Study on the Method of Detection of the Marks of Ferromagnetic Material Based on the Array of Hall Element

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Abstract:

This study introduces a new imaging method of detection marks of ferromagnetic material, based on the Hall sensor array. Unlike the traditional NDT imaging technology, the technique presented is measuring magnetic field of ferromagnetic material surface and reading the difference by imaging the magnetic signals to find the marks. The study also introduces the principle and the system architecture of the method. Different from the method based on a single integrated linear hall sensor, this new method uses the surface array of Hall sensors. Sensor array method can improve the detection efficiency and spatial resolution but facing a key problem which is to reconstruction of the data scanning at different time and position. This study presents the processing method and results, the magnetic images of marks.

Keyword: nondestructive evaluation, sensor array, Hall element, mark of surface, imaging by scanning

Introduction

The traditional NDT imaging technology has been widely applied in industry, such as ultrasonic scanning imaging, eddy current scanning imaging. With Hall sensor the advantage of high sensitivity, small size, adapt to a wide range of frequency and temperature, the study presents a new imaging technology based on the Hall sensor array, which could detect marks of ferromagnetic material. Through experiments, we make sure sensor array method can improve the detection efficiency and spatial resolution. And we believe this method has broad application prospects, for example, in the fields of aerospace marks detected on the surface, the security detection of automobile engine[1]. In this paper, we introduce the principle and the device structure of this method, and present the processing method and results, the magnetic images of different marks.

1. Marks Impact on the Magnetic Field Distribution

The technique is Hall element through measuring magnetic field of ferromagnetic material surface, and reading the difference by imaging the magnetic signals to find the marks. So, the result of measurement is average magnetic induction intensity (B) within the area covered by Hall element[2]. As the sensitive area of Hall element is small (generally below $10^{-2} mm^2$), it is easy to find the small marks by this new technique.

In order to analyze the marks of ferromagnetic material surface impact on the magnetic field distribution, the study makes an analysis of the magnetic field simulation. Fig.1 shows the design model used in simulation. There is a magnet above the sample which has a small

gap (mark) on the surface. Compared to two different state (with gap and without gap) simulation results (Fig.2), it is known that the distribution of magnetic field is changed, specially the area near gap. When defects are in ferromagnetic material, the area of magnetic flux would decrease. Then there is a trend that magnetic field release from internal to the external. If defects on the surface, the internal magnetic field line close to the surface will overflow at certain angle to form leakage magnetic field, because of the refracted of magnetic induction intensity[3]. Accordingly, the magnetic induction intensity Hall sensor reads at the gap (defect) becomes smaller.

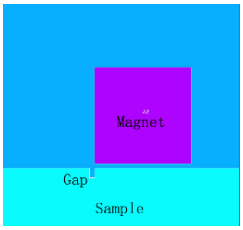
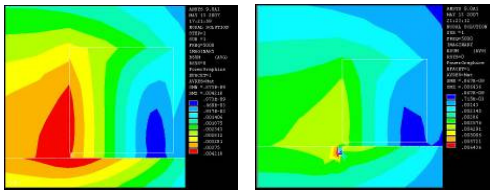


Fig.1. The design model used in simulation.



a. Without gap b. With gap

Fig.2. Simulation results

2. Detection Imaging System Based on a Single Integrated Linear Hall Sensor

Fig.3 shows the diagram of detection imaging system based on a single integrated linear hall sensor[4], including following 4 parts, magnetic sensor, signal circuit, data acquisition, data processing (imaging by PC).

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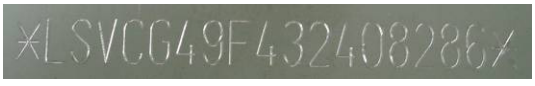
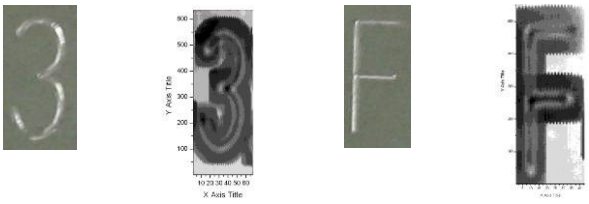
Fig.3. The diagram of detection imaging system based on a single integrated linear hall sensor

Magnetic sensor consists of an integrated linear hall sensor and a small magnet. The sensor measures the change of magnetic field, and output voltage signal with proportional to the surrounding magnetic field. Control 2-D motor mobile stage to scan on a XY surface, and begin data acquisition at the same time. Finally, process the data collected by the division, filter processing, then made image (gray image) by software.



(a)ID of automobile engine



(b) “3” (c) “F”

Fig.4. The scanning result of the ID of automobile engine

Based on this system, we scan some characters on the ID of automobile engine. The result is as Fig.4 shown. The size of character is about $10\times5mm$.

3. Basic Principle of Hall Sensor Array Technology

Compared to the method based on a single integrated linear hall sensor, using Hall sensor array method, area measurement can be increased on the one hand, on the other hand

scanning can improve efficiency and achieve quick scan. By contrast, Hall sensor array method has broad application prospects.

