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Hall Effect Speed Sensors Offer Reliable Operation in Severe Environments

Ed Ramsden, Cherry Electrical Products, Pleasant Prairie, Wisconsin

For high contamination environments and those subject to wide temperature extremes, Hall effect devices provide rugged, reliable and cost effective speed sensing. They may be implemented with ring magnets, vanes and gear-tooth configurations.

The speed of a rotating shaft is a common measurement made across a wide variety of applications. Optical encoders are typically used where high angular resolution or update rates are required, but in many applications they are overkill. For many industrial, consumer, and automotive applications, a few pulses per shaft revolution are more than adequate.

Hall effect speed sensors provide rugged, low-cost solutions to shaft-speed measurement problems. They operate on the principle of sensing magnetic fields, so they are essentially immune to dust, oil and other sources of contamination, which can cause severe malfunctions in optical sensors. In addition, because strong magnetic fields (100+ Gauss) are not commonly found in nature, magnetic speed sensors are relatively immune to accidental actuation and other forms of interference.

The three most common speed sensing schemes that can be implemented with Hall Effect based speed sensors are:

- Ring Magnet Detection
- Vane Detection
- Gear-tooth Detection

Each of these methods requires the addition of a special target to the shaft being monitored, and requires a particular type of sensor to detect that target. We will look at the characteristics of both the targets and the sensors used to implement each of the above sensing schemes.

Hall Effect Sensors

One of the major reasons for choosing Hall effect sensing technology over competing technologies is that silicon Hall effect transducers can be fabricated on standard bipolar and CMOS integrated circuit processes.

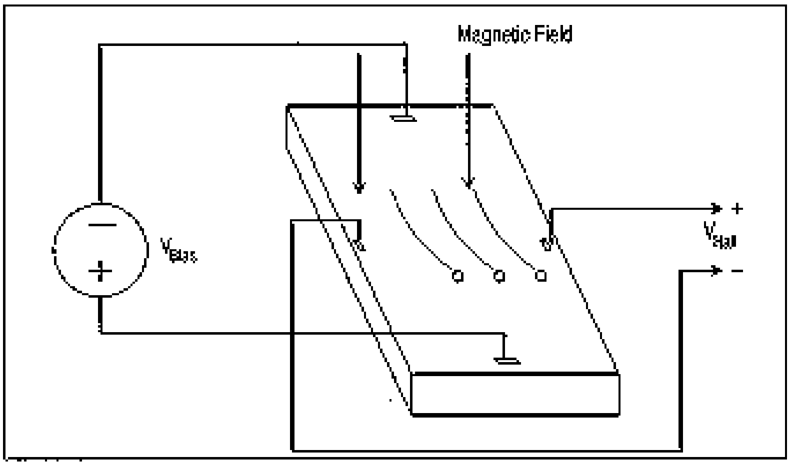

Figure 1. Hall Effect mechanism.

This means that significant amounts of signal processing circuitry can be incorporated on the same die as the transducer. It also means that Hall effect sensors can be manufactured relatively inexpensively.

The basis of the Hall effect is that moving charge carriers in an electrical current are deflected at right angles to both their original trajectory and an externally imposed magnetic field, as illustrated in *Figure 1.* In metals, this effect is very small and very difficult to measure. In semiconductors such as silicon and gallium arsenide, while still small, the Hall effect is sufficiently pronounced to be useful for making magnetic sensors to measure fields in the 1 - 10,000 Gauss range.

