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Detection capabilities evaluation of the advanced sensor types in Eddy Current Testing

***Abstract**. The purpose of this paper is to compare performances of various sensing elements in eddy current non-destructive inspection. A new eddy current testing probe is designed to compare detection and resolution capabilities of different sensors. Four magnetic sensors, specifically GMR (1D and 3D- sensor), AMR, Fluxgate, and a standard induction coil are used as a sensing element. For comparison of these sensors the numerical simulations and experimental measurements are performed under the same conditions. The results are presented and discussed in the paper.*

Streszczenie.** W artykule umieszczono wyniki porównania czujników wykorzystywanych w defektoskopii wiroprądowej. Autorzy dokonują porównania przy pomocy próbnika własnego projektu, badając czujniki: GMR, AMR, czujnik pola magnetycznego i standardową cewkę indukcyjną. Dodatkowo zostają wykonane symulacje numeryczne odzwierciedlające wykonane pomiary. **(Ocena zdolności detekcyjnych czujników używanych w defektoskopii wiroprądowej)

Keywords: inductance coil sensor, giant magneto resistive sensor, anisotropic magneto resistance sensor, fluxgate sensor, 3D sensor.
Słowa kluczowe: in the case of foreign Authors in this line the Editor inserts Polish translation of keywords.

Introduction

Non-destructive evaluation (NDE) methods enable the detection of inhomogeneities in materials and characterizing their properties without impairing function of the material [1]. Electromagnetic NDE by means of eddy current (EC) offers various advantages compared to the others NDE techniques. EC testing is based on the electromagnetic induction principle. Changes in the coil impedance (self inductance sensor) or in the induced voltage (mutual inductance sensor) due to a presence of discontinuity are sensed during mechanical movement of a sensor over an inspected region of a material. Traditional eddy current testing methods based on excitation-detection coils is fundamentally limited by the lower sensitivity of the detection coils at low frequencies, [3]. Nowadays, different types of magnetic detection elements such as Hall sensors, SQUID, GMR, Fluxgate, AMR and others have been employed in order to increase the detection probability and the sensitivity. The shape, cross-section, size and configuration of coils and sensing elements have been varied to design an eddy current probe for a specific application [2], [3], [4], [5].

The magneto-resistive (MR) sensors offer a good trade-off in terms of performance versus cost. They have small dimensions, high sensitivity over a broad range of frequency (from hertz to megahertz domains), low noise, they operate at room temperature, and are inexpensive. It has been demonstrated that the MR probes perform better than conventional probes for low-frequency applications, e.g. when detecting deeply buried flaws [10], [12]. This is because the electromagnetic sensors are sensitive to the magnitude of the magnetic field. In the case of inductive-based probes, the output voltage is proportional to the time variation of the magnetic field, therefore, their sensitivity is reduced at low frequencies.

The paper compares four types of the 1D sensing elements: inductance coil, Fluxgate magnetometer, Anisotropic MagnetoResistance (AMR) sensor, Giant Magneto Resistive (GMR) sensor - for detection of surface cracks. Comparison of the 1D sensing and 3D sensing is discussed too. For this purposed the new 3D GMR- based probe for ECT is designed. The reason for such study is to show that the higher information content about the inspected flaws can be obtained using 3D components sensing in comparison to 1D sensing. Numerical simulations as well as experimental measurements are carried out to compare their properties.

Numerical investigation

Numerical simulations based on the FEM using the OPERA 3D software are carried out. Conductive plate specimen with a thickness of h = 10 mm and having the EM parameters of the stainless steel SUS316L (σ = 1.35 MS/m, μ_r = 1) is inspected in this study. The specimen contains five non-conductive defects with the rectangular shape as shown in Fig.1. The plate has the cracks with a width of w_c = 0.2 mm, a length of l_c = 10 mm and their depth d_c is varied in a range 1÷9 mm with a step of 2 mm. New ECT probe is designed for this study. It consists of two exciting coils that are positioned normally to the surface of inspected material apart from each other.

