CONTACTLESS CURRENT MEASUREMENTS BY MEANS OF A GMR SENSOR

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Abstract: Giant Magneto-Resistive (GMR) sensors are solid state sensors suited to detect magnetic fields produced by variable currents. In this work, a GMR sensor is used in a contactless fashion in order to measure current from a load or from a power line distribution cable in order to detect perturbations or disturbances. The aim of this work is to demonstrate the feasibility for using this technology for current measurement in manufacturing field. Results shown that GMR technology is competitive with respect to other technologies and can be useful in health monitoring of industrial equipment

Keywords: GMR, current measurements, conditioning circuit, data processing.

1. INTRODUCTION

Nowadays, technology goes toward the discovery of new materials and new systems to replace devices that use principles and technologies out-of-date difficultly improvable. Most part of modern devices utilise the Hall Effect [1] to measure current because its assures good performance and high reliability. In these years new sensors based on Anisotropic Magneto-Resistance (AMR) [2] and on GMR [3] effect are becoming more and more popular.

New applications are continuously found for solid state magnetic field sensors due to their small size, low power, and relatively cost effectiveness [4]: heads in hard drive, magnetic sensors, devices for monitoring various physical quantities such as vibrations [5] or to detect some material characteristic such as cracks in planar specimen [6].

In particular, various are the current sensing applications: current measurement within electronic circuitry, printed circuit board, current probe, and nonintrusive AC or DC current detection. Generally, the factors that determine the choice of the best sensor for a given current sensing application are: magnitude of the current, accuracy, hysteresis, linearity, response time and cost.

In this paper an optimization of the output characteristics of a magnetic sensor by NVE corporation with respect to current measurement is presented. The design and the preliminary testing of an hand-held prototype, able to measure the current flow through a wire is

described. After the Introduction, some basics about GMR technology are given. In Section 3 the prototype stages are briefly described while in Section 4 some experimental results are reported.

2. BASICS

A GMR magnetometer consists of two magnetic material layers, designed to have anti-ferromagnetic coupling, and a non-magnetic interlayer. When no external magnetic field is applied to the GMR element, a high resistance between these layers results. If an external magnetic field, is applied the magnetic direction of the two magnetic layers are aligned causing a drop of the resistance value between 10% to 15% [4].

As shown in Figure 1, the typical magnetic field vs voltage (*B-V*) characteristic for a GMR consist of two different ranges. The former is the linear range where the resistance rate is constant; the latter is the saturation range in which the application of additional magnetic field does not imply changes of the resistance.
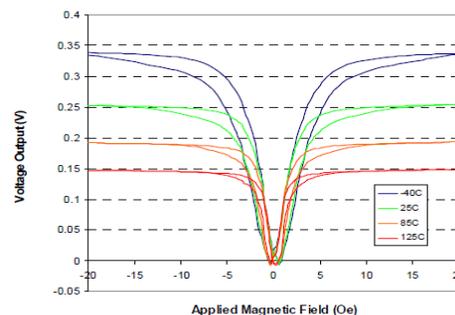

Figure 1 Typical temperature performance of a AAH002 NVE GMR sensor

Figure 2 shows the typical layout of a commercial GMR magnetometer sensor based on four GMR elements arranged in a Wheatstone half bridge configuration [7]. In order to make the value of two of the four resistances independent from the applied magnetic field, two shields are needed; these shields (also known as flux concentrators) are two metallic large plated structures that cover two of the resistors in the bridge. In this way it can be prevented the magnetic applied field to reach them.
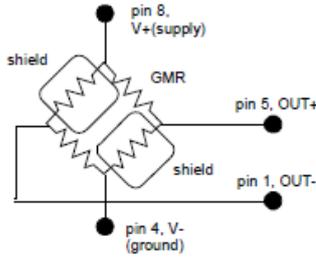
Figure 2   GMR sensor in half bridge configuration

