Chapter 6

Applying Hall-effect Sensing Devices

Hall effect sensing devices can be used to sense many physical parameters, ranging from the direct measurement of a magnetic field to the detection of ocean currents. Although these applications vary in nature, the same design approach can be used. The beginning of this chapter addresses general design strategies. It begins with a requirement to sense some quantity through a fundamental concept.

The remainder of the chapter covers Hall effect as the particular technology used. It describes the various design phase approaches, procedures, alternatives and the factors to be considered when designing sensing devices using the Hall effect. The Hall sensor's input, output and magnetic characteristics are brought together and defined.

Using this chapter, a designer can choose the internal components (Hall effect sensor, magnetic system and the input and output interfaces) from manufacturer's data sheets or catalogs to provide the required electrical signal from the sensed quantity. This chapter, together with the next, Application Concepts, forms the basis for sensing device design.

General sensing device design

Figure 6-1 illustrates the procedure for designing sensing devices using any sensing technology.

The first step in any sensing device design is to define what is to be sensed. The identification of the physical parameter (quantity) to be sensed is not always obvious. Measuring the rotation of an impeller blade is one approach to building a flow meter. In this case, it would be easy to assume what is to be sensed is the rotation of the impeller blade. In fact, fluid flow is the desired quantity to be sensed. The limiting identification of the impeller blade motion as the parameter to be sensed, reduces the possible design approaches and available technologies open to the designer.

In most cases, several methods of sensing a physical parameter can be identified. Each of these methods will consist of a conceptual approach with an associated technology. The conceptual approach describes how the sensing function might be implemented without considering the engineering details and component specifications. At this level of detail, some conceptual approaches can be immediately eliminated on the basis of cost, complexity, etc. Take, for example, a simple motor tachometer application. Although a laser-gyro could be used to sense rotary motion, it would be immediately removed from consideration because it is much too complicated for the design objective.

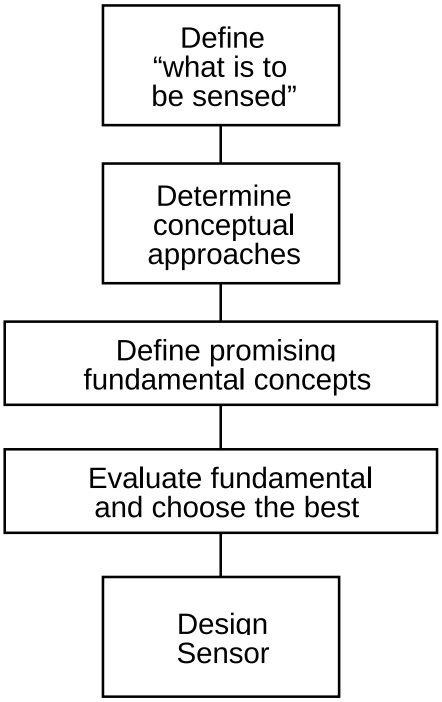

Figure 6-1 General sensing device design approach

It is important that the designer not limit the method of sensing a physical parameter to the obvious. Physical parameters can often be sensed using indirect methods. As an example, the requirement to sense temperature changes. An obvious approach would be to use a thermocouple since it is a temperature sensor. An alternate method of sensing temperature is shown in Figure 6-2.

In this example, an increase and/or decrease in temperature causes the bellows to expand or contract, moving the attached magnet. The corresponding change in magnetic field is sensed by the Hall effect sensing device. The end result is conversion of the temperature input to a measurable electrical field.

Once the most promising sensing techniques are identified, a decision must be made as to the concept which will be followed. In order to make this decision, the conceptual approach must be expanded into a fundamental concept (Figure 6-1). A fundamental concept includes the identification of input and output requirements, the major sensing device components, and the application requirements. With all requirements at hand, the resulting fundamental concept can be analyzed. The result of this analysis will be the choice of a concept for further development.

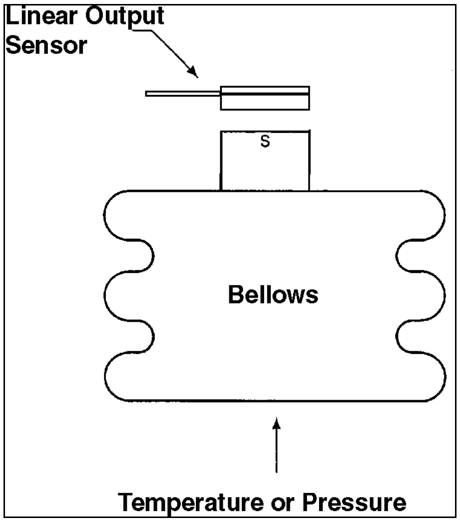

Figure 6-2 Hall effect based temperature sensor

Consider a simple motor-tachometer application where each rotation of the motor shaft is to be detected. Two conceptual approaches are shown in Figures 6-3 and 6-4. The approach shown in Figure 6-3 consists of a ring magnet on the motor shaft and a radially-mounted digital output Hall effect sensor. As the ring magnet rotates with the motor, its south pole passes the sensing face of the Hall sensor with each revolution. The sensor is actuated when the south pole approaches the sensor and deactuated when the south pole moves away (see Chapter 3 for details). Thus, a single digital pulse will be produced for each revolution.

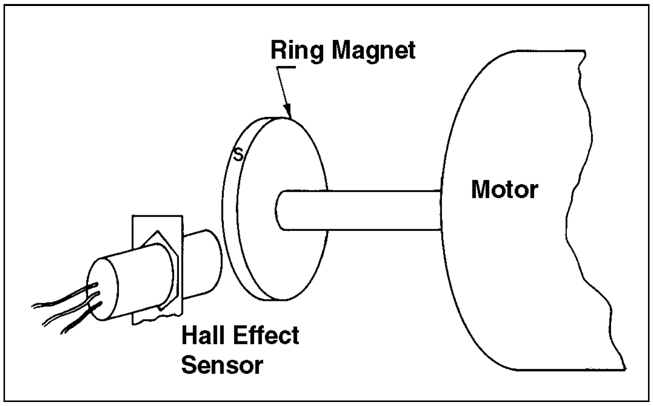

Figure 6-3 Hall effect conceptual approach

The conceptual approach shown in Figure 6-4 consists of a vane on the motor shaft with a phototransistor and LED pair mounted parallel to the shaft. As the vane rotates with the motor, the cutout in the vane passes between the LED and the phototransistor, allowing light to pass. The phototransistor is turned ON for each rotation. Again, one pulse will be produced per revolution.

