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Research Article

DESIGN OF LARGE-RANGE OPEN-LOOP CURRENT SENSING SYSTEM BASED ON GIANT MAGNETO RESISTANCE SENSOR

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ABSTRACT

Based on the measurement requirements of current sensor with a wide range and high accuracy, a new open-loop current sensing system design method based on the combination of soft magnetic shunt technology and giant magnetoresistance (GMR) sensor is proposed. In this paper, a soft magnetic shunt structure is used to shunt and attenuate the large magnetic field generated by the large current into a smaller magnetic field, and a high sensitivity GMR sensor is used to detect the field, to achieve the detection of small magnetic field under large current and achieve the design purpose of a wide range. The measurement results showed that the sensitivity of the open-loop current sensing system is 3.95679 mV/A and the linearity is 0.38%. The open-loop current sensing system designed in this paper has the advantages of high feasibility, low nonlinear error, and wide range, and can be applied to high-precision power metering.

INTRODUCTION

Current sensors are devices that detect the magnitude of current, which are widely used in smart grid, medical, and new energy vehicles. At present, the technical principles of large-range current sensors are mainly Hall-type, fluxgate-type, and shunt-type. The Hall-type current sensor has a large measurement range, but its signal-to-noise ratio is low and its temperature stability is poor. The fluxgate-type current sensor has good resolution and good temperature stability, but its size is large and its bandwidth is low. The shunt has high measurement accuracy, but it needs to be directly connected to the measured circuit, and the heat generated by the shunt itself will make the system temperature stability poor. In this paper, the magnetic field generated by the signal current is shunted and attenuated by the soft magnetic shunt technology, and the magnetic field is detected by a highly sensitive giant magnetoresistance (GMR) sensor. By combining the soft magnetic shunt technique and GMR sensor, the current sensor sensitivity can be improved and the current detection range can be increased. The current sensor designed in this paper features high sensitivity, a wide range, and high linearity.

Experiments

Current sensing system design

The current sensing system includes a soft magnetic shunt structure, a sensing probe, a signal processing circuit, and an upper computer, and its workflow is shown in Figure 1.

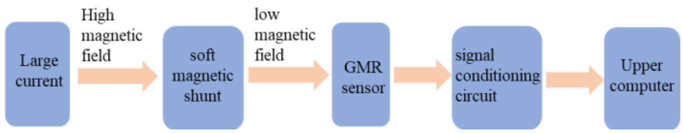

Figure 1 Workflow of the current sensing system

The GMR sensor is placed on the sensing probe. After shunting and attenuation by the soft magnetic shunt structure, the magnetic field signal is sensed by the GMR sensor. The GMR sensor converts the magnetic field signal into a voltage signal, which is processed by the signal conditioning circuit and then displayed by the upper computer. The sensing probe is connected to the signal conditioning circuit via a flexible circuit board. The schematic diagram of the current sensor system is shown in Figure 2.

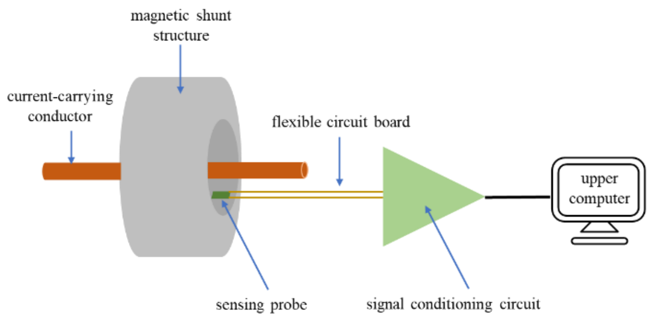

Figure 2 The schematic diagram of the current sensor system

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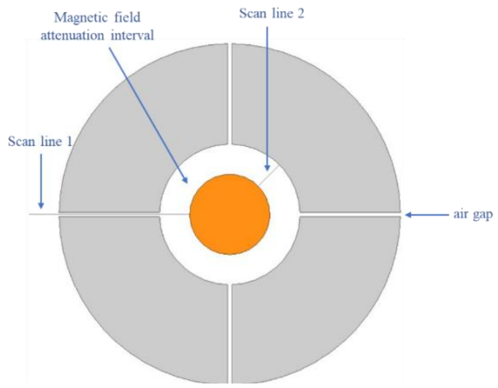
Soft magnetic shunt structure parameters and simulation

