Properties of GMR based sensor for Magnetic field measurement at increasing Temperature Conditions

Nagu Sathappan[1], Mohammad Osman Tokhi[1], John Rudlin[2], Liam Penaluna[1]
Aman Kaur[1], Zhangfang Zhao[1], Fang Duan[1], Ghloamhossein Shirkoohi[1],

[1]School of Engineering, London South Bank University, London, UK
[2]NDT Section(NSIRC), TWI, Cambridge, UK
[1]London South Bank Innovaton Center, Cambridge, UK.
[1]sathappn@lsbu.ac.uk

Abstract. This paper presents investigations and associated results for characterisation of a giant magneto resistance (GMR) sensor at varying temperature conditions. The approach constitutes an experimental setup using a commercial GMR sensor for measurement of the magnetic field response of the system. The work aims to act as a fully-operational evidence of the application, with an emphasis on the standard mode of operation and to improve the sensitivity of the measurement system. The system provides high flexibility in design applications where local magnetic fields must be detected. The measurement setup can be modified and redesigned for a wide variety of applications, thus allowing path for future research, for better accuracy and extended operation range.

Keywords: GMR effect, Magnetic field, Magnetic Flux Leakage testing, Condition monitoring.

1 Introduction

In industries like nuclear, solar thermal and oil & gas, bound parts and components ought to operate in hostile conditions. Pipelines, tanks, pressure vessels and absorbent tubes carrying flammable liquids suffer from defects like creep, thermomechanical fatigue and hot corrosion due to high temperatures [1-5]. This could lead to the collapse of the internal or external structure of the parts and components that might result in the closing of the plant, economic harm and in some cases to severe hazard for human life. The structural assessment of these parts and components is of immense importance, as early detection of defects will prevent , an irreversible failure of the structure and reduce the probabilities and possibilities of the structures being drained and in that case, NDT techniques will be used for structural observance or monitoring of structures operating at high temperature conditions [5].The challenging factors for the use of NDT techniques in such environments include the operational conditions , access, size of the structure, and structural complexity of the component under observation and previously certain NDT techniques such as Acoustic Emission (AE), Eddy Current (EC), Laser Ultrasonic, Interferometry, Thermography and Guided Wave Testing (GWT) have been used at increasing temperature conditions. The performance of the sensors or transducers at high temperatures may degrade, and this will limit the potency of the technique being implemented [13-18].
Magnetic sensors provide a more rugged, reliable and maintenance-free technology compared to other sensor technologies [6-7]. Different sensor types such as; fluxgate sensors, the giant magneto resistive (GMR) sensors, anisotropic magneto resistive (AMR) sensors or hall effect

sensors can be used for the magnetic field measurements. However, a major disadvantage of these sensors is its inability to be used for sensing large areas of a specimen [6].

Rochaz et al. [7,8] introduced a Wheatstone bridge circuit with GMR sensor consisting of about 21 magnetic layers composed of Nickel-iron (NiFe) separated by a nonmagnetic material silver (Ag) in between. The NiFe magnetic layer thickness measured was 2 nanometres and that of Ag spacer was 1.1 nanometres. The advantage of this GMR structure is its stability when exposed to high temperatures compared with other GMR sensor structure designs that have a Cu layer spacer. Moreover, these sensors have a better output linearity, the hysteresis signal is low (less than 1 Oersted) and the effect of magnetic resistance decreases by a temperature factor between 1.5 to 3 at a temperature between 4 K and room temperature [7]. The increase in temperature increases the number of electrons scattered in NM, which is said to be nano layers, causing the number of electrons to move between the layers of GMR structure, and this reduces the efficiency of the GMR mechanism at increasing temperatures. Although power transducers based on Hall sensors act as multiplying elements, and can be used for direct power measurement, their insufficient sensitivity usually results in the need for ferromagnetic cores to concentrate the magnetic flux into the sensor area. Thus the high sensitivity of GMR based sensors can be used as potential substitutes of Hall sensors as in this application at room temperature, magneto resistive sensors are, generally, more sensitive than Hall effect based ones, so avoiding the need for major amplification signals [7].

