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Split Core Closed Loop Hall Effect Current Sensors and Applications

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Abstract

In this paper a new split core Hall Effect current sensor based on closed loop principle is introduced. With the split core configuration, the current sensor system can be constructed more conveniently. The signal conditioning circuitry is designed by utilizing closed loop principle in order to improve the measuring accuracy of split core current sensors with low additional costs.

Key words: Hall Effect current sensor, closed loop current sensor, split core current sensor

1. Introduction

Current sensors and devices are widely used in inverters, rectifiers, AC/DC motor drives, power supplies, battery supplied applications, telecommunications, electric powered locomotives, transformer substations, hybrid electric vehicle applications, solar panels and photovoltaic equipment. With the increasing use of solar energy, the current sensors and devices find more and more applications to photovoltaic power systems.

There are various kinds of current sensors, for instance, shunt resistors, current transformers, Hall Effect current sensors, magnetoresistive current sensors and fiber-optic current sensors etc. [1-4]. The most economical current sensors are the first three current sensing devices.

Compared with the shunt resistor and current transformer, a Hall Effect current sensor has much more benefits in wide measuring range, good linearity and accuracy, high isolation between input and output, diverse sensor configurations and applications etc. It can be used both for AC and DC current measurements of all applications mentioned above [5].

There are two Hall Effect current sensing methods, i.e. open loop and closed loop configurations. Both kinds of sensors use a magnetic core with air gap, where a Hall Effect sensor is inserted. A primary conductor of current to be measured passes through the magnetic core. The magnetic flux generated by the primary current is concentrated in the core, which is proportionate to the current and detected with the Hall Effect sensor. [2-3]

In an open loop topology (see Fig. 1) the voltage output of Hall sensor is simply amplified. The output is read as a voltage that represents the measured current in proportion. Open loop sensors cost less than closed loop sensors and can be made with split core easily. They are preferred in battery powered circuits due to their low operating power requirements. [5]

In a closed loop topology (see Fig. 2) a secondary coil is wound around the soft magnetic core. The magnetic field concentrated in the core is sensed by the Hall sensor. The Hall voltage is connected to an integrating amplifier to generate a current for driving the coil. The current through the coil produces an opposite magnetic field. Thus the magnetic flux in the core is constantly driven to zero. The coil connects the output of the sensor. Therefore the output is a current, which is equal to the primary current divided by the number of turns on the coil. The current output is converted into a voltage by connecting a measuring resistor between the output of the sensor and ground. The output is scaled by selecting the resistor value [6].

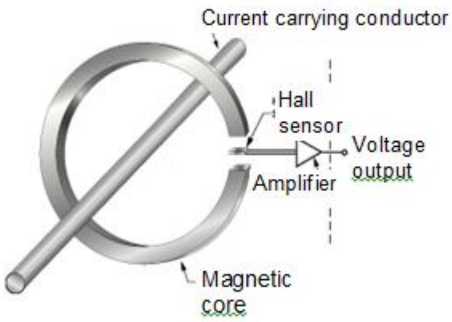


Fig.1. open Loop Current Sensor

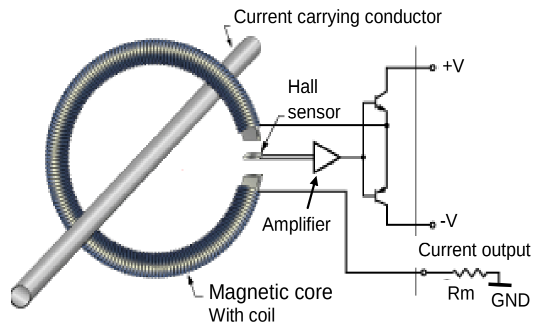


Fig.2. Closed Loop Current Sensor

The closed loop sensor has the advantages of wide frequency range, good overall accuracy, fast response time, low temperature drift, excellent linearity and no insertion losses. But the price is higher than that of the open loop current sensor. However, they are not easy to be made with split core.

