IJCTA, 9(5), 2016, pp. 2415-2421

Magnetic Imaging Concept Using Giant Magnetoresistance (GMR) Sensor

M. K. Roslan*, Norhisam M., Ishak A.***, M. Nizar H.*** and K. Tashiro*****

ABSTRACT

Metal embedded in walls or floors cannot simply be determined by visual inspection. Thus, this paper presentsregarding the development of a magnetic imaging system based on giant magneto-resistance (GMR) sensors for metal shape detection inspection. The system function based on the magnetic flux leakage testing (MFLT) principle for shape detection of ferromagnetic materials. The operation system is made up of a 21 linear GMR sensors array which detect changes of induced magnetic field on a ferromagnetic metals shape under evaluation. All the experimental result presents the effect of perpendicular gap towards accuracy of system in magnetic imaging of ferrous SS400 mild steels specimens; which are square, round and triangle in shape. These experimental results proved the functionality of the system in magnetic imaging of ferrous object shapes. Magnetic images produced from the actual ferromagnetic metals specimens are illustrated according to their respective finite shape.

Keywords: Giant Magneto-resistance (GMR) sensors, Magnetic Flux Leakage Testing, shape detection

1. INTRODUCTION

Magnetic flux leakage testing (MFLT) principles uses a wide range of idea and phenomena from both physics and material science field. Recently, it is proved that MFLT is useful for non-destructive evaluation (NDE) for ferromagnetic surface such as steel pipeline, oil-gas pipeline and aircrafts structure. The idea is to evaluate the condition of the surface and carry out basic maintenance to evade critical accidents [1]. Nondestructive evaluation (NDE) is an examination and inspection on tested object without alteration in order to find out the discontinuities that may effect on the function of the object. NDE may also be carried out to measure characteristics of the test objects, such as size, dimension, configuration, and structure [2]-[4].

There are many kinds of magnetic sensor developed for NDE application such as solenoid coil, hall sensor and GMR sensor. The effectiveness of these sensors varies according to their performances. Besides than GMR sensors, other sensors operate under high magnetic field condition [5].Three major criteria in choosing the suitable magnetic sensor are: low field operating range, wide operating frequency and small dimensions in order to obtain high spatial resolution[6]-[8]. Hence, GMR sensor is suitable for NDE application because of aforementioned performance.

This paper studied about a new application of GMR sensor for NDE application. For the MFLT application, the GMR sensor for magnetic flux leakage testing (MFLT) probe was fabricated. This device functions as a metal inspection probe for shape detection. From GMR sensors advantages mentioned above, the metal inspection with shape detection can be performed by the proposed device.

* Research Scholar, Dept. of Electrical & Electronic, Faculty of Engineering, UPM, 43400 UPM Serdang, Selangor, Malaysia, *Email: kamelroslan@gmail.com*

** Research Supervisor, Dept. of Electrical & Electronic, Faculty of Engineering, UPM, 43400 UPM Serdang, Selangor, Malaysia, *Email: norhisam@upm.edu.my*

*** Research Co-Supervisor, Dept. of Electrical & Electronic, Faculty of Engineering, UPM, 43400 UPM Serdang, Selangor, Malaysia, and Faculty of Engineering, Shinshu University, Wakasato 4-17-1, Nagano, 380-8553, Japan

2. MAGNETIC FLUX LEAKAGE TESTING (MFLT)

2.1. Basic Principles

Industries introduced MFLT as a magnetic method of nondestructive testing that is used to detect corrosion and pitting in steel structures, most commonly pipelines and storage tanks as in Figure 1. The basic principle is that a powerful magnet is used to magnetize the steel. At areas where there is corrosion or missing metal, the magnetic field "leaks" from the steel. In an MFL tool, a magnetic detector is placed between the poles of the magnet to detect the leakage field.

The work explain in this paper allows the metal and shape detection verification in a metallic steel using flux leakage testing method. By using this method, magnetic flux is induced in the sample plate from a magnetic field is created by an excitation coil placed near to the specimen material. The flow of magnetic flux is disturbed when a metal edge is present and resulting in magnetic field which contains the information concerning the perturbation. In this work, magnetic flux is induced by moving constant magnetic field in the vicinity of the sample plate surface. The constant magnetic field produced by the excitation coil, it creates a relative magnetic field variation in the metallic surface as it moves.

