STUDY OF MAGNETIC SENSORS FOR PULSED EDDY CURRENT TECHNIQUES

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Abstract: In this study we compare the suitability of a Hall device and a GMR sensor as the sensing device in pulsed eddy current systems. The comparative study is carried out by using both experimental results and manufacturers' data. The factors to be analysed are sensitivity, noise level, and operational bandwidth. Conclusions are given following the analysis of the data.

Keywords: Pulsed Eddy Current NDT, magnetic sensors

1. Introduction: The pulsed eddy current has recently gained intensive attention in research and development work in non-destructive testing (NDT)[1]. In contrast to conventional eddy current techniques, where a single frequency sinusoidal field excitation is used, pulsed eddy current (PEC) techniques use rectangular excitation waveforms that are characterised by the richness of frequency contents. This inherent richness of frequencies is thought to be potential in bringing up more information about discontinuities in the testing sample. The pulsing excitation induces diffusing eddy currents in the sample. Discontinuities in the sample that are closer to the surface will affect the eddy currents sooner than those lie deeper in the sample will.

It has been acknowledged that the sensitivity of PEC techniques is enhanced when magnetic field sensors are used instead of coils for picking up the field [2, 3]. Coils are not particularly sensitive to low frequency field as shown by the following equation:

$$\varepsilon = \frac{A}{c} . \frac{dB}{dt} \qquad (1)$$

The electromotive force, ε, around a loop is proportional to area multiplied by the rate of change of the magnetic field through the circuit. Therefore the effectiveness of the coil decreases with decreasing frequency. The enhancement can especially be beneficial when deeply buried defects are of the prime concern.

There are a family of magnetic field sensors available, namely SQUID, flux gate sensors, anisotropic magnetoresistive (AMR), giant magnetoresistive (GMR) and Hall devices. SQUID has the highest sensitivity; however its use is generally still limited due to practicality and cost-related reasons. Flux gate sensors are too big in size for these applications. The AMR has low measurement ranges that are not suitable for use with the PEC. The GMR and Hall device are therefore considered to be the best options, at least for the time being.

2. The GMR and Hall Device

GMR sensors contain of several ferromagnetic metallic thin films that are separated by thin nonmagnetic layers. When these layers are subjected to a magnetic field, the resistance can reduce by up to more than 20%. A typical layout of GMR sensors is shown in Figure 1[4].

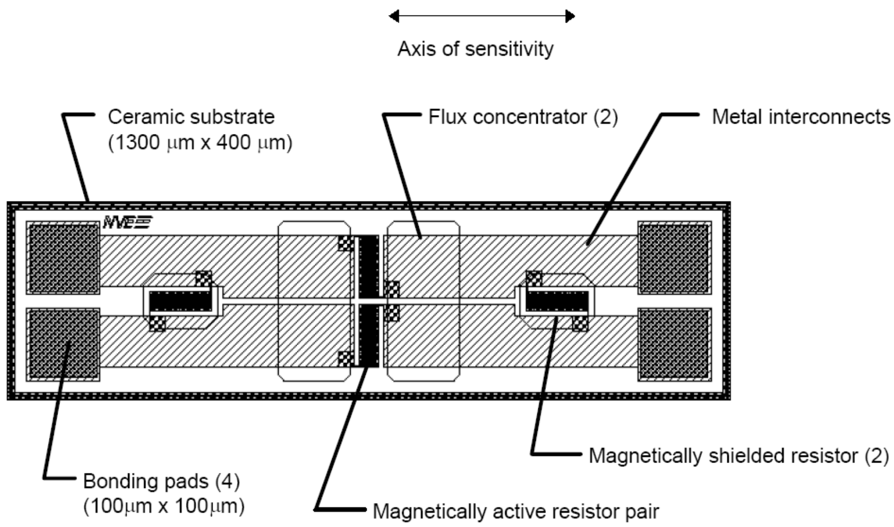


Figure 1 Typical GMR sensor layout

The layout shows four magnetoresistors are used. These resistors are connected in a Wheatstone bridge structure. Two of the magnetoresistors are shielded so that they are insensitive to external magnetic field and function as balancing resistors. When an external magnetic field is applied, the resistance of the magnetoresistors in the centre will reduce and proportional differential output voltage is then present at the output pins. We use NVE's AA005-02 GMR sensor in this study, and its output can reach around 200 mV at 5 V supply. It is an advantage to have this relatively large maximum differential output voltage. Forms of magnetic flux concentrators are embedded to the sensors to improve the sensitivity of the devices.

