Sensor Hall Effect on Analyses Mechanical Stress

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Received: November 14, 2014 / Accepted: December 24, 2014 / Published: January 25, 2015.

Abstract: Measuring the magnetic field is a common practice in industrial processes. We can cite the voltage measurements through PTs (potential transformers). This is a classic example of inductive field measuring, predicting to be measured quantity is of oscillatory nature, with the circuit instrumentation scaled and calibrated for a typical frequency of 50/60 Hz. For a long time, only the binary information: “this field” and “missing field” is needed. For example, only with this information can we identify the frequency of the rotating shaft. Currently, new technologies employ magnetic sensors for measuring positions (distances, angles, etc.) from the intensity of the magnetic field. Inductive sensors are inefficient on measurements of static fields, such as magnets, opening spaces for new linear Hall effect sensors, and static which deal with these situations without difficulty. The present study examines the behavior of the Hall sensor, making the measurement of the intensity of the static magnetic field of the rotating magnet and the same, verifying the effect of the speed at which the magnet passes the sensor in some way alter the measurement. The results are favorable and the versatility of these sensors in many different applications.

Key words: Dynamic measurement, Hall effect, instrumentation, sensors and actuators in robotics.

1. Introduction

Due to the nature of the electromagnetic fields, and the intrinsic and inseparable connection between electric current and magnetic field, adequately explained by Maxwell's equations (Amper Law and Faraday's Law-Lenz), can be said to measure the magnetic field, electric current is measured.

Thus, as soon realized the importance of measuring the intensity of the magnetic field. Early am-meters, the analog, make use of a coil and a magnet (or other coil with controlled feeding). The intensity of the field generated from the current to be measured, translates the interaction between two magnetic fields which as a consequence moves a pointer on a scale calibrated in advance.

With the advent of electronics, am-meters, volt-meters and other gauges of electrical analog, were gradually being replaced by digital equivalents, with

comparators and A/D converters, but efficient and accurate, and that the old method was restricted to facilities high power, or indirect measurements.

The example of these applications can cite the CTs (current transformers) and PTs (potential transformers), able to provide the voltage and current through the magnetic field produced by these quantities. Importantly, the systems are built to operate at frequencies in the range 50-60 Hz, or at least fixed values of frequencies.

These sensors are usually called inductive sensors, as its operating principle is based on Faraday's Law and Lenz Law, which in essence tells us that “Electromotive force induced in a circuit is equal to the change of the magnetic flux concatenated to the circuit”. That is, when a coil is subjected to variation in the intensity of the magnetic field emergence, this induced electric current which will be greater the amplitude of the variation or the shorter the time it occurs.

Thus, the same magnetic sensor measuring electric current, for example, can provide us with wrong

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values, if any significant changes in the frequency of the current. A current of 1.0 A, 60 Hz, 100-fold induction produces a current less than 1.0 A, 6 kHz, although both have current intensity of 1.0 A.

Therefore, a correction is necessary because of the frequency of values of the quantity in measurement, resulting in more complex circuits and high cost, it is necessary to calibrate the correction factor for each new application.

Besides measuring electrical quantities, the magnetic field sensors are widely used in measurements of mechanical quantities such as position, velocity and acceleration.

To measure the frequency of a rotating shaft or gear, for example, use is made of a magnet or a coil in the movable element and the sensor on the fixed element. For this application, the circuit presents the results in a logical way: “this field” or “field missing”. What is measured, so is the sequence of jumps, and so we have values of speed, frequency or acceleration.

Importantly inductive sensors are inefficient in static field measurements, such as measuring the field of a magnet or a current.

However, a new technology for measuring magnetic field has been increasingly space in industrial applications. The Hall effect sensors, in particular linear sensors, are capable of measuring the intensity of the magnetic field with high precision.

The paper is organized as follows: Section 2 discusses the Hall effect sensor; Section 3 details the methodology of measurements in mechanical deformation; Section 4 presents implementation and testing of measurements; Section 5 is the displacement test; finally, Section 6 gives conclusions.

2. Hall Effect Sensor

The first Hall effect sensor with industrial application merely to replace the inductive sensors for measuring position and velocity, generating a logic level (or pulses) whenever there was the presence of a minimum intensity of the magnetic field. These

sensors are grouped several advantages, such as reduced space, better thermal stability and the ability to detect a static magnetic field. But ultimately, what the Hall effect?

Initially, imagine an electric current, continuous, in a thread in the horizontal direction. If a magnetic field is applied in the region of space that is this thread, perpendicular to the plane, will rise to a magnetic force directed to vertical. This explanation classical electromagnetism refers to only one driver linear, finite-length, and it is considered the region of space as infinite, this driver can move up continuously.

