Experimental analysis of magnetic field sensors

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Abstract. In this study, the process of measuring the magnetic field through the principles of the Hall and magnetoresistance effects was examined. Measuring the magnetic field is of great importance in electronics and mechatronic systems. This process depends on the electric charge passing through a conductor or a semiconductor. The magnetic and electric field flux makes it possible to observe motion and position. The Hall sensor converts the magnetic flux density into an electrical signal. The sensor provides high linearity and sensitivity. The research was carried out under laboratory conditions. In this, a Hall sensor mini-module was used. Additionally, using it, the dependence on distance from the magnetic source was measured at various points. The results demonstrated the relationship between the output voltage and the distance. It was found that this relationship has a direct nature. This enabled the possibility of measuring the presence of the magnetic field. The system responded promptly to real-time changes in the magnetic field. This response made it possible to determine the system's operational parameters. The result demonstrated that this solution can be applied in automated monitoring and adaptive control systems.

INTRODUCTION

Modern electronics, electrical engineering, and mechatronic systems are rapidly developing. This process is carried out using a three-terminal magnetoresistance sensor. It allows the measurement and control of the magnetic field [1]. Magnetic field sensors are used in electrical, electromechanical, and information systems [2]. Hall sensors made of iron (Fe) and platinum (Pt) elements are used. They provide high stability in measuring the magnetic field [3]. They ensure the stability of the electric charge flow. For this reason, they are used to observe physical processes in conductors or semiconductors [5]. Magnetic field sensors measure magnetic field induction and electric voltage. Additionally, they also rely on the principle of measuring magnetic field direction vectors [4]. They are used in physical processes such as the Hall effect and the magnetoresistance effect [6]. This process represents the change in the direction of magnetic force acting on the charge flow in materials. They also exhibit a change in conductivity depending on the magnetic inductance. In this case, as a result of the Hall effect, when current passes through the semiconductor, a magnetic field perpendicular to it is generated. As a result, a transverse voltage appears in the material [7]. This process is used in various electrical measurement systems. Hall sensors, in turn, possess a linearity parameter in their analogue output signal. For this reason, they provide current measurement, rotational speed, and angular position. Additionally, this process is widely used in motion monitoring [8, 9]. Such sensors are distinguished by having few mechanical components. For this reason, they ensure long-term stable operation and energy efficiency. For this reason, they are widely used in notification, safety, and measurement systems [10]. The magnetoresistance effect changes the electrical resistance of a material to the current flowing through it under an external magnetic field. It measures the change in magnetoresistance of conductive or semiconductor materials under a magnetic field [11, 12]. The speed, sensitivity, and accuracy of magnetic sensors depend on their physical parameters and internal components. For this reason, the experimental study of magnetic sensors is of great importance. This allows for the analysis and evaluation of their main parameters.

EXPERIMENTAL RESEARCH

Hall effect. An electric charge passing through a conductor or semiconductor is subjected to a force by a magnetic field and an electric field. As a result, a transverse voltage is generated. This force is related to the motion of the charged particle. Its direction depends on the vector characteristics of the charge motion and the field.

$$F=q(E+v\cdot B) \tag{1}$$

Here: F is the force exerted by the magnetic field and the electric field; q is the charge; E is the electric field vector; v is the charge velocity; B is the magnetic flux density.

In this case, the plate with thickness d, length l, and width b is supplied with the current I. It generates the magnetic field B_z in a direction perpendicular to this sample. In this case, the Hall voltage (U_H) is generated at points 3 and 4 of the sample (Figure 1).

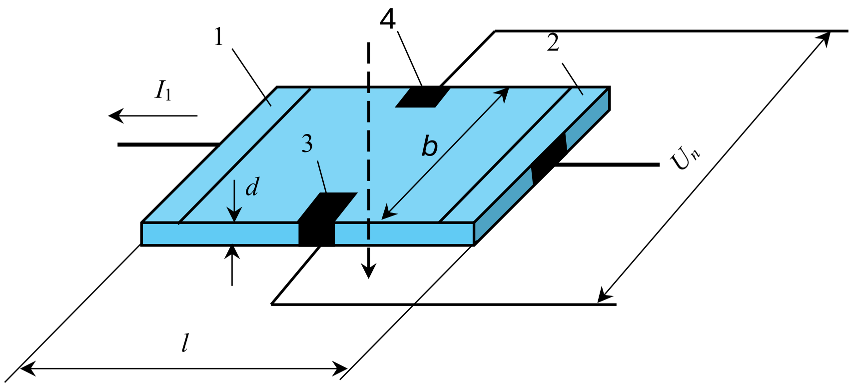

FIGURE 1. Schematic diagram of the Hall sensor operation principle.

