

Using Giant Magneto-Resistance Sensors in Remote Field Eddy Current Tube Inspection

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Abstract- This paper presents a remote field eddy current probe that includes a giant magneto-resistance (GMR) as magnetic sensor in order to detect longitudinal and circumferential defects in stainless steel tubes. The high sensibility of the GMR sensor in a large frequency range (0 Hz – 1 MHz) allows us to consider that it can be a good candidate to analyze several defects in tubing by a remote field testing method. Experimental data were acquired by a measurement system to verify the sensibility of the GMR in defect detection and to create a new probe. In this work, simulations were also made in order to verify the veracity of the obtained experimental results.

I. Introduction

Eddy current testing (ECT) is a method used to inspect metal discontinuities in non-ferromagnetic tubing. This method is suitable for detecting defects caused by corrosion, erosion, wear, pitting, baffle cuts and wall loss. The technique requires a coil excited with a time-varying current to produce a magnetic field that penetrates the tube, inducing currents in the material which are approximately in phase opposition with the primary excitation current. These currents are called eddy currents. The current flow changes in the presence of a defect and the magnetic field produced by it also changes. These changes can be measured and used to detect defects in the tube.

The remote field testing (RFT) is a method that can be applied with eddy currents in order to find defects in steel pipes and tubes. In theory, the remote field testing is based on the through-wall indirect coupling that allows the propagation of the waves both inside and outside of the tube. This propagation reduces the attenuation of the magnetic field along the tube making it an attractive non-destructive testing (NDT) for the analysis of several defects (corrosion, erosion, wear, pitting, baffle cuts and wall loss). An RFT probe is moved inside the tube wall to detect internal and external discontinuities with approximately equal sensitivity.

In this paper, a candidate of probe that includes an excitation coil and a giant magneto-resistor (GMR) sensor was projected and developed in order to inspect wall tubes. The GMR provides a constant high sensibility in a wide range of frequencies (0 Hz- 1MHz) which allows us to consider an inspection of thick materials with high permeability, due to the need of using low frequency excitation to increase the depth of field penetration into the material.

II. System Architecture

Fig. 1 shows the measurement system architecture used in this work. A FLUKE 5700A calibrator is used to excite a coil with a time-varying current with constant amplitude. The magnetic sensor in use is an AA002-02 by Non Volatile Electronics. This sensor includes four GMRs configured as a Wheatstone bridge, where two of them act as passive resistors because they are shielded and the other two act as sensing elements.

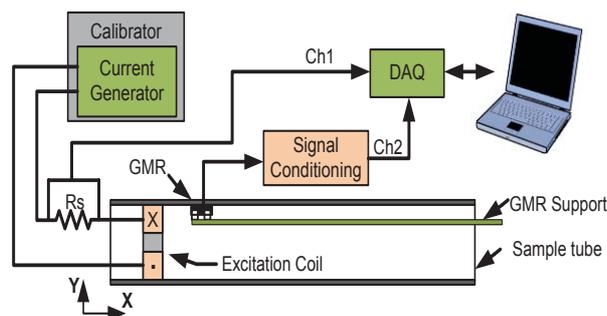


Figure 1. Experimental Setup.

The sensor provides a high and constant sensibility in a large frequency range along its axis. The output of the sensor is differential and the signal conditioning includes two capacitors to cutoff the DC component and an instrumentation amplifier INA118 from Texas Instruments with 40 dB of gain. A Matlab application is used in a personal computer to manage the system operation. It controls the acquire data of the GMR output voltage and the excitation current through the DAQ. It also processes the acquired signals in order to convert the data to the SI unit system.

III. Simulation Result

A commercial 3D finite element model (FEM) simulation software was used to obtain simulated data to compare with the data obtained by the experimental setup. Fig.2 represents the several operating zones that exist when the remote field testing method is applied. In RFT inspection, the direct zone has an intense varying magnetic field from the excitation coil which doesn't allow the detection of the defect. The transition zone is where the excitation field is replaced by the field produced by the eddy currents, which is in phase opposition with the excitation, resulting in minimum magnetic field amplitude in this zone. The remote zone is the region where the sensed magnetic field is only produced by the eddy currents. Hence, this is the best zone to place the magnetic sensor.

