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Metal Shape Detection and Evaluation using Giant Magneto Resistance System

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ABSTRACT

Visual inspection to locate metals embedded in walls or floors is impractical. Detection of these metals can only be done with a proper metal detection. Accordingly, the development of a magnetic imaging system based on giant magneto-resistance (GMR) sensors is presented for metal shape detection . This system is based on magnetic flux leakage testing (MFLT) principle for detecting the shape of ferromagnetic material specimens. The imaging system is constructed using 21 linear GMR sensors array as signals sensing unit (SSU). In this study, a few ferromagnetic SS400 mild steels specimens in various shapes are used as specimens. Image produced confirm system functionality in detecting and evaluating metal shapes.

Keywords: Magnetic flux leakage testing (MFLT), giant magneto-resistance (GMR) sensors, shape evaluation

INTRODUCTION

Metal embedded in walls or floors cannot simply be determined by visual inspection. This research focuses on detecting and evaluating metal shapes using giant magneto resistance sensor magnetic imaging (GMR-i) system. The GMR-r system is proposed as a method carry out inspections to determine shapes of metal specimens. Magnetic flux leakage (MFL) is introduced to discover any cavity or defect in embedded metal specimens.

Examination and inspection of tested objects without alteration is a kind of non-destructive evaluation (NDE) in order to find out the discontinuities that may affect the function of a specific system as discussed by Lee et al. (2008). Many studies have examined the effectiveness of NDE for system

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maintenance. The key feature in NDT industries is the measurement time. Therefore, it is not practicable to use a single small sized magnetic sensor element to scan an object in a fine grid. Instead, a sensor array housing a number of simultaneously operating elements is more effective.

Magnetic sensors for various NDE applications are developed for solenoid coil, hall sensor and GMR sensor (Lehnz & Edelstein; 2006). The effectiveness of these sensors varies according to their specific systems. These magnetic sensors function under high magnetic field condition except the GMR sensor which also functions at low magnetic field condition. According to Wakiwaka (2004) in order in determine the right magnetic sensor, three criteria must be met: low field operating range, wide operating frequency and small dimensions in order to obtain high spatial resolution. Hence, based on previous studies, GMR sensor is suitable for NDE application.

New application of GMR sensor for NDE application is presented in this paper. The GMR sensor for magnetic flux leakage testing (MFLT) probe was fabricated as a metal inspection probe for shape detection of ferromagnetic metal specimens.

MAGNETIC FLUX LEAKAGE TESTING (MFLT)

Basic Principles

In recent years, non-destructive testing industries have set up magnetic flux leakage testing (MFLT) as a magnetic method to identify pitting and corrosion in steel structures. It is most frequently used during inspection of metal storage tanks and steel pipelines using a powerful magnet to magnetise the steel; where there is rust, corrosion or missing metal, the magnetic field “leaks” from the steel. The MFLT could distinguish the condition of metal steel according to the distribution of magnetic field produced. In a MFL tool, a magnetic detector is to be found between the poles of the magnet to detect the leakage field. Magnetic sensors may be used in most conditions using MFLT.

This paper examines the metal and shape detection in a metallic steel using flux leakage testing method. This method allows magnetic flux to be induced into the specimen plate from a magnetic field which is formed by an excitation coil placed near the specimen metal. A temporary magnetic field environment is created near the specimen material. The flow of magnetic flux is disturbed when a metal edge is present resulting in magnetic field which contains the information relating to the perturbation. In this work, magnetic flux is induced by moving a steady magnetic field in the area of the sample plate plane. An even magnetic field is produced by the excitation coil creating a constant magnetic field variant in the metallic surface as it moves.

Under normal condition, Figure 1(i) illustrates permanent magnet with magnetic flux flow through it. As shown in Figure 1 (ii), magnetic flux leakages (MFL) are developed and some of the magnetic flux flows through the specimen as the ferromagnetic specimen moves along the y-axis. When the specimen is at the GMR sensor, the MFL is detected by the array. A higher MFL density value is sensed as the specimen gets closer to the GMR sensor as in Figure 1 (iii).

