 2.63 | 2.69 | 227.10 | 222.57 | 1.99 |
| Average of Error | | | | | | **5.22** |

| Table 2. Results of Testing Transformation sensor 1 to sensor 2 range of 900-1400 Gauss |
|-------------------------------------------------|---------------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| distance | V1 | V2 | V2 (V1) | B (V1) | B (V2) | Error |
| (cm) | (Volt) | (Volt) | (Volt) | (Gauss) | (Gauss) |  |
| 0.4 | 4.27 | 3.92 | 3.72 | 1472.64 | 1454.26 | 1.25 |
| 0.5 | 4.24 | 3.71 | 3.70 | 1235.08 | 1226.36 | 0.71 |
| 0.6 | 4.15 | 3.52 | 3.34 | 1072.24 | 1059.08 | 1.23 |
| Average of Error | | | | | | **2.45** |
From Tables 1 and 2 above, the increase in the working area sensor 1 is obtained with an average relative error of 3.83%. The error occurs because there are several factors which influence it, such as the distance between the sources of the magnet with a Hall Effect sensor, which is relatively close to that of Hall Effect sensors, are too sensitive. Another factor is the influence of the magnetic field around and error or tolerance measurements. The value of $B (V_1)$ and $B (V_2)$ is plotted for the entire range of the obtained graph such as shown in Figure 11.

![Figure 11. Graph comparing the results of measuring sensor 1 and sensor 2](image)

The graph in Figure 11 shows that the results of the transformation curve equation sensor 1 as a whole has followed the pattern of the magnetic field measurement results which is done directly by the sensor 2. This proves that sensor 1 is already behaving like sensor 2 and can work over a range of magnetic field measurements the same as work area sensor 2.

4. Conclusion
At the sensors work area ranges that intersect, i.e. 0-900 gauss, the characteristic curve of Hall Effect sensors are not coincident with it so that the transformation should be performed in all ranges of the working area. In the span of an intersecting area of work, the process of transformation can be termed as the sensor calibration of the sensor reference.
Transformation equation characteristic curve to increase the area of the sensor work began to happen to the value of 900 gauss magnetic field. Improved working area can be made within the particular work area of the sensor reference.

References
[1] James Sedgwick, William R and Reinhold Ludwiq 1998 *Design of a Digital Gauss Meter for Precision Magnetic Field Measurements* Department of Electrical and Computer Engineering Worcester Polytechnic Institute Worcester USA.
[2] Mitra Djamal, Ramli, Rahadi Wirawan and Edi Sanjaya Sensor Magnetic GMR *Teknologi dan Aplikasinya, dalam Prosiding Pertemuan Ilmiah XXV HFI*, Jateng & DIY.
[3] Arya Krishna S and Lizy Abraham 2014 *Analysis of Different Hall Effect Current Sensors for Space Applications* *International Journal of Innovative Science* Engineering & Technology 1 Issue 5.
[4] Bachtera Indarto, Melania Suweni Muntini, and Darminto 2009 *Pembuatan Magnetometer ber-tranduser Efek Hall* Jurusan Fisika FMIPA ITS, Surabaya.

[5] Jaromír Jezný, Miloslav Čurilla, 2013 Position Measurement with Hall Effect Sensors *American Journal of Mechanical Engineering* 17 231-235.

[6] Johan Wahyudi, Gurum Ahmad Pauzi and Warsito 2013 *Desain dan Karakteristik Pengunggunaan Sensor Efek Hall UGN3503 untuk Mengukur Arus Listrik pada Kumparan Leybold P6271 secara Non Destruktif* Jurusan Fisika FMIPA Universitas Lampung Bandar Lampung.