Achuta [9] presents an enumeration and discussion of the physical, thermal, mechanical and magnetic properties of AlNiCo permanent magnet materials and sheds light on their different grades. The article shows AlNiCo as a mature product in the industry and the data obtained includes comparison of maximum temperature of the AlNiCo grades and the changes occurred below the room temperature conditions.

2 Methodology for High Temperature Testing

The measurement system used includes the components described below.

Table 1 shows specifications of the GMR sensor [10] used:

Table 1 Specifications of the GMR sensor.

Analog Series	NVE AA002-02
Maximum operating temperature	150^0 C
Magnetic field range	>400 milli Tesla

2.1 Permanent Magnet

Alnico5 grade type of dimensions 54×83×70 mm [11] was chosen as it has some excellent characteristics at varying temperature conditions. Its maximum operating temperature is 500º C, which makes it easy to test at increasing temperature conditions. AlNiCo magnet has a pull force of 47 kg, which indicates the maximum magnetic force the magnet can hold on a steel surface to be tested with respect to the magnetic sensor.

2.2 GMR sensor

This system is set up to generate a magnetic field in the direction that is sensitive to the axis of the GMR sensor. The GMR sensor is positioned exactly between the two poles of the magnet in a direction i.e. perpendicular to the magnetic field (see Figure 1). The permanent magnet is placed such that the magnetic field measured for every sensor is higher and precise and is necessary for obtaining the required output.

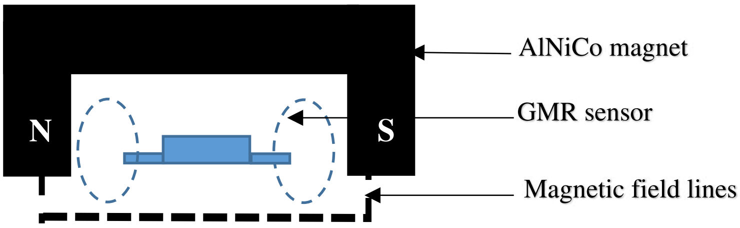

Figure 1. (Side view of GMR sensor) indicating the flow of magnetic field lines

2.3 Measurement system

The measurement system includes two separate environments, a harsh high temperature environment where the whole magnetic circuit needs to be placed. The magnetic circuit: an AlNiCo magnet, a holder and the GMR sensor, which is placed inside an oven. DC power supply and oscilloscope are placed at room temperature environment. The DC power supply is used for supplying voltage to the circuit and oscilloscope for detecting the change in voltage. A holder was designed using Autodesk Inventor and printed using 3D printer and this is used for placing and positioning the sensor. The holder is made of a polymer material which has a maximum operating temperature of 90° C. In order to measure the temperature stability, a thermocouple is connected to the magnetic circuit inside the oven. The thermocouple readings are recorded using Picologger software placed in the room temperature environment.
Figure 2 shows a schematic diagram of the experimental setup.