Because the sensitivities of semiconductor Hall transducers are still very low, falling in the 10µV to 100µV/Gauss range, additional signal conditioning is usually required for any practical application. Fortunately, many semiconductor manufacturers provide a preamplifier and a threshold detector integral to their Hall effect sensor ICs. A block diagram for a typical Hall Effect IC, such as would be used for implementing a ring magnet or vane detector, is shown in *Figure 2.*

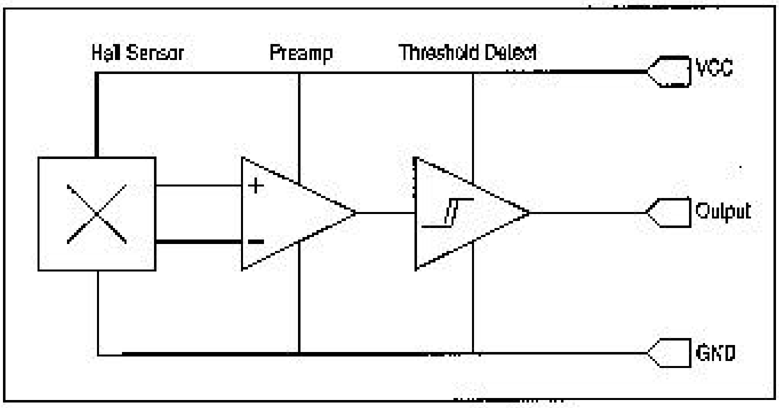

Figure 2 Digital output Hall IC

Ring Magnet Detection

A ring magnet is a disk or toroid-shaped magnet onto which an alternating pattern of north and south poles has been magnetized. These magnets may be made from a variety of magnetic materials, such as alnico, ferrite, samarium-cobalt, or neodymium-iron-boron. The most commonly used materials, however, are ferrite compounds embedded in a plastic binder. The use of bonded materials allows one to inexpensively mold magnets in a wide range of sizes and shapes. *Figure* 3 shows a few examples of ring magnets. Because the boundaries of the poles usually are not marked in any way, the number, placement, and size of the individual poles are not always obvious. It is possible to visualize the pole-pattern using magnetic view-film, which when placed over a ring magnet clearly indicates the outlines of the poles, as shown in *Figure 4*

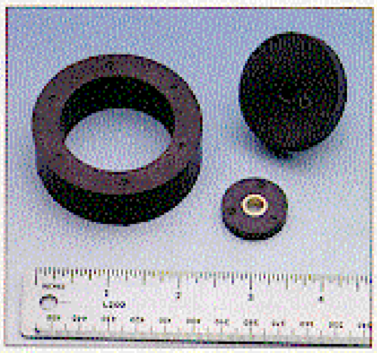

Figure 3. Examples of small ring magnets.

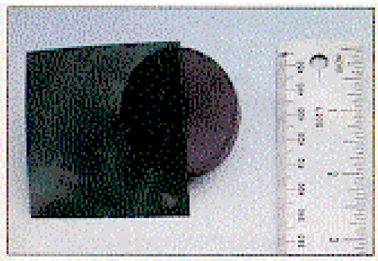

Figure 4. Visualizing magnet pole placement with magnetic view film.

Conceptually, a ring magnet is the simplest type of Hall effect speed sensor. The ring magnet is mounted on a shaft and spun past a suitable magnetic pickup. The Hall effect sensor element in the magnetic pickup only provides microvolt-level signals in response to the field provided by the ring magnet, so most commercial models include onboard signal processing and interface electronics, providing a TTL-compatible logic output. Most commercially available offerings operate in one of two modes:

- Switched - The output is activated in response to the presence of a particular pole (most often the south pole), and deactivates when the south pole is removed.
- Latched - The output is activated in response to the presence of one pole, and remains activated until deactivated by the presence of the opposite pole.

The advantage of the latched mode of operation over the switched mode is that it provides a more uniform duty cycle output, and allows increased spacing from the ring magnet to the sensor. In either case,

the sensor provides one pulse per revolution for each north-south pair of Gear-tooth poles. A 10-pole ring magnet, for example, would generate only five pulses per revolution. It is possible to obtain ring magnets with as many as 25 poles per inch of circumference. For a l in. diameter target this would provide nearly 40 pulses per revolution.

