Research about Miniature Vibration Sensor based on Hall Effect

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Abstract. When we move the Hall component in a uniform gradient magnetic field under the constant current, the Hall electromotive force it outputs depends only on the amount of its displacement in the magnetic field. According to this characteristic, this paper analyses the basic principles, the selection of uniform gradient magnetic field and the output of displacement expression data. This paper makes a research from the four aspects. With improvement and innovation, we try to design a sensor which can measure miniature vibration.

Introduction

Nowadays, as the deepening of the scientific research, we have become increasingly demanding for the accuracy of measurements. That, how to measure small vibrations conveniently and quickly, is a research aspect that receives much concern. Hall displacement sensor, compared with other displacement sensors, has features such as quick response, simple structure and low cost, and some disadvantages about the measurement as well. To achieve the effect small vibrations to be measured, we will improve and research the sensor, based on its disadvantages.

Fundamental principles

Hall effect

When a magnetic field is present to the semiconductor that is perpendicular to the direction of the current, the electrons and holes inside the semiconductor will experience a force, which is called the Lorentz force, and the electrons and holes will accumulate on one face of the material, establishing an electric field. The force from the electric field opposes the Lorentz force. When the electric field reaches a certain value, the electric force and the Lorentz force experienced by the holes and electrons are balance. The electric field opposes the migration of further charge, so a steady electrical potential is established, making the subsequent electron and holes can pass without deflection. This is called the Hall effect.

As is shown in the Fig.1. Suppose the conductor is a cuboid, whose length, width and height are a, b, and c respectively, the electricity flows in from surface cd vertically, and that the magnetic field intensity is B vertical to surface ab, the voltage between the two boards front and back is therefore Hall voltage

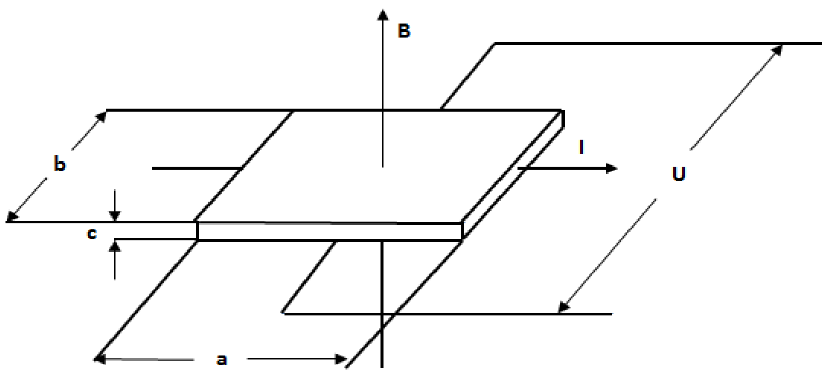

Fig.1: Hall effec

According to the formula of Hall voltage U, with a fixed electric current I, as long as the magnetic field gradient is constant, the value of Hall voltage across the Hall element will show a positive liner relationship with its displacement within the Hall element.

Hall element.

Produce Hall element using the principle of Hall Effect. The performance curve of Hall element is as follows:

The purpose is to find appropriate electric current and magnetic field, so that with a fixed electric current and constant magnetic field gradient, the Hall element will work with in interval AB in the phase diagram.

The working status of Hall element is also associated with temperature. For the sake of measuring accuracy, SS495A1 Hall element is chosen, whose working temperature is between -40C and 150C with strong flexibility, matching the requirement of measurement and design.

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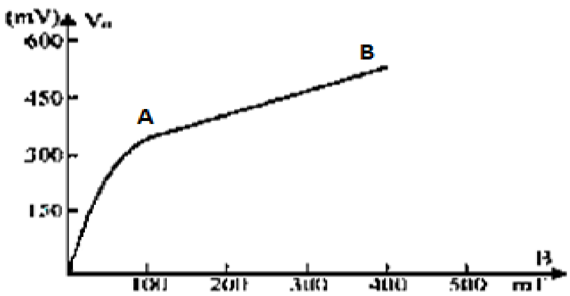

Fig.2: Characteristic

Choosing the magnetic field

As is shown in the first step, in order to make the instrument reflect tiny vibration, a liner relationship between Hall voltage and displacement is in need. Thus, we need to select a magnetic field with constant gradient. This essay develops the study according to an experiment – correction - verify procedure, fitting Hall voltage and displacement of Hall elements in magnetic field of various shapes, through which we find that magnetic field of bar magnet is pretty close. Consequently, we made further improvement based on this idea, and finally choose to fix two angel-shaped iron on the two sides of the bar. The specific measuring method is as follows:

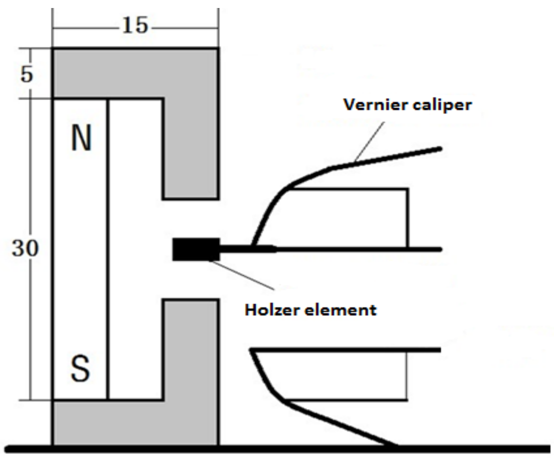

Fig.3 Measuring method

Fitting this set of data using MATlAB, we have Fig.4:

