COMPARISON OF SPIN VALVE AND MAGNETIC TUNNEL JUNCTION MAGNETO RESISTIVE SENSORS IN EDDY CURRENT TESTING PROBES

Luis S. Rosado [1], *Filipe A. Cardoso* [2], *Susana Cardoso* [3], *Telmo G. Santos* [4], <u>*Pedro M. Ramos*</u> [5],
Paulo P. Freitas [6], *Moisés Piedade* [7]

[1] INESC-ID, IT, IST, Universidade de Lisboa, Lisboa, Portugal, luis.rosado@tecnico.ulisboa.pt
[2] INESC-MN Instituto de Engenharia de Sistemas e Computadores Microsistemas e Nanotecnologias,
Lisbon, Portugal, fcardoso@inesc-mn.pt
[3] INESC-MN Instituto de Engenharia de Sistemas e Computadores Microsistemas e Nanotecnologias,
Lisbon, Portugal, scardoso@inesc-mn.pt
[4] UNIDEMI Departamento de Engenharia Mecânica e Industrial, Faculdade de Ciências e Tecnologia,
Universidade Nova de Lisboa, Caparica, Portugal, telmo.santos@fct.unl.pt
[5] Instituto de Telecomunicações, Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal,
pedro.m.p.ramos@tecnico.ulisboa.pt
[6] INESC-MN Instituto de Engenharia de Sistemas e Computadores Microsistemas e Nanotecnologias, Lisbon,
INL International Iberian Nanotechnology Laboratory, Braga, Portugal, pfreitas@inesc-mn.pt
[7] INESC-ID, IST, Universidade de Lisboa, Lisboa, Portugal, msp@inesc-id.pt

Abstract – This paper compares two different magneto resistive sensor technologies used on the same configuration of eddy current testing probe. Two dimensional testing results on a friction stir welding aluminum joint were used to compare spin valve and magnetic tunnel junction sensors. These results showed that, magnetic tunnel junction sensors, provided a significant improvement on the signal to noise ratio and signal amplitude over spin valves.

Keywords: Eddy Currents Testing; Differential; Magneto-Resistive; Spin Valve; Magnetic Tunnel Junction

1. INTRODUCTION

Eddy Current Testing (ECT) is a Non-Destructive Testing (NDT) [1] method applied in the detection of cracks and other defects on metallic parts. An alternating magnetic field is generated using a coil or other element positioned next to the part being tested. This primary magnetic field induces eddy currents in the tested part which, when modified due to the presence of a defect, modify its original disposition [2]. Typical ECT probes make use of winded coils [3] or planar coils processed by photolithography [4] on both tasks of generating and sensing the magnetic field. More recently, promising results were obtained using Magneto-Resistive (MR) sensor technology applied in the magnetic field measurement [5].

Results obtained with a previously proposed probe design are discussed in this paper. This probe was designed to cope with the detection of very small crack defects on Friction Stir Welding (FSW) [6] joints. A comparison between the use of different MR sensors technologies [7], Spin-Valve (SV) and Magnetic Tunnel Junction (MTJ) is reported.

2. PROBE STRUCTURE AND OPERATION

In the proposed probe, which is shown in Fig. 1, a single conductive driver trace is used as the primary magnetic field generator. The trace is etched on a Printed Circuit Board (PCB) substrate with the shape shown in Fig. 1. Sensing of the resulting magnetic field is accomplished by measuring a pair of MR sensors (SV or MTJ type) designed and processed at the INESC-MN clean room facilities on a silicon substrate. Both sensors are measuring the magnetic field component perpendicular to the part under test surface and biased with the same current. In a defect free situation, this results on a similar voltage drop across the two sensors and in a null measurement when they are measured differentially.
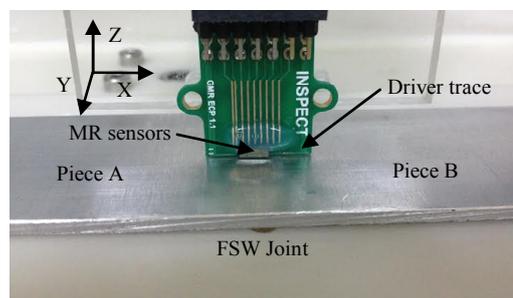

Fig. 1. Eddy current testing probe prototype while testing a FSW joint.

