

# Comparison of flux leakage transducers used for evaluation of stress loaded materials

T. CHADY\*, G. PSUJ, S. NAGATA<sup>a</sup>

*Department of Electrical Engineering, Szczecin University of Technology, ul. Sikorskiego 37, 70-313 Szczecin, Poland*

*<sup>a</sup>Faculty of Engineering, University of Miyazaki, 1-1 Gakuenkibanadai-nishi, Miyazaki, 889-2192, Japan*

In this paper several concepts of transducers were proposed to measure magnetic flux leakage. Different configurations of transducers' pick-up section and magnetizing section were used. Differential and absolute GMR were applied as field sensing elements. The measurements were done on stress loaded planar specimens made of low carbon steel (SS400). Obtained results are presented and compared.

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## 1. Introduction

The magnetic flux leakage method of nondestructive testing finds widespread use in a number of industries. It is based on a detection of leakage fields, caused by a change in the reluctance of ferromagnetic materials, which are magnetized in a DC field. The method is very sensitive and therefore even minor changes of material properties can be observed. The magnetization of a tested material can be achieved using a permanent magnet or a coil driven by a DC current. The leakage magnetic fields are then measured by scanning a surface of the specimen with a flux density sensitive transducer. In this paper results obtained by method in which the specimen was magnetized prior to the experiment are compared with the results achieved using transducer having integrated magnetizing circuit. Several configuration of pick-up section consisting of differential or absolute GMR elements were also investigated. All measurements were carried out using the universal computerized NDT system shown in Fig. 1.

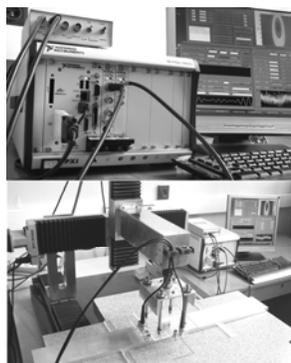


Fig. 1. Photo of the compact measuring system and the XYZ scanner.

## 2. Measuring methods

During experiments two methods of measurements were considered (Fig. 2). In the first method tested samples were magnetized by a DC field before

measurements. Next, the surface of specimen was scanned with the pick-up transducer. In this case, an important task is to obtain a uniform magnetic field during the magnetization of a tested object. If such condition is not fulfilled, significant growth of a probability of false call and fall of probability of detection can be observed. As a result, wrong estimation of a material's degradation stage is achieved. This is why a concept of an integration of a magnetizing section with a pick-up section is appeared (Fig. 2). Such construction allows to magnetize only the area, where the measurement will be taken in the next step. The magnetizing unit consists of a coil wound on a rod ferrite core. The whole magnetization section is placed in a front of the pick-up transducer. The integrated transducer can be more easily applied in practical cases. Moreover, the sensitivity of this type transducers does not depend on a geometrical shape of the tested specimen.

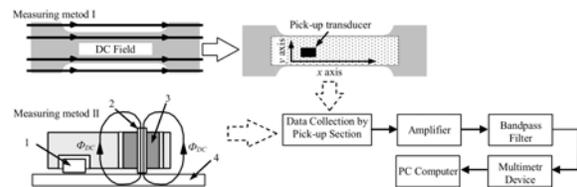


Fig. 2. Schematic view of measuring methods, measuring system and transducer (1 – pick-up section; 2 – rod ferrite core; 3 – excitation coil; 4 – test sample).

## 3. Transducers

Several configurations of pick-up sections of the transducers were investigated in order to find the optimal construction of the measuring unit and enhance performance of the system. Absolute (NVE AAH001–02) and differential (NVE ABH000–01) GMR elements were used as the pick-up transducers. The AAH – series sensor is made of high sensitivity GMR elements and is very suitable to measure low magnetic fields [2]. The ABH – series sensor is extremely sensitive to the gradient of magnetic field. In order to select an optimal construction four transducers with different configuration of pick-up

sections were evaluated (Fig. 3): P\_ABS – transducer consisting a single absolute GMR, P\_GRAD – transducer with a gradiometer GMR, P\_DIFF1 – transducer consisting of two differentially connected absolute GMR placed one by another and P\_DIFF2 – transducer consisting of two differentially connected absolute GMR placed one over another.

**4. Experiments**

All measurements were carried out on planar specimens made of SS400 low carbon steel. Each sample were tensile deformed in longitudinal direction using a different value of stress (scanning axis x). More information about the samples can be found in [1]. The transducers were supplied in two different ways. First a DC source (6 V battery) was used. In selected cases an AC sinusoidal generator was utilized as an alternate supply. In this case the measured signal was filtered using band-pass filter to reduce noises. Then, the measured signals were digitalized by an AD converter and analyzed using a dedicated software written in MATLAB®. Selected results of measurements are shown in Fig. 4 – Fig. 10.