With normal circumstances, Figure2 (i) shows the magnetic flux flow through the permanent magnets. As shown in Figure 2 (ii) magnetic flux leakages (MFL) are developed and some of the magnetic flux flows

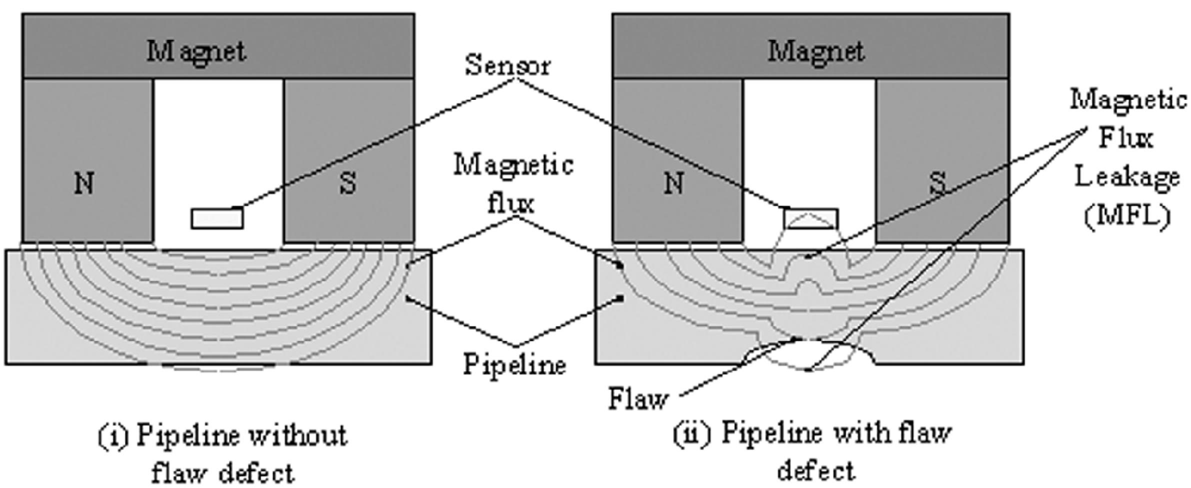


Figure 1: The Magnetic Flux Leakage Testing (MFLT)

