Hall Effect Sensor Analysis for Industrial Motor Speed Control System

Problem Statement:

An industrial conveyor system uses a Hall effect sensor for precise speed monitoring of a DC motor driving the belt. The maintenance team needs to calibrate the sensor system and analyze its performance characteristics for quality control applications.

System Configuration:

- **Motor shaft**: Contains 8 equally spaced permanent magnets around circumference
- **Hall effect sensor**: Linear type, positioned 3 mm from magnet surface
- **Magnet specifications**: Neodymium magnets, each producing 0.35 Tesla at sensor location
- **Sensor supply voltage**: $V_{supply} = 5.0$ V
- **Sensor material**: Silicon with Hall coefficient $R_H = 3.6 \times 10^{-4}$ m^3/C
- **Sensor thickness**: t = 0.8 mm
- **Operating current through sensor**: $I_{control} = 10$ mA
- **Target conveyor speed**: 2.5 m/s with 0.6 m diameter motor pulley

Given Parameters:

- **Magnetic flux density**: B = 0.35 T (when magnet passes sensor)
- **Background magnetic field**: $B_{background} = 0.02$ T
- **Hall coefficient**: $R_H = 3.6 \times 10^{-4}$ m^3/C
- **Control current**: I = 0.010 A
- **Sensor thickness**: $t = 8.0 \times 10^{-4}$ m

- **Supply voltage**: V_s = 5.0 V
- **Pulley diameter**: D = 0.6 m
- **Number of magnets**: N = 8
- **Sensor resolution**: 12-bit ADC (4096 levels)

Hall Effect Equations

Fundamental Hall Effect Relations:

Hall voltage:

```
V_H = (R_H × I × B) / t
```

Hall coefficient:

```
R_H = 1 / (n × e)
```

where n = charge carrier density, e = elementary charge (1.6×10^{-19} C)

Hall electric field:

```
E_H = V_H / w
```

where w = width of the Hall element

Signal Processing Relations:

Output voltage (with amplification):

```
V_out = G × V_H + V_offset
```

where G = amplifier gain, V_offset = offset voltage

Peak-to-peak voltage:

```
V_pp = V_H(max) - V_H(min)
```

Signal-to-noise ratio:

$$SNR = 20 \times \log_{10}(V_{signal} / V_{noise})$$

Speed and Frequency Relations:

Pulse frequency from sensor:

```
f_pulse = (N × RPM) / 60
```

Motor angular velocity:

```
ω = 2π × RPM / 60
```

Linear belt speed:

```
v_belt = ω × (D/2)
```

Time between pulses:

```
T_pulse = 1 / f_pulse
```

Digital Signal Processing:

ADC resolution:

```
V_LSB = V_ref / (2^n - 1)
```

where V_ref = reference voltage, n = ADC bits

Digital count:

```
Count = V_out / V_LSB
```

Analysis Questions:

Question 1: Hall Voltage Characteristics

a) Calculate the Hall voltage generated when a magnet (B = 0.35 T) passes directly over the sensor.

b) Calculate the Hall voltage when only background magnetic field (B = 0.02 T) is present.

c) Determine the peak-to-peak Hall voltage variation as magnets pass the sensor.

Question 2: Speed and Frequency Analysis

a) Calculate the required motor RPM to achieve the target conveyor belt speed of 2.5 m/s.

b) Determine the pulse frequency generated by the Hall sensor at this target speed.

c) Calculate the time interval between consecutive pulses at target operating speed.

Question 3: Signal Conditioning

a) If the signal conditioning circuit has a gain of 50 and offset voltage of 2.5 V, calculate the conditioned output voltage range.

b) Calculate the digital count range for the 12-bit ADC system (assuming 5V reference).

c) Determine the speed resolution of the system (minimum detectable speed change).

System Requirements:

- Minimum detectable speed: 0.1 m/s
- Speed accuracy: ±2%
- Operating temperature range: -20°C to +80°C
- Update rate: Minimum 10 Hz for control system