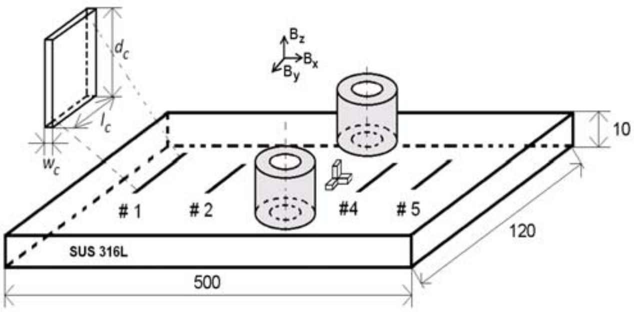

Fig.1. Spatial configuration of the specimens with defects.

High sensitivity of a pick-up circuit can be adjusted in such case. The coils are positioned 1 mm above a plate specimen. The exciting coils are driven by the harmonic current with a frequency of f = 1 kHz. Three spatial components of the magnetic field density vector at the middle point between the exciting coils are taken as the response signals. The response signals are sensed for one dimensional scanning above a defect along its length.

Experimental investigation

Experimental measurements are performed under the same conditions as the numerical simulations. The plate specimen shown in Fig. 1 made of SUS316L with five EDM notches is inspected using the newly designed ECT probe. Two exciting coils with self inductances of L_1 = 0.44 mH, L_2 = 0.41 mH are connected in anti-series. The commercially available magnetic sensors (Sensitec, Canon) are used as the 1D sensing elements. Fluxgate, AMR (AFF755) and GMR (GF708) sensors are supplied by voltage of 5V DC. For 3D sensing new 3D - GMR sensor is designed. Three GMR sensing elements in special configuration are used to pick-up the response signals in each axis. One dimensional scanning is performed over each crack along its length in a range <-30 mm, 30 mm> relative to a crack centre.

Numerical and experimental results

Results of numerical simulations and the realized experiments are presented in this section.

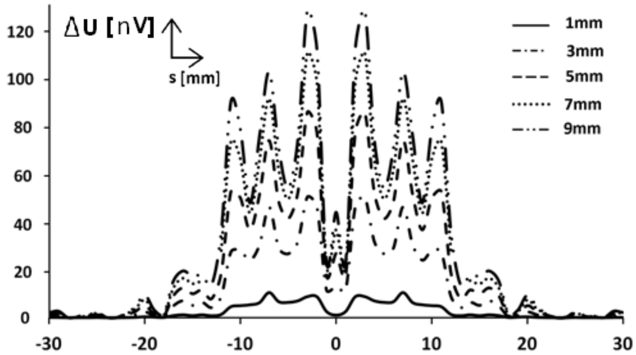

Fig.6. Numerical results - X component.

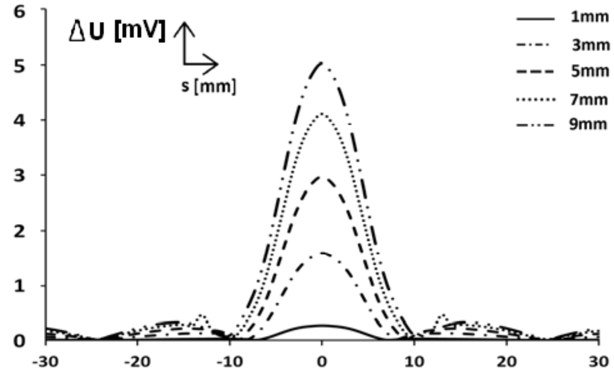

Fig.7. Numerical results - Y component.

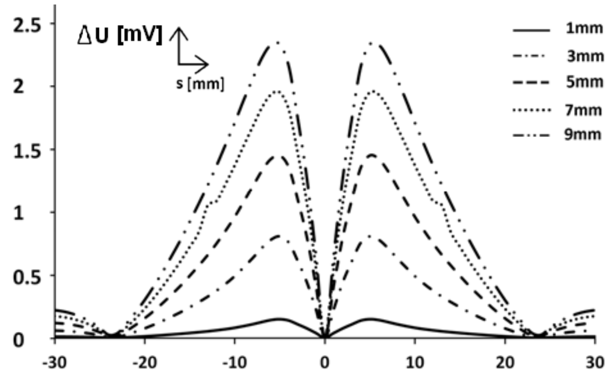

Fig.8. Numerical results - Z component.