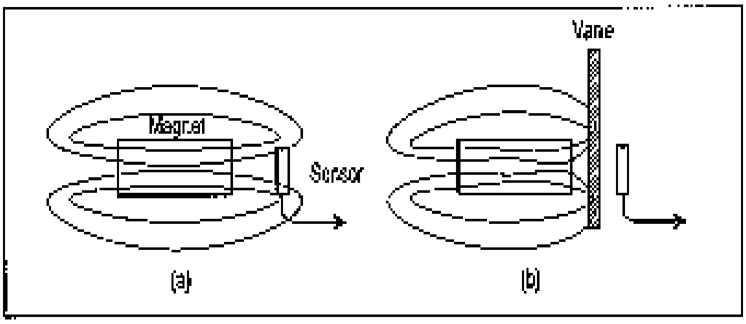

Figure 5. Operation of a vane detector, (a) vane absent, (b) vane present.

Vane Detection

Ring magnets offer an easy-to-implement speed sensing method, but the cost of a suitable ring magnet can be significant. For price sensitive, high-volume applications the best scheme is often vane detection.

A vane detector (or vane interrupter) works by using a thin ferrous target (the vane) to shield a magnetic sensor from a magnetic field generated by a bias magnet. When the ferrous target is absent, a magnetic sensing element can detect the presence of the bias magnet, as shown in *Figure* 5(a). When the target is placed between the magnet and the sensor, it shunts the field lines away from the sensor *(Figure* 5b). In order to effectively shunt the field, the area of the vane must be comparable to that of the magnet and the airgap between the magnet and the sensor. When vanes are placed close to each other on the same target, the "window" between vanes also has similar constraints on minimum size. For this reason it is difficult to obtain high-pulse counts out of vane detectors. Some examples of vanes are shown in *Figure 6.*

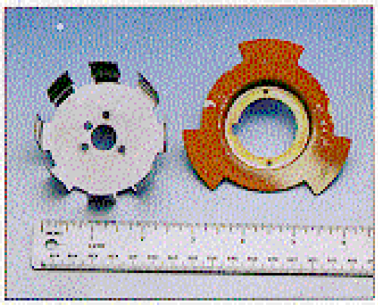

Figure 6. Examples of vane interrupter targets.

An example of a vane detector is the Cherry VN101501 (formerly known as HE6450), shown in *Figure 7.* This device is enclosed in a package similar to many opto-interrupters. The bias magnet resides in one of the towers, while the sensor element resides in the other. The sensor incorporates integral signal conditioning, and provides a switched digital output, which is normally on, and turns off when a vane enters the gap. Because the magnet, sensor and housing have all been designed to work together for a wide variety of targets, the need for magnetic engineering on the part of the user has been largely eliminated.

Two problems are commonly encountered when using vane detectors and they usually result when one tries to migrate an optical-interrupter design to a magnetic vane design. The first is the matter of material selection. For a magnetic vane to function, the vane must be able to shunt the field (must be ferromagnetic).

This immediately rules out the use of materials such as plastic, aluminum and most stainless steels. Even appropriate materials, when too thin, will fail to reliably actuate a magnetic vane detector.

The second problem is that the bias magnet will exert a significant mechanical force on the vane, and attempt to pull it into the detection gap. If the shaft provides significant torque, such as the output of a motor, this is usually not a big deal. If there is only a limited amount of torque, such as in a flow meter, a ring magnet-sensing scheme is usually a better choice.

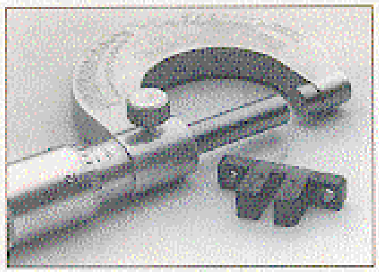

Figure 7. Cherry HE6450 vane detector.

