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Geomagnetic Anomalies Method for Crack Inspection of Steel Plate

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Abstract. Steel plate is widely used in bridges, ships, pressure vessels and other fields, and its safe operation is of great importance. In order to ensure its safe and effective service and avoid major safety accidents caused by defects such as corrosion and cracks, it is necessary to carry out full coverage and effective detection. In this paper, an effective method of steel plate crack detection with geomagnetic anomalies detection is proposed. By analyzing experimental data, the relationship between geomagnetic field signal and defect size is obtained, which provides a clear basis for quantitative detection of defects size, and verifies the effectiveness and reliability of geomagnetic anomalies detection method in steel plate defect detection.

Keywords: Geomagnetic anomalies, Crack inspection, Defect size, Steel plate

1. Introduction

During long-term service, ferromagnetic structures such as steel plate will be corroded or cracked to varying degrees under the influence of natural conditions, structural stress and internal media. In order to ensure the safe and reliable operation of steel plate, its structural reliability needs to be evaluated and maintained regularly with many different NDT methods. At present, non-destructive testing methods for defects of steel plates and other structural parts mainly include metal magnetic memory[1], weak magnetic flux leakage testing [2,3], eddy current testing and ultrasonic testing.

There have been a large number of research results based on magnetic flux leakage, eddy current and ultrasonic testing, but each has its own limitations. The equipment of magnetic flux leakage testing is generally bulky and not portable because it needs permanent magnet excitation device. Eddy current testing has a good effect on surface defects; Ultrasonic testing requires high surface flatness. Therefore, how to more easily and effectively combine non-destructive equipment with robot system to realize a complete "reachable and measurable" system, and improve the efficiency and effectiveness of detection without increasing system complexity and robot load is the basic content to be considered.

The geomagnetic anomaly detection technology of defects uses the change of ferromagnetic magnetic characteristics caused by defects to detect the crack, fracture and corrosion of materials by detecting the change of geomagnetic anomaly signal at the defects. At present, most geomagnetic anomaly detection technologies are tested in the geomagnetic field environment. When there are no defects, the magnetic field lines of geomagnetic field are evenly distributed in the steel plate. When there are defects in the steel plate, geomagnetic field disturbance will occur. The disturbed magnetic field is detected by magnetic sensor such as GMR[4] and three-axis magnetometer[5] to realize defect detection, By studying the variation relationship of magnetic characteristics at defects under geomagnetic field, the signal characteristics of defect concentration area can be effectively analysed, which is of great significance for on-line and real-time detection of steel plate defects.

The basic principle of magnetic anomaly is that ferromagnetic materials are magnetized due to the existence of geomagnetic field, resulting in induced magnetic field, and these induced magnetic fields will disturb the geomagnetic field distribution in the space around ferromagnetic materials, resulting in magnetic anomaly signals. Fig. 1 shows the magnetic anomalies related to defects, as in the defects-free area, the geomagnetic line is in uniform distribution. By processing these magnetic anomaly signals, the location of ferromagnetic materials can be realized. In general, the magnetic induction intensity of the geomagnetic field is about 0.2 ~ 0.5gs, which is a relatively stable magnetic field with balanced distribution and small spatial change rate in a certain area. Geomagnetic anomaly is anther type of MFL test method which could also be constructed with magnetic dipole model[6,7].

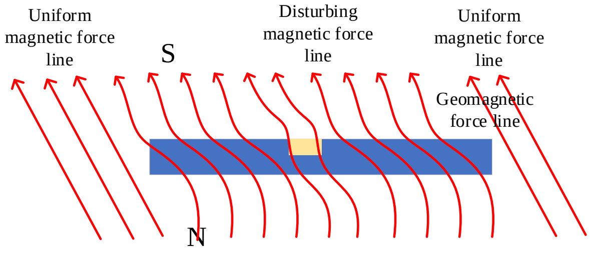

Fig. 1. Geomagnetic force line distribution under abnormal conditions

2. Design of Geomagnetic Anomaly Detection System

The magnetic anomaly detection system is mainly composed of hardware and software, including magnetic sensor, control unit, signal sampling unit, signal analysis and processing unit and display module. It also includes the standard sample for testing the performance of the system. Corresponding defects of different sizes are made in the standard sample to verify the performance of the testing system and relevant technical indicators.

The geomagnetic anomaly detection system is composed of three-axis giant magnetoresistance sensor, encoder and data acquisition and display unit. The main system structure diagram is shown in Fig.2, and Fig.3 show the composition and structure of the geomagnetic anomaly detection system. The moving trolley with encoder and geomagnetic anomaly sensor moves back and forth on the steel plate. Considering that the geomagnetic anomaly signal belongs to the spatial distribution signal, the spatial spacing needs to be encoded by the encoder, and the equidistant sampling control pulse is generated through the movement of the encoder wheel. After receiving the control pulse, the data acquisition and display unit starts the signal acquisition of the geomagnetic anomaly sensor, pre-process and displays it.