Fig. 2 shows a detail of a single prototyped SV sensor. Note that the probe shown in Fig. 1 has an array with 16 of these sensors but only two are used in the differential measurements.
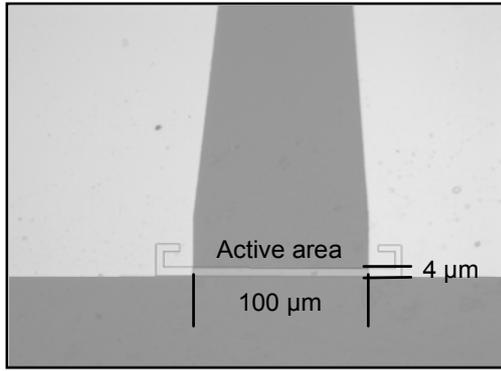
Fig. 2. Detail of a single prototyped SV sensor.

The transfer curve of one of the used Spin Valve sensors is shown in Fig. 3. For this particular case, the sensor sensitivity is $9.3\,\Omega/\mathrm{mT}$ and the resistance value when no field is applied is near $558.8\,\Omega$.
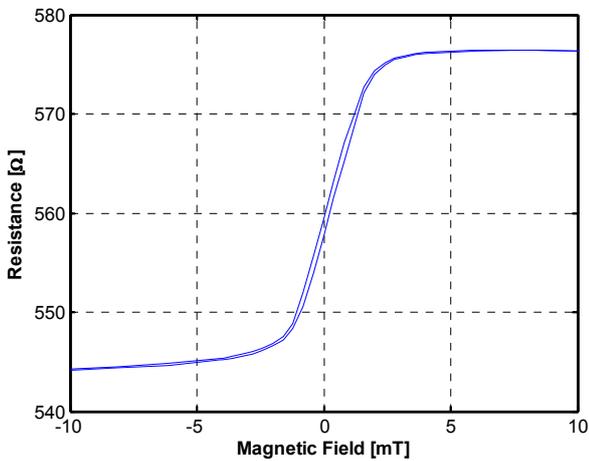

Fig. 3. Transfer curve of a Spin Valve sensor.

Fig. 4 shows a detail of one MTJ sensor which includes 10 individual MTJs connected in series.
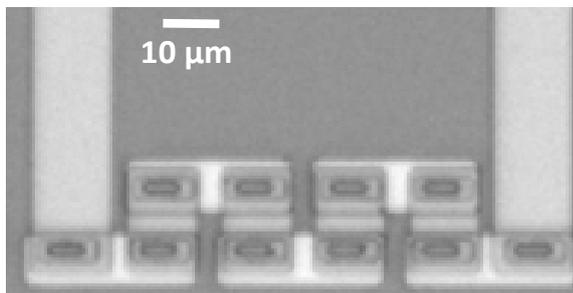

Fig. 4. Detail of a MTJ sensor with the 10 individual MTJs.

The transfer curve of one of the used Magnetic Tunnel Junction sensors is shown in Fig. 5. The sensor sensitivity is $186.6\,\Omega/\mathrm{mT}$ and the resistance value when no field is applied is around $955.0\,\Omega$.
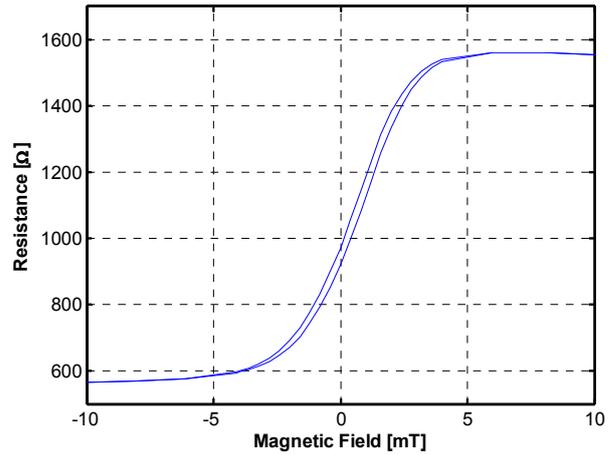

Fig. 5. Transfer curve of a Magnetic Tunnel Junction sensor.

