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MEASUREMENTS & CONTROL

HALL-EFFECT GAUSSMETER

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Centuries of research into magnetics has resulted in the development of electric motors, computer disks, video and audio tape, telephones, imaging devices, electric generators, credit cards, video displays and audio speakers. Permanent magnets are used to stir chemical solutions, entertain children, help auto mechanics retrieve dropped parts, keep travelers on course, and transform refrigerators into billboards. As much as the science of magnetics has shaped our lives, it is a subject that most people, including many engineers and scientists, know little about. Historically there has been little emphasis placed on magnetics in the classroom. Even those familiar with magnetics often have a difficult time visualizing magnetic fields and are intimidated by the nonlinear behavior of magnetic materials, the difficulty of controlling magnetic fields, and the confusing units of measurement.

Of the many instruments designed to measure magnetic fields, it is the Hall-effect gaussmeter (teslameter) that is perhaps the most versatile and easy to use. The only requirement for its use is a basic understanding of magnetic fields and the units of measure that quantify them.

BASIC MAGNETIC PROPERTIES

When a magnet is placed under a piece of paper covered with iron particles, we observe that the magnet is surrounded by lines of force and that the lines of force are concentrated at two points on the magnet (Figure 1). In 1269 Pierre de Maricourt, using a spherical magnet, observed that these lines surround the sphere just as the meridian lines encircle the earth, passing through points at opposite ends of the sphere. Because of this analogy he called the points the *north pole* and *south pole*, and noted that the force exerted by the magnet was strongest at these points. Subsequent research found that magnetic poles always occur in pairs (although recent discoveries suggest that the "monopole" does exist). If a permanent magnet of any shape is broken into pieces, each piece will have a new set of poles.

The lines of force surrounding a magnet are called *flux lines*. It is common to depict these as exiting the north pole and returning through the south pole. The strength of a magnet can be determined by measuring the number of flux lines passing through a given area, referred to as *flux density*. One flux line is called a *maxwell* (Mx), and one flux line passing through one square centimeter is called a *gauss* (G). These units are used commonly in the United States, but most of the world now uses the *weber* (Wb), which is 10^8 lines, and the *tesla* (T), which is 10^8 lines per m^2. The conversion between the two is simple:

1 tesla = 10,000 gauss
1 gauss = 0.0001 tesla

A typical refrigerator magnet might produce 300 G, a magnet in an audio speaker 3000 G. The earth, itself a weak permanent magnet, produces roughly 0.5 G.

If the north poles or south poles of two magnets are brought close together the magnets will repel each other; unlike poles are attracted to each other. The properties of magnetic attraction and repulsion allow motor shafts to spin, audio speaker voice coils to move, and compass needles to remain stationary. Recent studies indicate that the cells of certain migratory animals contain magnetic material that is believed to help them navigate using the earth's field as a reference.

Matter can be classified as either magnetic or nonmagnetic. Actually all materials react in some way to magnetic fields, but those with very weak reactions are considered to be nonmagnetic. Because of the particularly strong magnetic properties of iron (Fe), the term "ferrous" is often used to classify a material as magnetic.

THE ELECTROMAGNET

The connection between electricity and magnetism was not made until the 19th century. It was found that an electric current creates a magnetic field around a conductor with a flux density proportional to the magnitude of the current (Figure 2). If a wire is wrapped into a cylindrical shape and current flows through the wire, a magnetic field is created that is virtually identical to that shown in Figure 1. If the flux density around a nonmagnetic conductor is forced to change, a current will flow in the conductor, the principle behind electric generators.

THE HALL EFFECT

A simple magnetic sensor can be constructed using a rectangular sheet of gold foil, four wires, and a source of electric current. The wires are attached to the midpoints of each side of the foil (Figure 3). The current source is connected to the two wires attached to the shorter sides of the foil, and the other two wires are attached to a sensitive voltmeter. In the absence of a magnetic field there will be no reading on the voltmeter, but as the intensity of a magnetic field passing through the foil increases, so will the reading on the voltmeter.