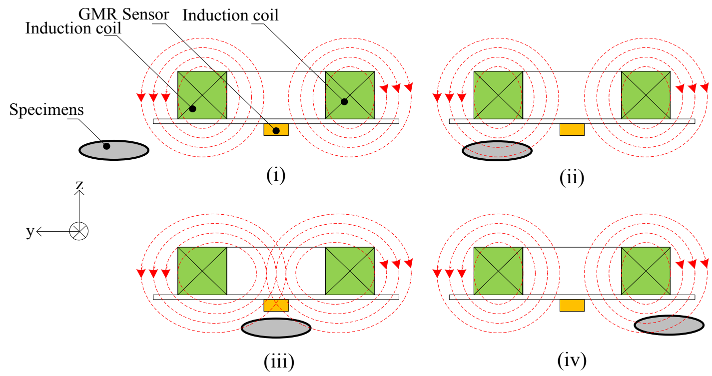

Figure 1. The application of MFLT method where (i) condition before evaluation, (ii) specimen navigates into the system, (iii) the magnetic flux distribution changes according to the disturbance and (iv) system fully evaluates the specimen

As the specimen moves further away from the GMR sensor array as in Figure 1 (iv), there is no MFL flow detected, indeed, no induced signals are developed by the sensor array. A complete evaluation of metal specimen is deemed done when the evaluation is comprehensive .

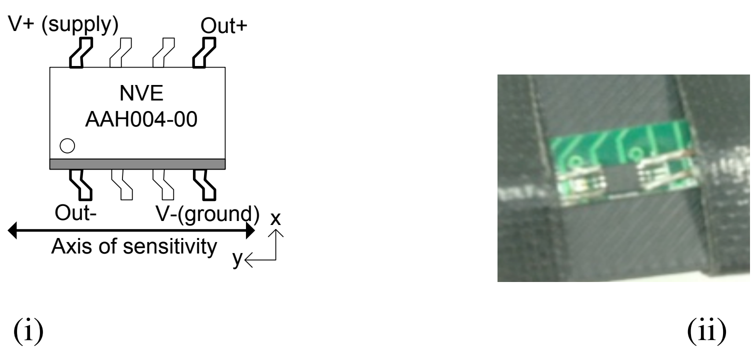

Figure 2. GMR sensor pin-out where (i) shows the axis of sensitivity of sensors in y-axes. (ii) GMR sensors is simply miniaturised and could be easily mounted simultaneously as it is small in size

Giant Magnetoresistance (GMR Sensor)

In this study, GMR sensor is selected from an AA-Series analog of NVE's company as in Figure 2. These GMR sensors are versatile as they are characterised by high sensitivity to applied magnetic fields, low power utilisation, outstanding temperature stability, and small in size. The sensor has distinctive and unparalleled magnetic sensing capabilities.

These GMR sensors have broad applications, from rough industrial and automotive position, speed and current sensors to low-voltage battery-powered sensors for hand-held instruments and implantable medical procedures(see Table 1). These GMR sensors are unique and flexible which makes them an excellent choice for a range of analog sensing applications.

Table 1
GMR specifications

Parameter	GMR AAH004-00
Applied fields sensitivity	Very high
Operation field range	Low
Hysteresis	High
Range of temperature	Very high

These sensors employ patented GMR materials and on-chip flux concentrators to supply a directionally sensitive output signal. Table 2 displays the overall performance of GMR sensors. These sensors are sensitive with a cosine-scaled falloff in sensitivity as the sensor is rotated away from the sensitive direction and it is also sensitive in one direction in the plane of the IC. The GMR sensors are designed in a Wheatstone bridge configuration to provide temperature compensation. Besides, these devices offer the same output for magnetic fields in the positive or negative direction along the axis of sensitivity which is the omni-polar output.