Let us now take a conductor in the form of a thin tape, an electric current passed through it from left to right (Fig. 1a). When applying a magnetic field perpendicular to the plane, there is an upward displacement of the chain, similar to our previous example (Fig. 1b). We will have an accumulation of negative carriers at the bottom of the tape, and positive at the top. These displacements occur until the magnetic force to be balanced with the electrostatic force.

In 1879, during his Ph.D., Edwin H. Hall discovered this effect, under the guidance of Henry A. Rowland. The voltage between points A and B came to be called the Hall voltage, and the effect described here. This voltage is proportional to the applied magnetic field, regardless of whether it is continuous or oscillatory.

It is important to note that currently has equivalent quantum Hall effect, and the effect described here can

Fig. 1 (a) Thin ribbon traveled by electric current and (b) effect of magnetic field on the curries.

also be found in the literature as “classic Hall effect”.

2.1 Linear Hall Sensors

As mentioned above, the first sensor had only two logical levels: with/without magnetic field. Soon after, there were sensors multilevel or tracks magnetic/output voltage. Currently, we have the linear. The output voltage is linearly proportional to the applied field, and can thus accurately measure the intensity of the magnetic field or the variation of this in several applications.

Each sensor operates in a predetermined range of magnetic field intensity. Within the limits of this range the internal circuit, composed primarily of comparators and current sources, saturates, and the output voltage becomes constant. As general rule, the sensors also distinguish the direction of the field (North Pole or South Pole), varying the voltage to the negatively and positively North Pole to South Pole, can find the opposite sense, as the manufacturer [2].

Without the presence of the magnetic field, the sensor remains constant in a quiescent reference voltage, usually half of the supply voltage, so they are constantly referred to as “relaciometric”. Fig. 2 illustrates the typical behavior of such sensors.

Among the various applications, we can mention the linear Hall effect sensors: “The current sensing, measurement of energy, detection of metals, measurement of rotation of moving parts, reservoir level detection, electronic potentiometers” [3].

One possible application is the sensor “proximity”. We can measure small distances, because the approach or departure from the magnetic field source will provide us with an equivalent amount in voltage from the sensor.

The developed system made use of sensor linear Hall effect of “Winson semiconductor”, WSH 202, which has a sensitivity of 20 mV/G. That is, for an increase of 1.0 Gauss field intensity leads to an increase of 20 mV at the terminals of the sensor. 01 Gauss corresponding to 10^{-4} T (Tesla). We will use

Fig. 2 Voltage variation with the applied field [2].

this system to measure the relative displacement between two magnets. Recent applications are requiring precisely to measure the intensity of a magnetic field under these conditions.

3. Measurements in Mechanical Deformation

Two magnets are positioned on a structure element subjected the more different voltages. The movement between these two magnets will provide the variation of the resulting magnetic field, which will be recorded by the sensor hall effect. As an example, the element represented by Fig. 3, which is initially no load applied (axial forces). Then, it applies a tension, which causes linear deformation throughout the piece. The effects representation is purposely increased.

Measure the linear deformation is a simple task if the element is in a static application, which is not the case. Imagine extensometer gauge or a micrometer this deformation during rotation.

It is apparent that there is a gap between the two magnets. By measuring this magnetic field, it is possible to measure this deformation. We will measure the magnetic field at a point of symmetry between the two magnets (Fig. 4):

Fig. 3 Element subjected to tensile.

Fig. 4 Field magnetic dipoles.

Importantly, due to the symmetry of the electromagnetic problem, and making a cut in the x-z plane, we have the magnetic field in the z direction in the x direction. The field in the x direction vanishes along the z axis. In this axis, measurement is performed with the Hall sensor, where the component perpendicular to the field can be expressed as [6-8]:

$$\vec{B}_z = \frac{\mu_0 m}{4\pi} \left[\frac{2z^2 - \left(\frac{d}{2}\right)^2}{\left(z^2 + \left(\frac{d}{2}\right)^2\right)^{\frac{5}{2}}} \hat{e}_z + \frac{2z^2 - \left(\frac{d}{2}\right)^2}{\left(z^2 + \left(\frac{d}{2}\right)^2\right)^{\frac{5}{2}}} \hat{e}_z \right] \quad (1)$$

This same equation can be applied also in compression and in torsion, and twist the magnets must be aligned at 45° with the axial axis. It is also possible to perform measurements in flexion, but we must adapt the equations.

That is, the variation in z (height) d (distance between magnets) will translate into variations in the magnetic field. Since z (height) remains constant, it is possible to relate the displacement between the magnetic elements and deformations.