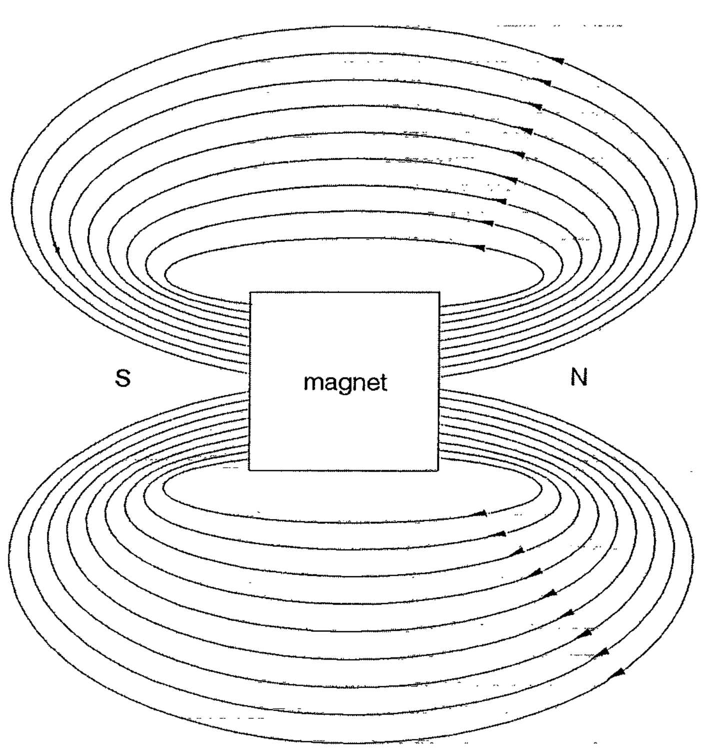

FIGURE 1. Magnetic flux lines and poles.

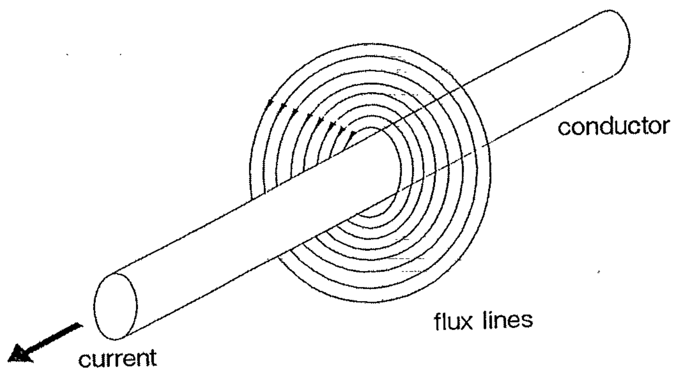

FIGURE 2. Current-induced magnetic flux.

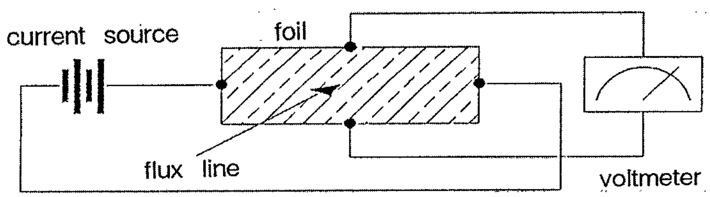

FIGURE 3. A simple Hall-effect sensor.

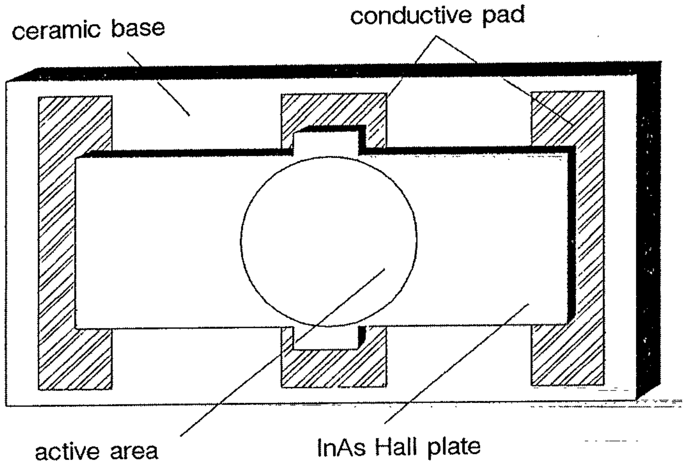

FIGURE 4. Typical Hall sensor construction.

