Hall Effect Sensors: The History, Theory, and Future

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Intro:

The hall effect sensor is a sensor that detects the presence of magnetic fields. This sensor is based off the hall effect which was discovered by Edwin Hall during his PHD studies. Even though this discovery is not well known it was one of the most important of the 19th century and has many uses in todays technology. This paper covers the history, theory, applications, and future of the hall effect sensor, beginning with the history and progression of this sensor.

History

In 1897, while conducting an experiment at John Hopkins University, Edwin Hall discovered the Hall Effect. By facing two electromagnets towards each other with a strip of gold foil carrying an electrical current between them, using a galvanometer Hall discovered that the magnets produced a potential difference across the foil that was perpendicular to its current. He stated that this was due to electrons converging to one side of the foil on the introduction of the magnets. This also proved that the carrier of electrical current was the negative charge contrary to the popular belief. This experiment was months in progress when he finally came to this conclusion. But before this experiment another important discovery paved the way to Hall's discovery, Maxwells relationship between electricity and magnetism (John Hopkins University & 2019, 2020).

Maxwell published his 'A Treaties on Electricity and Magnetism' in 1873 which was a revolutionary discovery that gave the relationship between electricity and magnetism. Before this paper electricity and magnetism were thought of as two separate forces. For the most part Maxwell's discovery was correct; however while reading through this paper in his second year at John Hopkin's, Hall felt that Maxwells claim that an electrical current would not deflect from its path due to a magnetic field did not make sense. Stating that it "seemed to me to be contrary to the most natural supposition in the case considered" (John Hopkins University & 2019, 2020). So, with this doubt in mind, Hall started his experiment that would lead to the discovery of the hall effect. This effect’s main purpose in its early years consisted of detecting magnetic fields and studying their strength using Hall effect sensors.

Contrary to its humble beginnings, the hall effect sensor is now used a lot in todays world. These sensors can be found in most types of electrical devices that need to measure the position, speed, or the proximity of an objects neighbors in an electrical or mechanical system (John Hopkins University & 2019, 2020). This paper lists these uses in a later section, but before that the theory behind these sensors needs to be covered.

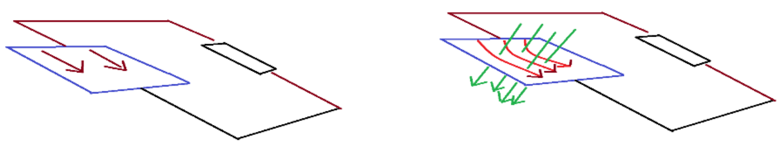
Theory:

Hall Effect Sensors implement the Hall effect to measure and detect nearby magnetic fields. These sensors gauge the magnetic flux, or the total magnetic field passing through a general area by measuring the amount of voltage that appears across the objects area. To understand how this effect occurs it helps to start by understanding the way charged particles move due to various fields (Ramsden, 2006).

To find the force exerted on a charged particle the equation:

$$F = q_0\mathrm{E} + q_0\mathrm{v} \times \mathrm{B}$$

With F being the force, E the electrical field, q the charge, v the velocity, and B the magnetic field. This equation combines the effects of an electrical and magnetic field to get the overall force on a particle. The particle will feel a force in the direction of the electric field with a strength proportional to the field and if this particle is in motion it will feel a force from the magnetic field at a right angle to that field (Ramsden, 2006). These two facts together are what cause the curved path of the particle in the figure below when an electrical field is introduced into the circuit.



When this occurs, the electrons flowing through the plate are concentrated on one side, causing a potential difference across the plate. In a hall effect sensor, the equation above can be reduced to force in the z axis, movement of voltage in the x axis, and magnetic field in the y axis. This in turn makes the equation for force:

$$F_z = q_0 v_x B_y$$

Then once the produced voltage(potential difference) is measured one can find the magnitude of the magnetic field by rearranging this formula above to be:

$$\frac{F}{q} = E$$

$$E = \frac{V}{D}, where\ V\ is\ \ and\ D\ is\ the\ length\ of\ the\ plate$$

$$\frac{V}{D} v_x = B_y, where\ v_x\ is\ the\ velocity\ of\ the\ particle$$

With that the magnetic field can be determined after measuring the potential difference it induces on the plate.