As shown in Fig.2, the system is composed of sensors, DAQ equipment and computers. The external encoder realizes spatial coding, sends spatial equal interval trigger pulse signals, controls the DAQ equipment to sample, completes the collection of spatial magnetic field signals, performs signal conditioning and algorithm processing on the collected data, and the results are displayed on the computer platform. Fig.4 shows the three-axis giant magnetoresistance sensor and the measured three magnetic parts. Fig.5 shows the photo of the geomagnetic anomaly detection experimental platform.

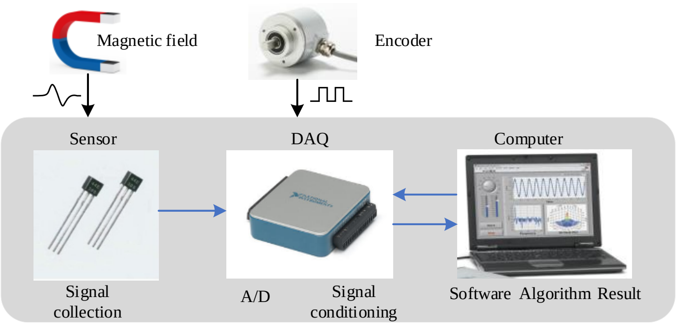

Fig. 2. System composition structure

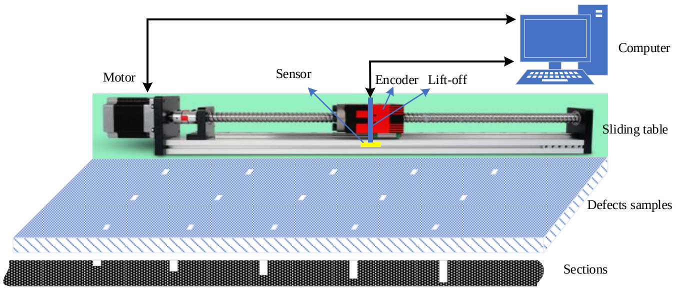

Fig. 3. Composition of geomagnetic anomaly detection system

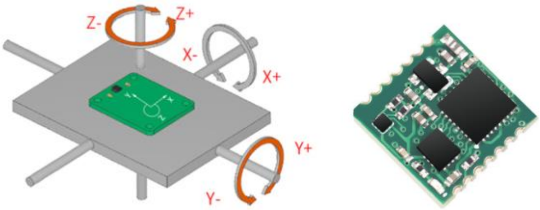

Fig. 4. Geomagnetic sensor

Fig. 5. Geomagnetic anomaly detection experimental platform

Geomagnetic anomaly signals are spatially distributed, which means that the acquisition of geomagnetic anomaly signals is different from the acquisition of other time-related signals, and it needs to be realized by equal space sampling. Therefore, the acquisition trigger is carried out through the pulse signal of spatial encoder to realize equal space / equal distance sampling, and through the corresponding relationship between the obtained data sequence and space, So as to obtain geomagnetic anomaly signals at different positions. The signal acquisition methods of geomagnetic anomaly detection are wired scanning and area scanning. Line scanning is to detect the geomagnetic anomaly signal on a specific path through a single sensor to form a one-dimensional geomagnetic anomaly signal. Through the analysis and extraction of the characteristics of the magnetic anomaly signal, the relationship between its characteristics and defect related structural parameters is obtained to provide key basis for quantitative inversion of defects [8].

In order to verify the effect of geomagnetic anomaly detection and analyse the impact of different forms of defects on geomagnetic anomaly, the standard sample is an effective tool. Therefore, the detection effectiveness is measured by making the standard sample, and the defect positioning and quantitative detection are realized. In this paper, defects with different widths, depths and lengths are made on a standard steel plate to verify and evaluate the effect of geomagnetic anomaly detection.

The standard sample is one of the important basis for measuring the quality of non-destructive testing. By measuring the test results of different standard samples, the geomagnetic anomaly detection methods and related influencing factors are deeply analysed and discussed, from which the relationship between the defect size and the geomagnetic anomaly signal can be found to achieve the goal of quantitative inversion from geomagnetic anomaly signal to defect size.

3. Signal Analysis

The magnetic leakage signal is obtained through the detection of sample defects by the geomagnetic anomaly acquisition system. The defect scanning is illustrated in Fig.6 which is used as line scanning method for collecting the signals.