Table 2
GMR performances

Sensor	Saturation field (Oe[1])	Linear range (|Oe[1]|)		Sensitivity (mV/V- Oe[1])		Resistance (Ohms)	Package[2]	Die size[3] (µm)
GMR AAH004-00	15	Min 1.5	Max 7.5	Min 3.2	Max 4.8	2K ± 20 %	MSOP	411 x 1458

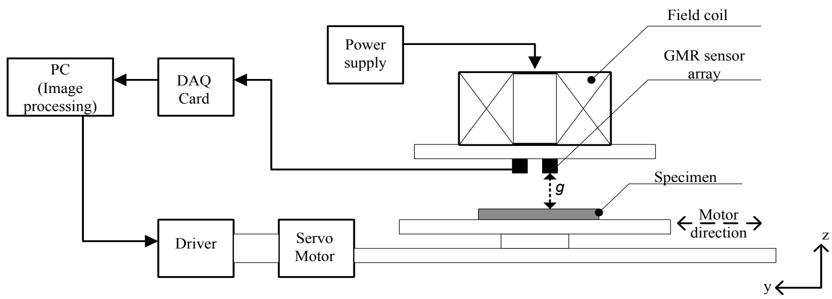

Figure 3. The experimental setup block scheme

System

A sensing application system consists of an induction coil as the flux source and GMR sensor for the sensing application. As shown in Figure 3, there are induction coils winded up between a holder and an array of GMR sensors located beneath it. The induction coil is made up of two sides, left and right, which producing flux to the centre direction between them. An array of GMR sensors is located at the centre in between the coils for better sensing purposes. The magnetic imaging system is displayed in Figure 4. As depicted in Figure 3, an array of GMR sensors is installed in a plate which moves above the specimen. The sensors are made up of 21 high sensitivity GMR sensors. The Induction coil above the sensors has an array of functions to produce the magnetic flux in the conductive material and GMR sensors measure the magnetic field in the vicinity of the specimens.

A San-MotionR motor (Sanyo Denki) with 200mm long sliding glide system was placed below the sensor that seizes the specimen during inspection. The motor is powered by an AC servo motor which can accelerate the specimen holder at a rate 8000pulse/mm. A R-setup motion driver/controller which controls the motor is used based on the input. The GMR sensors array is connected to the National Instrument USB-6229 DAQ which is used to measure the output voltage of the sensor with 16-bit resolution. This is illustrated in Figure 3 where there are R-setup motion device, the driver/controller, an array of GMR sensors, DAQ, computer and ferromagnetic plate specimen.

The signal flow

This section explains the operations of the magnetic imaging system which is based on the magnetic flux leakage testing principle. Magnetic flux leakage is sampled on the surface of ferrous objects which is then detected by the signal sensing unit (SSU) of the system. The SSU detects the changes of induced magnetic field, B, on the ferrous object's surface. The signals are then forwarded to the Signal Acquisition Unit (SAU) and finally, to the Signal Processing Unit (SPU) for signals processing as shown in Figure 4.

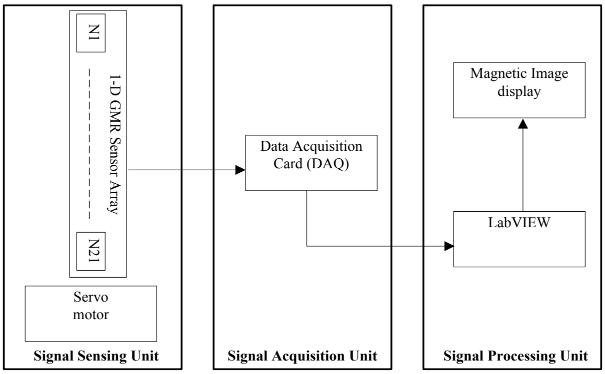

Figure 4. Signals flow of system

SYSTEM EVALUATION

This section discusses results of the magnetic imaging system experiment for ferromagnetic material shape evaluation. One could observe magnetic images of ferromagnetic shapes being plotted. Three ferromagnetic metal specimens of a square shape, round shape and triangular shape were used as specimens for magnetic imaging inspection verification. These specimens are standardised with 3.0mm thickness. They are made up of a soft iron ferromagnetic (SS400) as shown I Figure 5. Specimens are referred to as sp i, sp ii, sp iii sp iv. They are classified according to their shapes and structures.