The detection of defects is done by driving the driver trace with an alternate current and measuring two MR sensors. The induced eddy currents will be concentrated underneath the driver trace following the same direction. When the defect has an expected orientation (as usually happens in welded joints cracks), the probe is aligned with the conductive trace perpendicular to this orientation promoting the eddy currents modification by the defect. If a defect is present underneath only one of the sensors, the measured magnetic field has an higher amplitude since no eddy currents will be cancelling the primary magnetic field leading to an increase of the sensor signal and to a non-null measurement. The circuit that interfaces the sensors and performs the measurements is shown in Fig. 6. It consists on a Wheatstone bridge with two fixed 10 kΩ resistors in each arm and the two sensors complete each bridge arm. The measurement technique uses a sinusoidal bias on the MR sensors [8]. Three identical generators are used and are inter-connected to share the same clock reference to ensure synchronization. DDS#3 defines the trace current frequency (set to 1 MHz) and a transconductance amplifier transforms the generator output voltage into the current that flows in the driver trace. DDS#2 supplies the bias current at a frequency near the trace frequency (set to 990 kHz) and DDS#1 is set to 10 kHz. Further details can be found in [9].
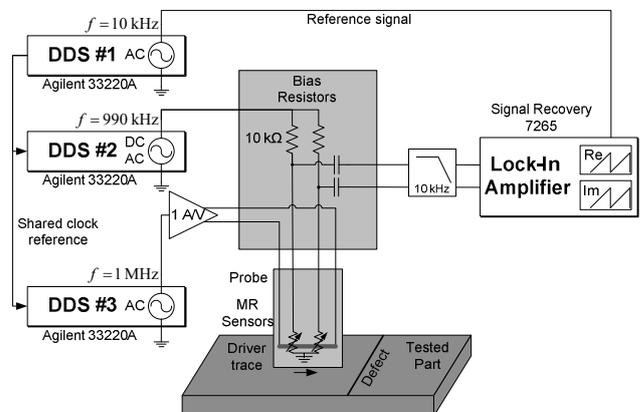

Fig. 6 Sensor interface and measurement circuit.

3. EXPERIMENTAL RESULTS

The probe was tested on a real FSW performed to join two aluminum alloy AA2024 pieces. After processing, the weld was sectioned and a treated to perform the transversal micrograph shown in Fig. 7 where the weld nugget and a defect with around 400 μm depth are revealed.
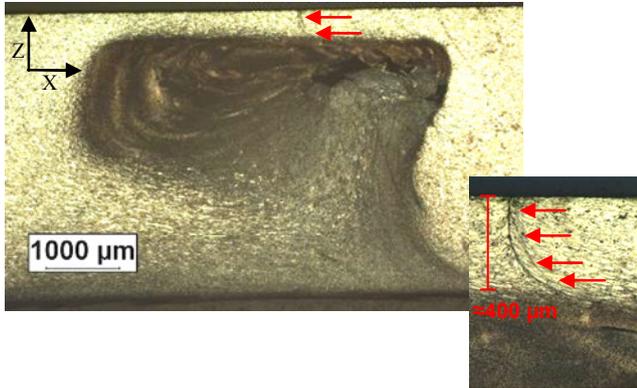

Fig. 7. Transversal micrograph of the tested FSW joint. The defect is highlighted by the red arrows.

The conductive trace was driven using a 1 A amplitude current whose frequency is equal to 1 MHz. Specifically for the presented results, the bias frequency was set to 990 kHz leading to the generation of a beat frequency component (the difference between the magnetic field frequency and the bias frequency) at 10 kHz. The measurement of this low frequency component allowed recovering the sensor output with minor influence of any unwanted inductive coupling which may have substantial amplitude.