It is possible to observe from the numerical simulations, Fig. 6, 7, 8 that all cracks are clearly detectable and the response signals from the cracks with different depth are well separated only for components Y and Z. It should be noticed that the numerical results are gained under ideal conditions. Practical experiences are summarized in the next section. Figures 6, 7, 8, 9, 10 and 11 display the GMR sensors' response signals magnitude on the probe position relative to the crack centre for the near side inspection.

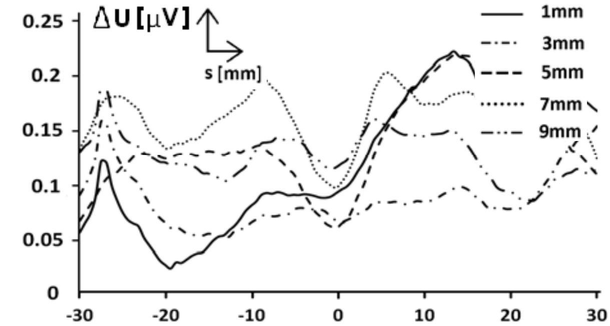

Fig.9. Experimental results - 3D GMR sensor - X component.

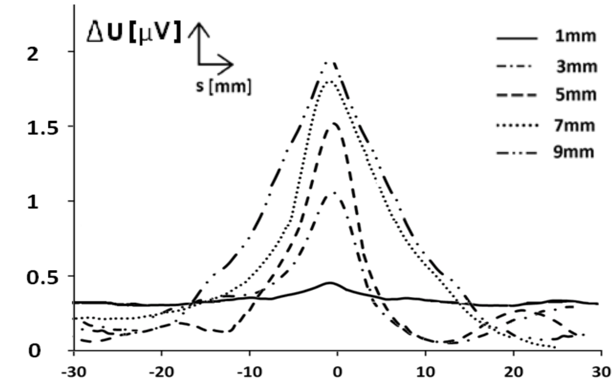

Fig.10. Experimental results - 3D GMR sensor - Y component.

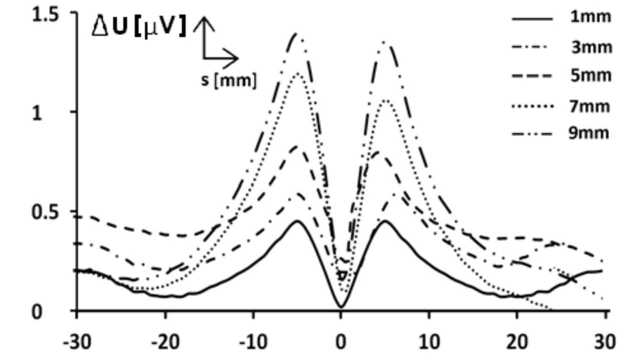

Fig.11. Experimental results - 3D GMR sensor - Z component.

It can be observed that the numerical results coincide well with the experimental ones except the result for the X-component. This discrepancy is caused due to very low measured values of the sensed signal, below the sensitivity of the sensor (typical sensitivity is 130mV/V/mT). The individual Y and Z - component signals for all the defects are well-separated from each other. Other differences between the simulation and the experimental results are caused by the wobbling noise.

The experimental results proved findings from the numerical simulations that it is possible to detect defects using developed ECT probes. Because each measurement was realized under the same condition the comparison of the selected sensors could be realized. The experimental results fig.11, 12, 13, 14 shows that the detection capability of each sensor is almost similar for the detection of surface cracks. In spite of very high sensitivity to magnetic field measurements of the GMR, AMR, Fluxgate sensor, the experimental results show that the inductance coil has under the same conditions the same sensitivity to surface cracks.