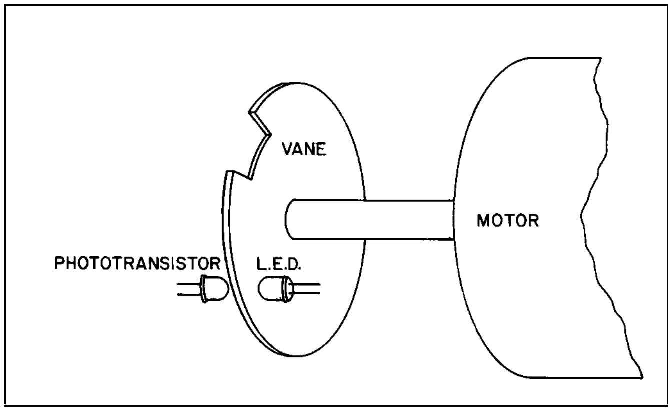

Figure 6-4 Optoelectronic conceptual approach

The details given in the two previous examples are insufficient to determine which one to develop. Input and output requirements must be considered. For example, what are the electrical characteristics of the output pulse required for the application (current, voltage, rise time, fall time, etc.)? The major components in the sensing device must be identified. If the required electrical characteristics are not met at the output of the phototransistor, what additional circuitry is required? The environmental requirements must also be identified. For example, if the sensing device is to be used in oil laden air, the optical approach would be discarded.

There are no universal step-by-step procedures that can be followed in the selection of a particular fundamental concept. Engineering judgment must be used. The strengths and weaknesses of each approach must be weighed. The features and benefits of each technology must be evaluated with respect to the application. During the process of making tradeoffs, it is important that all key information be considered. Among the key considerations are:

- Overall cost
- Volume producibility
- Component availability
- Complexity
- Tolerance of part-to-part variations
- Compatibility with other system components
- Reliability
- Repeatability
- Maintainability
- Environmental constraints

MICRO SWITCH sensor products include complete position sensors, non-contact solid-state switches and current sensors. If one of these products fits the desired application, it will be the most cost-effective solution.

Although several of these considerations cannot be quantified until a detailed design is completed. they must, nevertheless, be weighed at this point.

Once a fundamental concept has been chosen, the detail sensing device design can begin. The remainder of this chapter will be devoted to the detailed design of sensing devices for which the fundamental concept includes a discrete Hall effect sensor or a sensor combined with a magnetic system in a single package.

Design of Hall effect based sensing devices

Figure 6-5 illustrates the functional blocks that must be considered when designing Hall effect based sensing devices.

The design of any Hall effect based sensing device requires a magnetic system capable of responding to the physical parameter sensed through the action of the input interface. The input interface may be mechanical (most sensing devices) or electrical (current sensing devices). The Hall effect sensor senses the magnetic field and produces an electrical signal. The output interface converts this electrical signal to one that meets the requirements of the system (application).

The objective of the design phase is to define each of the four blocks that comprise the sensing device in Figure 6-5. Then determine all the components and specifications, mounting, interfacing and interconnection of these blocks with each other and with the system.

Not every Hall effect based sensing device requires all four functional blocks. A magnetic field sensor, for example, does not require a magnetic system or input interface. Other sensing devices have the magnetic system already designed and integrated into a package with the sensor chip. The design phase is somewhat simplified for these cases, but the objective is still the same.

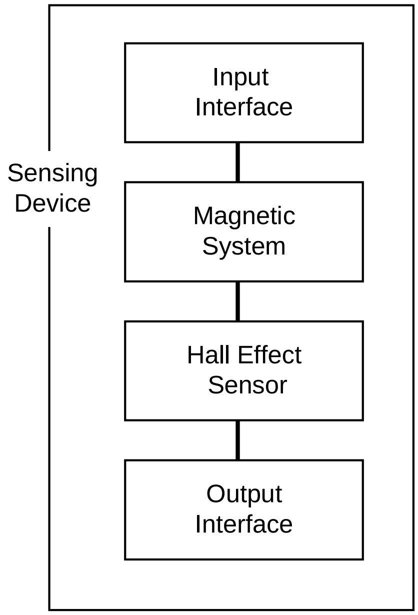

Figure 6-5 Hall effect based sensing device

The design phase begins with the fundamental concept chosen. Next, the detail configuration, specification and requirements for the application are defined. This is the system definition phase. Initial configurations and specifications for the sensing device are determined. Discrete sensing devices and sensing device packages will be treated separately, beginning with the concept definition. The final phase is detailed design. The approach to detailed design is broken into digital and linear.

System definition

Once the fundamental concept has been chosen, system definition begins. System definition is the process in which detailed information is gathered about the application. This information includes configuration, specifications, and requirements of the application as they relate to the sensing device. Figure 6-6 shows the major steps in system definition.

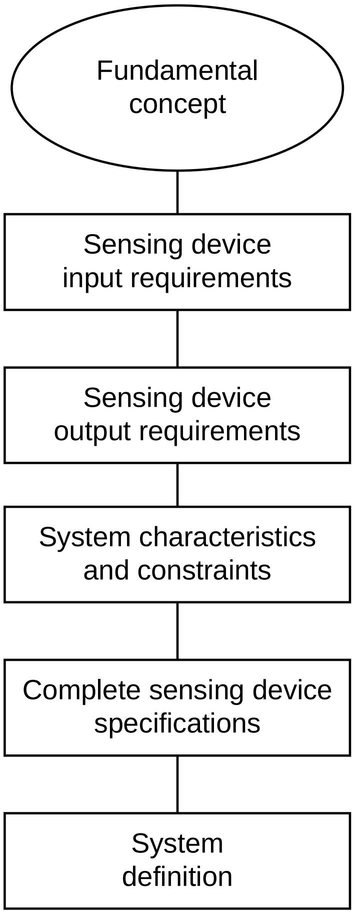

Figure 6-6 System definition

First, the sensor input characteristics must be defined. These include:

- Range of input values
- Minimum and maximum rate of change of input values
- Factors which affect the input values such as time, temperature, etc.
- Safety factors
- Error sources
- System tolerances as they affect the input
- Environmental conditions

Next, the sensing device output requirements must be defined. These include:

- Electrical characteristics . . . current, voltage, etc.
- Output . . . logic level, pulse train, sum of pulses, etc.
- Definition of logic levels . . what voltage represents a logic 1
- Requirement for NPN (current sinking) or PNP (current sourcing) output
- Output level when sensing device is OFF
- Type of load . . . resistive, inductive, etc.
- Type of interconnection between the sensing device and the system, including ength of cable, connector type, etc.
- System characteristics and constraints must also be defined. These include:
  - Location of sensing device
  - Space available for the sensing device
  - Weight limitations
  - Available power supplies for the sensing device
  - Basic sensing device requirements including accuracy, repeatability, resolution, etc.

The preceding lists of defined characteristics do not include all possible factors to be included in the system definition. Nor do all sensing device designs require that all these factors be considered. They are included here to indicate the scope of system definition.

The end result of system definition is to generate complete specifications for the sensing device.

Concept definition . . .Discrete sensing devices

Concept definition is the process where the initial configuration and specifications for the Hall effect based sensing device are determined. The specifications are analyzed and the internal components (Hall sensing device, magnetic system, input and output interfaces) are chosen based on manufacturer’s catalog data.

