Application Brief

Hall-Effect Sensors

A Hall-effect sensor is a transducer that varies its output voltage in response to changes in a magnetic field. Hall sensors are used for proximity switching, positioning, speed detection and current-sensing applications. In principle, they are analog but can be used to operate digitally by a Schmitt trigger output. These sensors are very common, small and inexpensive; they also have the advantages of being insensitive to dust, humidity, vibration, etc. Hall-effect sensors exhibit constant-over-time behavior.

Products

ANSYS® Maxwell® 3-D 15.0, ANSYS Optimetrics™, ANSYS Simplorer® 10.0

Keywords

Hall-effect sensor, magnetic sensor, magnetic field, finite element analysis

Problem Description

If a current flows in a conductor (or semiconductor) and there is a magnetic field present that is perpendicular to the current flow, then the combination of current and magnetic field will generate a voltage perpendicular to both. This phenomenon is called the Hall effect, discovered in 1879. The generated voltage is known as Hall voltage and is approximately linear to the magnetic flux density.

A single device that works as a magneto-electric transducer and uses the Hall effect to measure or sense a magnetic field is called a Hall element. For digital applications the Hall element is combined with signal-conditioning circuitry in a single package, referred to as a Hall-effect (switch) integrated circuit (IC), that converts the internal Hall element analog output into a digital output. As the Hall element reacts to the magnetic flux perpendicular to its surface, therefore, the placement of the Hall element with respect to the magnetic field of the magnet (its position and strength) is important for correct IC operation.

Typical applications of Hall-effect sensors include speed detectors (motor control), current sensors (disk drives, variable-frequency drives, power supply protection), position sensors (flow meters, BLDC), rotary encoders, voltage regulators, ferrous metal detectors, vibration sensors, pulse counters (printers), valve position sensors, door interlocks, proximity detectors, security (magnetic card or key entry), pressure sensors, lens position sensors, paper sensors, vending machines and embossing machines.

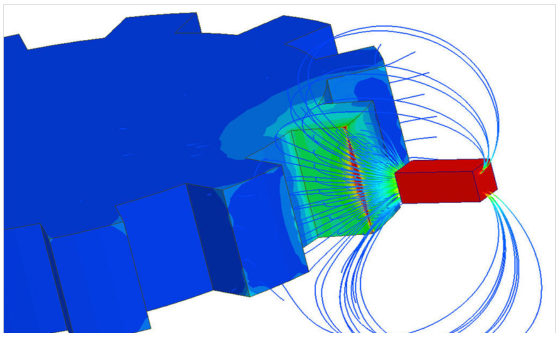

Figure 1. Magnetic flux density and flux lines plot on toothed wheel, magnet (red) and Hall element (located on magnet facing wheel) in ABS application model in ANSYS Maxwell

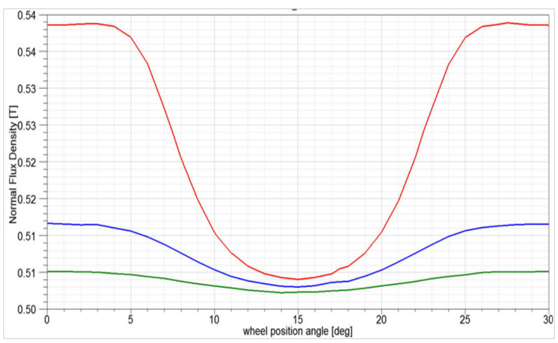

Figure 2. Variation of normal flux density as sensed by Hall element as a function of toothed wheel position for various distances (red > blue > green) between element and wheel

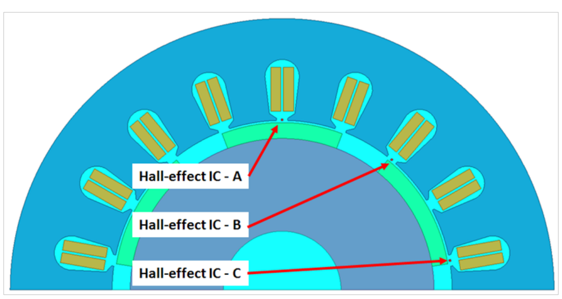

Figure 3. Hall-effect sensors placed over one electrical period of PMDC motor with distance of 120 electrical degrees apart