2. Theoretical Analysis

For the common closed loop current sensor, the configuration of core is solid, and Hall Effect element is mounted in the air gap. The split core of current sensor consists of 2 or 3 partial cores shown in Fig. 4. The partial cores form 1 or 2 additional air gapes. Therefore, it needs to analyze the change of magnetic flux in the closed split core.
The inductance of a soft magnetic core is calculated by [7]

$$L = \frac{\mu_i . N^2 . A}{l_m + \mu_r . l_g} \tag{1}$$

with μ_i as the initial permeability of the core, μ_r as the relative permeability of the core, N as the turns of primary inductor, A as the effective cross-sectional area, l_m as the mean length of core, l_g as the gap width. By using the definition for inductance, $L=N*B/I$, where B is the magnetic flux and I is the primary current, the magnetic flux in a core of current sensor is calculated as follows [7-8]:

$$B = \frac{\mu_i . N . A . I}{l_m + \mu_r . l_g} \tag{2}$$

The total gap width l_g of split core current sensor is increased by additional air gapes so that the magnetic flux through the core becomes smaller.
The output voltage of Hall Effect element is defined as $V_H=K*B$, where K indicates the sensitivity of the Hall element. Therefore the secondary current can be written by

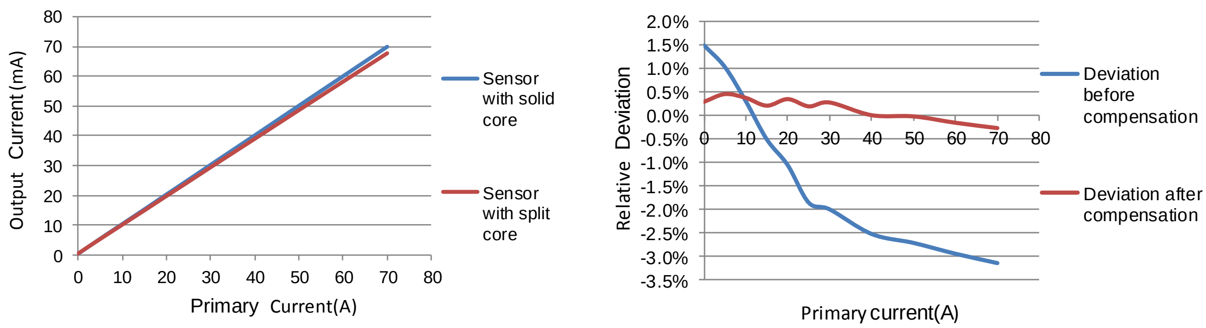
$$I_S = \frac{V_H . G}{R_L + Z_S} = \frac{K . B . G}{R_L + Z_S} \tag{3}$$

with G as the voltage gain factor, R_L as measuring resistor and Z_S as secondary winding impedance [7-8]. The output current of the sensor is dropped by the reduced magnetic flux B in case of using split core.

The task for developing closed loop current sensor is to find methods to compensate the reduction of the output current. A very simple method is to reduce the turns of the secondary coil from N_1 to N_2, i.e., $N_1>N_2$. For compensating the magnetic field generated by the primary current the secondary current must be increased from I_1 to I_2, i.e., $I_1<I_2$ according to the relation $N_1I_1=N_2I_2$.
The second method is to increase the permeability of the soft magnetic core of the sensor by suitable heating processing. However this method will increase manufacture costs of the sensor. The third method is to build a compensation circuit in the sensor to adjust the output signal of the sensor.

3. Experimental Results

The theoretical analysis and proposed method have been proved by experimental results shown in Fig 3. Under using same sensor circuit, the output current of a closed loop current sensor with split core is smaller than that of sensor using solid core, see graphics shown in Fig.3 (a).



(a) Output Current (b) Relative Deviation of Output Current

Fig.3. Experimental result of split core hall-effect current sensor based on closed loop principle

By reducing the turns of the secondary coil the output current is increased. Fig.3 (b) shows the comparison of relative deviations before and after compensation. The deviation of current sensor with split core after compensation can be limited within the wished range of ±0.5%. It is approximate to the same accuracy of conventional closed loop current sensors.
The structure of split core closed loop sensor is shown in Fig.4. The secondary coil is wound around one of the soft magnetic half core. One or two Hall elements are mounted in the air gap of the core. The magnetic field generated by the current carrying conductor is compensated by the opposite magnetic field generated by the current passed through the secondary coil.
Based on the experimental results and new sensor structure, some parameters of the spilt core sensor should be determined and optimized to make the sensor with wide measuring range and high accuracy. These parameters are given below:

(a) The air gap of sensor core,
(b) Dimension of partial split cores,
(c) The turns and position of secondary coil,
(d) Relative section of soft magnetic core and
(e) Position of Hall elements.