Figure 6-7 shows the principal steps in concept definition for sensing systems which are actuated by a magnet.

The first step in concept definition is to determine the sensing device component specifications. These include:

- The minimum and maximum gap between the magnet and the Hall effect sensor
- The limits of magnet travel
- Special requirements for the magnet such as high coercive force due to adverse magnetic fields in the system
- Mechanical linkages (if required)
- Sensor output type . . . NPN or PNP
- Operating temperature range
- Storage temperature range
- Various input/output specifications from the system specification

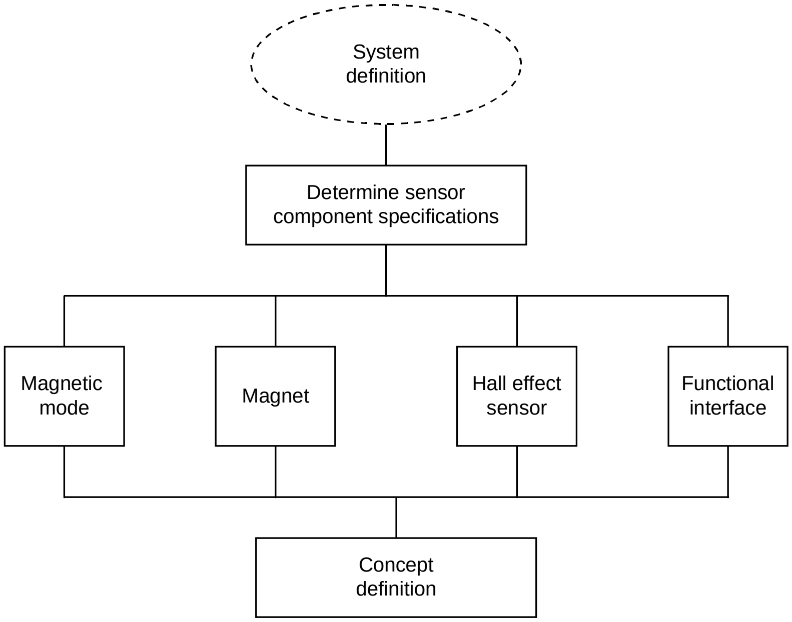

Figure 6-7 Concept definition - discrete sensing devices

The next step is to choose the magnetic mode, magnet, Hall effect sensor, and functional interface. These four items are shown in parallel (Figure 6-7) because the choices cannot be made independently. The required magnet strength is dependent on the gap and the limits of magnet travel (magnetic mode). The sensor is dependent on the strength of the magnetic field and therefore, on the magnetic mode and the magnet chosen. The functional interface is dependent on the sensor output type and electrical characteristics.

In order to assure that the characteristics of these four items are compatible, the designer must have an idea of the type of characteristics to be expected and the available components. Chapter 3 should be consulted for basic magnet information, as well as description of the most common modes. Appendices B and C contain additional magnet application data, including plots of gauss versus distance for various magnets. Chapter 2 describes Hall effect sensing devices, their power supply characteristics and transfer functions. Chapter 4 should be consulted for output characteristics and various interfaces. With this background, the designer can analyze catalog data and make an initial choice of a magnet, sensor and a functional interface. This choice will give a set of parameters upon which design trade-offs can be performed and detailed sensing device design can be initiated.

Digital output Hall effect based sensing devices

Design approach . . . Non-precision applications

In non-precision applications, the exact point of actuation is not a major consideration. Accuracy of these sensing devices is a function of reliability and large tolerances are acceptable for the operate and release points. A good design assures reliable operation under the following conditions:

- Unit-to-unit variations (as sensor components)
- Temperature extremes
- Power supply variations
- Electromagnetic interference (EMI)
- Ferrous material in the system
- Manufacturing and assembly tolerances

The design procedure for non-precision type sensing devices is illustrated in Figure 6-8. The concept definition previously determined is the basis for the design.

The first step is to develop the input interface (a concept for the input interface was determined by the fundamental concept, Figure 6-1). In this step, the detailed design and layout of the input interface is developed. For a simple position sensor, this may involve only the mounting and adjustment of the magnet and the basic Hall effect sensor. More complex applications may require the design of mechanical linkages, gearing, bellows, or cams that control the motion of the magnet.

Design of the input interface requires attention be given to good mechanical design practices. Consideration should be given to:

- Mounting magnets, pole pieces, Hall effect sensing devices, and flux concentrators
- Positioning and adjustments that may be required at assembly
- End play and run-out in rotary systems
- Thermal expansion characteristics where temperature extremes are encountered
- Tolerance build-up

The next step is to develop the output interface. In many applications, the output interface will be quite simple, consisting of a single pull-down or pull-up resistor. Other applications may require an electronic circuit be designed, for example, where the Hall effect sensor output must be buffered.

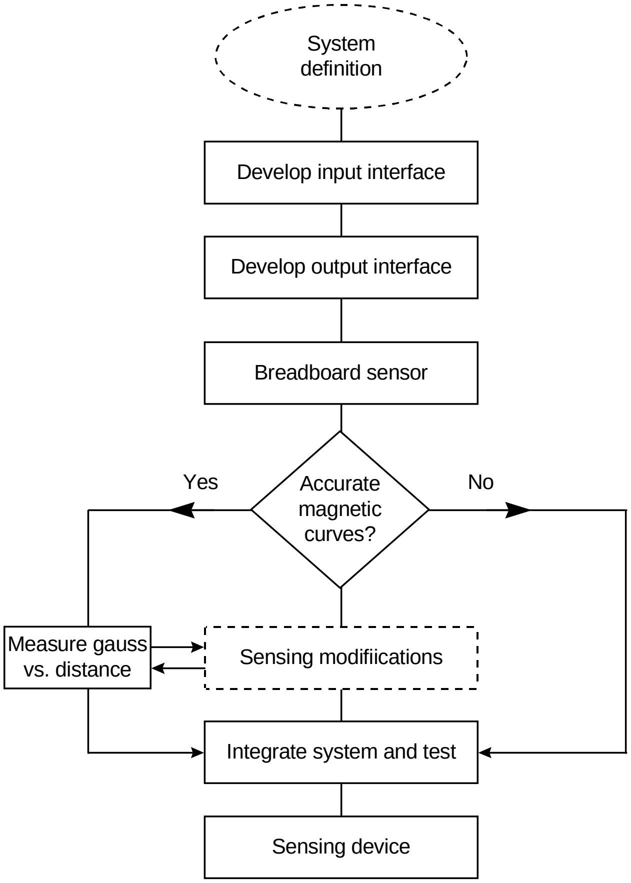

Figure 6-8 Detailed design procedure - Non-precision digital output Hall effect based sensing device

In Chapter 4, the electrical characteristics of Hall effect sensing devices are discussed and common output interfaces are examined in detail. When high electrical noise is present or when long electrical cables are used to connect the sensing device to the system, special attention should be given to potential noise problems. Standard reference books on electronic design, digital design or noise reductions techniques may be consulted to supplement the information in Chapter 4.