When an external magnetic field is applied, two GMR resistors decrease their resistance values, whereas the other two, under the flux concentrators, remain constant. This imbalance leads to a differential output voltage at the output pins. The sensor output sensitivity could be varied changing the shape and the material of the shield, making it possible to realize different magnetometer sensors.
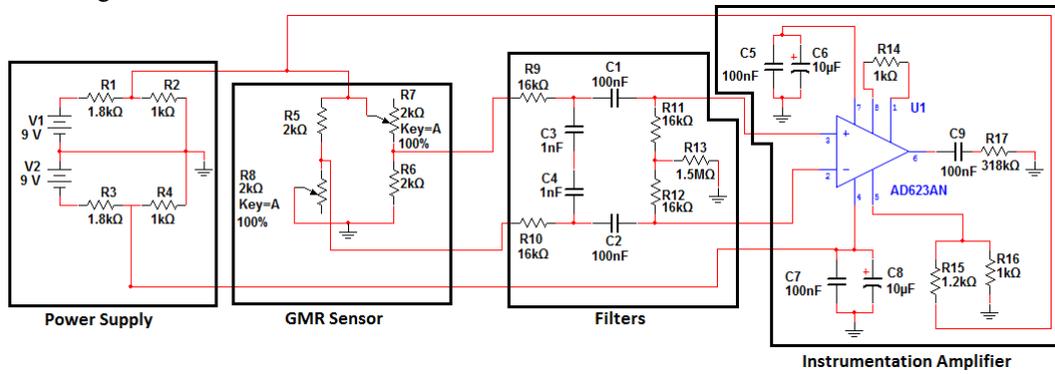
3. PROTOTIPE DESIGN

In order to obtain current measurements a suitable choice of the GMR sensor and a careful design of the pre-processing stage are necessary. Moreover, to guarantees accurate measurement and good resolution, a suitable amplification with proper filtering have to be used. Figure 3 shows the schematic circuit of the prototype; the realized PCB has a dual input supply made by two 9 V batteries and voltage divider to obtain 3.3 V for powering the sensing stage. A Data Acquisition (DAQ) NI USB 6251 by National Instruments [8] has been used to acquire the signal; a LabVIEW[TM] GUI is designed to control the acquisition process while a MATLAB® code was implemented to elaborate the signal, to calculate the Fast Fourier Transform (FFT) and for data post-processing.

Figure 3   Schematic of the prototype

GMR sensor

For this work an AAH002-02 magnetometer by NVE corporation has been chosen because of its higher sensitivity respect to other commercial GMR sensors. The main properties of the AAH002-02 sensor are reported in Table I.

As it can be seen in Figure 1 the chosen GMR sensors operate as bipolar a sensor producing a positive output when a sinusoidal current is applied. So a like rectified sinusoidal waveform output voltage is obtained. This effect can be changed varying the offset in operating point. The method used for creating a bipolar output to bias the sensor element with an external magnetic field, for example by suspending a magnet over the sensor. A set of test were made varying the distance between the GMR sensor and the magnet in order to obtain the best output.

Filter

In this study, a first-order differential low-pass filter (DLPF) and a first-order differential high-pass filter (DHPF) are used. The DLPF reduces signal bandwidth preventing aliasing phenomena; the cut-off frequency was set to 10 kHz. The DHPF is grounded through a 1.5 MΩ resistor in order to provide a path to ground for the input bias currents of the differential amplifier (DA).

Instrumentation Amplifier

In order to have significant current readings, it is necessary to amplify the acquired signal; for this work the AD623 Differential Amplifier (DA) by Analog Devices [10] has been chosen. Line noise, as well as line harmonics, will be rejected since the CMRR remains constant up to 200 Hz.

For this work the reference voltage is 1.5 V while a 1.02 kΩ gain resistor is chosen to obtain a gain factor of 100.

Table I – Properties of AAH002-02 GMR sensor

Property	value
linear output	10% -70% of full scale
GMR effect	13% to 16%
temperature coefficient	0.14%/°C
temperature tolerance	+150°C
magnetic field range	0 to ±300 Gauss
current measurement	1-10 A
sensitivity	11 – 18 mV/V*Oe
linear range	0.6 - 3 |Oe|

4. TEST AND RESULTS

Firstly some measurements were made in laboratory controlled condition in order to verify the capability of the sensor; in detail the current through a load powered by an Agilent 33220 A AWG was detected, then the prototype was employed to measure the current obtained by the distribution line on a 3 kΩ power resistor bench and finally the phase current of a three-phase asynchronous motor by Marathon Electric was measured. During all measurements the GMR axis was perpendicular to the cable so the presence of other magnetic fields it was pointless because of the auto-isolating of GMR technology.