The Hall device, as its name implies, works on the basis of Hall effects. When a moving electron is subjected to a magnetic field, the Lorentz force will be acting upon the electron and forcing it to move perpendicular to both its moving direction and the magnetic field. In this way, when a current carrying element is located in a normal magnetic field, the electrons will be pushed to one side creating a potential difference on the opposite sides. This potential difference is the output of the device. In reality, the output is very small. Therefore, normally an amplifier is built in the sensor device in order to magnify the signal and minimise the noise by placing the amplifier very close to the Hall element. This gives rise to the fact that most Hall sensors have an absolute output, which is often undesired as differential outputs are generally more noise resistant. The Hall device used in this study, Honeywell's SS495A1 [5], is one of them. Other hall devices with built-in amplifiers include Infineon's TLE4990 [6] and Allegro's A3515 [7]. Attempts to find one in the market with differential outputs have not been fruitful. With this Hall device, the output is at half the supply voltage when no magnetic field is detected.

3. Manufacturer's Data

The AA005-02 is one member of NVE's AA family that have different sensitivity figures. It was chosen based on its largest magnetic range. The magnetic measurement range is inversely proportional to the sensitivity, the larger the range the lower the sensitivity becomes. It is widely known that GMRs are more sensitive than Hall devices. Although the figures here do not directly show this, the statement still holds true when we look at the output based solely on the basic principle how each device works. The Hall device looks to be more sensitive here because of the built-in signal amplifier; otherwise, the sensitivity is very much lower.

Table 1 Manufacturer's Data

	GMR AA005-02	Hall Device SS495A1
Sensitivity	2.75 mV/G at 5V	3.125 mV/G at 5V
Bandwidth	>1 MHz	65 kHz*
Magnetic range	-10 to +10 mT	-67 to +67 mT
Non - Linearity	2%	1%

* *This results from linearly extrapolating the data in the data sheet. At this frequency, the output is about a half of that at 1 kHz*

The GMR has a much higher operation bandwidth than that of the Hall device. This will be particularly advantageous when very small surface cracks are to be detected. However, it is highly involved to design such a wide bandwidth system with high signal to noise ratio. In many PEC systems, the bandwidth is usually limited in the order of several tens of kHz.

The GMR has a lower saturation field than the Hall device has. This sets the limit for the excitation current that can be used. Using a higher excitation current is one way of increasing the signal-to-noise ratio.

4. Experiments and Discussion: In this series of experiment, attempts were made to investigate the noise and magnetic directional sensitivity of each device.

In the first experiment, the noise level of each device was investigated. The devices were connected to the same signal pre-amplifier, signal conditioning and data acquisition system in succession. For the Hall device, a reference voltage of 2.5V was introduced to shift the output to 0V when no magnetic field is detected. No deliberate magnetic field was applied in this experiment. It was measured that the noise of the Hall device's signal was 10 mV peak-to-peak and that of the GMR was 2 mV peak-to-peak. Thus, the GMR has a lower noise level. This can be greatly due to the differential outputs of the device.

To investigate the directional sensitivity of the devices, each device is exposed to a magnetic field. The angle between the magnetic field and the sensitivity axis of the device is increased from 0 to 180 degrees by steps of 15 degrees and the output voltage is recorded every time. The results are plotted in a polar plot shown in Figure 2. The plot shows that the GMR's output is more sensitive to non-parallel magnetic field, which is undesired characteristic.

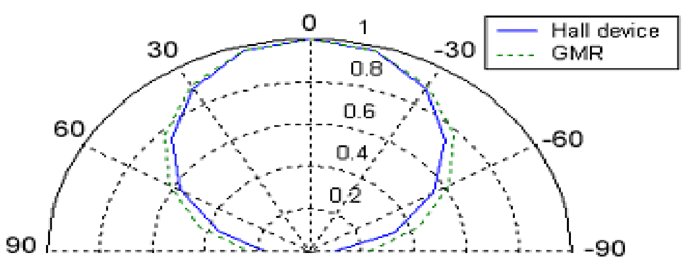


Figure 2 Polar Plot of Normalised Output vs. Angle of Magnetic Field

Finally, we investigate the performance of both sensors for detection by scanning a metal testing sample. The testing sample used in the experiment is made of Aluminium and illustrated in Figure 3. An example of 30 mm x 7.5 mm surface area scanning result based on signal peak heights using the GMR is shown in Figure 4. The peak in the plot represents the signal peak obtained when the probe is above the slot central axis. It can be seen that the actual width of the slot has not been captured. The smearing is mainly due to the large diameter of the coil. The peaking parts on both x-direction ends are showing the edge effects.