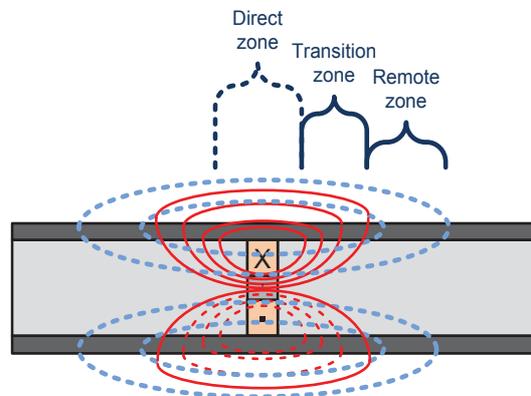


Figure 2. The several operating zones in RFT.

The simulated data depicted in Fig.3 shows the obtained magnetic flux density according to the distance between the excitation coil and GMR sensor, along the inner and outer tube surfaces without defect. The simulation was made considering a stainless steel tube (AISI 304) and the applied excitation current was 200 mA at 5 kHz.

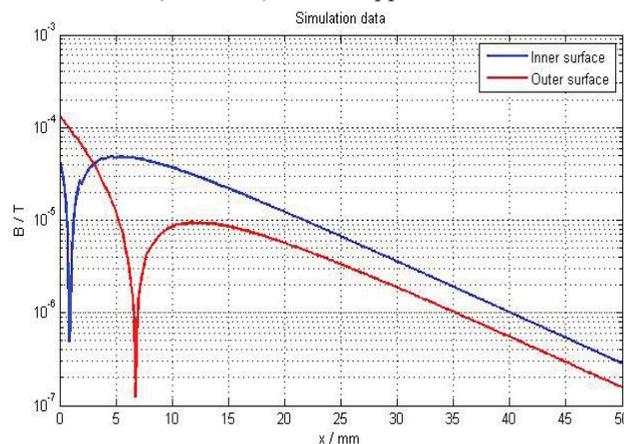


Figure 3. Simulated magnetic field obtained with the finite element model.

The simulation data represented in Fig.3 shows clearly the separation between zones. Observing Fig.3 it is possible to conclude that the distance between the excitation coil and the GMR sensor should be around 15 mm to ensure that the captured field is from the remote zone, with minimal attenuation. It should be noted that several simulations were made with different excitation frequencies (1-100 kHz) and the position of the minimum magnetic field amplitude in the transition zone was not frequency dependent.

IV. Experimental Results

The first experimental test was made by scanning a stainless steel tube (AISI 304), moving the GMR along a tube without defect, inside and outside the wall in order to obtain the magnetic flux density. The obtained results are depicted in Fig.4.

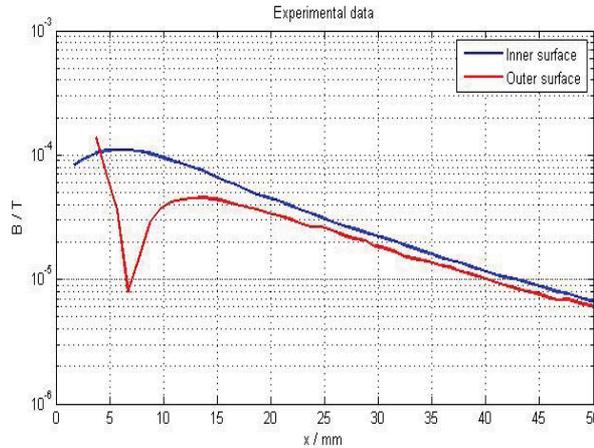


Figure 4. Experimental magnetic field obtained with the setup represented in Fig.1.

As expected, the experimental results to obtain the magnetic flux density are similar to the simulation results. In the experimental data the separation is not so clear because it was difficult to locate the detector in the proximity of the excitation coil. In fact, for the geometry under analysis it is verified that the transition between zones is very close to the excitation coil. Experimentally, it is also possible to conclude that the distance between the excitation coil and the GMR sensor is slightly bigger than the simulated distance. Hence, the chosen distance was 17.5 mm. The created probe structure is depicted in Fig.5.

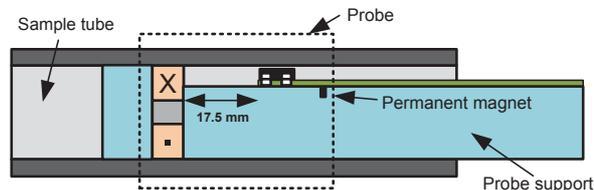


Figure 5. The constructed RFT probe structure.