An initial design for all of the basic components of the sensing device is now available: the input interface, the magnetic system, the Hall sensor, and the output interface. The next step is to breadboard the sensing device, based on this initial design. The breadboard sensing device is a mock-up for making fine adjustments, minor modifications, or in some cases, major design changes.

Once the breadboard sensing device has been built, a decision must be made as to the need for accurate magnetic system curves. The magnetic system will present a range of flux density values to the sensing device as a function of the sensing device input. In the operate state, the maximum flux density of the magnetic system must exceed the maximum operate level for the Hall sensing device. Similiarly, for a release condition, the magnetic system's minimum flux density must be less than the minimum release under the worse case conditions.

The excess flux density available for actuation is referred to as a guardband. A guardband of at least 100 gauss is desirable for non-precision applications. If the data used to design the magnetic system was not adequate to assure this guardband, then magnetic system data must be taken and magnetic curves plotted. Refer to Chapter 3, Magnetic Considerations and Appendix C for plots of gauss versus distance for various magnets.

A Hall element can be used to measure gauss versus distance. This can be used to measure the response of the magnetic system to the sensor inputs. From the resulting magnetic curves and sensing device specifications, the guardband can be determined. If the guardband is inadequate, the design must be modified and new magnetic curves plotted. This is a repetitive process and continues until an adequate guardband is obtained.

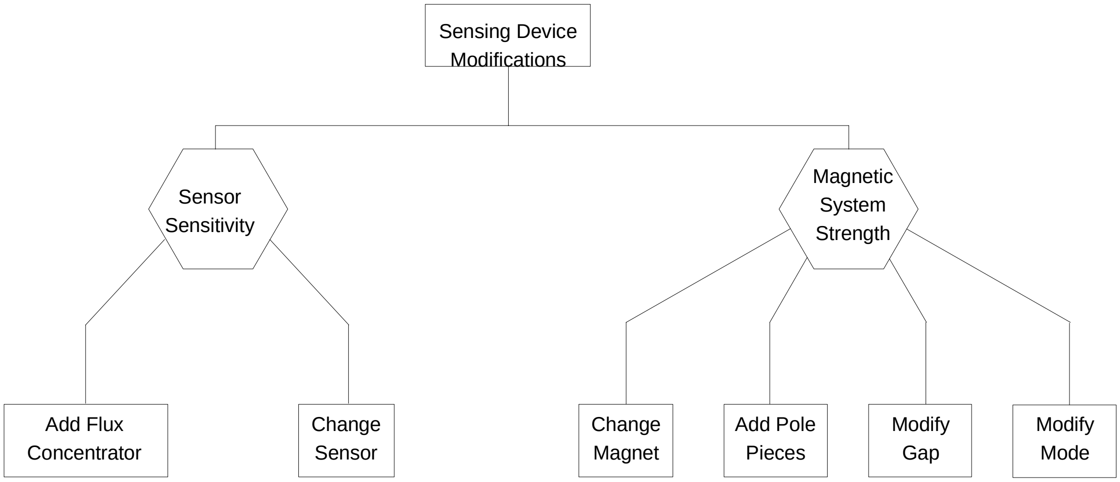

Figure 6-9 Sensing device modification options

If sensing device modifications are required to increase the guardband, refer to Figure 6-9.

Two approaches are available: the sensing device's sensitivity and/or the magnetic system field strength can be increased.

The sensing device's sensitivity can be increased by either selecting a sensing device with a lower operate gauss level, if available.

The field strength of the magnetic system can be increased in a number of ways:

- The magnet can be replaced by one with a greater flux density
- Pole pieces can be added to concentrate the flux in the sensing area
- The gap between the magnet and the sensor can be decreased
- Secondary magnets can be added to the system to alter the mode

All of these techniques are discussed in Chapter 3. Note that any of these modifications may require a corresponding modification to the input interface.

The final step in the design approach for non-precision digital output sensing devices is to integrate the sensor into the system and test it to determine that all design objectives have been realized. Sensor integration involves the layout, location and mounting of all sensor components, interconnections, and electrical wiring. It also includes writing any procedures that may be required during final assembly. The result of successful testing of the integrated sensor is a finalized sensor design.

Design approach . . . Precision applications

The design approach for precision digital output Hall effect based sensors is similar to the non-precision types (Figure 6-10) except that the exact point of operation and/or release is a prime consideration. The various design considerations previously covered apply again.

Reliable operation alone is not sufficient for precision digital type sensors. The operate and release points must be within specified tolerance limits. Two types of errors that will affect precision operation are:

- Unit-to-unit variations resulting from tolerances on components, manufacturing, and assembly
- Operation variations resulting from temperature changes, voltage transients, etc.

The effect of both of these error sources can be reduced by increasing the sensitivity of the sensing device to its input or reducing the sensitivity to error sources. Unit-to-unit variations can also be compensated by adjusting the sensor at assembly or by calibration of the completed sensor.

A detailed design procedure for precision digital output sensing devices is illustrated in Figure 6-10.

The initial steps, concept definition through breadboard device are the same as those covered by the non-precision types, Figure 6-8. An additional consideration to the design of the input interface is provision for adjusting the device to operate at a specified point (if required).

Once the breadboard sensing device has been built, it is necessary to measure gauss versus distance between the magnet and the sensor. Analysis of the resulting magnetic curve will determine the sensitivity of the device to changes in the sensor's operate/release characteristics. A portion of a typical magnetic curve is shown in Figure 6-11. (Refer to Appendix C for actual curves of gauss versus distance for various magnets offered by MICRO SWITCH Sensing and Control.)

To analyze this curve, let G_1 be the operate gauss level of the sensor; the operate position will be d_1. If the operate level changes to G_2 (due to unit-to-unit variations in the sensor, temperature change, etc.), then the operate position will be d_2. Thus, a sensor variation of (G_1 - G_2) will result in a sensing error (d_2 - d_1). Note that:

$$d_2 - d_1 = \frac{(G_2 - G_1)}{(\Delta G / \Delta d)} \qquad \textbf{(6-1)}$$

Where:

- $\Delta G/\Delta d$ is the slope of the magnetic curve at G_1. A steeper slope (larger $\Delta G/\Delta d$) will result in a smaller sensing error.

The sensitivity of the sensing device to changes in the magnetic system can be determined by examining the magnetic curve in Figure 6-12. It shows a portion of a magnetic curve (Curve A) and the same curve after it has been shifted by a gauss level of ΔG (Curve B).