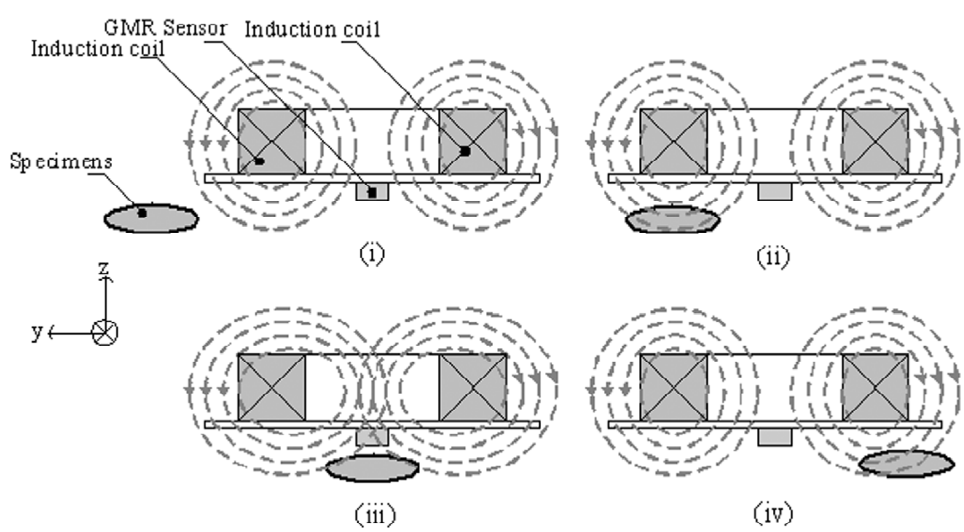


Figure 2: The application of MFLT method

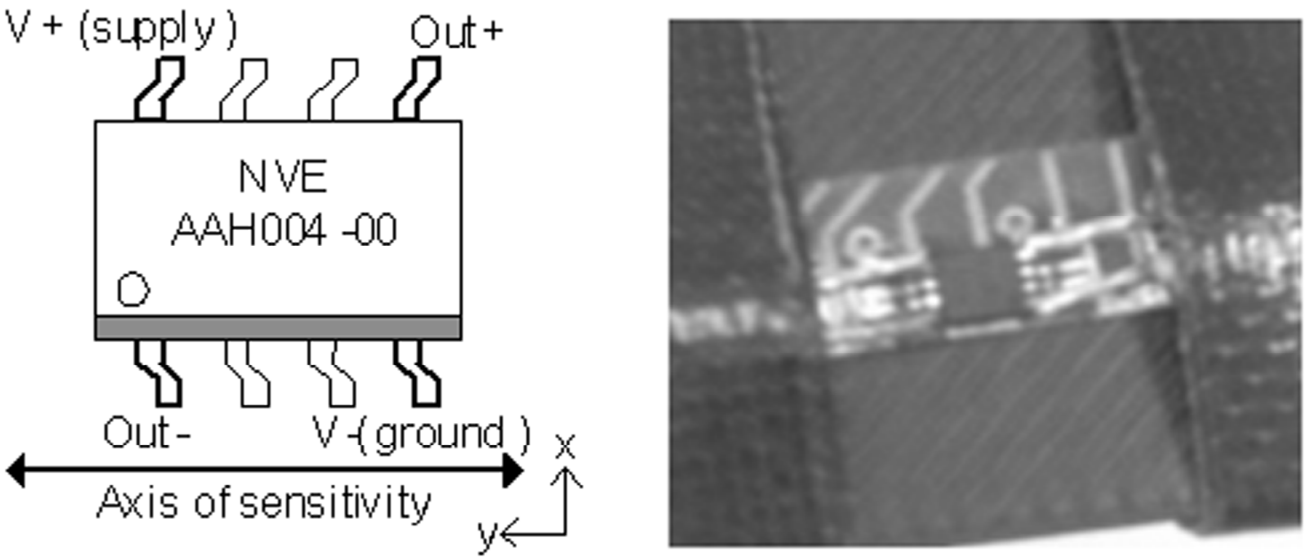
through the specimenas the ferromagnetic specimen moves along the *y*-axis. When the specimen reaches the GMR sensor, the MFL is detected by the array. A higher MFL density value is sensed as the specimen gets closer to the GMR sensor as in Figure 2 (iii). As the specimen moves further away from the GMR sensor array as in Figure 2 (iv), there is no MFL flow detected, thus, no induced signals are developed by the sensor array.

2.2. Giant Magnetoresistance (GMR Sensor

In this study, GMR sensor is chosen from an AA-Series analog of NVE's company (Figure 3). These GMR sensors are characterized due to high sensitivity to applied magnetic fields, low power utilization, outstandingtemperature stability, and small in size. It offers distinctive and unparalleled magnetic sensing capabilities.

Broadselection of applications such asrough industrial and automotive position, speed and current sensors; to low-voltage, battery-powered sensors for employ in hand-heldinstrumentation; and implantable medical procedureare fit with these unique sensors characteristics as in Table 1. Withthis uniqueflexibility of basic magneticsensors, it makes them an excellent choice for a large range of analog sensing applications.

These sensors use patented GMR materials and on-chip flux concentrators to providea directionally sensitive output signal. Table 2 stated the overall performances of GMR sensor. 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 theIC. 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 directionalong the axis of sensitivity which is the omni-polar output.



(i) (ii)

Figure 3 – GMR sensor pin-out

Table 1
GMR specifications

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

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 × 1458

2.3. System

For sensing application system, it consists of induction coil as the flux source and GMR sensor for the sensing application. As shown in Figure 4, there are induction coils winded up between a holder and an array of GMR sensor located beneath it. The induction coil is made up of two sides, left and right, which producing flux to the center direction between them. An array of GMR sensors is located at the center in between the coils for better sensing purposes. The concept of magnetic imaging system is displayed in Figure 4 below.

An array of GMR sensors is installed in a plate which moves above the specimen as depicted in Figure above. The sensors are made up of 21 high sensitivities GMR sensors. There is an induction coil above the sensors array to produce the magnetic flux in the conductive material and GMR sensor to measure the magnetic field in the vicinity of the specimens.

A San-MotionR motor from Sanyo Denki with 200mm long sliding glide system was assembled below the sensor that holds the specimen during inspection. The motor is powered by an AC servo motor which can accelerate the specimen holder at a rate 8000pulse/mm. An R-setup motion driver/controller which controls the motor is used, by using the input given as feedback.