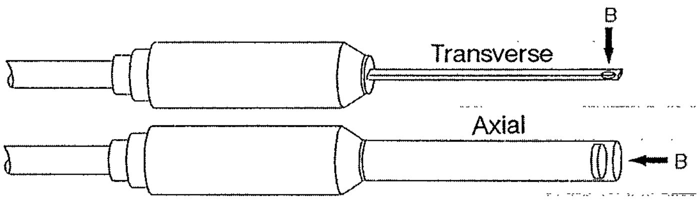

FIGURE 5. Typical transverse and axial Hall probes.

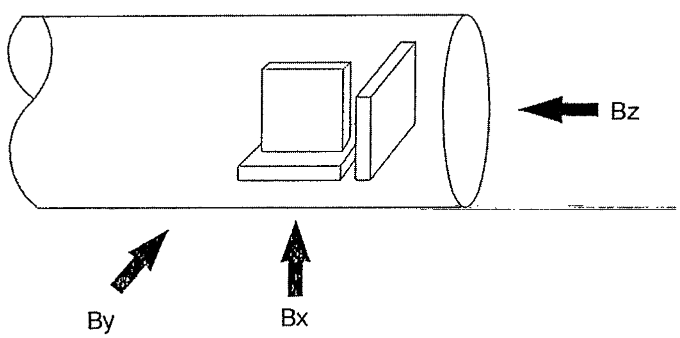

FIGURE 6. Three-axis Hall probe.

Edwin Hall discovered this effect in the 19th century. With a constant current passing through the foil, he found that the output voltage (now called the Hall voltage) is primarily affected by the *flux density* and the *angle* between the flux lines and the foil. Because of the extremely low output voltages of the foil, the Hall effect remained a laboratory curiosity until the development of certain semiconductor compounds such as silicon (Si), gallium arsenide (GaAs), and indium arsenide (InAs). These materials provided much greater sensitivity and led to practical use of the Hall effect in science and industry.

Modern Hall-effect devices, commonly called *Hall generators*, consist of a thin, rectangular or square sheet of Si, GaAs or InAs, to which four contacts are made (Figure 4). This is commonly called a Hall plate. Often the plate is affixed to a ceramic substrate which provides improved mechanical support and thermal stability, or wire-bonded to a nonmagnetic lead frame and encapsulated. Sensitivity is greatest when the angle between the plate and the flux lines is 90°. One particularly useful aspect of a Hall device is its sensitivity to the *direction* of flux travel, allowing for accurate sensing of both bipolar static (DC) and alternating (AC) magnetic fields.

One of the most important things to understand about a Hall generator is that the flux density is measured only over the area of the Hall plate itself. The area of greatest sensitivity, called the *active area*, is generally defined as the largest circle that can fit within the Hall plate.

THE HALL-EFFECT GAUSSMETER

A Hall-effect gaussmeter is an instrument that conditions and amplifies a Hall sensor output and provides its user with calibrated flux-density information. Portable and benchtop versions cover the measurement range of milligauss to kilogauss, providing analog and digital outputs and computer interfaces. Though commonly used in educational and research facilities, a growing number of industrial concerns are using gaussmeters to automate production lines, improve product performance, and ensure product quality.

The Hall generator determines the usefulness and flexibility of a gaussmeter. Typically, the Hall device is mounted within a tube made of nonmagnetic material, and is terminated by a length of cable and a mating connector — the assembly is referred to as a *Hall probe*. Gaussmeter manufacturers generally offer hundreds of probe configurations to meet their customers' needs and readily support the design and manufacture of customized probes.