The experiment was conducted to evaluate the shape of the ferromagnetic metal specimens as shown in Figure 5 and performed based on the steps described in Figure 4. The system is moving with a constant displacement of 1.0mm. It is placed within the imaging area underneath the GMR sensors system. The magnetic gap which is the distance between sensors and specimens is kept constant at 7.0mm.

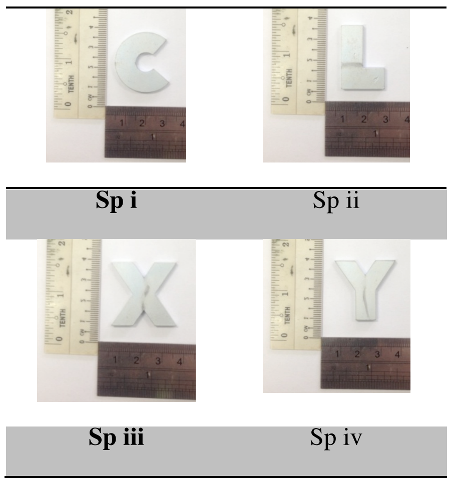

Figure 5. Dimensions of specimens

In the magnetic flux leakage testing (MFLT) application, the absolute induced voltage signals are obtained in order to employ the image interpolation technique in the OriginPro8 application used for magnetic image display. Figure 6 illustrates the magnetic image of ferrous specimens which are round, triangular and square shaped. Since the induced current signals are directly proportional to the magnetic field, B, it can be said that the magnetic field strength is increasing with induced current signals. The induced current signal is fixed at 3.0A. This is due to too low magnetic field when less current is used as the system malfunctions when high magnetic field is used. In Figure 6, images are produced at the parameter of 3.0A with the magnetic gap of 7.0mm. The shapes of the specimens are visible.

Table 3
Experiment condition

Item	Values
Coil number of turn, n	200
Coil size (mm)	0.5
Current, I (A)	3.0
Magnetic gap, g (mm)	7.0

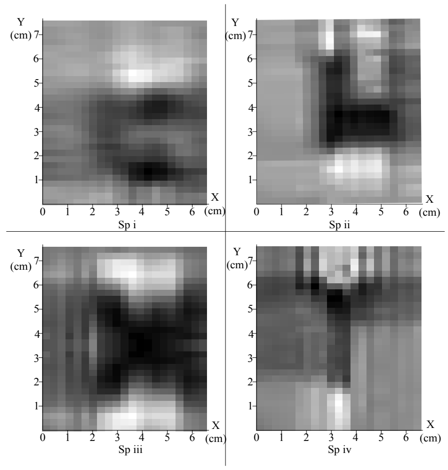

Figure 6. Magnetic image produced using Origin-Pro 8.0

CONCLUSION

The development of a magnetic imaging system using Giant Magneto-resistance (GMR) sensors has been discussed in this paper. It focuses on the development of magnetic imaging system for shape evaluation of ferrous metal specimens. The magnetic flux leakage testing (MFLT) principle is used in developing the system. All measurements taken out are taking care regarding the shapes evaluation of metal. The prototype of this system is successfully developed by integrating SSU, SAU and SPU. The SSU launches the system with sensing capabilities which captures the flux changes between the sensors and specimen and data is later analysed analysis. Finally, images are formed by the SPU using Origin-Pro 8 software. An induction coil is fixed with 200n of 0.5mm copper wire and current supply of 3.0A to produce a suitable magnetic flux for the system to function well. The sensor is able to detect the shape of ferromagnetic metal specimen with a perpendicular gap of 7mm between the sensors and specimen. The GMR sensor is able to produce the measurement by crossing the edge of the specimens. Future research is needed to improve the usage model of the magnetic imaging system of GMR sensor.

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