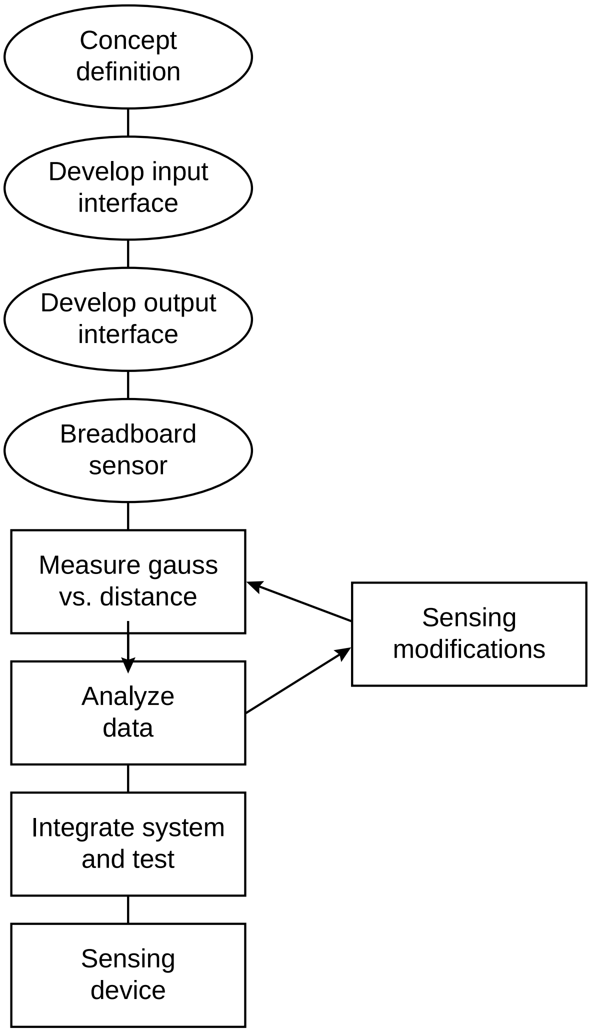

Figure 6-10 Detailed design procedure . . . Precision digital output Hall effect based sensors

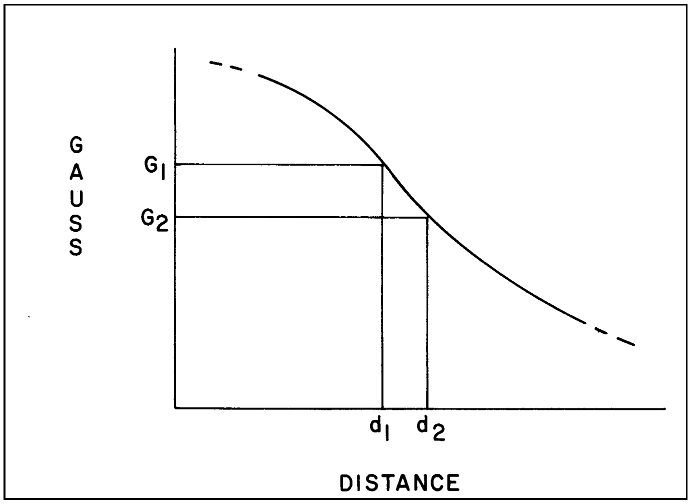

Figure 6-11 Operate gauss versus distance analysis

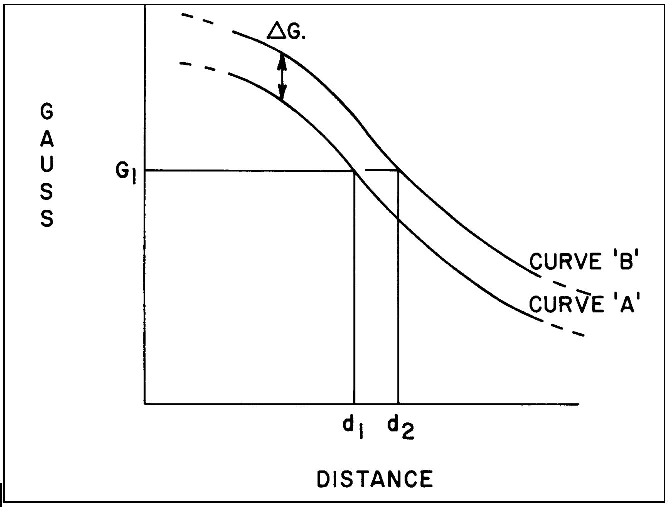

Figure 6-12 Effect of a shift in operating gauss

The sensing error, $d_2 - d_1$, is given by:

$$d_2 - d_1 = \frac{G}{(\Delta G / \Delta d)}$$

Again, a steeper slope will result in a smaller sensing error. The analysis step involves determining if the slope of the magnetic curve is sufficiently steep for the sensor's operate/release points to meet the tolerance limits of the sensor.

Several modification options are available if the analysis determines the tolerancelimits of the sensor have not been met. One option could be changing the Hall effect sensor to one with different operate/release points so it will operate on a different portion of the magnetic curve. The magnetic curve itself can be changed by modifying the magnetic system. The methods shown for modifying the magnetic system are discussed in Chapter 3. A third alternative is to individually calibrate each sensor after assembly. Any of these changes may require a corresponding change to the input interface.

The final step in the design procedure (Figure 6-10) is to integrate the sensing device into the system and test to determine that all design objectives are met. Successful testing of the sensing device into the system completes the design.

Linear output Hall effect based sensing devices

Design approach . . . Linear output sensors

The design approach for linear output Hall effect based sensors is similar to the digital output sensors previously covered. However, linear output sensors require a range of inputs to be considered, rather than a single operate/release point. The sensor response over the entire range of inputs must meet specifications.

A general procedure for designing linear output Hall effect based sensors is illustrated in Figure 6-13.

The initial steps, concept definition through breadboard sensor, are the same as previously discussed for digital output sensors. Additional considerations include:

- Transfer function
- Resolution and accuracy
- Frequency response
- Output conversion . . . e.g. analog to digital
- Output compensation

The overall transfer function for a linear output sensor describes its output for a given input value. A typical example of the transfer function for a linear output sensor is illustrated in Figure 6-14.