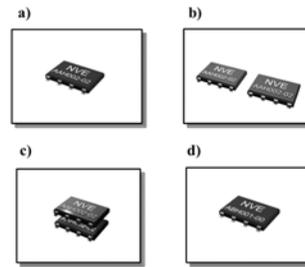


Fig. 3. Pick-up sections of the transducers used in experiments: a) P\_ABS – with a single absolute GMR, b) P\_DIFF1 – with two differentially connected absolute GMR placed one by another, c) P\_DIFF2 – with two differentially connected absolute GMR placed one over another, d) P\_GRAD – with a gradiometer GMR.

In order to compare performance of various transducers results of measurements obtained for samples stressed up to different level are presented. Figs. 4, 6, 8 are showing the measured signals, while Fig. 5, 7 and 9 are showing gradient of the signals. Gradient operation allows to enhance fine details of images and observe the differences.

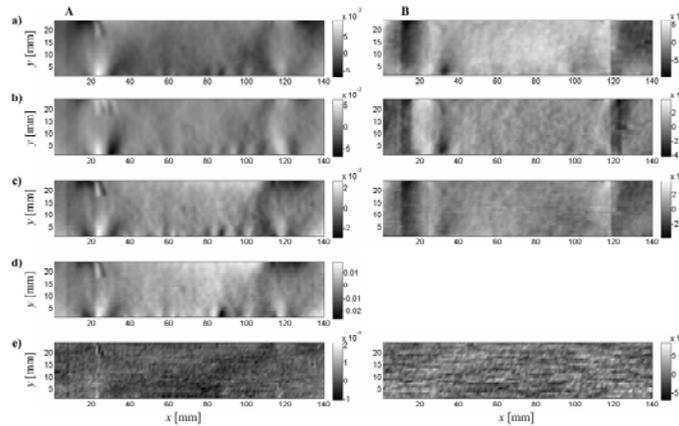


Fig. 4. Signals obtained for sample loaded below material’s yield point (strain  $\epsilon = 1,2\%$ ): a) P\_ABS transducer; b) P\_DIFF1 transducer; c) P\_DIFF2 transducer; d) P\_DIFF2 transducer with AC supply signal; e) P\_GRAD transducer; column A – uniform magnetization of a test sample using a solenoid; column B – local magnetization utilizing coil driven by a DC current.

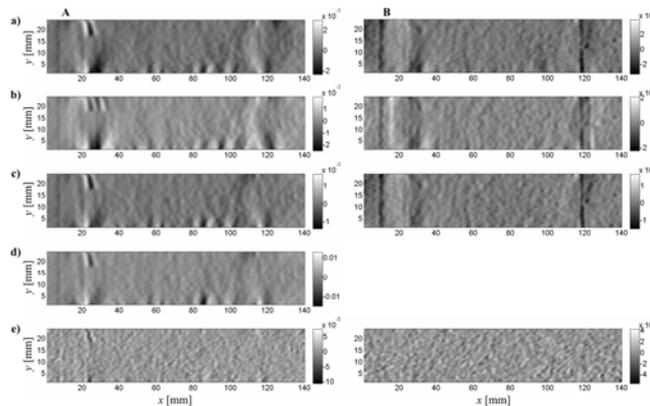


Fig. 5. Gradient of signals obtained for sample loaded below material’s yield point (strain  $\epsilon = 1,2\%$ ): a) P\_ABS transducer; b) P\_DIFF1 transducer; c) P\_DIFF2 transducer; d) P\_DIFF2 transducer with AC supply signal; e) P\_GRAD transducer; column A – uniform magnetization of a test sample using a solenoid; column B – local magnetization utilizing coil driven by a DC current.