Current measurements

The first set of measurements was taken on a 1 Ω precision resistance powered by a 100 Hz, 1 V of peak-peak AC voltage supplied by the AWG opportunely amplified. In Figure 4 it is shown the FFT of the signals obtained on the resistance using the DAQ to acquire the signal at 10 kHz sampling frequency and a HOIKI 3283 current clamp [10] as reference instrument.
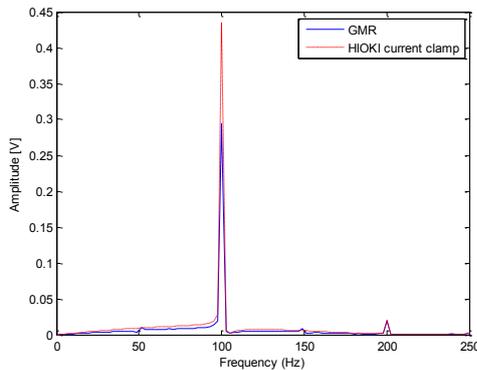
Figure 4 Comparison between spectra acquired by the GMR sensor (blue solid) and current clamp (red dotted) for a 1 Ω resistance load.

The blue line is the signal acquired by means of the GMR sensor and the red dotted line is the signal acquired by the current clamp. It is possible to note the overlapping of the 100 Hz harmonic of the acquired signal by the two different sensors. It should be note that the measured current was 1 A peak-peak and in this range the reading of the current clamp is 1:1.

In Figure 5 the result for this test in time domain is shown. The time domain representation puts better in evidence the noise detected by the GMR sensor, however it can be considered negligible because its order of magnitude is lower than the peak value; moreover it can be easily suppressed by the averaging the acquisitions.

The second test has been made on a 3 kΩ resistors test bench supplied with the laboratory supply line (220 V RMS voltage). In Figure 6 the FFT of the signals for this second test is shown. It is possible to see that the signal acquired with GMR sensor (blue line) has the fundamental harmonic at the frequency 50 Hz as expected.
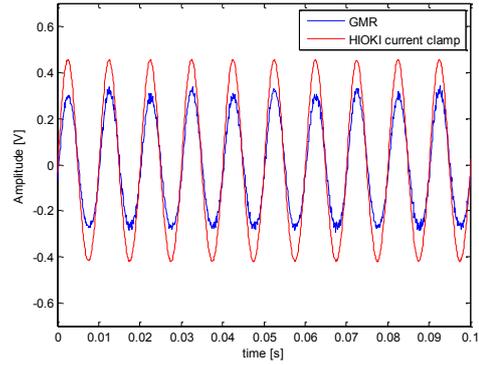
Figure 5 Comparison between time domain signals acquired by the GMR sensor (blue solid) and current clamp (red dotted).
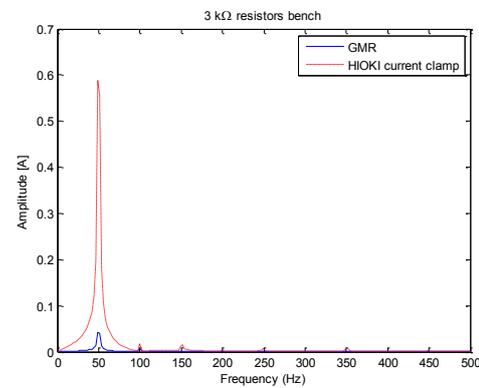
Figure 6 Comparison between spectra acquired by the GMR sensor (blue line) and current clamp (red dotted)
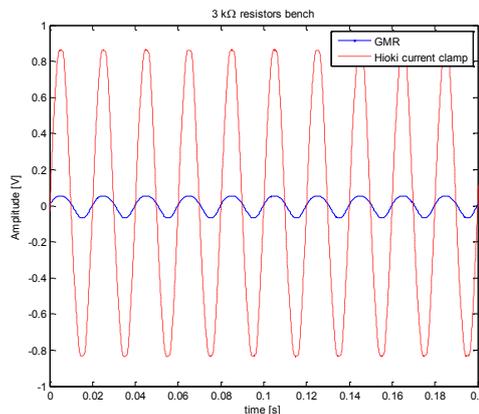
Figure 7 Comparison between time domain signals acquired by the GMR sensor (blue solid) and current clamp (red dotted).