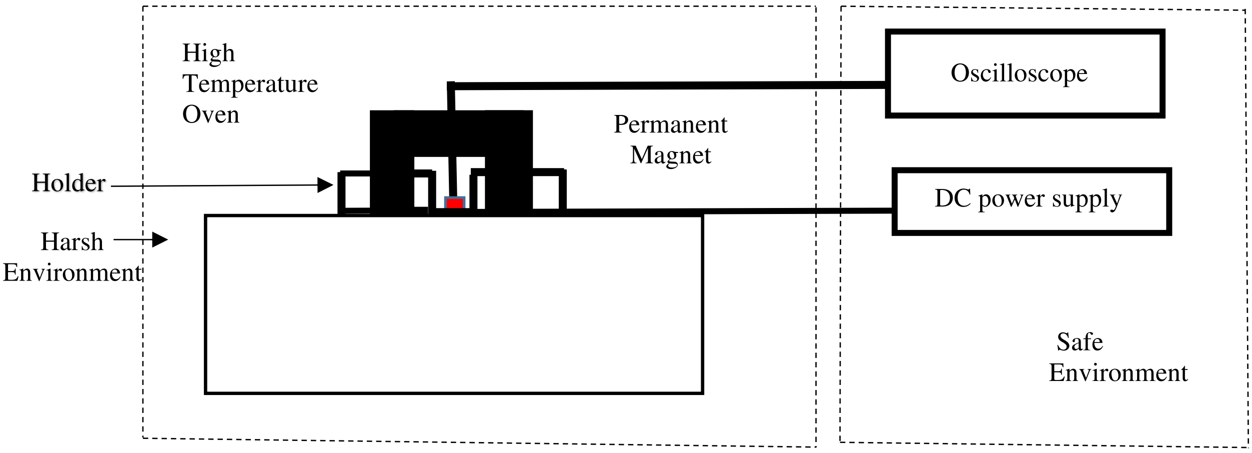

Figure 2. Measurement system using GMR sensor

3 Results

The results presented in this section are a summary of six tests done for every increment in temperature. Ranging from room temperature with a progressive step of 10°Celsius, the data was recorded up to 80°Celsius, as the holder material had a maximum operational temperature of 90°Celsius.
Figure 3 shows the measurement system including the corroded pipe sample of 8 mm thickness with the magnetic circuit placed inside the oven.

Figure 3. Measurement system using GMR sensor

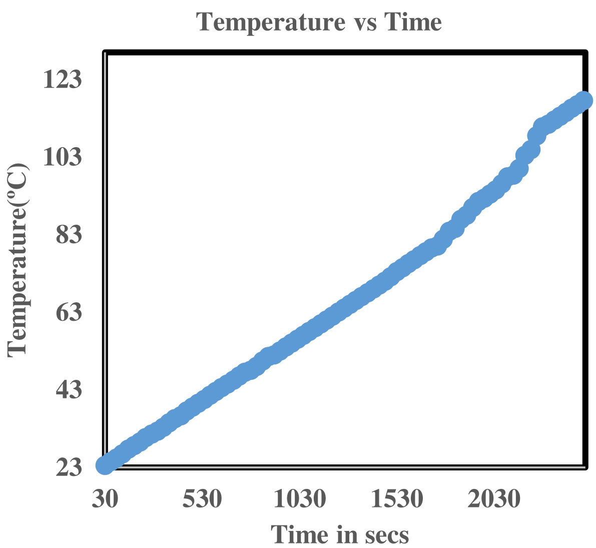

Figure 4. Thermocouple temperature measurements over time

Figure 4 shows the measurements obtained from the thermocouple at different temperatures plotted accordingly with respect to time. With time intervals of 30 seconds the temperature increase is shown on the y-axis, exhibiting an almost linear curve of temperature as a function of time.

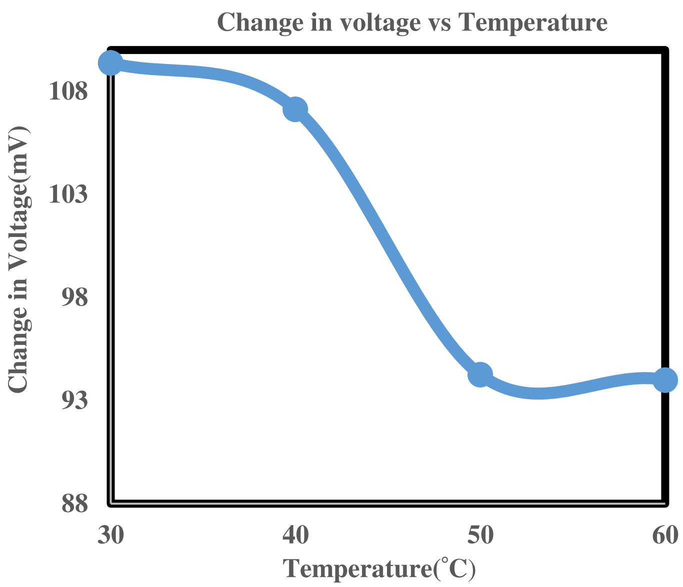

Figure 5. Measurement system response for change in voltage vs temperature

Figure 5 shows the change if voltage as a function of temperature. It is observed that with increase in temperature, the sensor output is decreased. Further sensor output measurements with relation to time were taken consideration over a range of temperatures from 30˚C till 60˚C as shown below in Figure 6.