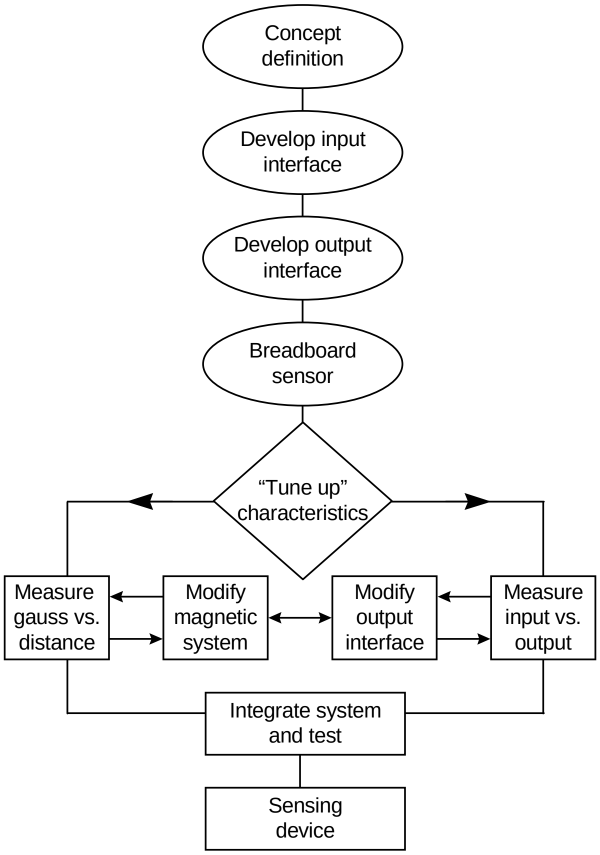

Figure 6-13 Design approach . . . Linear output sensors

In Figure 6-14, the sensor’s input is represented by the symbol (X) and the output (Y). Since the transfer function is linear, it is described by its slope (m) and the point where it crosses the Y-axis by (b). This graphical representation of a linear transfer function can be stated as a mathematical equation.

Where:

$Y = mX + b$ **(6-2)**

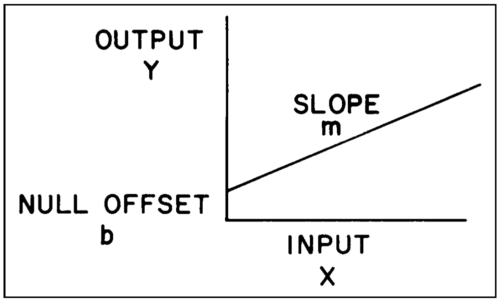

Figure 6-14 Linear transfer function

In chapter 2, the transfer function of a linear output Hall effect sensor was expressed as the relationship between magnetic field input and voltage output. In equation 6-2 (X) represents the magnet field input in gauss and (Y) the output in volts. Also in Chapter 2, the Hall effect sensor’s transfer function was characterized by sensitivity, null offset and span. In this case, m-slope is the sensitivity and b-bias is the null offset. Span defines the output range of the Hall effect sensor. This parameter is necessary because the sensor will saturate outside this range and not be linear. In order to include this parameter, equation 6-2 should be written as:

$Y = mX + B; X_{min} \leq X_{max}$ **(6-3)**

When designing linear output Hall effect based sensors, the overall transfer function will depend upon each of the four functional blocks shown in Figure 6-5. If the transfer functions for each of these functional blocks (input interface and magnetic system, sensor and output interface) are linear, then their respective transfer function can be represented by:

$B = m_M \bullet \text{Input} + b_M; \text{Input}_{(min)} \leq \text{Input} \leq \text{Input}_{(max)}$ **(6-4)**

$V_T = m_T \bullet B = b_T; B_{(min)} \leq B \leq B_{(max)}$ **(6-5)**

$\text{Output} = m_O \bullet V_T + b_O; V_{T(min)} \leq V_T \leq V_{T(max)}$ **(6-6)**

Where:

B = Flux density at the sensor

V_T = Sensor output voltage

m = Sensitivity ($m_M \bullet m_T \bullet m_O$

m_M = input interface and magnetic system

m_T = Hall effect sensor (sensor)

m_O = output interface

b = Null offset ($b_M \bullet b_T \bullet b_O$)

b_m = input interface and magnetic system

b_T = Hall effect sensor (sensor)

b_O = output interface

By substituting for B in equation 6-4 and V_T in equation 6-5, the overall linear transfer function can be written as:

$\text{Output} = m_S \bullet \text{Input} + b_S; \text{Input}_{(min)} \leq \text{Input} \leq \text{Input}_{(max)}$ **(6-7)**

Where:

$m_S = m_O \bullet m_T \bullet m_M$; overall sensitivity

$b_S = (m_O \bullet m_T) b_M + (m_O \bullet m_T) + b_O$; composite bias

Note that the input range in equation 6-7 is valid only if the input ranges in equations 6-5 and 6-6 are not exceeded. The input range is not the same as the safe operating range (B may be increased indefinitely without damage to the sensor). Rather, it is the range of values for which the transfer function describes the actual operation (within some tolerance). An important step in the design process is to assure compatibility of the input ranges of the four functional blocks, shown in Figure 6-5.

In equations 6-4 through 6-7, it was assumed that the transfer functions for each of the four functional blocks are linear. Linearity is always an approximation. No device or circuit is absolutely linear. The magnetic systems described in Chapter 3 were shown to be very non-linear. However, by limiting the input range to a region that the curve can be approximated by a straight line, linear transfer functions may be used.

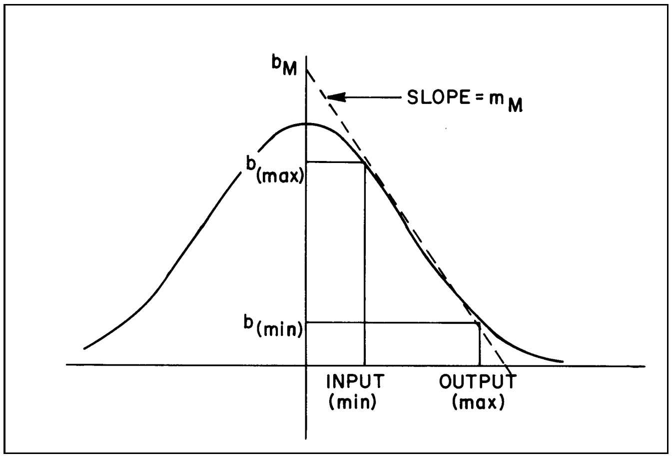

Figure 6-15 Linear approximation for magnetic curve

Figure 6-15 illustrates how a portion (from Input$_{(min)}$ to Input$_{(max)}$ of a unipolar slide-by curve might be approximated by a straight line. It is important to include an analysis of the error that results from this approximation to assure the sensor's tolerance limits are not exceeded.

For some applications, the input range cannot be limited to a region for which the magnetic curve can be approximated by a straight line. For these cases, overall sensor linearity can be achieved by including a complementary non-linearity in the output interface. Since this process involves sophisticated electronic design, it is not within the scope of this book.

Once the breadboard sensor has been built, two options are available for tuning the sensor to the desired characteristics and specifications (refer to Figure 6-13). The magnetic system transfer function may be adjusted or modified. This option requires that the gauss versus distance (or current in the case of a current sensor) first be measured. Using the ratiometric linear Hall effect sensor for this measurement will isolate the characteristics of the magnetic system from those of the Hall effect sensor. (Refer to Appendix C.)

The second option involves adjusting or modifying the output interface to achieve the same results. For this option, overall sensor input/output characteristics should be measured. The output interface can then be varied electronically to compensate for differences between the sensor and its specification. It may be necessary to investigate both options in order to complete the sensor design.