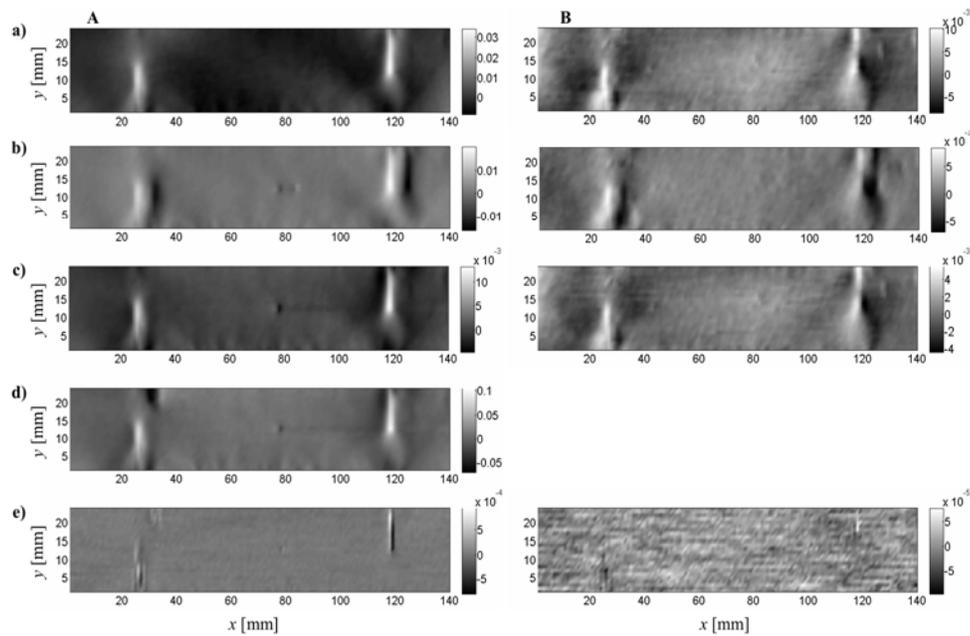


Fig. 6. Signals obtained for sample loaded below material's yield point (strain  $\varepsilon = 1,5 \%$ ): a)  $P\_ABS$  transducer; b)  $P\_DIFF1$  transducer; c)  $P\_DIFF2$  transducer; d)  $P\_DIFF2$  transducer with AC supply signal; e)  $P\_GRAD$  transducer; column A – uniform magnetization of a test sample using a solenoid; column B – local magnetization utilizing coil driven by a DC current.

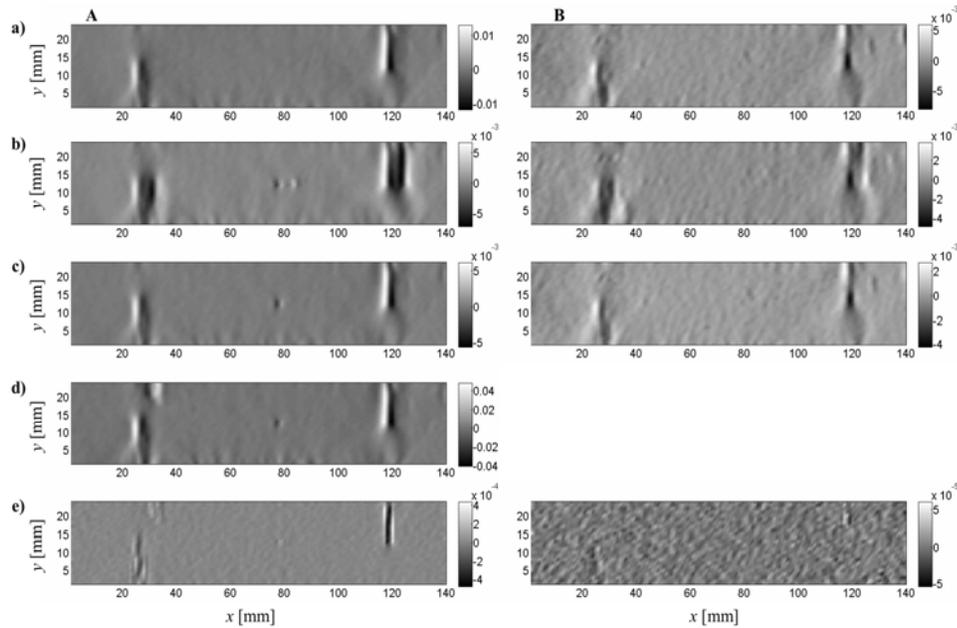


Fig. 7. Gradient of signals obtained for sample loaded below material's yield point (strain  $\varepsilon = 1,5 \%$ ): a)  $P\_ABS$  transducer; b)  $P\_DIFF1$  transducer; c)  $P\_DIFF2$  transducer; d)  $P\_DIFF2$  transducer with AC supply signal; e)  $P\_GRAD$  transducer; column A – uniform magnetization of a test sample using a solenoid; column B – local magnetization utilizing coil driven by a DC current.