In Figure 7 is shown a signal acquired by mean GMR sensor (blue line) and the signal acquired by mean HIOKI 3283 (red line). The GMR signal is obtained after averaging it on 128 acquisitions in order to suppress the noise. Since the measured RMS value by the current clamp was about 0.62 A, a calibration procedure is needed in order to estimate the same current by means of the GMR sensor. In this case the measured voltage was 0.044 V so the

calibration constant is 14.09 A/V. The calibration constant depends on the distance between the cable and the sensor; the authors are working to design a stable experimental setup for calibrating and characterize metrologically the prototype.

The last tests were conducted measuring the current through one phase of a three-phase asynchronous motor at a certain distance from it in order to prevent any disturbance in the magnetic field due to the leakage flux.

In Figure 8 and 9 the measurements on motor supply line are reported both in time domain as well as in frequency domain. The GMR data are averaged and scaled (blue solid line) to agree with the measurements made by the current clamp so the vertical axis is calibrated in Amps.
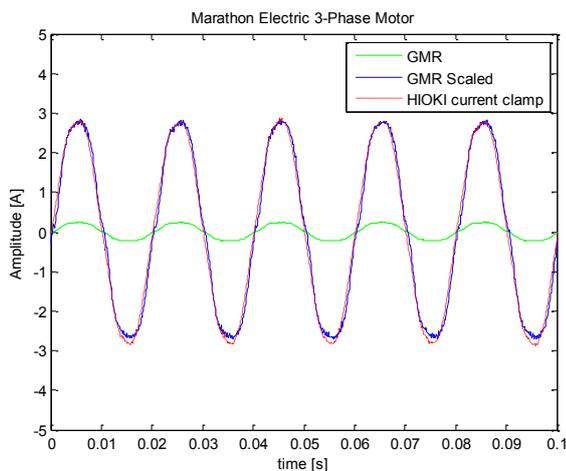

Figure 8 **Comparison between waveforms acquired by HIOKI current clamp and GMR sensor.**
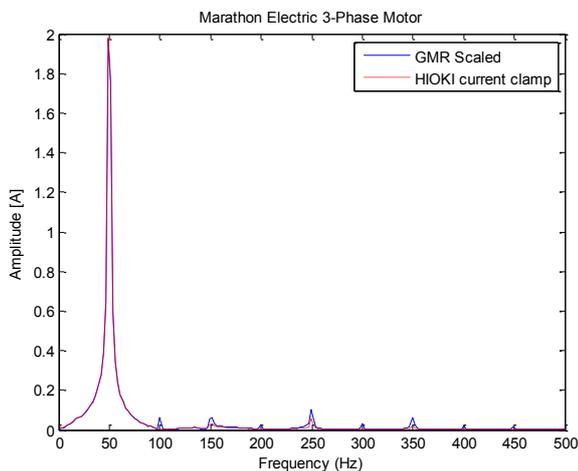

Figure 9 **Comparison between FFTs obtained elaborating data reported in Figure 8.**

It can be seen the good agreement between the two data set; the relative error obtained by the GMR sensor was about 0.06% of the RMS current measured by means of the current clamp. The latter test demonstrates the feasibility of contactless current measurement in manufacturing field by means of GMR technology based sensors.

CONCLUSIONS

This work has described an hand-held system to measure the current for manufacturing application. The developed prototype is characterized by very low installation cost, higher sensitivity and higher temperature stability than Hall and AMR sensors.

All preliminary tests demonstrate the usefulness of the GMR technology for current measurement for manufacturing applications. A lot of work needs to do to design a reliable device for field application but the first results convinced the authors to respond to this challenge. The authors are working to develop a stable test bench in order to metrologically characterize the prototype and to test the use of the GMR sensor to detect the vibrations of crank shafts for them health monitoring. Some tests were made on a motor with balanced and unbalanced rotor but, at this time, these results are object of analysis.

5. REFERENCES

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