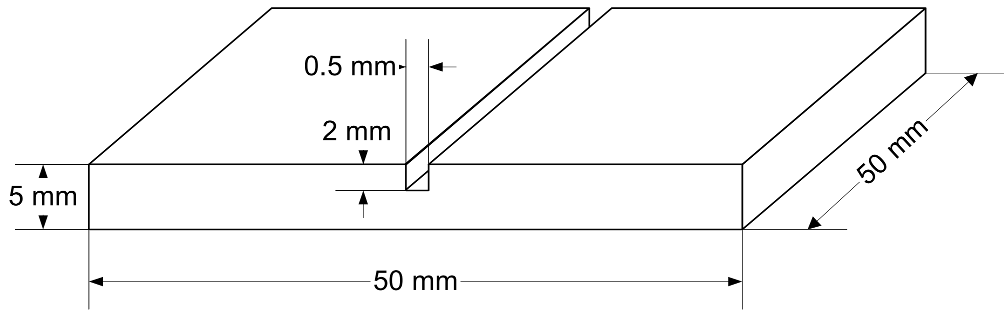


Figure 3 Aluminium Testing Sample with a Surface Slot

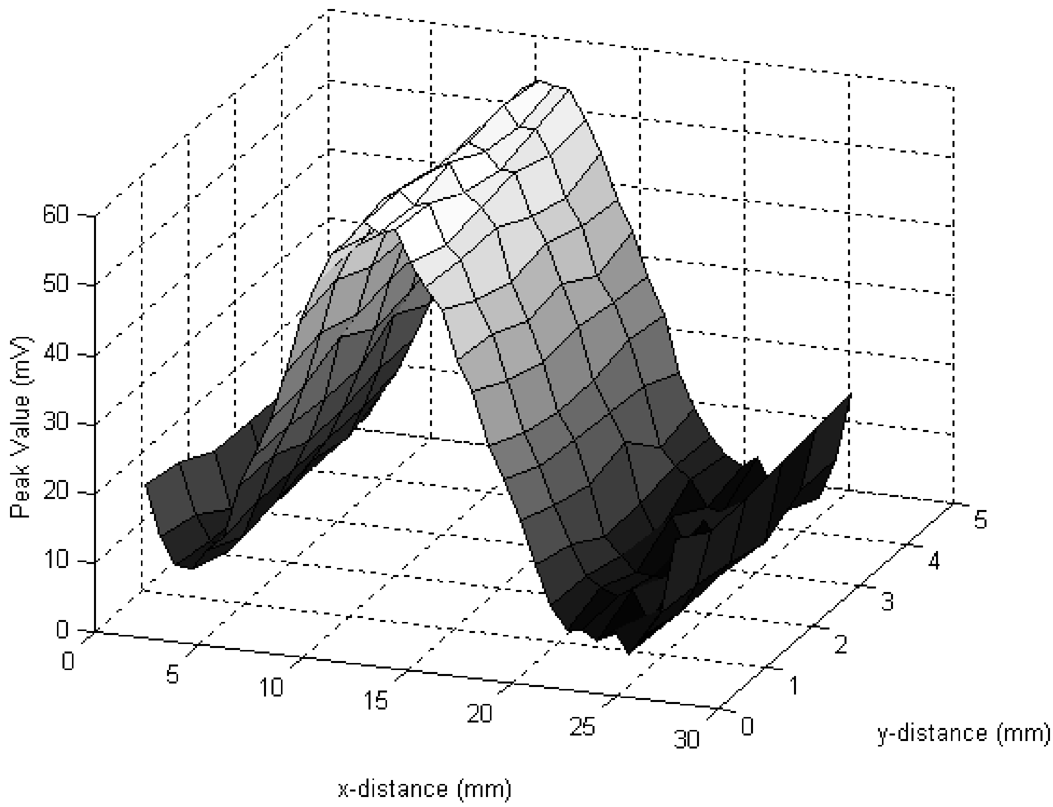
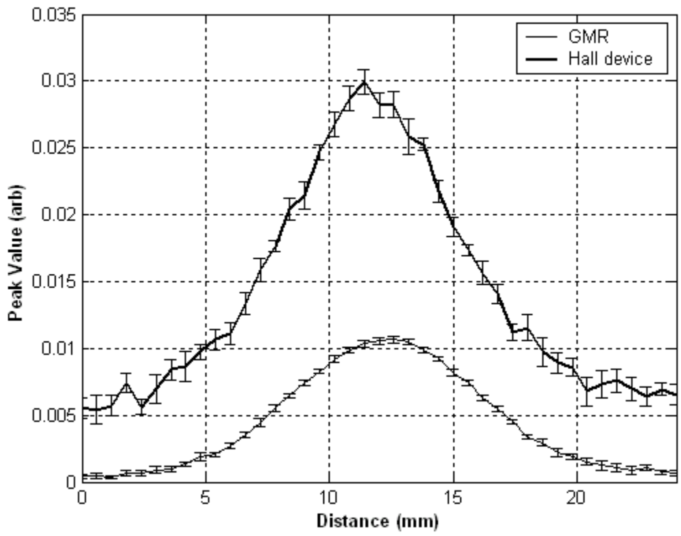