4. Implementation and Testing

For implementation and testing, a system was set up with the objective of measuring the mechanical deformations in rotating systems. For signal acquisition was used the platform my-DAQ (data acquisition device), national instruments, with 16-bit resolution and a sampling rate of 12.5 kS/s. VI (virtual instrument) was implemented in LabView® to perform the analysis and recording of data.

To simulate a real situation, coupled to a magnet to

the shaft of a motor, in Fig. 5, to check the operation of the data acquisition, facing different rotation speeds.

The magnet used was permanent magnet N48, also known as neodymium-boron (Nd₂Fe₁₄B) magnets or “rare-earth”, since the elements that compose receive this rating in the periodic table [9]. These magnets are produced by sintering, from oxides and metals, all operations being performed under inert gas protection. Due to their high oxidation, coatings are employed metal such as zinc, gold and nickel. Currently, these are among the most energy permanent magnets and accessible, being widely used in academic research and industrial products [10, 11]. Their reference values are available in the literature.

Previous work has demonstrated the sensor is stable, sensitive and highly accurate, smoothly operating at different frequencies used, and that the peak value of the dynamic field, independent of frequency coincides with the value of the static field, and the Hall effect sensor seemingly immune to disturbances in amplitude of the hall voltage due to the rotation frequency. This peak value is only changed when approaching or departing the entire set-piece magnet.

Comparative measurements with the traditional methods are ongoing and preliminary results have proved the efficiency of the measuring system employed by conventional methods.

Fig. 5 Prototype used in measuring magnetic field magnet DC motor attached.

5. Displacement Test

Initially, it is necessary to verify that the relative spacing between the magnets results in a change in the amount of magnetic field which provides a variation in output of the Hall effect sensor which is capable of being read by the data acquisition unit used in the system measurement, which has a resolution of 16 bits, which in terms of voltage is equivalent to 30 mV approximately.

To have such an understanding, set up the first magnet, while the second moves away gradually, with the aid of a micrometer. The value of magnetic field (sensor output voltage) is measured, keeping the sensor at a fixed height of the plane on which the magnets lie and immediately above the magnet is fixed. The theoretical behavior of the displacement between the magnets can be seen in Fig. 6.

You can see that as the movable magnet moves away, the field value decreases until there is only influences the fixed magnet on the sensor. The height of the sensor, represented by the letter z , plays a fundamental role in the measurement, since the greater the value of the field, and consequently, the better the reading of the voltage values of the Hall sensor.

Thus, the visible-mounted system in Fig. 7, with the plate already developed a linear Hall effect a sensor WSH (Hall Wilson semiconductor), designate as WSH 202, connected to my-DAQ national instruments, which is interfaced with the LabView software from the same company.

The micrometer used was an inside micrometer, caliper's type—25-50 mm with resolution of 0.01 mm, manufactured by precision instruments Digimes Ltda. Neodymium magnets (they characterized and used in the previous chapter) were fixed on the inner ends of the stop just below the Hall sensor. In Fig. 8, we can see the details of the assembly.

With all elements fixed, the variation was carried away in “steps” of 0.05 mm, registering its value voltage and magnetic field corresponds. This procedure was repeated five times, and the results are expressed as a function of the average of the measurements. Three different heights (5 mm, 6 mm, 7 mm) were also used, as the theoretical prediction shown in Fig. 9 indicates that in these larger variations, field/voltage heights are barely perceptible. The same occurs at distances between magnets larger than 6 mm, so we chose to measure up to this position.

Fig. 6 Variation of the magnetic field on the distance between the magnets—theoretical.

Fig. 7 System mounted micrometer displacement test.

Fig. 8 Detail of the position of magnets and Hall sensor.

Fig. 9 Magnetic field measurements.

6. Conclusions

Conclude that the magnetic system presented here is extremely advantageous, showing an excellent alternative for applications with limited space, high engine speeds and systems that need to stay long time without manual inspection.

The mathematical model developed from the basic equations of electromagnetism, and evolved into a complex solution, which proved to be consistent with experimental measurements, validating the theoretical prediction of system operation, including what proved to be immune to variations of rotational speed axis,

which is not possible with inductive windings or sensors.

The Hall effect sensor used is one of the best on the market because it features low noise and high sensitivity. Before the WSH 202 were tested three other sensors available in the semiconductor market, but all showed lower performance. The manufacturer of this sensor, the “Winson Semiconductor Corp.”, is based in Taiwan and specializes in Hall effect sensors.

The interface LabView proved successful, to perform the measurement in real time graphical display of the values of voltage/magnetic field and reasonably simple to implement digital filters, thereby

simplifying the circuit board made. The analog-digital converter was used with 16-bit resolution and a maximum sampling rate of 200 kS/s, and met the need of the project. Measurements of linear displacement among the magnets showed that this resolution is possible in the reading and record the voltages without problems.

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