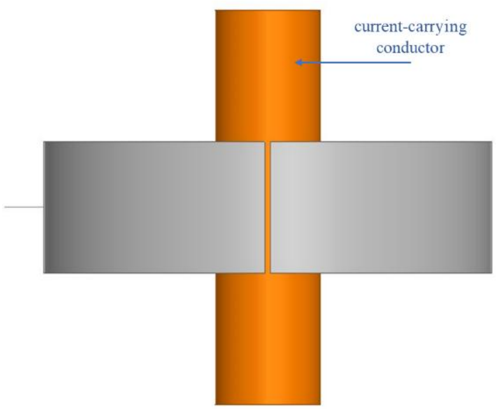
To make the magnetic field around the current-carrying conductor uniformly distributed, the soft magnetic shunt structure is designed in a circular shape in this paper. The current-carrying conductor passes through the center of the soft magnetic shunt structure. The current sensor range is set from 0 A to 1500 A, and the radius of the current-carrying conductor is 40 mm.

The parameters to be determined for the soft magnetic shunt structure include the magnetic ring material, inner and outer diameter dimensions, and the height of magnetic ring. To avoid magnetic saturation, air gaps in the soft magnetic shunt structure are required to increase the magnetic reluctance of the magnetic path. To minimize the magnetic field between the current-carrying conductor and the soft magnetic shunt structure, while taking into account the volume of the entire current sensing system, the height of the soft magnetic shunt structure is set to 100 mm. The magnetic ring material is permalloy with an initial permeability of 80,000, and the saturation magnetic induction intensity is about 0.7 T.

The simulation model of the soft magnetic shunt structure is shown in Figure 3, with four air gaps symmetrically distributed throughout the ring and an air gap width of 4 mm.



(a) Top view



(b) Side view

Figure 3 The simulation model of the soft magnetic shunt structure

In the simulation model, scan line 1 and scan line 2 are set up. Scan line 1 starts at the center of the magnetic ring and runs through the air gap. Scan line 2 starts at the center of the magnetic ring and is close to the inner wall of the magnetic ring. Scan line 1 and scan line 2 are at equal distances from the top and bottom of the ring. Scan line 2 has equal distances to the left and right air gaps.

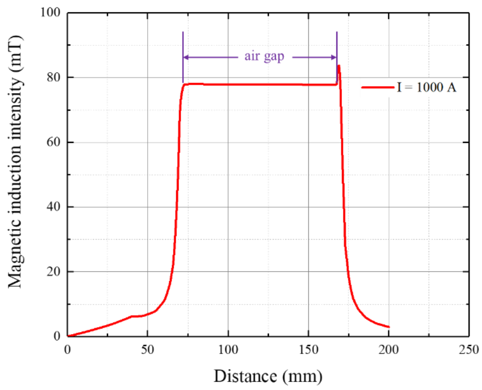
The reluctance of the magnetic path can be calculated by the Ohm's law of the magnetic circuit, as shown in equation (1).

$$B = \frac{NI \Big/ \left(\frac{l_c}{\mu_c A} + \frac{l_0}{\mu_0 A} \right)}{A} \qquad (1)$$

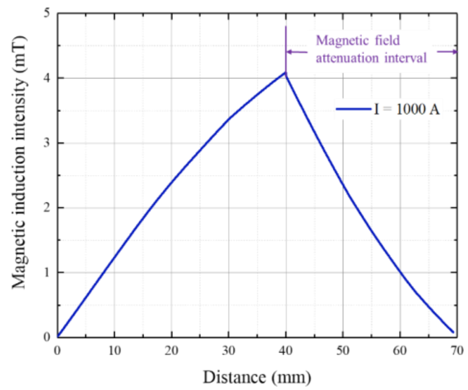
where B is the magnetic induction intensity in the magnetic path, I is the current under measurement, N is the number of turns of the original side conductor, l_c is the length of magnetic ring, μ_c is the permeability of the permalloy, l_0 is the length of the four air gaps, μ_0 is the permeability of vacuum, and A is the is the cross-sectional area of the magnetic path.

$$B = \frac{NI \Big/ \frac{l_0}{\mu_0 A}}{A} = \frac{NI\mu_0}{l_0} \qquad (2)$$

Since the permeability of the permalloy is much larger than the vacuum permeability, equation (1) can be simplified to when the measured current is 1000 A, the magnetic induction intensity in the magnetic path is 78.5 mT according to equation (2), and the above calculated result is verified using Maxwell simulation software, as shown in Figure 4.



(a) Simulation result for scan line 1



(b) Simulation result for scan line 2

Figure 4 The simulation results of the soft magnetic shunt structure

It can be seen that the magnetic induction intensity in the air gap is basically consistent with the theoretical calculated result.