GMR sensors array is connected with the National Instruments USB-6229 DAQ which isused to measure the output voltage of the sensor with 16 bit resolution. The whole experimental setup is depicted in Figure 4, where there are the R-setup motion device, the driver/controller, array of GMR sensors, DAQ, computer and ferromagnetic plate specimen.

2.4. The signal flow

This section explains the principle of operation for the magnetic imaging system. The system is oriented with the magnetic flux leakage testing principle. Magnetic flux leakage is sampled on the surface of ferrous objects which then will be detected by the signal sensing unit (SSU) of the system. SSU detects the changes

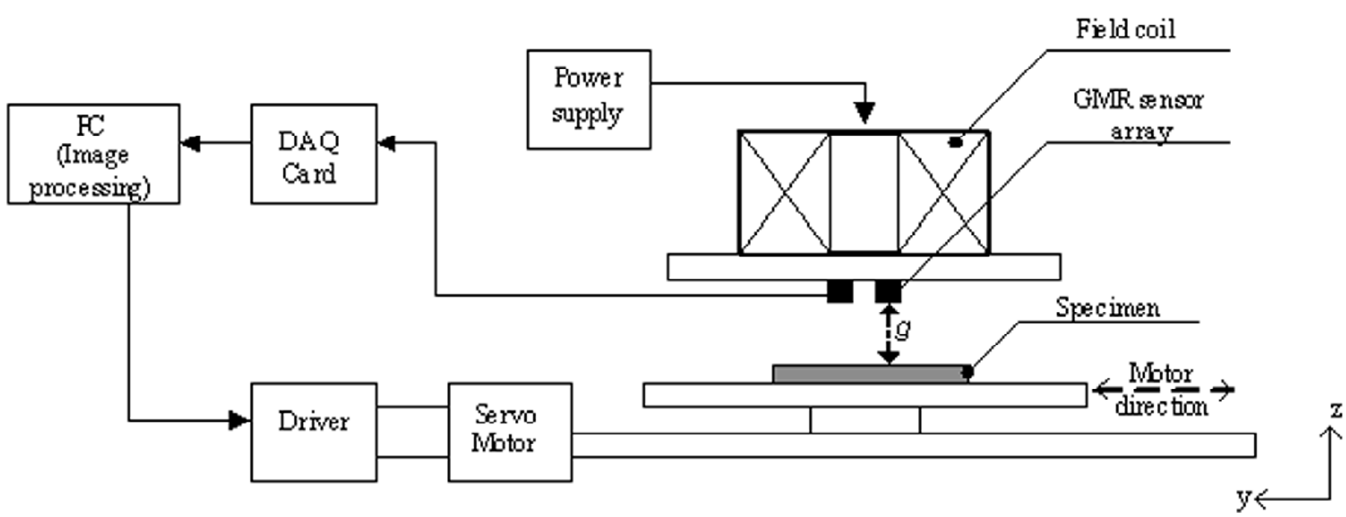


Figure 4: Block scheme of the experimental setup.

of induced magnetic field, B on the ferrous objects surface. The signals is then forwarded to the Signal Acquisition Unit (SAU) and finally to the Signal Processing Unit (SPU) for signals processing.

3. SYSTEM EVALUATION

This part presents the experimental results of the magnetic imaging system for the shape evaluation of ferromagnetic materials. Magnetic images of ferromagnetic shapes evaluated by the system are plotted. Three ferromagnetic metal specimens of a square shape, round shape and triangular shape were used as the specimens for magnetic imaging inspection verification. The thickness of each of the specimens is 3.0mm. The material for these specimens is a soft iron ferromagnetic (SS400) as in shown Figure 6.

Specimens described as spA, spB, spC, spD, spE and spF. They are classified according to their shapes and also structures. Flat and hollow structures of metals between the specimens represent a different numbers of edges. Specimens with hollow structure will have more edges compared to the flat specimen metal.

The experiment conducted to evaluate the shape of the ferromagnetic metal specimens as shown in Figure 6 are performed with the setup shown 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.