The equation above is more of a perfect world type of solution. In a real setting the equation would be as follows: $V_{Hall} = \frac{G}{t}\frac{r_n}{qN}I_{bias}B$, where G is the geometric factor, t is the thickness of the device, N is the impurity of the devices concentration, r_n is the Hall factor, q is the amount of charge, and I and B are the bias current and the applied magnetic field strength (Fan et al., 2021). So, after plugging in these values, the magnetic field can be found after rearranging the equation to be: $B = \frac{V_{Hall}}{\frac{Gr_n}{tqN}I_{bias}}$

The Hall effect sensor has had a boom of uses in the past years, due to its early applications as a magnetic field detector. The next two sections cover this progression and the future of this device.

Applications:

The hall effect sensor's early uses mainly consisted of the measurement and detection of magnetic fields. These sensors served this purpose until the rise of the semiconductor in the mid-20th century. With this new boom in tech, hall effect sensors were able to become smaller and more powerful (John Hopkins University & 2019, 2020). This allowed for these sensors to be implemented in crankshafts, tachometers, anti-break locks, satellites, smart phones, alarms, keyboards, disk drives, joysticks, GPS, speed controls, and many other devices. These devices are widely used due to their simplicity of input and output. Hall Sensors are active sensors that can provide analog or binary output (Froehlich, 2021). This output, the voltage induced by the magnetic field, is used to control these various devices. One of most common uses of this device is the Binary (switch-based) Hall Effect Sensor. These switches are on in the presence of a strong magnetic field and off otherwise. Some of these switches are latching which means they remain activated even after the magnetic field is no longer present and only unlatch when in the presence of a field in the opposite direction (Froehlich, 2021). In recent years hall effect sensors have turned towards use in biological and chemical sensors. The next section covers this new-found phenomenon.

Future Projections:

Since it is possible for the hall sensor to be several micrometers in size, it is a prime candidate for biochemical sensing. Magnetic substances produce stable signals in biological systems. Therefore, when a substance needs to be detected if there are magnetic particles mixed into this substance a magnetic sensor can easily detect and measure it. Today applications of this process range from blood pressure wave velocity detection to the characterization of soft biological material (Fan et al., 2021). This section will cover each of these new application of the hall sensor in more depth starting with blood pulse wave velocity detection.

Artery pulse signals contain a lot of information about the cardiovascular system. The speed and strength of these waves provide very accurate information regarding diseases present in this system. At this time to study these pulses we must use ultrasound or MRIs to collect this important data. To make this process easier in the last few years a new type of pulse wave velocity detection system was created composed of Hall sensors and permanent magnets. The permanent magnets rest on the skin near where the artery is located to measure this pulse, which then generates a temporary magnetic field. The pulse of the artery causes fluctuations in this field which is examined and then recorded by the hall effect sensor (Fan et al., 2021). This new form of testing is cheaper than previous methods and provides quality data on the patient’s pulse signals.

Another cutting-edge use of these sensors' pairs with the new practice of minimally invasive surgery. This new type of surgery allows surgeons to minimize the effects of surgery, which in turn reduces pain, blood loss, and hospitalization time. To assist in this new practice hall sensors are used to characterizes various biological material, such as muscle, organs, fat, and tendons. A force sensor compromised of magnets is inserted into the patient which changes position based on the external forces present. This allows for a potential difference which is unique to each type of material. This allows surgeons to classify what material the sensor is touching (Fan et al., 2021).

Conclusion:

Hall Effect Sensors have many uses in todays world. This device started out as a simple gauge of magnetic fields and has not really changed much over the years. Many of the applications above use the hall sensor for this simple purpose. However, it is what has been done with the gauge that is revolutionizing the use of this sensor. From its use in cars, alarms, and now in the medical field it is apparent that the uses of this device are only limited by the imagination of those who are using it. I feel that we will hear much more about the advances driven by this device in the years to come.

Resources:

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