The final step is to integrate the sensor into the system and perform a complete system test. This step, with successful testing, completes the sensor design.

Design approach . . . Linear current sensors

The design approach for a linear current sensor is similar to the general approach for linear output sensors, as shown in Figure 6-13. However, the magnetic system will consist of a soft magnetic core with an air gap and a coil wrapped around the toroid core, forming an electromagnet (Figure 6-16). A linear output Hall effect sensor is positioned in the air gap to measure the flux density at that point.

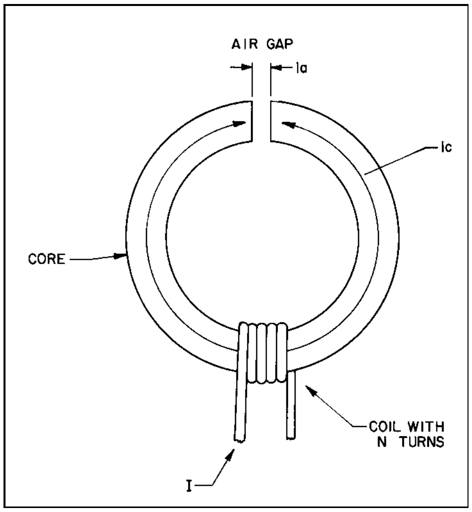

Figure 6-16 Simplified linear current sensor

Where:

I_a is the length of the air gap in centimeters

I_c is the mean length of the core in centimeters

I (current) is flowing through a coil with N turns

If the air gap is narrow (when compared to the cross sectional area of the core), the flux can be considered to be concentrated in the air gap, and the flux density in the core will be equal to that in air. Applying Ampere's Law results in the transfer function.

$$B_a = \frac{0.4\Pi\mu_c NI}{I_c + \mu_c I_a} \qquad \textbf{(6-8)}$$

Where:

B_a is the flux density (gauss) in the air gap

μ_c is the relative permeability of the core

For simplicity, the equation can be rewritten as

$B_a = m_M \bullet I$

Where:

$$m_M = \frac{0.4\Pi\mu_c \bullet N}{I_c + \mu_c I_a} \qquad \textbf{(6-9)}$$

Note this equation is valid only if the flux density in the core has not reached saturation level. That is:

$-B_{sat} \leq B_a \leq B_{sat}$ (6-10)

Where:

B_{sat} is the core saturation flux density

Now consider the linear output Hall effect sensor described in Chapter 2 with a transfer function:

$$V_T = m_T \bullet B + b_T; -400 \leq B \leq +400 \qquad \textbf{(6-11)}$$

Where:

$$m_T = 6.25 \bullet 10^{-4} \bullet V_S \qquad \textbf{(6-12)}$$

$$b_T = 0.5 \bullet V_S \qquad \textbf{(6-13)}$$

V_S = the supply voltage to the Hall effect sensor

The two transfer functions (equations 6-8 and 6-10) can be combined to give the overall sensor transfer function:

$$V_O = (m_T \bullet m_M) \bullet I + b_T \qquad \textbf{(6-14)}$$

Design of the current sensor then involves:

Choosing a core such that B_{sat} is much greater than 400 gauss

Choosing I_a and N so that $m_M \bullet I_{max} \leq 400$ gauss and $m_M \bullet I_{min} \leq -400$ gauss

Choosing V_S so that $m_T \bullet m_M$ yields the desired overall sensitivity if no output signal conditioning (output interface) is to be used

Other design factors must be considered when designing current sensors. The thermal dissipation of the coil and its insertion loss must be considered when choosing the wire size and the number of turns. Provision for high overcurrents may require the air gap be supported by a non-magnetic material to prevent collapse of the gap and core breakage. Output signal conditioning may be required, such as bias voltage removal, amplification, filtering, etc.

Also, eddy currents are an error source in AC current sensor design and in DC current sensor design when high ramp speeds from one DC level to another must be measured. Eddy currents are induction currents resulting from the time rate of change of flux density. The eddy currents, in turn, produce magnetic flux with an opposing polarity. Thus, the net flux density is reduced. Eddy currents create errors that appear as magnitude errors, time delays (phase lags), and thermal heating effects. Minimizing eddy currents requires careful choice of core material and the core design.

The final step in the design approach for a current sensor is to integrate it into the system and perform a complete system test. This step, with successful testing, completes the design.

Sensor packages

Design approach

Designing sensor packages using Hall effect sensors that include an integral magnetic system is straight forward. Since the magnetic system and transducer are already combined, no additional magnetic design is required. All that remains is to select the appropriate assembly along with determining the required input and output interfaces. Refer to Chapter 5 for operating principles and specifications for sensor packages.

The first steps, defining a fundamental concept and determining the system definition, are identical to sensors using discrete Hall effect devices. The discussion for designing sensors using Hall effect transducers (that are combined with a magnetic system) begins with concept definition. The principle steps are shown in Figure 6-17.

The sensor specifications were determined during system definition and are analyzed to determine the required sensing device package, as well as the functional characteristics and specifications for the input and output interfaces. This step is a simplification of the corresponding step for discrete sensing devices (Figure 6-7). Chapter 5 should be reviewed for the characteristics and specifications of sensing device packages. Chapter 4 should be consulted for the electrical characteristics and output interfaces. With this background, the designer can make an initial choice of transducer package and functional interface. This choice will give a set of parameters upon which design trade-offs can be performed and detailed sensor design can be initiated.

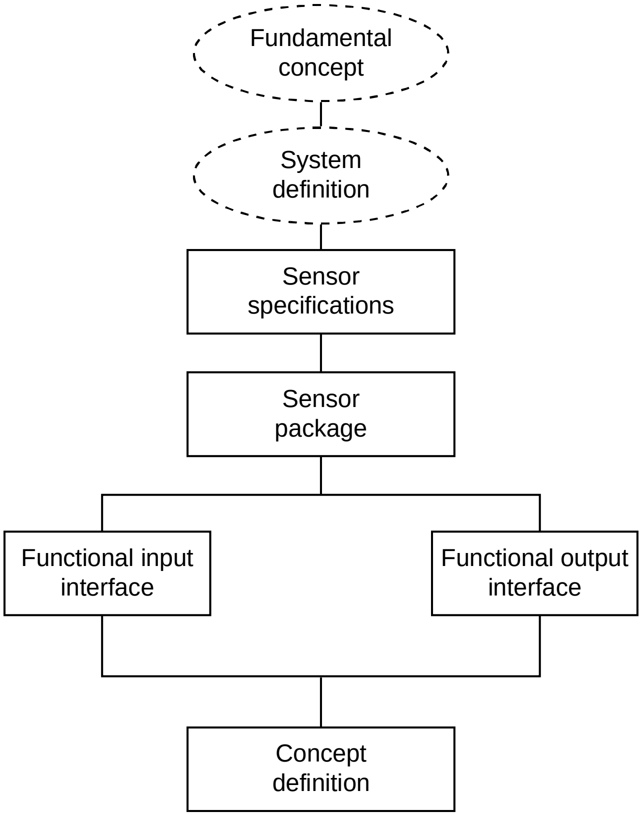

Figure 6-17 Concept definition - Sensing Device packages

Design approach . . . Vane operated sensors

The design of sensors based on vane operation involves designing the vane, determining methods for mounting and adjusting the initial position, and designing the output interface. Chapter 5 should be reviewed for operational characteristics and parameters of the vane sensor. The electrical characteristics of vane sensors and common output interfaces are examined in Chapter 4.