Most Hall probes fall into two categories, (1) *transverse* and (2) *axial*, defined by the direction of flux lines through the probe (Figure 5). In both cases the Hall generator is located near the tip of the stem. Axial probes are generally cylindrical with diameters down to 0.060" (1.5 mm).

Transverse probes are generally flat with thicknesses down to 0.010" (0.25 mm). Stem materials include aluminum, phenolic, epoxy resin, rigid rubber, or stainless steel. Stem lengths can vary from several inches (50 mm) to 60" (1.5 m); cable lengths can vary from 5′ (1.5 m) to 100′ (30 m).

Special probe configurations allow for cryogenic operation down to −269°C (4K). Others facilitate the simultaneous measurement of magnetic flux in two or three axes (Figure 6). Combined with multichannel gaussmeters, users can obtain immediate vector summation information without having to reposition the probe, take separate readings, and perform manual calculations.

For very low field measurements in the sub-milligauss range, the Hall device can be combined with ferrous concentrators (Figure 7) to increase the flux density through the Hall plate, yielding sensitivity 100 times greater than a standard Hall probe at the expense of a larger package (Figure 8).

Because the concentrators have a saturation limit, this type of probe is useful up to about 2 gauss. Several probes can be positioned to provide simultaneous multiaxis measurements, useful when measuring Helmholtz coil assemblies or making geographical surveys.

UNDERSTANDING AND USING A HALL PROBE

Because of the small active area of a Hall generator (0.02" diameter in some cases), a flux density reading taken at one area on a magnet is valid for that area only and not the entire surface of the magnet. This makes a Hall device particularly useful in field mapping applications in which the Hall probe is sequentially positioned through a volume of space to determine the exact profile of a magnetic field. Another growing application is to scan the surfaces of a permanent magnet to detect interior flaws that would otherwise go undetected by visual inspection. These flaws (cracks, bubbles) can result in field distortions.

The position of a Hall generator within the probe stem is affected by normal manufacturing variations and a position tolerance is usually given. For those requiring a high degree of precision, the probe should be "peaked" — i.e., with the probe in a known field the stem is moved

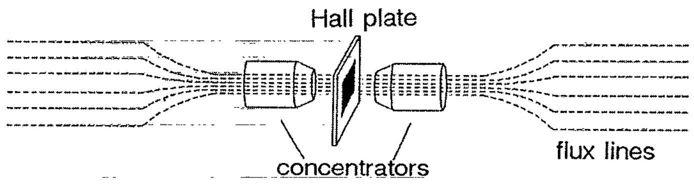

FIGURE 7. Using concentrators to boost sensitivity.

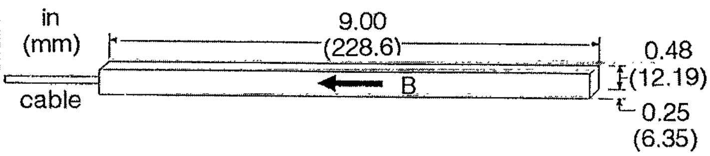

FIGURE 8. High sensitivity Hall probe.