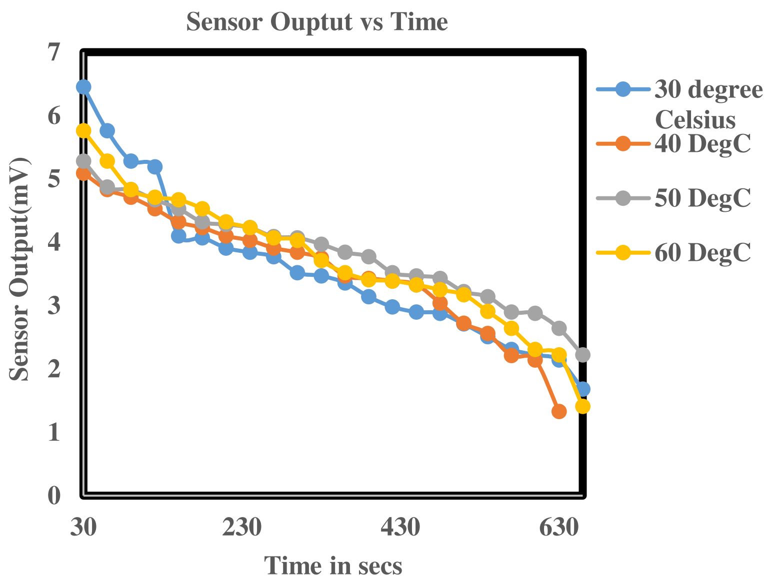

Figure 6: Variation in sensor output with respect to time for varying temperatures

It can be seen in Figure 6 that as the temperature increased, the voltage tended to decrease. Furthermore, the voltage decreased over time from 30 to 630 secs. There was a voltage drop by a factor of 0.5 V for every 30 secs time. There were variations observed in readings and this was due to measurement noise. The lift off between the pipe sample and the sensor caused the decrease in the sensor output.

4 Conclusion

A magnetic field measurement system and methodology have been presented for high temperature environments. The measurement set up developed has been found to be suitable for high temperature conditions with suitable holder for positioning of the magnetic sensor. Metallic samples up to 8 mm can be tested effectively with the developed system for high temperature conditions. It can also be concluded that the effect of temperature on the sensor does not cause changes in voltage within the range of temperature tested. GMR sensor had a maximum operating temperature of 150ºC, but the polymer holder can sustain heat only up to 80 ºC. Thus, the tests were performed up to 60 ºC. Realisation of a non-magnetic metal holder, will allow for temperatures above 60 ºC, and such tests will be done for increasing temperatures above 60ºC, and such tests will be done in future work with varying pipe sample thicknesses.

Acknowledgements

The work presented in this paper is supported by Lloyd's Register Foundation. Lloyd's Register Foundation helps to protect life and property by supporting engineering-related education, public engagement and the application of research. The work was enabled through, and undertaken at, the National Structural Integrity Research Centre (NSIRC), a postgraduate engineering facility for industry-led research into structural integrity established and managed by TWI through a network of both national and international Universities.

Declaration of Interest

The authors declare no conflicts of interest.