Gear Tooth Detection

Ordinary ferrous (iron or steel) gears present the most challenging type of target for a speed sensor. They are also, unfortunately, a preferred choice of target, as they often are already present in a mechanical system as power transmission components. *Figure 8* shows examples of gears. Besides gears, gear-tooth sensors can also be used to detect "gear-tooth-like" objects, such as bolt heads, roller chain and metal stampings.

Because gears are not normally magnetized, they must be detected by the perturbations they cause in a magnetic field generated by the sensor assembly. There are many different schemes for implementing gear-tooth sensors with a wide variety of technologies. We will limit our discussion to just a few of the most common types that can be implemented with Hall effect technology.

The simplest gear-tooth sensing architecture is shown in *Figure 9.* The sensor element is placed on the face of a magnet.

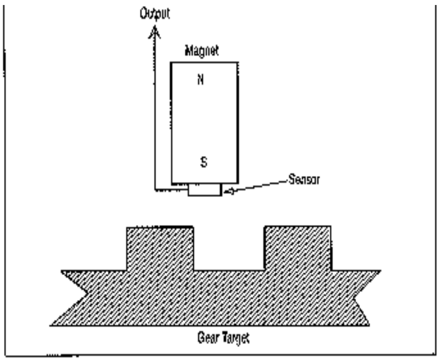

Figure 9. Face-sensing gear tooth sensor.

When a gear-tooth passes in front of this assembly, it causes an increase in the magnetic field as seen by the sensor element. When a valley passes in front of the sensor, the magnetic field drops. By setting a suitable threshold level, the presence of a gear-tooth may be discerned. The key problem with this type of sensor, however, is in determining what constitutes a suitable threshold. Sensors using this approach often will incorporate circuitry that dynamically adjusts the threshold value in response to the magnetic fields that are actually detected. *Figure* 10 shows examples of the signals obtained from this type of sensor.

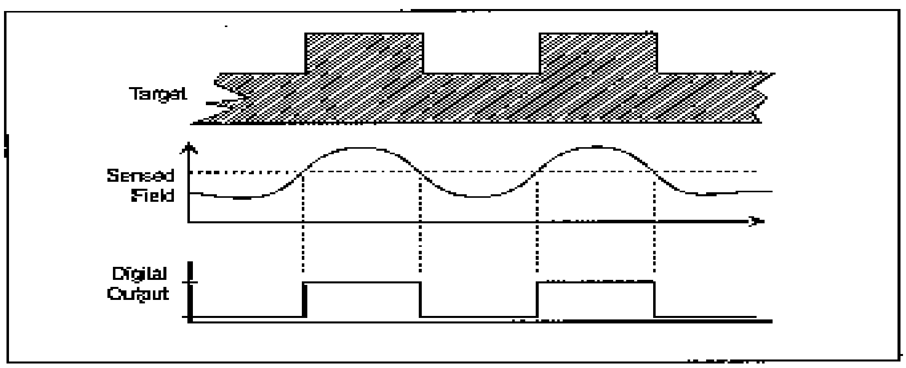

Figure 10. Signals from face-sensing gear-tooth sensor.

The next type of gear-tooth sensor we will discuss is the gradient detector. For many applications, such as automobile ignition timing, it is important to know exactly when the edge of a target passes the sensor. The single-element gear-tooth approach previously discussed often does not provide very good edge detection consistency, particularly if there is variation in the target-to-sensor spacing.

Measuring the magnetic field gradient at the face of the sensor, however, provides an excellent indication of where the edge of a tooth is. It is difficult to measure the actual gradient, but a good approximation can be obtained by subtracting the outputs of two sensors placed close together, as shown in *Figure* 11.

The signals obtained from the individual sensor elements are similar in appearance to those that come from the sensor in the single element scheme, but are skewed as they each "see" a different part of the target; one signal leads the other. Subtracting the two signals yields a resultant gradient signal that clearly indicates where the edges of the target teeth are, as is shown in *Figure* 12. To obtain a high quality gradient signal requires good matching of the sensitivities and offsets of the individual sensor elements.