Taking into consideration the sample loaded below material's yield point (strain  $\varepsilon = 1,2 \%$ ) one can observe that:

- different elements of material's structure are enhanced using uniform magnetization and local magnetization,

- the highest sensitivity was achieved in case of the transducers  $P\_DIFF1$  and  $P\_DIFF2$ ,
- the transducer  $P\_DIFF2$  offers high sensitivity but interpretation of the achieved signals is more complicated that in case of  $P\_ABS$  and  $P\_DIFF1$ ,

- there are no significant differences between the signals achieved using DC and AC power supply,
  - the transducer P\_GRAD does not allow to detect majority of the materials' changes.
- The further results confirm the mentioned findings. Additionally, one can observe that the transducer

P\_GRAD has low sensitivity but on the other hand it offers very high spatial resolution. In case of heavily loaded sample (Fig. 8, Fig. 9) the local magnetization method is showing some advantages. The signal in specific measuring point is nearly independent from the neighborhood area.

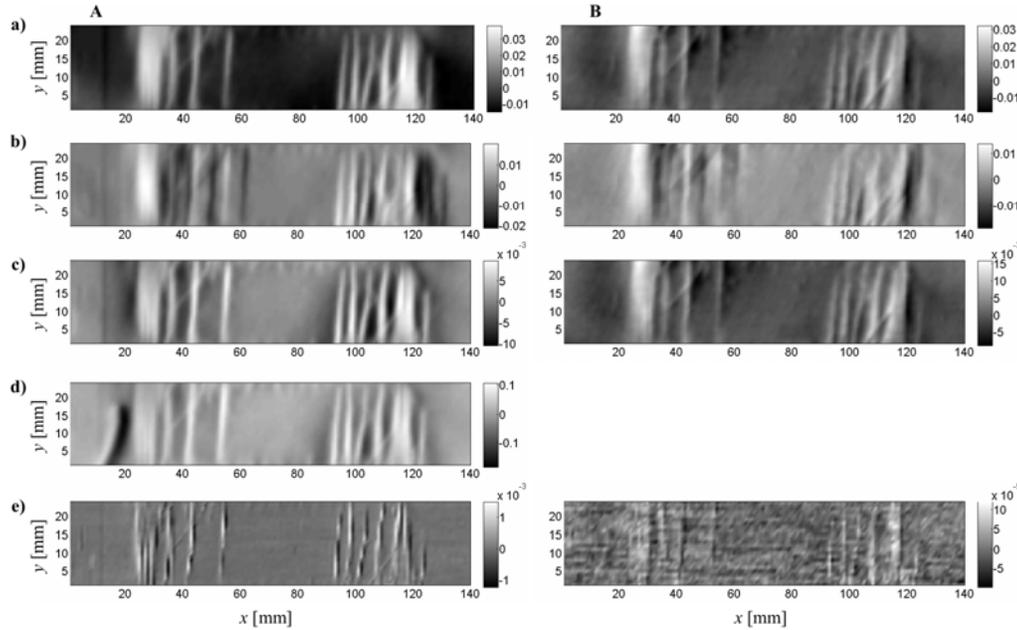


Fig. 8. Signals obtained for sample loaded close to material's yield point (strain  $\epsilon = 2,0 \%$ ): a) P\_ABS transducer; b) P\_DIFF1 transducer; c) P\_DIFF2 transducer; d) P\_DIFF2 transducer with AC supply signal; e) P\_GRAD transducer; column A – uniform magnetization of a test sample using a solenoid; column B – local magnetization utilizing coil driven by a DC current.