Vane operated position sensors have steep magnetic curves and may be used for precision and/or non-precision applications. However, these devices are not specified in terms of their magnetic characteristics, but rather of their operate and release position and associated tolerances. This manner of specification greatly simplifies the analysis of accuracy and subsequent design.

One important factor that limits the range of applications is the sensors' magnetic attraction to the vane. Since this sensor contains a magnet, and the vane must be made of ferromagnetic material, there is an attractive force between the two. (As the vane tooth approaches the sensor, this force pulls the vane toward the sensor. As the vane tooth leaves the sensor, this force tries to restrain the motion of the vane. While the vane is in the gap, this force will tend to pull the vane tooth off center.) As a result a vane operated position sensor should not be used in applications where the force driving the vane is small or where the vane cannot be mounted rigidly enough to move through the sensor gap without being pulled off center.

A design procedure for sensors which use a vane is illustrated in Figure 6-18.

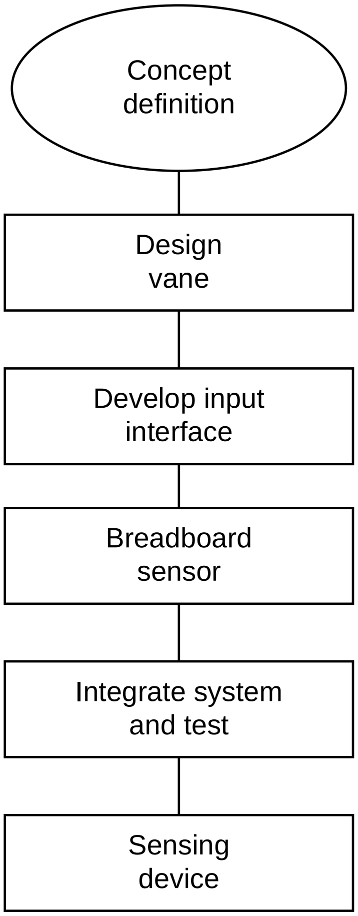

Figure 6-18 Detailed design - Vane-operated sensor

With the concept definition as the basis for the design, the first step is to design the vane. Important considerations are:

- Vane material
- Vane thickness
- Shape of tooth and window
- Dimensions and tolerances

The material used for the vane must be magnetically soft and free of any magnetization. A good choice is low carbon steel which has been fully annealed. The constraints on vane thickness are discussed in Chapter 5 as is the shape of tooth and window. The dimensions and tolerances of the vane are subject to the constraints of the sensor and are chosen to meet the overall accuracy requirements.

The next step is to complete the design of the input interface by defining the mounting for the vane and the sensor. Important mounting considerations include:

- Centering of the vane in the gap
- Allowances for end play and run-out (rotary vanes)
- Provisions for initial positioning of the vane relative to the sensor

The output interface must now be designed. The output stage of a vane operated position sensor is identical to that for discrete digital output Hall effect sensing devices. Thus any of the techniques or circuits used for discrete sensors may be applied.

The final steps are:

- Prototype the sensor (breadboard)
- Integrate the vane, sensor and output interface into the system and test the completed sensor

Design approach . . . Digital output current sensor

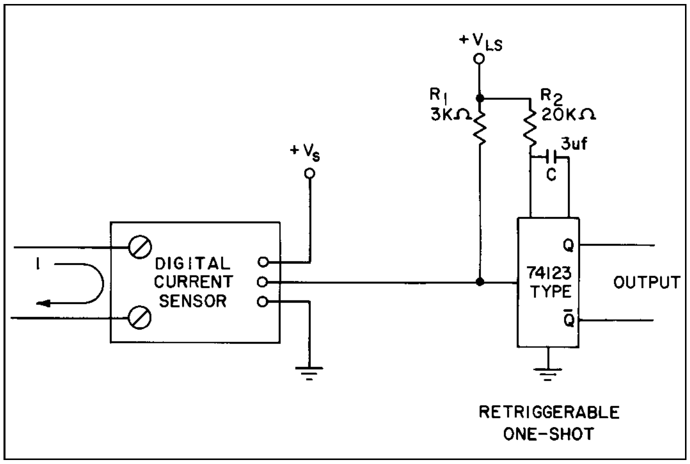

Figure 6-19 AC current sensor with logic level sensor

The digital output current sensor is perhaps the simplest to apply since it is already a complete sensor. Not only has the design of the magnetic system been eliminated, but also the design of the input interface. All that remains is to select the proper current sensor and design the output interface. Chapter 5 should be reviewed for operational characteristics and common output interfaces are discussed in Chapter 4.

An important consideration when applying digital output current sensors is whether AC or DC currents will be detected. As was found in Chapter 5, these sensors are specified in terms of DC current operate and release characteristics. They may, however, be used to detect AC currents as well. When the instantaneous AC current exceeds the operate level, the sensor output will turn ON as for DC current. Since the instantaneous AC current must fall to zero at the end of the positive half cycle, the sensor output will turn OFF again during that half cycle. Thus the sensor output will be a train of pulses for AC currents with a peak value exceeding the operate current level. An interface curcuit which converts these pulses to a constant level signal is shown in Figure 6-19.

The retriggerable one shot (monostable multivibrator) is a digital device which responds with an output pulse when triggered by an input pulse. The output pulse width (time) is independent of the input pulse, depending only on the values of R_2 and C. The retriggerable feature refers to the property that when another input pulse comes before the end of the output pulse, the output pulse will be extended an additional pulse width without changing state. Thus, if R_2 and C are chosen to give a pulse width slightly longer than the period (1/frequency) of the AC current, the output will remain constant until the pulses stop. The Q output will give a High (Logic 1) during the pulse train (overcurrent condition) and a Low (Logic 0) otherwise (normal current condition).

Figure 6-19 shows nominal values of R_2 and C for 60 Hz AC current and a 74123 type retriggerable one shot. Manufacturers' data sheets should be consulted for other frequencies or other types of retriggerable one shots. Chapter 4 should be reviewed for choosing R_1. Design of the output interface completes the design of the digital output current sensors.

Summary

This chapter outlined the steps involved in designing sensors based on a Hall effect sensing device. Many design considerations have been included, but others will depend on a particular application.