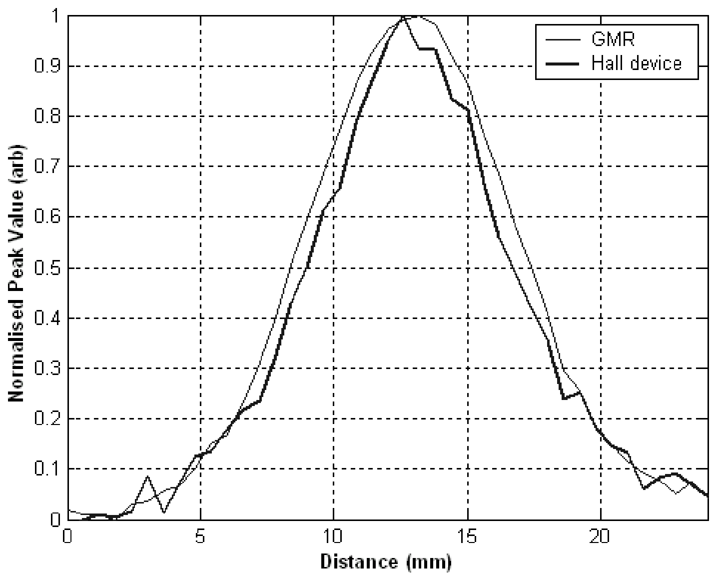
Figure 4 Area Scanning using GMR

Figure 5a shows the peak values measured when scanning the sample with both the GMR and Hall device. It can be seen that the Hall Device is more sensitive in this measurement as it has a higher peak value for the centre of the slot. The error bar in Figure 5a represents the standard deviation of noise. As can be seen in the figure, the noise of Hall device is significantly larger. The signal to noise ratios for the slot measurement using the GMR and the Hall Device are approximately 59 dB and 33 dB respectively.

Figure 5b shows the normalised results of linear scanning using both the GMR and the Hall device. It can be seen that the blurring effect is slightly worse with the GMR. This is thought to be caused by the higher sensitivity 'leakage' of the GMR to non-parallel magnetic field. The smearing effect can obviously be reduced by using smaller diameter coils or by employing a ferrite core or shielding. However, even as it is, the effect is just slightly worse.



(a)



(b)

Figure 5 Linear Scanning using Both GMR and Hall Device: (a) Peak values with error bar representing standard deviation of error; (b) Normalised peak values

5. Conclusions: As long as the magnetic measurement range permitting, GMR is the preferred option considering its lower noise, leading to a higher signal-to-noise ratio. The low noise level becomes crucial, especially when dealing with small defect, where the signals will be small. The inclination towards using GMR will be even stronger when detection of surface defects is the only or one of the targets due to its suitability for higher operational frequencies. This effect can be solved by the use of adaptive threshold.

In situations where stronger primary magnetic fields are required, such as in the case of very deep defect detection, or when magnetisation is required, then the Hall device might be chosen because of its larger magnetic field measurement range.

References:

1. Sophian, A., G.Y. Tian, D. Taylor, and J. Rudlin, *Electromagnetic and Eddy Current NDT: A Review.* INSIGHT, 2001. **43**(5): p. 308-313.
2. Smith, R.A. and G.R. Hugo, *Transient eddy current NDE for ageing aircraft - capabilities and limitations.* Insight: Non-Destructive Testing and Condition Monitoring, 2001. **43**(1): p. 14-25.
3. Sophian, A., G.Y. Tian, D. Taylor, and J. Rudlin, *Design of a pulsed eddy current sensor for detection of defects in aircraft lap-joints.* Sensors and Actuators A: Physical, 2002. **101**(1-2): p. 92-98.
4. NVE, *Engineering and Application Notes - Giant Magnetoresistive (GMR) Sensors*. 1998.
5. Honeywell, *SS490 Series Miniature Ratiometric Linear Solid State Sensors.* 2000.
6. Infineon, *TLE 4990 Data Sheet*. 2001.
7. Allegro, *3515 AND 3516 Data Sheets*. 2003.