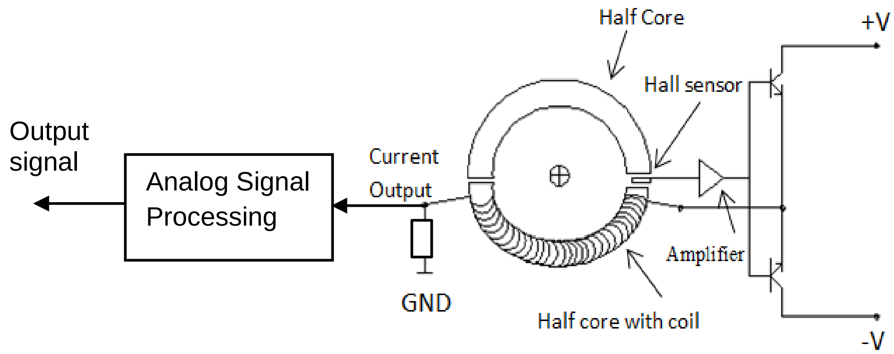
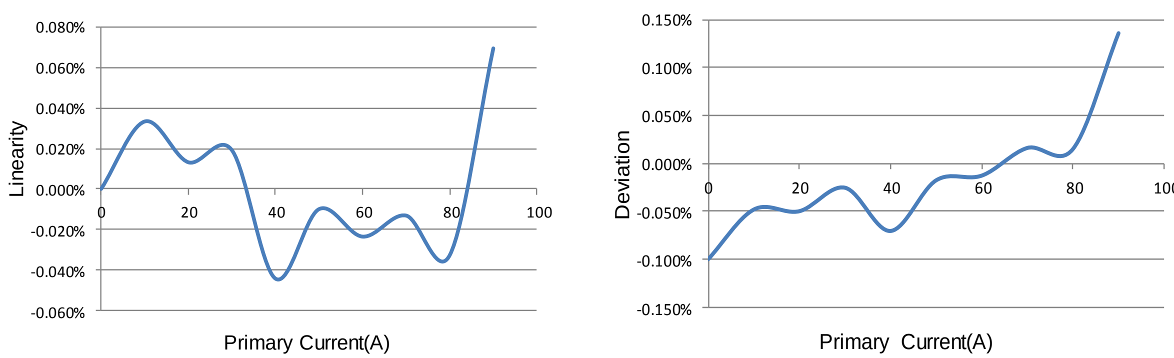


Fig.4. Split core closed loop Hall Effect current sensor

After determining all parameters of the split core closed loop Hall Effect current sensor, the voltage gain of the analog signal processing circuit must be adjusted in order to ensure the sensor to fulfill the requirements of accurate current measurement.
In this experiment, a coil with 1000 turns is wound around soft magnetic half core. The rated input current of split core closed loop current sensor is 40A corresponding to rated output 5V. Through the signal processing circuit, the linearity and relative deviation of the output signal are calculated and shown in Fig. 5. For the conventional closed loop sensor, the linearity should be within ±0.1%. From the graphic shown in Fig.5 (a), the linearity of the spilt core current sensor under test is within ±0.08%. Fig.5 (b) shows that the relative deviation of the sensor is less than ±0.2%. The standard maximum deviation of conventional closed loop sensor is normally within ±0.5% [9-10]. The measuring range of the sensor under test is 2 times of the rated input current, i.e., 80A.



(a)Linearity of sensor

(b) Deviation of sensor

Fig.5. Linearity and relative deviation of split core closed loop current sensor

4. APPLICATIONS

The proposed split core structure of closed loop current sensors and compensation methods are applied to the development of different current sensors. Fig.6 shows a typical example of current sensor with round split core. The developed sensors have the advantages of conventional closed loop current sensors and convenient installation. Therefore they can be widely used in operating power systems without remounting the current conductors, and make sensor installation also in new power systems much easier than solid core sensors.

In other word, split core sensors give the user more options when implementing a current sensing application and improve the measuring accuracy of split core current sensors with low additional costs [9-11].

Fig.6. Application of Split core current sensor based on closed loop principle

5. CONCLUSIONS

In this paper split core Hall Effect current sensors based on closed loop principle are introduced. From the experiment results one can draw the following conclusions:

- The magnetic flux produced by the primary current can be estimated by the equation (2).
- Under using same sensor circuit, the output current of a closed loop current sensor with split core is smaller than that of sensor using solid core.
- The output current can be increased by reducing the turns of the secondary coil and by increasing the magnetic permeability of the cores.
- The relevant parameters of the current sensors could be adjusted by analog signal processing to guarantee accurate current measurement. This is proved by the experiment results.
- The linearity and relative deviation of the current sensor is less than ±0.08% and ±0.2%~±0.5%, respectively. Therefore this split core structure of closed loop current sensor can be used in various kinds of industrial applications.

The proposed current sensor has the advantages of easy installation and high measuring accuracy. It can extend the application area by increasing the cross region of the open loop and closed loop sensors. Therefore, high accurate split core current sensors will be widely used in the future.
For further study, it will be useful to improve the parameters and structures to make the output of current sensors more accurate and stable based on signal compensation technology.

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