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 7 illustrates the magnetic image of ferrous specimens which are round, triangular and square shaped ferromagnetic metal specimens. Sincethe 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

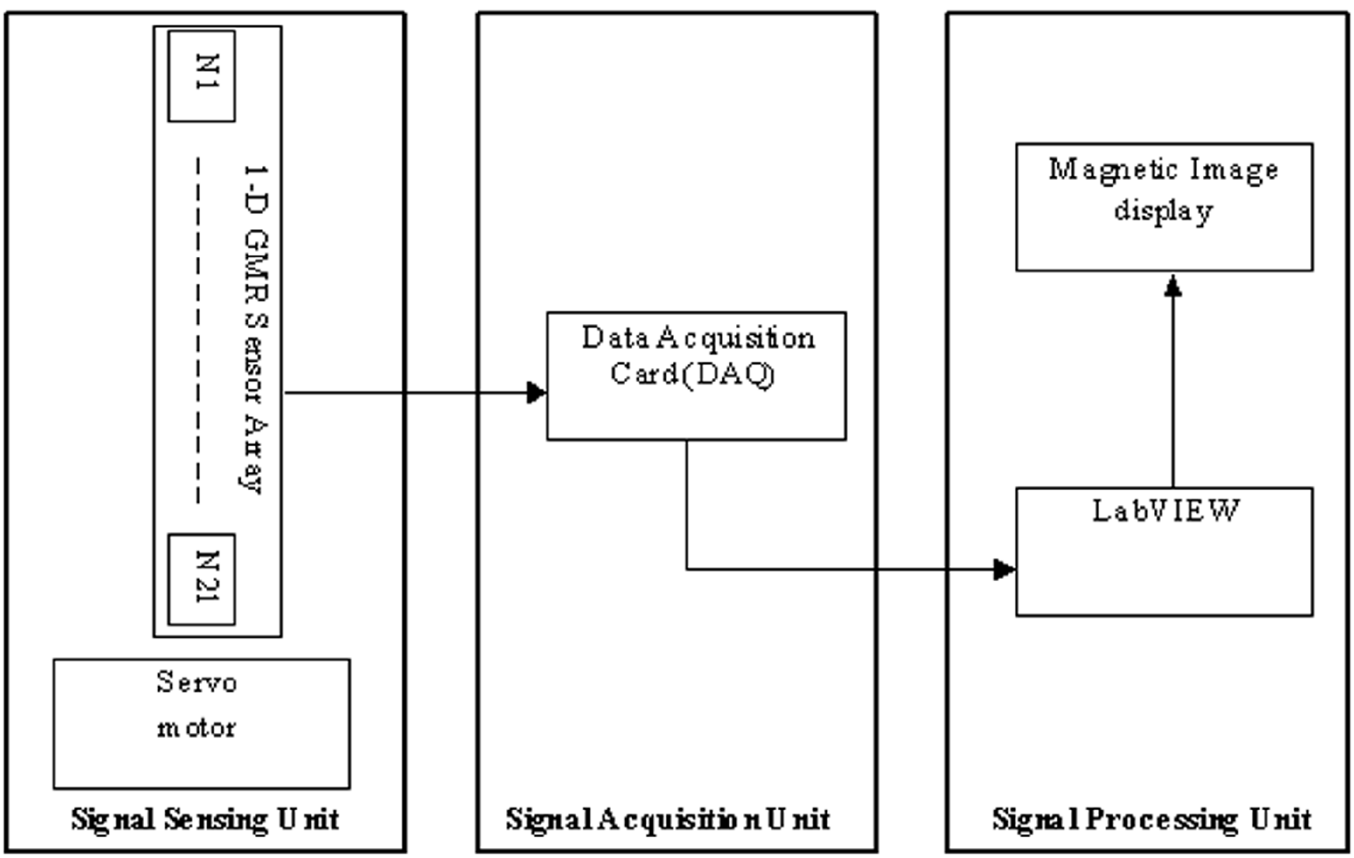


Figure 5-Signals flow of system

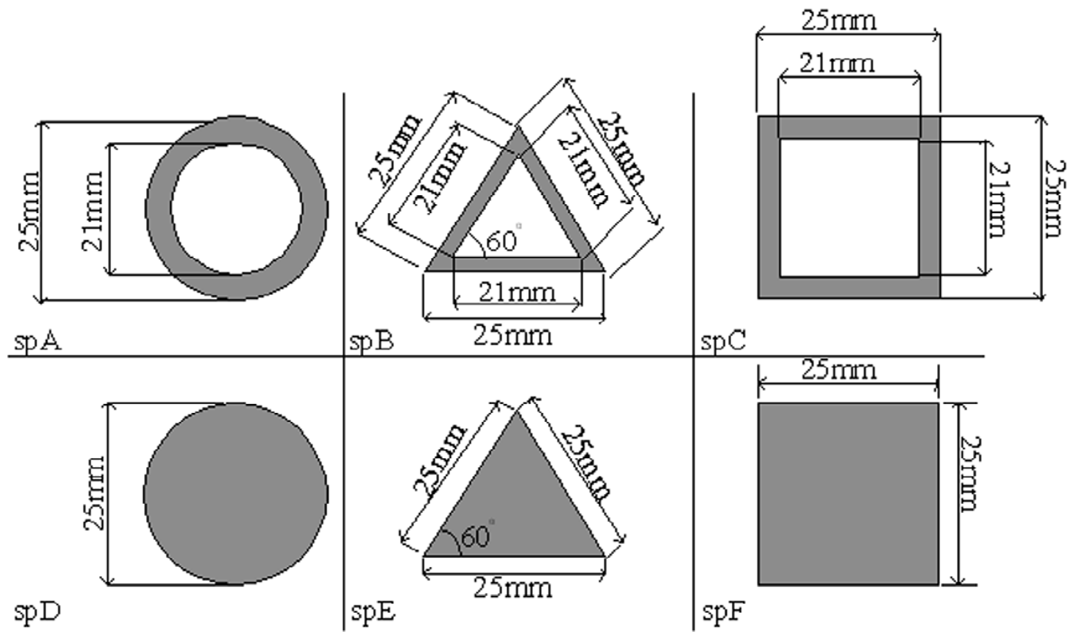


Figure 6: Dimensions of specimens

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

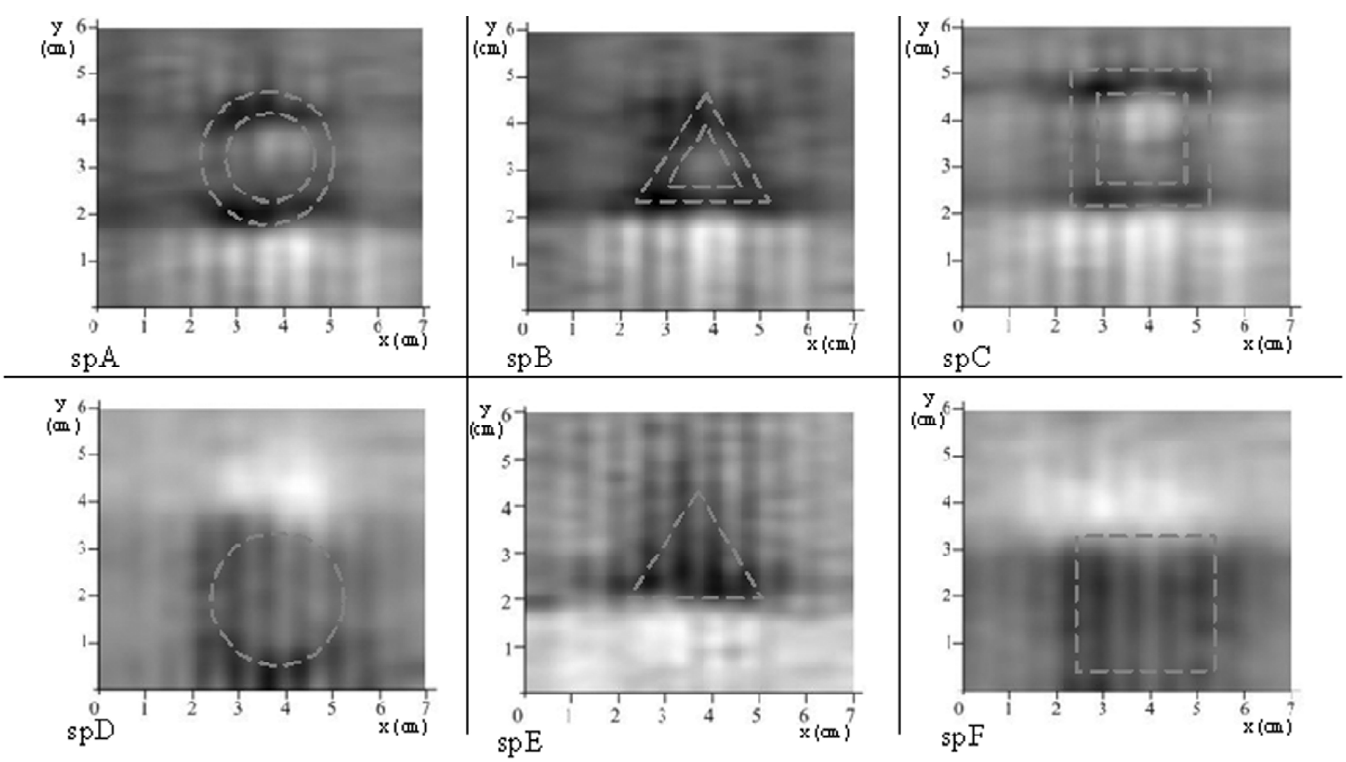


Figure 7: Magnetic image produced using Origin-Pro 8

being used andthe system malfunction when high magnetic field is used to the system. In Figure 7, image is produced at the parameter of 3.0A with the magnetic gap of 7.0mm. Nearly visible shape image of the specimens can be seen. They can be distinguished accordingly.

4. CONCLUSIONS

This paper discussed the development of a magnetic imaging system by using Giant Magneto-resistance (GMR) sensor. It also discussed about the measurements obtained from the GMR sensors using the MFLT principle method. The chosen methodology used in this paper shows that the system functions to detect shape of ferromagnetic metals.The prototype of this system is successfully developed by integrating SSU, SAU and SPU. SSU started the system with the sensing capabilities, which captured the flux changes occurred between the sensors and specimen. The data captured later is bringing along by the SAU prepared for data analysis. Finally image is produced by the SPU by using Origin-Pro 8 software. 