The next experimental results were obtained by scanning three stainless steel tubes (AISI 304), moving the probe inside the wall tubes. The first tube is a sample without defect. The other two samples are depicted in Fig.6 and include a machined longitudinal defect and a circumferential defect also machined along the wall of the tube.



Figure 6 - Sample tube with longitudinal and circumferential defects machined with 1 cm of length.

The magnetic flux density obtained by scanning a stainless tube with a circumferential defect is compared with a scan without defect in the left side of Fig.7. The phase difference of those magnetic fields in relation to the excitation current is represented in the right side of the same figure. It should be noted that the applied excitation was made by a sinusoid with fixed voltage amplitude at 25 kHz.

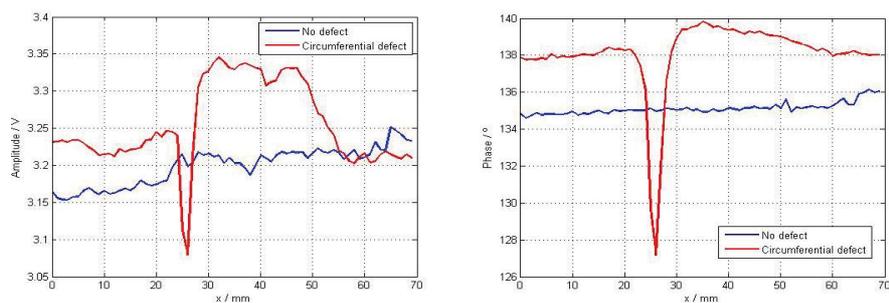


Figure 7. GMR output amplitude and phase with circumferential defect and with no defect.

The experimental data represented in Fig.7 shows the amplitude and phase perturbation at 27 mm that matches the position where the GMR passed over the defect. The amplitude variation around this position is about 0.25 V and the phase variation is about 10°.

The same comparison with a longitudinal defect is depicted in Fig.8.

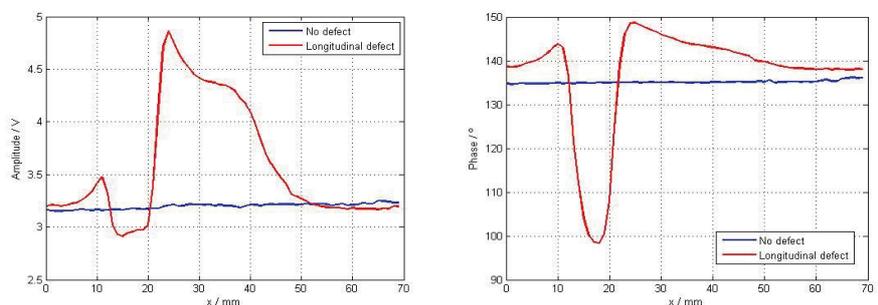


Figure 8. GMR output amplitude and phase with longitudinal defect and with no defect.

Observing Fig.8 it is possible to conclude that an amplitude perturbation and phase perturbation is present between the positions 10 mm and 23 mm that matches the defect position. The amplitude variation around these positions is about 2 V and the phase variation is about 40°. Hence, it is possible to conclude that it is easier to detect the longitudinal defect than the circumferential defect.

In both cases, the observed perturbation after the defect positions is due to the passage of the excitation coil over the defect, which changes the coil's impedance affecting the excitation magnetic field. This effect is due to the fixed amplitude voltage of the excitation signal.

V. Conclusions

The GMR embedded in the probe to work as a magnetic sensor proved to be able to detect defects in stainless steel tubes. The experimental results obtained show that it is possible to detect longitudinal and circumferential defects in tubes. As expected, a longitudinal defect is easier to detect than a similar dimension circumferential defect due to the orientation of the GMR and the direction of the induce eddy current by the excitation coil. Simulations were also presented to confirm the veracity of the experimental results measured by the GMR sensor. The information obtained with the experimental setup allowed us to choose the best distance between the GMR and the excitation coil for optimal defect detection. As future work we consider using other methods in conjunction with the presented method to improve the detection in characterization of the defects.

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