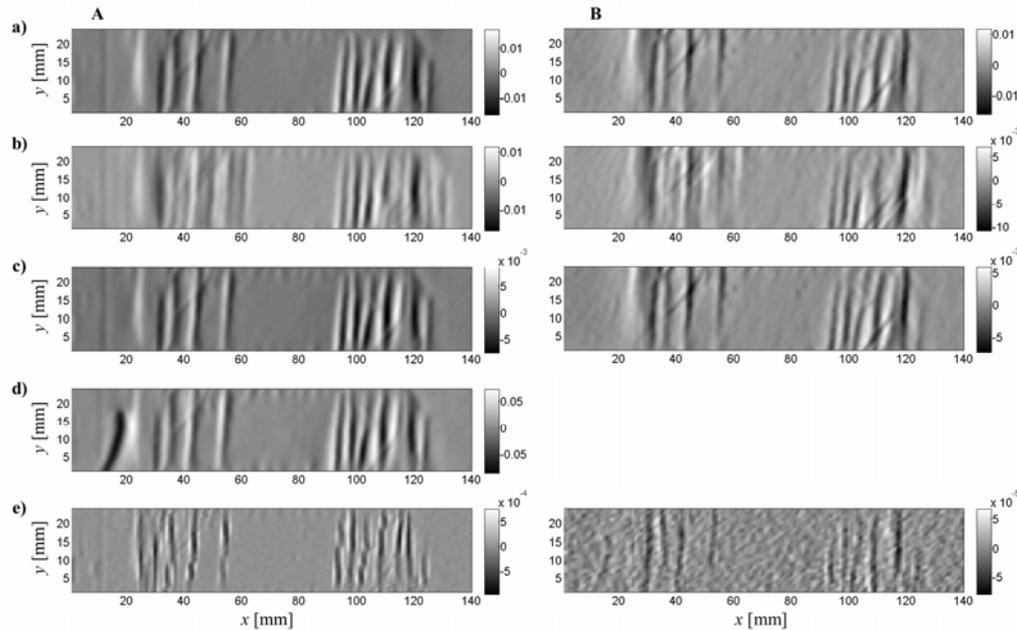


Fig. 9. Gradient of signals obtained for sample loaded close to material's yield point (strain  $\epsilon = 2,0 \%$ ): a) P\_ABS transducer; b) P\_DIFF1 transducer; c) P\_DIFF2 transducer; d) P\_DIFF2 transducer with AC supply signal; e) P\_GRAD transducer; column A – uniform magnetization of a test sample using a solenoid; column B – local magnetization utilizing coil driven by a DC current.

The highest sensitivity in case of the selected samples were observed for the transducer P\_DIFF2. Therefore, extended set of the samples were tested using this

transducer. Results of all the measurements are shown in Fig. 10.

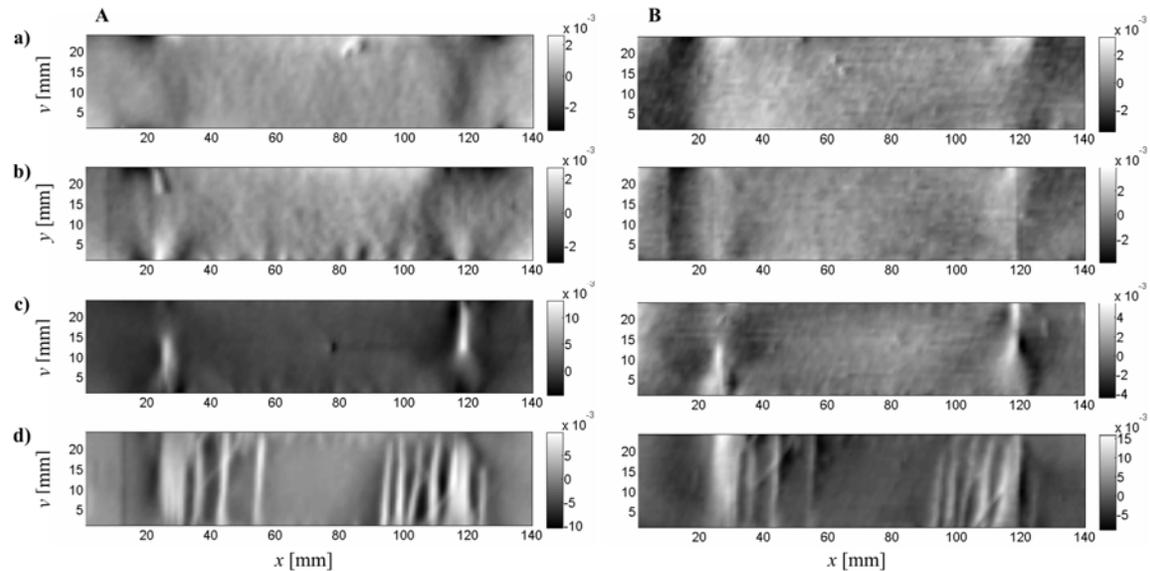


Fig. 10. Signals obtained for transducer P\_DIFF2 with uniform magnetization of a tested samples using a solenoid (column A) and local magnetization of a tested samples utilizing coil driven by a DC current (column B): a) sample unloaded (strain  $\varepsilon = 0\%$ ); b) sample loaded below materials' yield point (strain  $\varepsilon = 1,2\%$ ); c) sample loaded below material's yield point (strain  $\varepsilon = 1,5\%$ ); d) sample loaded close to material's yield point (strain  $\varepsilon = 2,0\%$ ).

## 5. Conclusions

Non of the presented transducers were offering the highest performance in all categories. The highest sensitivity was achieved in case P\_DIFF2, while the highest special resolution was observed for the transducer P\_GRAD. The local magnetization method can be an interesting alternative but further improvements should be introduced in order to enhance the sensitivity.

## Acknowledgement

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## References

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\*Corresponding author: eh@metal.ntua.gr