ANSYS Maxwell is capable of modeling Hall-effect sensors in the context of their various applications. This enables engineers to study the magnetic fields to be measured or sensed, associated with any arbitrary geometries, considering all the flux fringing and nonlinear magnetic materials. This leads to determining the most appropriate configuration and placement of Hall sensors for a particular application. The use of Maxwell in connection with ANSYS Optimetrics enables the study of varius possible scenarios automatically. It also allows generation of an equivalent circuit model of a Hall sensor, which can be easily included in a systems-level simulation model with ANSYS Simplorer. The performance of the whole system can, thus, be modeled and assessed, making sure that the entire system meets defined design requirements.

Figure 1 shows an application of a Hall-effect sensor in an anti-lock braking system (ABS). The sensor consists of a permanent magnet that biases the Hall element and a toothed wheel, which could be an internal disk brake hub. Maxwell computes the magnetic fields for this configuration and determines the normal flux density that the Hall element senses. Parametric analysis in Optimetrics automatically changes the angle and distance of the magnet and Hall element from the wheel and computes the fields for every desired variation. Figure 2 shows the variation of the normal component of the flux density at the Hall element as a function of the toothed wheel rotational position for several distances between the Hall element and the wheel.

Another application of a Hall-effect sensor is a permanent magnet DC (PMDC) motor drive. Control of this motor is accomplished by controlling the current in its three phases. Therefore, one requirement is to know the right position of the rotor, so you know which phase to control in each time instance. Three discrete bipolar Hall-effect sensors are placed over one electrical period of the motor with a distance of 120 electrical degrees apart, as shown in Figure 3. Parametric analysis in Optimetrics is used to determine the flux density sensed by the sensors as a function of the rotor position. This information can be used in Simplorer, a multidomain systems-level simulator, to model the behavior of the entire motor drive system.

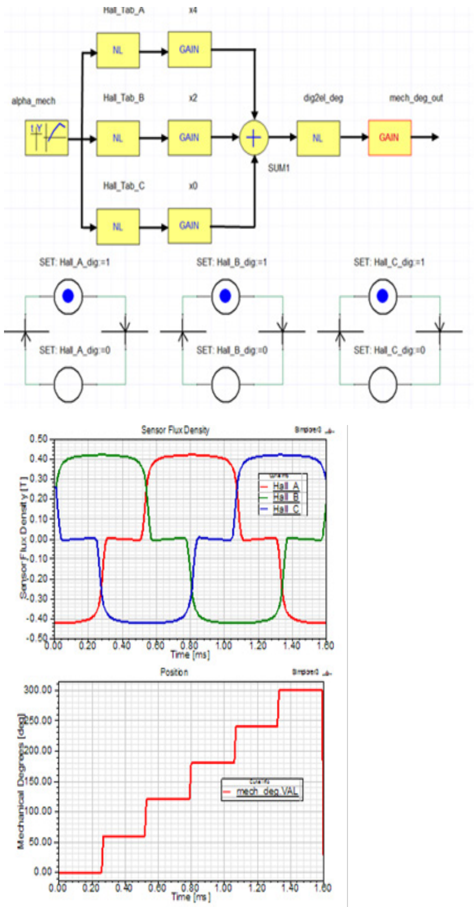

Figure 4. ANSYS Simplorer model of converting analog Hall-effect sensor signal (determined by ANSYS Maxwell) into actual mechanical rotor position using state graphs

Fig. 4 shows a simple example of taking the analog Hall-sensor IC signal determined by Maxwell, converting it first to a digital signal using state graphs, and finally to discrete mechanical rotor position. This example can be extended to include the actual motor control system and power electronics driving the motor. The combination of Maxwell and Simplorer then enables evaluation of whether the type, configuration and placement of Hall-effect sensors satisfy design requirements.

Summary

ANSYS Maxwell provides design engineers with an easy-to-use 3-D finite element method (FEM) modeling environment that is very well suited to evaluate Hall-effect sensors in the context of their various applications. As Hall-effect sensors typically influence the behavior of the entire system of which they are an integral part, systems-level analysis becomes important. ANSYS Simplorer offers a powerful systems-level design platform, allowing engineers to model the whole system, including the high-fidelity Hall-effect sensor model from ANSYS Maxwell.

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