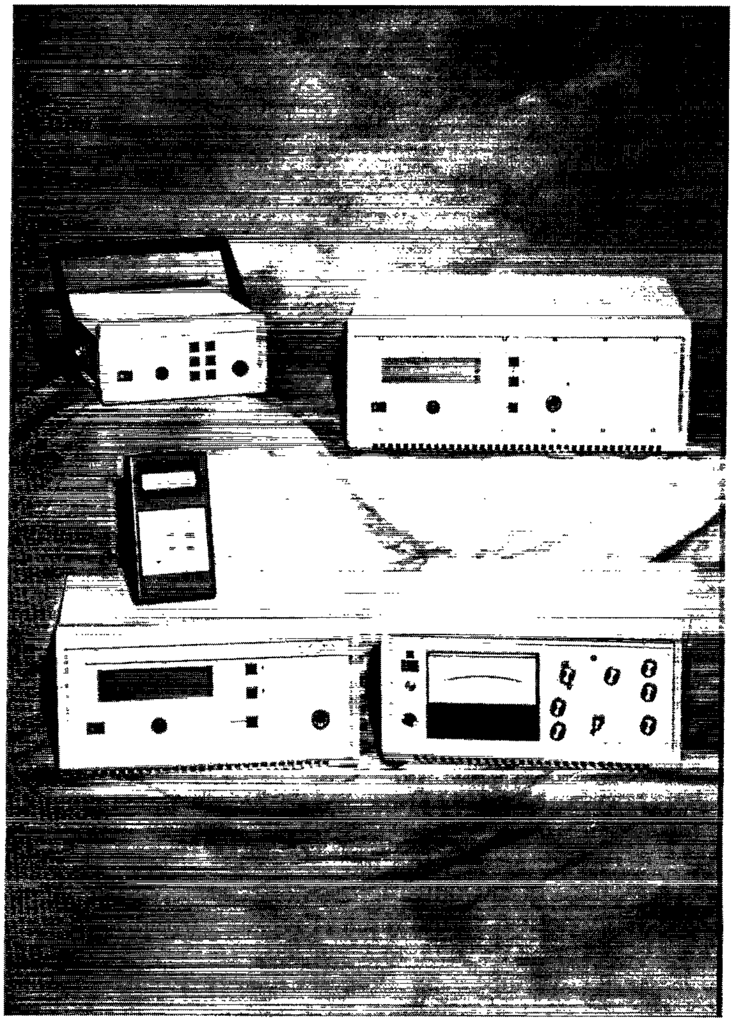

FIGURE 9. F.W. Bell gaussmeters.

about in several planes to obtain a maximum reading. The probe is then fixed in place for subsequent measurements.

Keep in mind that a Hall generator is sensitive to the angle between the Hall plate and flux lines. Probes with long thin stems tend to flex without proper fixturing, which can lead to measurement errors.

Hall generators are sensitive to temperature variations. Allow the stem temperature to stabilize before making measurements, or make the measurements quickly before the stem temperature has a chance to change.

The accuracy of a Hall probe is generally specified over a measurement range. For instance, one probe may have 0.25% of reading accuracy over a range of 0-30 kG, whereas another might have 2% accuracy from 0-10 kG.

SELECTING THE RIGHT GAUSSMETER AND PROBE

Before choosing a gaussmeter and its probes, review your application carefully by answering the following questions:

1. Gaussmeters and Hall probes offer a variety of measurement ranges, resolutions and accuracies. What is the range of magnetic flux density you expect to measure, and what kind of resolution and accuracy do you need? Do you need to make simultaneous measurements from several probes or in several planes?
2. When measuring alternating fields, the frequency-related performance is determined by both the probe and instrument. If you need AC performance, what is the expected frequency range? Do you require true rms readings?
3. Do you need a calibrated analog signal output in addition to the displayed results?
4. Do you need features such as peak hold, classifiers for production line testing, bargraphs, or vector summation for multiaxis measurements?
5. Do you need RS-232 and/or IEEE-488 communications?
6. Is battery-powered operation important?
7. The physical aspects of the area to be measured are important when selecting a probe. Where does the probe tip have to go? Do you need a transverse or axial measurement? Will the probe be exposed to a harsh environment? How long does the stem have to be? What thickness or diameter of the probe stem is needed? □

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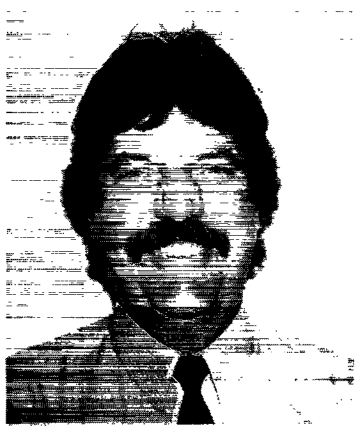
THE AUTHOR



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