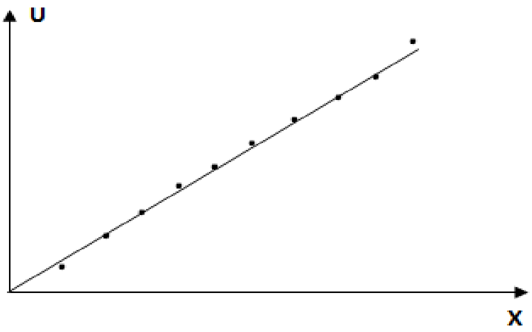

Fig.4 Fitting curve

According to the phase, we can learn that the magnetic field satisfies the requirement of constant gradient.

The expression of displacement

When the measured object vibration occurs, there will be a displacement, which is called the absolute vibration displacement. However, when the sensor is fixed on the measured object, the displacement of the Hall element in the magnetic field is not equal to the absolute vibration displacement, which is called the relative vibration displacement. Therefore, here comes two problems. The former one is how the relative vibration displacement is produced and the latter one is the relationship between the absolute displacement and the relative displacement. We used the inertial vibration method to solve these two problems.

The model can be divided into some steps. The sensor is fixed on the base of the object, in which there is a mass attached to the bottom of the sensor through a spring (elastic coefficient is k). The absolute vibration of the object will make the mass vibrate, causing the relative motion between the mass and the sensor. However, the relative motion will be blocked by the damper (the damping coefficient is c). In this way, the mass, spring and the damper constituted an "m - k – c” system.

Just like Fig.5.

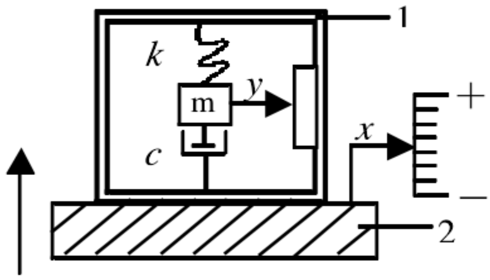

Fig.5 "m - k – c” system

The idea of improved perturbation method is:

In the diagram, x represents the absolute vibration of the object and y represents the relative motion between the mass and the sensor in other words the relative vibration.

The relationship between them can be expressed by a second order ordinary differential equation with constant coefficients.

$$\frac{d^2 y}{dt^2} + 2D\omega_0 \frac{dy}{dt} + \omega_0^2 y = -\frac{\mathrm{d}^2 x}{dt^2}$$

ω_0 for natural angular frequency :

$$\omega_0 = \sqrt{\frac{k}{m}}$$

D for the damping coefficient

According to the Laplace transformation, we can get the transfer function of the system.

$$\frac{Y(s)}{X(s)} = \frac{-s^2}{s^2 + 2D\omega_0 s + \omega_0^2}$$

So we can get the relationship between Y_m, and X_m :

$$\frac{Y_m}{X_m} = \frac{1}{\sqrt{\left(1 - \frac{\omega_0^2}{\omega^2}\right)^2 + \left(2D\frac{\omega_0}{\omega}\right)^2}}$$

Data output

For this session, we should address the following four major issues:

How to output Hall voltage, which is very small

How to convert an electrical signal into numerical information

How to translate relative information into absolute information

Which value should be used to calculate reaction vibration displacement when Hall voltage in movement constantly changes.

First, to output Hall voltage, we use a Hall circuit, which is composed of a Hall element, a differential amplifier, and a pole follower. Then, by A-D conversion signal, the SCM can process the electric signal, converting relative values to absolute values. According to the analysis above, we can see that as long as we process the positive and negative maximum Hall voltage, we will get the actual vibration displacement of the object. Finally, we should note that the conversion factor between the absolute displacement and relative displacement is related to the vibration frequency of the object itself, so a feedback process is needed to adjust real-time ratio factor to correct the output of small vibration displacement.

In summary, the schematic diagram of data output section is like Fig. 6 :

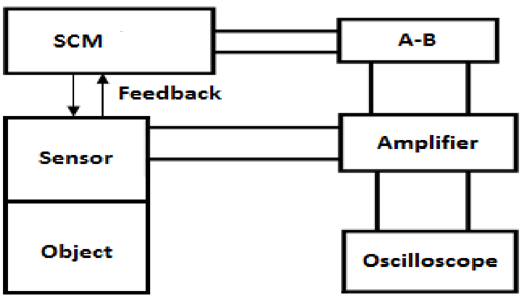

Fig. 6 data output

Conclusions

In this paper, we design a sensor to measure small vibration from four aspects, which are the analysis of the basic principles, the selection of uniform magnetic field gradient selection, the expression of displacement and the output of data. As a result, we find a better solution to this problem. However, there are still some shortcomings, for example, we did not take into account the impact of external magnetic field or external electric field on the Hall sensor, and we did not consider the robustness of the sensor itself. We should do more research on these aspects.

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