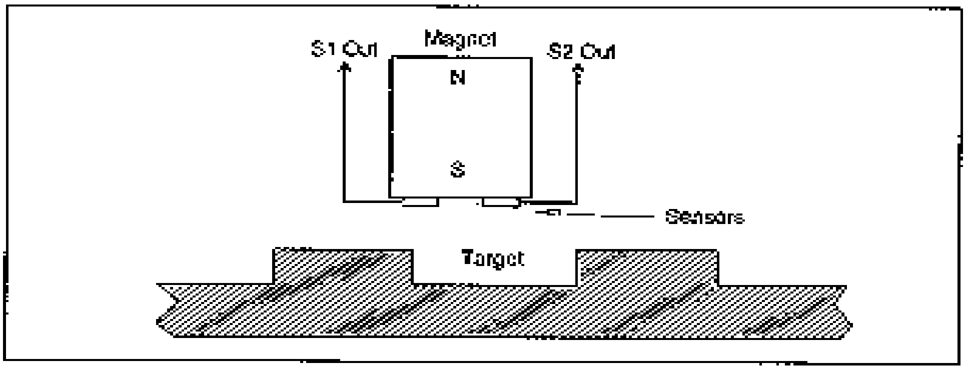

Figure 11. Gradient sensor.

Again, one of the key implementation issues is where to set the thresholds to discriminate between leading and trailing tooth edges. For demanding applications, a variety of signal conditioning schemes have been developed, ranging from simple analog threshold detection to elaborate digital signal processing systems. For many applications, however, a simple analog signal conditioning circuit will suffice. The Cherry GS100501 is a complete gear-tooth sensor comprising a bias magnet, a gradient detector, and signal conditioning and threshold detection circuitry, all packaged in a 65mm long M12 aluminum threaded housing. The output signal is provided in the form of an open collector NPN transistor switched to ground, allowing the device to be easily interfaced to digital systems such as counters and tachometers.

Table I summarizes some of the advantages and disadvantages of each of the three types of speed sensing schemes.

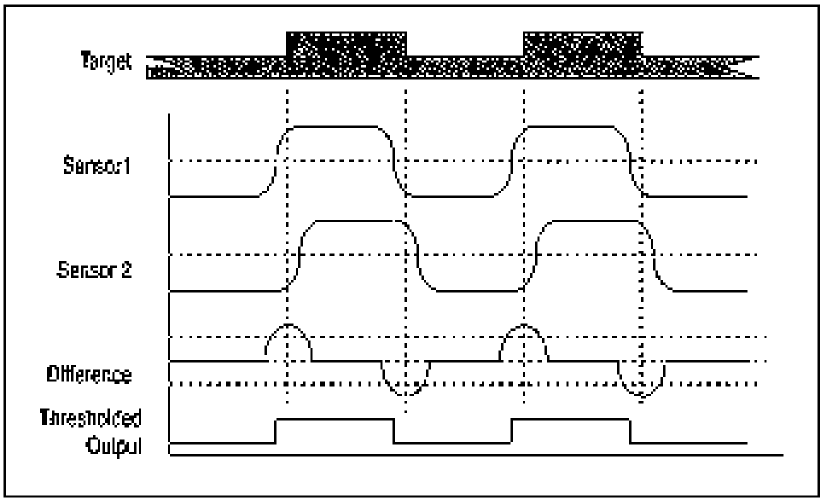

Figure 12. Signals from gradient sensor.

Table 1. Speed sensing scheme comparison.

Scheme	Advantages	Disadvantages
Ring Magnet	• Easy to implement • Zero torque on target • Wide airgap • High pulses-per-revolution	• Needs ring magnet for target
Vane	• Easy to implement • Inexpensive • Good edge accuracy	• Needs special target • High torque on target • Low pulses-per-revolution
Gear-tooth	• Can often use existing target • Easy to add to existing system • Choice of targets	• Most expensive sensor • Some torque on target • Some targets difficult to sense