The FSW results for SV and MTJ sensors are shown in Fig. 8 and Fig. 9 respectively. A two dimensional sweep was performed on a 10×12 mm^2 surface of the FSW. In the majority of the lines across the X direction, two amplitude indications of the defect are shown. The Signal to Noise Ratio (SNR) was computed dividing the maximum amplitude by a noise estimate in a defect free sweep segment.
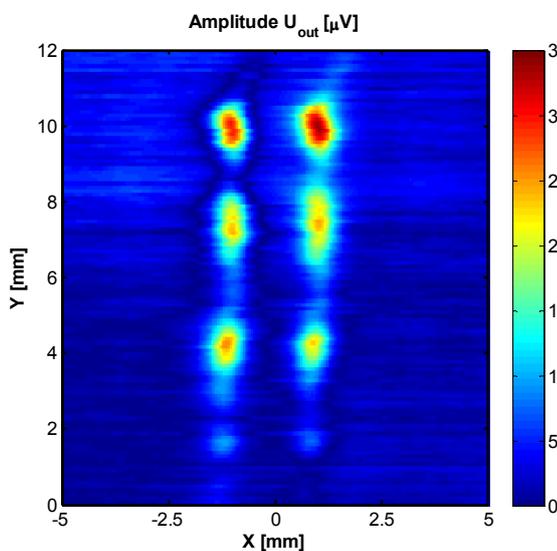

Fig. 8. FSW testing results using the SV sensors.

Comparison between the results of Fig. 8 (SV) and of Fig. 9 (MTJ) shows a better, clearer image in the result with MTJ sensors. For the SV sensors the SNR value is 39.6 dB while for the MTJ sensors it is 45.2 dB.
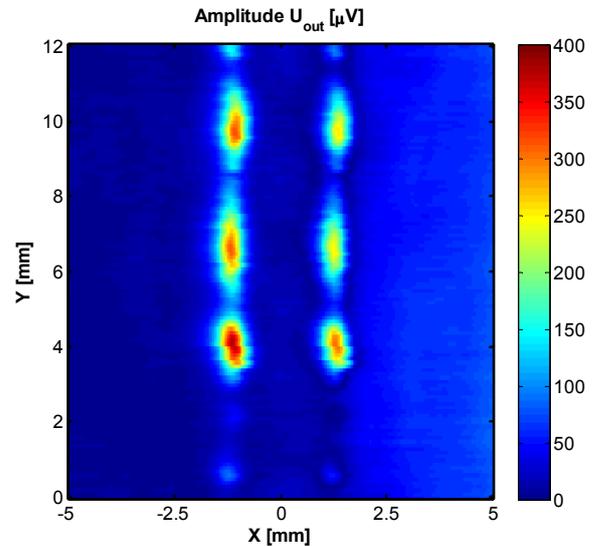

Fig. 9. FSW testing results using the MTJ sensors.

In Fig. 10, two profiles obtained with the SV and MTJ sensors are shown. These profiles correspond to the results of Fig. 8 and Fig. 9 at Y = 10 mm. It can clearly be seen the considerable amplitude difference between the two different MR sensors technologies. This means that the requirements to measure the MTJ sensor outputs are less strict than thos needed to measure the SV sensors outputs.
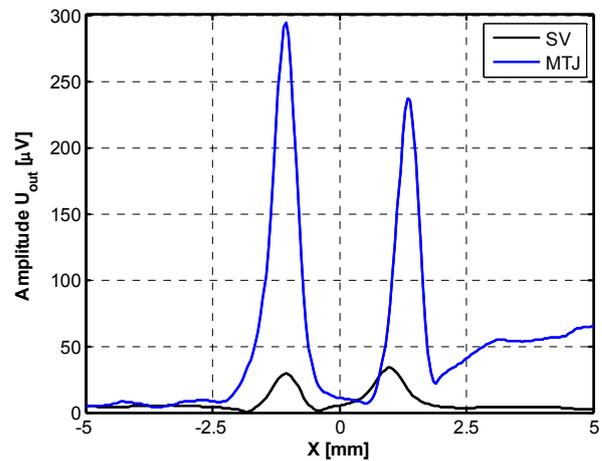

Fig. 10. Comparison of the measured output voltages for the SV and MTJ sensors. These profiles correspond to the cases displayed in Fig. 8 and 9 at Y = 10 mm.

4. CONCLUSIONS

Two different MR sensors technologies were evaluated and compared in a similar configuration of eddy current probe. The results using MTJ sensors showed better performance than SV sensors: (i) an SNR improvement of 6 dB and (ii) a signal amplitude increase of more than 10 times were observed.

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