Simulation Model of Hall Current Sensor Based on Simscape Environment

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Abstract. Focus on the problems of current sensor model based on MATLAB/Simulink/Simscape, such as the internal structure of the model is simple and not reflect the principle and structure itself, the measurement results is ideal and not reflect the influence of noises. Therefore, a model is designed, which can reflect the principle, internal mechanism and the measurement error of hall current sensor in the simscape modeling environment. The model reflects the closed-loop principle, includes the current noise and other interference factors, and the model has no load effect on the measuring circuit. Test results show that the model system can better reflect the actual phenomenon, and make a prominent contribution for the research of circuit.

Introduction

In the process of the current engineering research and development, building system simulation model is important. MATLAB/simulink is one kind of commonly used modeling and simulation environments. MATLAB/simscape is an effective physical modeling tool, which can easily achieve object modularity and systematization in the modeling and simulation. The simscape tools provide physical modules, which can be easily used to building the simulation system. The simscape includes a current sensor model. The model can be directly connected to the circuit to measure current in the system. But the model structure is too simple, not reflect the principle and structure of the actual current sensor. So the measurement results are ideal and not reflect the measurement noises.

The research on closed loop hall current sensor has been very mature, and commonly used. The study of closed loop hall current sensor is developed earlier, where the theoretical research more in-depth[1-3]. From the late eighty's, the closed-loop Hall sensor is introduced, and most of them are from the practical point of view. Through the isolation and control of the actual power system, it can ensure the protection of the power system [4-7].

Based on the theory and existing research, a closed-loop simulation model of hall current sensor is built. The model uses the closed-loop measurement principle of hall current sensor. The model can reflect the measurement errors of current sensor model, which can more accurately reflect the actual object, and make a prominent contribution for the research of circuit.

Simulation Model of Hall Current Sensor

Model of the sensor based on hall effect, established a zero flux hall effect current sensor model, as shown in Fig. 1. The model had no effect on the original edge circuit (no tap, no pressure, no energy drain), by setting the output voltage of hall drift consider measurement error and noise. The output of the model of 0 to 5 v voltage. That is:

\[ V_{out} = I \times 5/(I_{max} - I_{min}) \]  

(1)

In the formula (1), Imax and Imin can be adjusted.
Balanced Hall sensor’s principle is shown in Fig. 2. The primary side N1 and secondary side N2 coil are wound on a circular iron core with a gap. The current N1 and N2 will produce a magnetic flux in the opposite direction in the iron core. As long as the difference between the amount of magnetic flux is not zero, the gap has a corresponding magnetic induction intensity. The current is controlled by placing a Hall film at the two opposite side of the magnetic field at the gap. Hall film on the other two side will be proportional to the magnetic induction intensity of the voltage, the voltage will be Enlarged, used to control the secondary current, thus forming a negative feedback loop. When the amplifier factor is large enough, the magnetic flux in the Hall film becomes zero, so the Hall effect current sensor is a zero flux. The primary side current can be measured by measuring the current of the secondary winding.

**Coil Magnetomotive Force**

Assuming the current through the coil is I1 and the number of the primary winding turns is A, so magnetomotive force generated:

$$F_m = N_1 \times I_1$$

(2)

In the model of electromagnetic conversion module will be converted to current MMF.

**Reluctance**

The reluctance of the model mainly includes the iron core and the gap.

$$R_m = R_{iron} + R_{air}$$

(3)

Core reluctance:

$$R_{iron} = L_{iron} \mu S$$

(4)
Void resistance:

\[ R_{\text{air}} = L_{\text{air}} S \]  

(5)

Liron is the iron core length, Liron is the air gap length, S is Core section area, \( \mu \) is the core relative permeability.

**Magnetic Induction Intensity**

The magnetic induction intensity of Hall film:

\[ B = \frac{F_n}{R_n S} \]  

(6)

The calculation is realized in the Hall component module.

**Hall Film**

In Fig. 3, a rectangular semiconductor through magnetic induction intensity of B. Control current in a pair of side keys by I. The electric charge of the angle between the direction of motion and the direction of the magnetic field is influenced by the Lorenz force and lead to the carrier direction perpendicular to the current direction and the magnetic field direction of the side of the aggregation (specific direction depends on the positive and negative charge of the carrier). The voltage is established in the other side which the magnitude of the voltage is proportional to the magnetic induction intensity B and the product of the control current I.

\[ U_H = K_H IB \]  

(7)

\( K_H = \frac{R_H}{d} \), \( R_H = \frac{1}{ne} \), \( K_H \) is defined as hall element sensitivity, \( R_H \) is defined as hall coefficient of hall element.

Obviously the latter is only related to the material of the hall element, the former is related to the geometry of the hall element.

Hall element achieve the magnetic field convert to the hall voltage.

![Figure 3. Hall film.](image)

**Primary Current**

At equilibrium, Hall film flux is zero and the magnetomotive force is equal to the primary side and secondary side, thus

\[ N_1 I_1 = N_2 I_2 \]  

(8)

So the original side current is:

\[ I_1 = \frac{N_2 I_2}{N_1} \]  

(9)
In the model, the secondary current is measured with an ideal current meter, and the reverse current of the primary side current is obtained.