As is shown in fig.7, the raw data is collected with the sensors, then the processing method is utilized such as smoothing, normalization and adaptive cancellation[9], then a better signal-noise ration is obtained for defect localization. The defect can be localized with threshold detection, peak-peak detection and high-order crossing method[10]. After analysing the characteristic of the signals, the size of the defect could be obtained.

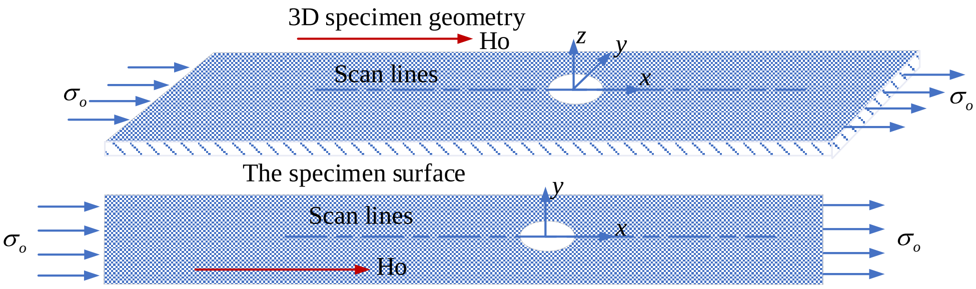

Fig. 6. Defect scanning illustration

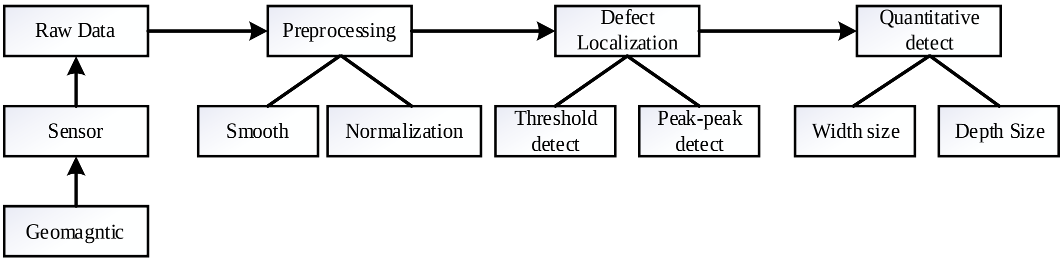

Fig. 7. Flow chart of magnetic anomaly signal acquisition and analysis

Because the geomagnetic field can be regarded as a constant magnetic field without change in a short time, according to this principle, the change rate of the magnetic anomaly gradient caused by the magnetic target in three directions, that is, the magnetic gradient tensor and the total magnetic anomaly field, can be used to invert the magnetic target and calculate the relative position between the test system and the target

For a magnetic field to be measured, the magnetic gradient tensor is a tensor matrix formed by the spatial change rates of the three-dimensional components of the magnetic field in three orthogonal directions in three-dimensional space. If *B* is recorded as the magnetic induction vector of the magnetic field to be measured and B_x, B_y and B_z are the magnetic induction vector components of the magnetic field to be measured at the observation point, the magnetic gradient tensor matrix *G* can be expressed as formula (1):

$$G = \begin{bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \\ \frac{\partial}{\partial z} \end{bmatrix} \begin{bmatrix} B_x & B_y & B_z \end{bmatrix} = \begin{bmatrix} \frac{\partial B_x}{\partial x} & \frac{\partial B_x}{\partial y} & \frac{\partial B_x}{\partial z} \\ \frac{\partial B_y}{\partial x} & \frac{\partial B_y}{\partial y} & \frac{\partial B_y}{\partial z} \\ \frac{\partial B_z}{\partial x} & \frac{\partial B_z}{\partial y} & \frac{\partial B_z}{\partial z} \end{bmatrix} = \begin{bmatrix} B_{xx} & B_{xy} & B_{xz} \\ B_{yx} & B_{yy} & B_{yz} \\ B_{zx} & B_{zy} & B_{zz} \end{bmatrix} \tag{1}$$

It is a 3 × 3, the three elements in the first row represent the spatial change rate of the magnetic field component B_x in the *x*, *y* and *z* directions respectively, the three elements in the second row represent the spatial change rate of the magnetic field component by in the *x*, *y* and *z* directions, and the three elements in the third row represent the spatial change rate of the magnetic field component B_z in the *x*, *y* and *z* directions respectively.

In the actual target positioning magnetic field environment, because there is no conduction current, according to Maxwell's equations, it can be concluded that the curl and divergence of the magnetic field B to be measured are always zero, that is:

$$\nabla \cdot B = \frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 0 \tag{2}$$

$$\nabla \times B = 0 \tag{3}$$

That is the *G* matrix which is a 3 with zero trace × 3 symmetric matrix, so it is known that there are only 5 independent components among the 9 components of *G* matrix, which are B_{xx}, B_{yy}, B_{xy}, B_{xz} and B_{yz} respectively. When the values of these five independent components are obtained from the experimental measurement, the magnetic gradient tensor matrix of the magnetic field to be measured at the observation point can be obtained.