GMR Sensor Location

The GMR sensor used in this paper is SAS030-1. The SAS030-1 is in the SOP8 package， and its linear operating range is -0.25 mT to 0. 25 mT with a sensitivity of 36 mV/V/mT. The SAS030-1 is soldered on the top layer of the sensing probe, and the distance from the internal sensing chip to the surface of the sensing probe is 1mm. The width of the sensing probe is 16 mm, and the sensing probe is placed close to the inner wall of the magnetic ring. The distance from the sensing chip to the center of the magnetic ring is 67.7 mm, as shown in Figure 5.

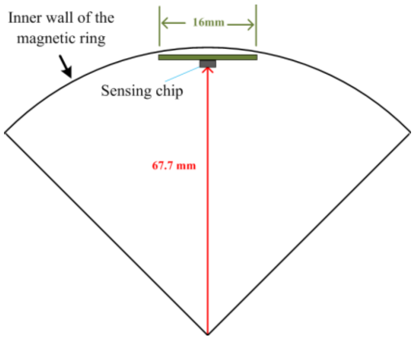


Figure 5 Distance from the sensing chip to the center of the magnetic ring

The distance from SAS030-1 to the top and bottom of the magnetic ring is equal, and the distance to the left and right air gaps is equal. The simulation results show that the magnetic inductance at the position of sensing chip is 0.22 mT at the measured current of 1000 A, which is in its linear operating range.

Signal Conditioning Circuit Design

Since the output of the GMR sensor is small, the differential voltage signal from the GMR sensor is amplified using an instrumentation amplifier AD620, which can reach a maximum gain of 10000. The output of the AD620 is converted to digital signal by the LTC 2500, a 24-bit successive approximation (SAR) analog-to-digital converter (ADC) with a reference voltage of 5 V and a maximum sampling rate of 1 MHz. The digital output of the LTC2500 is averaged using a microcontroller STM32F103 and then output to the upper computer.

RESULTS AND DISCUSSIONS

To measure the performance of the current sensing system, a current sensing measurement system was built as shown in Figure 6. The soft magnetic shunt structure and the current-carrying conductor are wrapped with aluminum support.

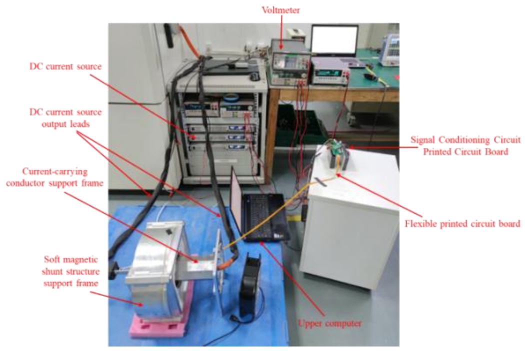


Figure 6 current sensing measurement systems

The GMR sensor is powered at 5 V. The gain of the AD620 is set to 100, the sampling rate of the ADC is set to 10 kHz, and the data is averaged by the STM32 for every 1000 samples. The DC power supply outputs 0 to 1000A, and the current sensing system outputs are shown in Table 1.

Table 1 Current sensing system outputs

Current (A)	Output (mV)
999.987	3970.834462
899.897	3576.576578
800.011	3159.345234
699.887	2784.564757
599.988	2375.846543
500.012	1990.767875
400.009	1589.423356
299.978	1193.465276
199.899	802.786435
99.975	405.324532

A linear fit was made to the data in Table 1, as shown in Figure 7.

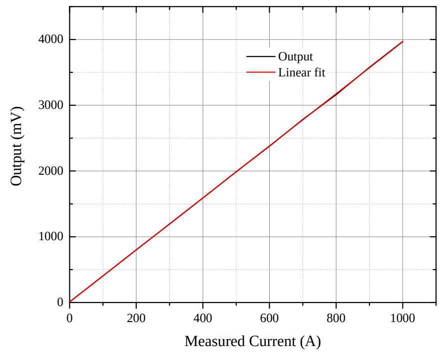


Figure 7 Linear fitting of the current sensing system outputs

The fitting results show that the maximum nonlinear error of the current sensing system is 15.10625 mV, and the linearity is 0.38%. The sensitivity of the current sensing system reaches 3.95679 mV/A.

CONCLUSION

In this paper, a large-range current sensing system is established by combining a soft magnetic shunt structure with a GMR sensor, which achieves a sensitivity of 3.95679 mV/A and a linearity of 0.38%. This sensing system can be applied to high-precision current detection. The work in this paper also provides a research basis and experimental validation for the design and preparation of larger-range current sensors.

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