The Hall sensor converts the presence or strength of a magnetic field into an electrical signal. It measures the magnetic flux density and provides an analog or digital signal at the output. When current passes through metals or semiconductors, a magnetic field perpendicular to it acts on them. As a result, the Hall voltage is generated on both sides of the sample. The presence of a magnetic field is determined through this voltage.

Magnetoresistance effect. For this reason, experimentally studying magnetic sensors is of great importance. This allows their parameters to be analysed and evaluated (Figure 2).

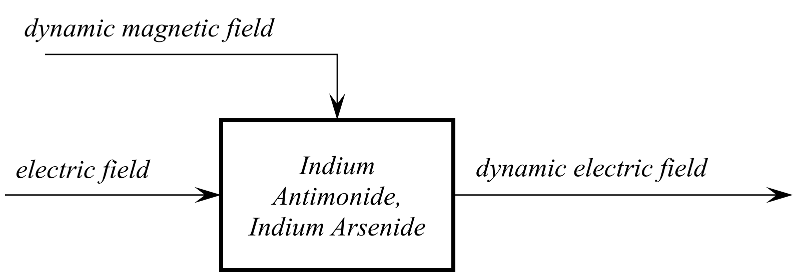

FIGURE 2. Structural diagram of the magnetoresistance effect.

In this case, a rectangular sample made of a conductor or semiconductor material is placed in a magnetic field. If the electric field direction is perpendicular to the magnetic field induction vector, the resistance of the sample increases. This is an important parameter of the magnetoresistance effect. This situation corresponds to the transverse magnetoresistance effect. If the magnetic field is parallel to the electric field direction, the longitudinal magnetoresistance effect is observed. In our experiment, this process is not used because the change in magnetoresistance is small.

The resistance of the sample, depending on the direction of the magnetic field, is expressed by the formula:

$$R=R_0+\Delta R\cos^2\propto \tag{2}$$

Here: R_0 is the resistance of the sample in the absence of a magnetic field; α is the angle between the electric field direction and the magnetic field vector; ΔR is the change in resistance in the given magnetic field at α=90°.

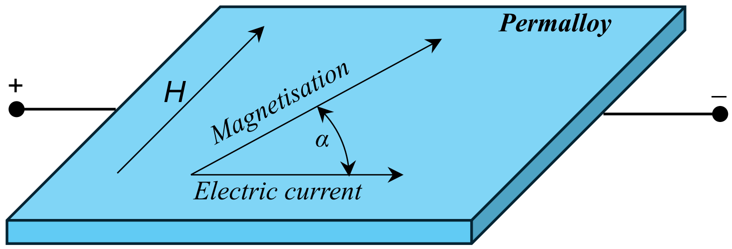

FIGURE 3. Direction of the magnetoresistance effect

The magnetoresistance effect, like the Hall effect, manifests only in semiconductors. In this case, the change in the sample's resistance moves through the electric field inside the semiconductor, but their velocities differ. It standardises the force exerted on the electric charge by the magnetic and electric fields. It regulates the force exerted on an electric charge by the magnetic and electric fields. The paths of particles with velocities greater or smaller than the average are deflected. At this moment, the resistance of the semiconductor increases.

$$\rho(B)=\rho_0\cdot(1+\frac{AB^2}{1+\mu^2B^2}) \tag{3}$$

Here: ρ_0 is the resistance of the material at B=0; A is a constant coefficient.

At small magnetic induction values ($\mu B \ll 1$), the resistance ρ of the semiconductor depends on the square of the induction B.

The dependence of the semiconductor's resistance on the magnetic induction can be expressed as follows:

$$\rho(B)=\rho_0\cdot(1+(\mu B)^n) \tag{4}$$

Here: n=1÷2 is a coefficient dependent on the value of μB.

The magnetoresistance effect also depends on the direction of the magnetic field and the dimensions of the sample. In the bridge circuit, the magnetoresistance sensor is connected as follows (Figure 4). In this case, the magnetic field changes in a sample made of ferromagnetic material. As a result, its resistance changes. The bridge circuit then detects this mismatch. The magnitude of the mismatch allows information about the state of the object to be obtained.