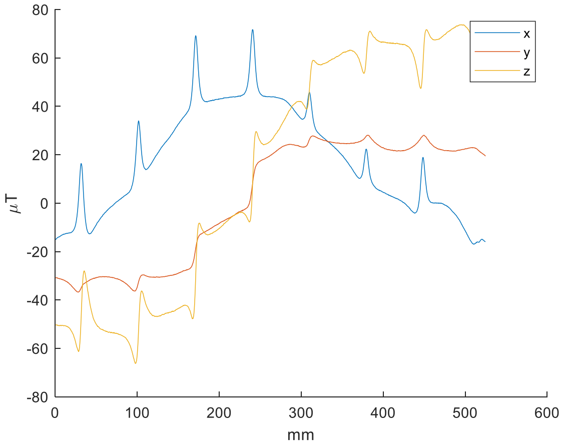

Fig. 8. Raw data of geomagnetic field

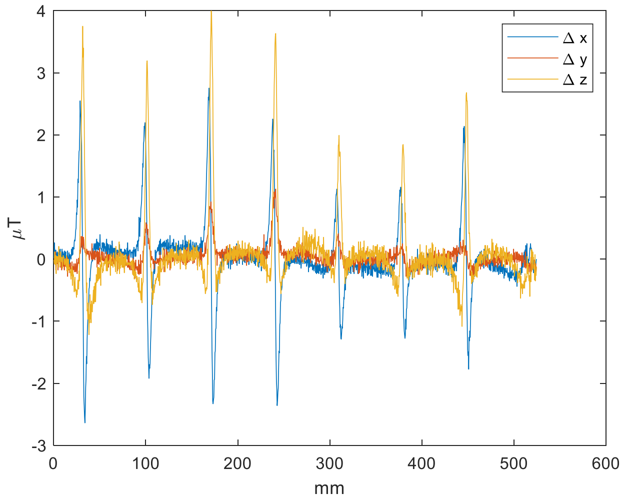

Fig. 9. Differential component of geomagnetic

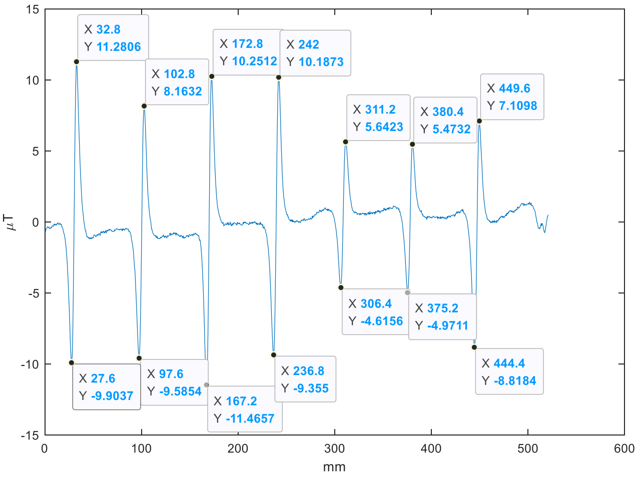

Fig. 10. Baseline cancellation for B_x

As Fig.8 is shown, the raw data of three-axis geomagnetic signals are obtained, the geomagnetic anomaly could be found due to the defect in the steel plate. With the gradients of each signals shown in the figure 9, the localization of defects could be obtained. After baseline cancellation of B_x shown in Fig.10, the distance between the peaks could be used for evaluating the width of the defect. The accurate inversion of defects is the ultimate goal of identification. Only by realizing accurate detection can the bearing capacity and integrity of steel plate be completely evaluated. Generally, the defect is simplified into a cuboid model for accurate inversion. Therefore, the main inversion parameters include length, width and depth information. The width information is the key point of quantitative inversion of defects, and accurate inversion is an important detection content.

4. Conclusion

The inversion of defects is the key step of detection, and the accurate inversion of defects is the ultimate goal of identification. Only by realizing accurate detection can the bearing capacity and integrity of steel plate be completely evaluated. Generally, the defect is simplified into a cuboid model for accurate inversion. Therefore, the main inversion parameters include length, width and depth information. The width information is the key point of quantitative inversion of defects, and accurate inversion is an important detection content. It can be found by comparing the geomagnetic anomaly signals of defects with different widths, The spacing between peaks and peaks of geomagnetic anomaly signals changes with the change of width, which could be used as the quantitative inversion for defect width.

5. Acknowledgement

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