Sensor array method has more advantages but facing a key problem which is to reconstruction of the data scanning at different time and position. The array system reads the magnetic induction intensity through every element of the array, and then the data each component reads compose in a certain rule. Finally, we can get all data that show information of surface marks. So, it is an important question that how we find and set the rule, In other words, how we reconstruct the data scanning at different time and position.

Choice of array mode is the key problem in array system design. In order to ensure resolution, generally per 0.2mm request a data. However, because of the size of Hall element (generally $1.5mm \times 1.5mm$), it can't lay out Hall element to implement array system directly. This paper presents a new array combination, namely through laying out panel array to achieve line array, and eventually realize the rapid detection array system.

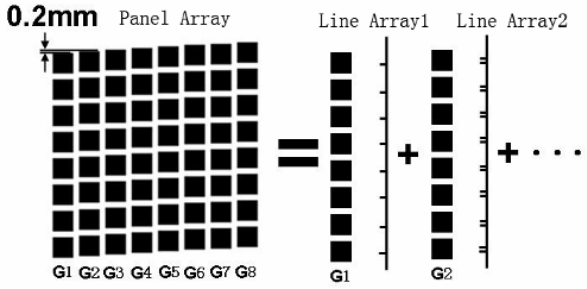


Fig.5. The diagram of sensor array

Fig.5 shows the diagram of sensor array. The panel array is composed by **Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.** Hall element, and divided into eight columns, G1, G2…… G8. Distance between adjacent columns is same. There are 8 elements in one column in the same vertical position, and same distance between adjacent elements. G2 vertical position relative to G1 increase of 0.2 mm, G2 relative to G3 increase of 0.2 mm, and so on.

Through the above array design, the eight components on the same line array of G1 to achieve 8 points evenly distributed scanning, on the same line array elements of G2 to achieve 8 points evenly distributed scanning, and the difference is that the scanning points of G2 relative to G1 upward increase 0.2 mm. Thus, reasonably design element spacing according to the size of Hall element, and line array can achieve 64 points evenly distributed scanning, point-to-point distance of 0.2 mm.

It must be noted that it is at different time and position to achieve line array through laying out panel array. So, we face with such a problem reconstruction of the data. Fortunately, we can write computer program to do this work easily. We can set a 2-D array, and according different time and position, fill data each Hall element every time generates in the corresponding blank. After all data acquisition, we can get a matrix and finish the reconstruction of data. Finally, process the data by filter processing, normalization, then make image (gray image) by software.

4. Experiment and Discussion

In order to test the new imaging method of detection marks of ferromagnetic material based on the Hall sensor array, we design a detection imaging system, using **Fehler! Es ist nicht möglich, durch die Bearbeitung von Feldfunktionen Objekte zu erstellen.** Hall element, as Fig.6 shown.

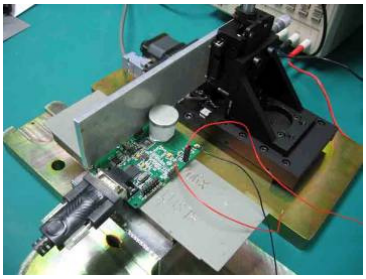


Fig.6. Detection imaging system based on the Hall sensor array

Fig.7 shows the diagram of detection imaging system based on the Hall sensor array, including 4 parts, front circuit module, data acquisition and processing module, stage control module, magnetic field incentive module.

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Fig.7. The diagram of detection imaging system based on the Hall sensor array

Front circuit module is to achieve Hall element power supply and signal conversion through the analog multiplexers. MCU is the core of data acquisition and processing module. It controls action of analog multiplexers, and realizes data acquisition, AD sampling. The main function of stage control module is controlling 1-D motor mobile stage work following orders sent from PC. Undoubtedly, magnetic field incentive module is to generate magnetic field to magnetize surface of ferromagnetic material. Finally, PC processes the data transferred from MCU through COM, by filter processing, normalization, then make image (gray image) by software.

Use this system, we scan some characters on the ID of automobile engine. Fig.8 is the gray image of result. From the image, we can see the ID clearly. The size of character is about $10\times5mm$.

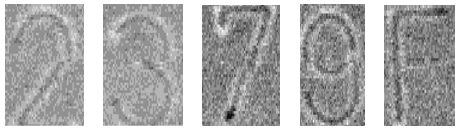

Fig.8. The gray image of the ID of automobile engine.

Through experiment, it is known that the detection imaging system based on the Hall sensor array has good result. It clearly shows the ID of automobile engine. If we develop the system, such as using $8\times8=64$ Hall element, it can expand the scanning area, and improve the detection efficiency.

5. Remarks and discussion

Different from the technique based on a single integrated linear hall sensor, the new method uses the surface array of Hall sensors. The detection device based on this new technique has good result through experiments.

The principle of this technique seems not complex. However, several factors will impact the performance:

1) Surface condition: only the data got from fine flat surface can be used for reconstruction, or it will be needed to measure the distance between sensor and the scanning target to modifying magnetic signals.
2) Scanning accuracy: the scanning part will affect the data reconstruction since the signals from different time and positions will be combined together.

3) The coherence of sensors of the sensor array, obviously, it will impact the finally image.

Acknowledgement

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