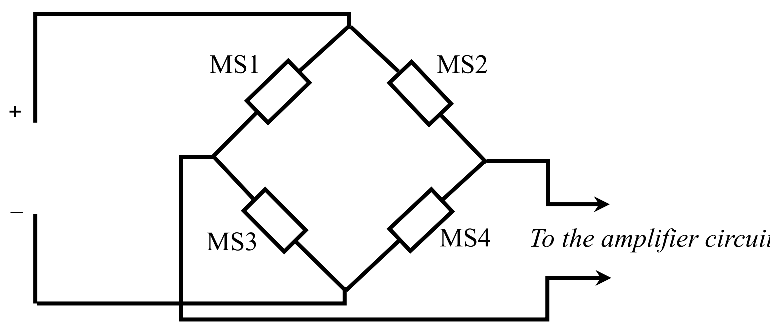

FIGURE 4. Power supply of four magnetoresistance sensors connected in a bridge circuit.

Conducting an experiment on the IA laboratory equipment. The experiments were carried out on IA (Instrumentation and Automation) laboratory equipment. A Hall sensor mini-module is installed on the output terminal of field 2 of its technological information module. A voltmeter is connected to the output terminal of the mini-module. Ten points are marked at the output of the mini-module. It shows the relationship between the output voltage and the distance to the sensor tip. Its U(L) graph was plotted.

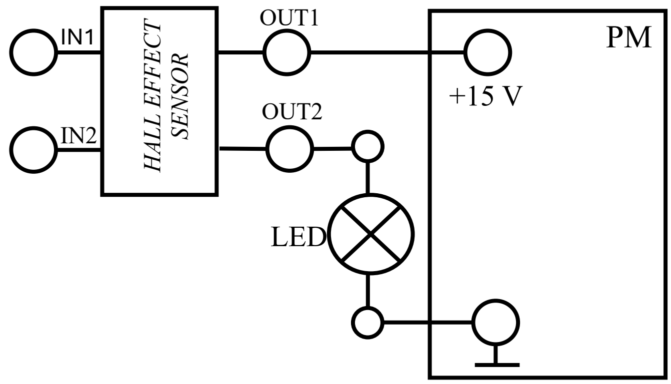

FIGURE 5. Connection diagram of the Hall sensor mini-module to the IA system.

PM-power module; LED-indicator showing the presence or state of various physical quantities.

RESEARCH RESULTS

A Hall sensor mini-module was installed on the laboratory equipment used in this study. During the experiment, the Hall sensor mini-module was connected to the output terminal of field 2 of the technological information module. Ten points were obtained by moving the sample closer to and further from it. The relationship between the output voltages and the distance between the sensor tip and the sample was shown. The forward and return paths were plotted on the same graph. This result measures the magnetic flux density through the Hall sensor module. As a result, the Hall voltage was generated on both sides of the sample. Through this voltage, the presence of the magnetic field was indicated (Figure 6).

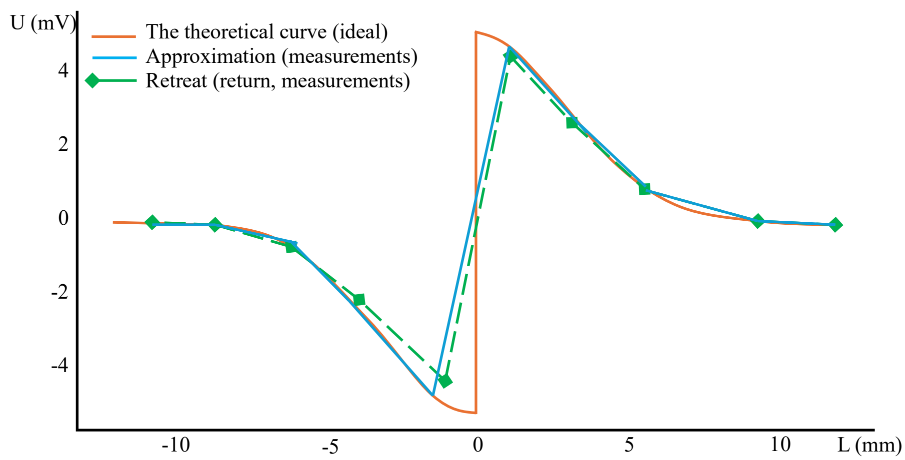

FIGURE 6. U(L) graph of approach and retreat paths obtained from the Hall sensor module

CONCLUSION

In our experiment, a Hall sensor mini-module was used. Using this module made it possible to measure the magnetic flux density. During the experiment, the presence of the magnetic field was observed through the voltage. The relationship between the output voltages and the distance between the sensor tip and the sample was shown. The forward and return paths were plotted on the same graph. The stability of the system to real-time changes in the magnetic field was observed. As a result, an automatic and adaptive control mechanism was formed in the system. This resulted in the formation of an automatic and adaptive control mechanism in the system. They can be used for application to real systems.

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