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 shape of ferromagnetic metal specimen with a perpendicular gap of 7mm between the sensors and specimen. The GMR sensor manages to do the measurement which made crossing the edge of the specimens. However, there are still future works to be carried out to enhance the usage model of the magnetic imaging system of GMR sensor.

REFERENCES

[1] J. Lehnz and A. S. Edelstein, “Magnetic Sensors and Their Applications,” IEEE sensors J., vol. 6, no. 3, pp. 631-649, 2006.

[2] J. Y. Lee, J. S.Hwang, J. W. Jun, and S. H. Choi, “Nondestructive Testing and Crack Evaluation of Ferromagnetic Material by using the Lineraly Integrated Hall Sensor Array,” Journal of Mechanical Science and Technology, vol. 22, September 2008, pp. 1310-1317.

[3] L. J. Yang, G. Liu, G. G. Zhang, and S. W. Gao, “Sensor development and application on the oil-gas pipeline magnetic flux leakage detection,” 9thIneternational Conference on Electronic Measurement and Instruments (ICEMI) 2009, August 2009, pp. 2876-2878.

[4] A. Gasparics, G. Vertesy, T. Farkas and J. Szollosy, “Magentic Imaging in non-destructive testing,” 2nd International Conference on Mechanical and Electrical Technology (ICMET) 2010, September 2010, pp. 47-49.

[5] S. Yamada, K. Chomsuwan, and M. Iwahara, “Application of Giant magnetoresistive Sensor for Nondetructive Evaluation,” IEEE Sensors 2006, October 2006, pp. 927-930.

[6] H. Wakiwaka, “Characteristics of Giant Magnetoresistance Sensors and Their Applications,” J. of Magnetic Society in Japan, vol. 28, no. 7, 2004, pp. 825-833.

[7] D. L. Graham, H. A. Ferreira, and P. P. freitas, “Magnetoresistive-based Biosensors and Biochips,” Trends inBioTechnology, vol. 22, no. 9, 2004, pp. 455-462.

[8] T. Dogaru and S. T. Smith, “Giant Magnetoresistance-Based Eddy Current Sensor,” IEEE Trans. on Magnetics, vol. 37, no. 5, 2001, pp. 3836-3838.

[9] M. Norhisam, N. W. Shin, M. H Marhaban, and S. Suhaidi, “Magnetic Imaging of Ferromagnetic shape with Mobile Hall Sensor Array System”.

[10] Dehmel, G. (1989). Magnetic Field Sensors: Induction Coil (Search Coil) Sensors. In Sensors: Magnetic sensors, Vol. 5, pp. 206-234.

[11] Tumanski, S. (2007). Induction coil sensors—a review. Measurement Science and Technology, 18(3), R31-R46

[12] Cacciola, M., Megali, G., Pellicanó, D., & Morabito, F. C. (2011). A GMR–ECT based embedded solution for applications on PCB inspections. Sensors and Actuators A: Physical, 167(1), 25-33.