**Measurement Error**

In the hall element module, the outside of the two magnetic circuit ports and the two circuit ports are 2 input terminals, respectively the output hall voltage drift and noise of hall probe. The module actual output hall voltage is

\[ U_H = U_a + U_D \]  
\[ \text{(10)} \]

If the measurement error caused by is, there is

\[ U_D = K_H I_{\text{control}} \Delta B \]  
\[ \text{(11)} \]

\[ F_m = N_1 \Delta I \]  
\[ \text{(12)} \]

\[ \Delta B = F_m / (R_s S_{nul}) \]  
\[ \text{(13)} \]

\[ R_s = (L_{iron} / \mu + L_w) / (\mu_0 S_{core}) \]  
\[ \text{(14)} \]

Finally, the current measurement error caused by the output voltage error of hall film is

\[ \Delta I = U_D \times \frac{S_{nul} (L_{iron} / \mu + L_w)}{K_H I_{\text{control}} N S_{core} \mu_0} \]  
\[ \text{(15)} \]

In the process of using, users only need input value (the gaussian distribution, including mean value and variance), in the model automatically

\[ U_D = N \times \frac{K_H I_{\text{control}} N S_{core} \mu_0}{S_{nul} (L_{iron} / \mu + L_w)} \]  
\[ \text{(16)} \]

UD is the hall film bias voltage.

**Model Parameters Setting and Interface Specification**

**Common Parameters**

Table 1 shows the parameters used in the model and their corresponding default values, including current and measurement noise. The default value of current measurement range is ±100. The default value of mean and variance of measurement noise and sampling time is 0, 10, 0.001s respectively.

| Parameter       | \(I_{\text{max}}\) (A) | \(I_{\text{min}}\) (A) | Noise mean (A) | Noise variance (A^2) | Noise simple time (S) |
|-----------------|-------------------------|-------------------------|-----------------|-----------------------|-----------------------|
| Default value   | 100                     | -100                    | 0               | 10                    | 0.001                 |
Coil, Iron-Core and Hall Film Parameters

Table 2 gives the relevant parameters of coil and iron-core, as well as their default values, the default value can be adjusted according to different modeling simulation requirements.

| Parameter                  | Turns of coil 1 | Turns of coil 2 | Length of the core (m) | Length of the core (m) | Area of the core (m²) | Length of the air gap (m) |
|----------------------------|-----------------|-----------------|------------------------|------------------------|-----------------------|--------------------------|
| Default value              | 50              | 2000            | 0.1                    | 2000                   | 0.0001                | 0.005                    |

Table 3. The related parameter and default value of hall file.

| Parameter                  | Area of the hall (m²) | Sensitivity of the hall (V/(A•T)) | Control current (A) |
|----------------------------|-----------------------|-----------------------------------|--------------------|
| Default value              | 0.000025              | 10000                             | 0.01               |

Interface Specification

In this paper, the closed-loop Hall current sensor simulation model has two input interfaces and two output interfaces. The interface specification of the model is shown in Table 4.

| Interface | i+   | i−   | O+   | O−   |
|-----------|------|------|------|------|
| Access    | Input positive pole | Input negative pole | Output positive pole | Output negative pole |

As shown in Fig. 4, build the following system to test the availability of the model.

![Diagram](image)

In Fig. 4, the system shown includes an AC current source (amplitude 40V, frequency 10Hz), a resistor (resistance 1Ω), ideal ammeter and current sensor model (using the default parameter values) in series. Translating the current sensor model 0 to 5 V results into actual current value, accessing to the oscilloscope and the ideal ammeter measurement value for comparison in the same coordinates; at the same time, the current sensor model measurement results directly access to the scope, and display in another coordinates. Setting the parameters of simulation system: power supply voltage amplitude is 40V, frequency is 10Hz, the resistance is 1Ω, the model uses the default parameters.

![Comparison Chart](image)
The measurement results are shown in Fig. 5, use the simscape own the ideal ammeter measurement results and the measurement results of module inverse calculate the measurement results of current (the output voltage of the module itself is 0 to 5V). We can see the measurement results have a certain range of fluctuations in the actual results.

Conclusion
A simscape physical model is established based on the closed-loop simulation model of hall current sensor. A Through the test results, the following conclusions can be achieved:

The model includes the closed loop of the principle of hall current sensor, the concrete internal structure, achieves better reflect of actual object, and provides possibilities to improve simulation model;

The closed-loop simulation model reflects the actual errors by establishing voltage drift and noise in Hall film, makes the circuits simulation more real and effective.

References
[1] Ziegler S., Woodward R.C. Current sensing techniques: A review [J]. IEEE Sensors Journal, 2009, 9(4): 354-376.
[2] Pavel Ripka. Electric current sensors: A review [J]. Meas Sci Technol, 2010, 21: 1-23.
[3] Honeywell Inc. Current sensors line guide [DB/OL]. [2008-09-01]. http://www.honeywell.com/sensing.
[4] Matsui bond, Rui-lin Liang. Application in sensor technique in 141 cases [M]. Beijing: science press, 2011: 169-170, In China.
[5] Ze-yong Li, Wen-sheng Wang. Closed loop hall current sensor applications in automotive power systems [J]. Journal of electronic applications, vol. 6, 5 May 2004, In China.
[6] Ying-zi Zhou, Fu-shan Shao, Wen-liang Xu. The hall current transformer simulation design [J]. Journal of low voltage apparatus, 2009 (15): 13 to 16, In China.
[7] Qing-Chen, Hong-bin Li, Ben-xiong Huang. Matrix model and realization of the hall current sensor [J]. Journal of huazhong university of science and technology (natural science edition), vol. 37, 3 March 2009, In China.