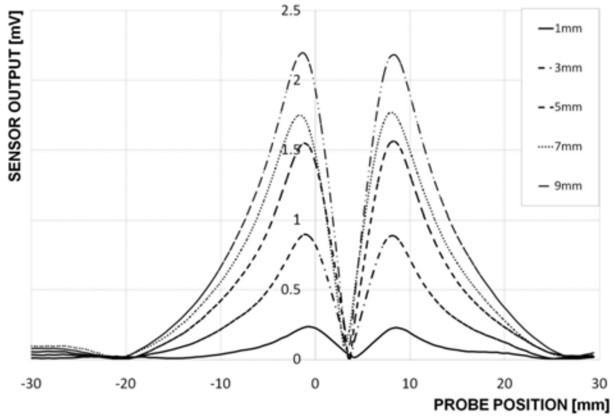

Fig.12. Experimental results – Inductance coil.

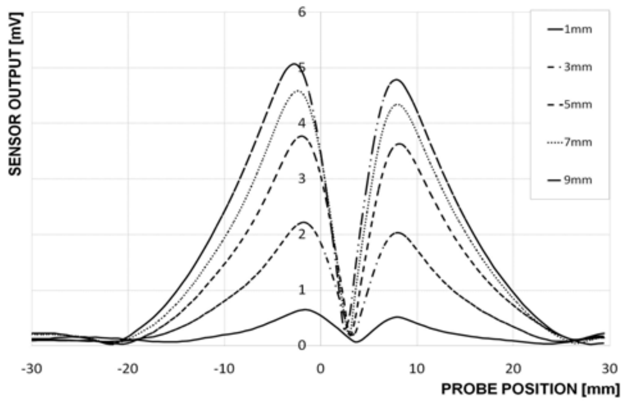

Fig.13. Experimental results – Fluxgate sensor.

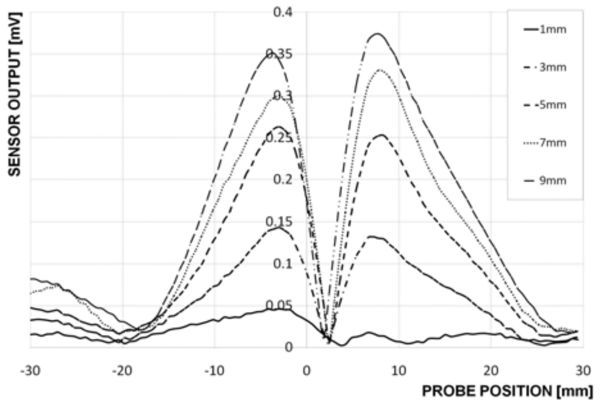

Fig.14. Experimental results – AMR sensor.

Concerning the resolution between the cracks with various depths from the ECT response signals it can be seen that the inductance coil is less sensitive to improper adjustment of the probe movement.

Conclusion

The paper concerned on comparison of different sensors for detection and resolution of surface defects in nonmagnetic conductive material using eddy current testing. A plate specimen having several notches with different depths was inspected with a special eddy-current probe driving uniform eddy currents. Several 1D sensing elements, specifically AMR, GMR, Fluxgate and the standard inductance coil, and one 3D - GMR sensor were used separately to pick-up the cracks' response. The results presented in the paper proved that when the capabilities of the sensors are compared to the ones of an inductance coil, one gets comparable performance when the testing is carried out under same conditions. In real environment the magnetic field sensors provide slightly better sensitivity comparing to the inductance coil. It is caused by a fact that the inductance coil senses the integral value of the magnetic field and thus it is more sensitive to the EMI than the sensors which senses the differential value of the magnetic field. However, the magnetic sensors are more sensitive to lift-off variations comparing to the inductance coil.

Comparison of 1D sensors and 3D sensors - With respect to the results, it can be concluded that sensing of the three spatial components of the magnetic perturbation field does not provide more information. It is sufficient to sense only one component perpendicular to the scanning direction. Also, both perpendicular components provide almost the same information. The component parallel to the scanning has the lowest information value when scanning above a crack just along its length. Of course, due to the dimensions and sensitivity of the GMR sensors, it is possible to perform ECT inspection with high spatial resolution. On the other hand, it is more difficult to manipulate with the sensors inside the probe due to the balancing each of them in the middle of the excitation coils.

Acknowledgement

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