References

1. Poullikkas,A.: Economic analysis of power generation from parabolic trough solar thermal plants for the Mediterranean region—A case study for the island of Cyprus, Renewable and Sustainable Energy Reviews. vol. 13, p. 2474–2484, (2009)

2. Papaelias, M., Cheng, L., Kogia, M., Mohimi, A., Kappatos, V., Selcuk, C., Constantinou, L., Gómez Muñoz, C.Q., Garcia Marquez, F.P., Gan, T.H.: Inspection and structural health monitoring techniques for concentrated solar power plants. Renew. Energy (2015), 85, 1178–1191

3. Scrubbs,T.: The role of NDE in the life management of steam turbine rotors, Insight, vol. 46, no. 9, p. 529-532, (2004)

4.Guillot, S., Faika, A., Rakhmatullina, A., Lambert, J., Verona, E., Echegut, P., Bessadaa, C., Calvet, N., Py, X.: Corrosion effects between molten salts and thermal storage material for concentrated solar power plants., Applied Energy, vol. 94, p. 174–181, (2012)

5.Kogia, M.: High Temperature Electro-Magnetic Acoustic Transducer for Guided Wave Testing.Ph.D Thesis, Brunel University of London, London (2017)

6. Rao, B.: Magnetic Flux Leakage Technique: Basics. Journal of Non-destructive Testing & Evaluation. 11(3), 7-17, (2012)

7. Rochaz, L.V., Cuchet, R., and Vaudaine, M.H.: Sensors and Actuators .81 53-56, (2000)

8.Rifai, D.,Abdalla,N,A.,Ali,K and Razali.: Giant Magnetoresistance Sensors: A Review on Structures and Non-Destructive Eddy Current Testing Applications .,Sensors (2016), 16(3), 298; https://doi.org/10.3390/s16030298

9.Rao, S.A.: ALNICO PERMANENT MAGNETS AN OVERVIEW.Ph.D., (1956), Thomas&Skinner, Inc. Indianapolis, Indiana

10.https://www.nve.com.Availableonline: https://www.nve.com/Downloads/catalog.pdf

11.https://www.first4magnets.com/horseshoe-c42/red-alnico-horseshoe-magnet-47kg-pull-54-x-83-x-70mm-p10533#ps_0_10948|ps_1_10429

12. Ramos, G, H and Ribeiro, L, A.: Present and Future Impact of Magnetic Sensors in NDE, 1st International Conference on Structural Integrity, (ICONS-2014)., Procedia Engineering 86 (2014) 406 – 419, Portugal.

13. Johnson, J.,Kim,K., S. Zhang, D. Wu, X. Jiang.: High temperature acoustic emission sensing tests using a Yttrium calcium oxyborate sensor, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, vol. 61, no. 5, p. 805-814, (2014)

14. Kasuya, T., Okuyama, T., Sakurai, N., Huang, H., Uchimoto, T., Takagi, T., Lu, T., Shoji, T.: Insitu eddy current monitoring under high temperature environment, International Journal of Applied Electromagnetics and Mechanics, vol. 20, p. 163-170, (2004)

15. Dewhurst, J.R., Edwards, C., McKie, W, D.A., Palmer, B.S., A remote laser system for ultrasonic velocity measurement at high temperatures, Journal of Applied Physics, vol. 63, no. 4, p. 1225-1227, (1988)

16. Dewhurst,J.R., and Shan,Q.: Modelling of confocal Fabry-Perot interferometers for the measurement of ultrasound,Measurement Science and Technology, vol. 5, no.6, 655, (1994)

17. Gongtian,S.,Tao,L.: Infrared thermography for high-temperature pressure pipe, Insight, vol. 49, no.3, p.151-153, (2007)

18. Cegla,B.F., Jarvis, C,J.A., Davies,O.J.: High temperature ultrasonic crack monitoring using SH cracks, NDT&E International, vol. 44, p. 669-679, (2011)

19. Sardini, E., Serpelloni, M.: High temperature measurement system with wireless electronics for harsh environments, (2011), Doi: 10.1109/SAS.5739768.Published in:2011 IEEE Sensors Applications Symposium.

20. Li, Z., Dixon, S.: A Closed-Loop Operation to Improve GMR Sensor Accuracy. *IEEE Sens. J.* (2016), *16*, 6003–6007