Modelling and construction of new detector for non-destructive magnetic testing

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ABSTRACT

The paper is oriented on modelling, construction and testing of new design of magnetic defectoscope for nondestructive inspection of pipes. This defectoscope is determined for protection of tube in steam generator of electric power station. This approach allows shifting the accuracy limit to be better than 0.3 % for internal and external defects.

Keywords: electromagnetic field modelling, magnetic measurements, sensor, nondestructive testing

1. INTRODUCTION

The nondestructive testing systems are important for the prevention of accidents. Magnetic method known as the magnetic defectoscopy has presently recognized as the most objective way of ferromagnetic wire rope assessment in the frame of steel rope inspection[1]. This method allows us to detect not only the surface breakages (broken wires, imperfections, cracks), but also the internal defects. The high accuracy of magnetic testing is directly connected with magnetization of the inspected object and the quantity of magnetic field sensors. The force exercised on a permanent magnet in a nonuniform field is dependent on the magnetization orientation of the magnet[2]. The most important parameters and properties of magnetic field detection units have been specified and described[3]. The differential type rotational magnetic flux sensor has been developed for detection of a miner reverse-side cracks[4]. An equivalent magnetic circuit of the sensor showed good agreement with experimental results. The implementation of a SQUID magnetometer in an eddy current testing system for the measurement of very thick structures of aircrafts has been presented[5]. A method proposed for computing the depth and width of simple surface cracks based on dipole model of a crack has been published[6]. The performed crack inversions show that the depth position of crack can be determined with 2% error, provided, that the crack length and with are measured independently. The new possibilities bring two-dimensional testing system, which has been applied to steel sheet inspection[7].

2. THEORETICAL

The physical principle of magnetic testing is based on the generation of secondary magnetic field, which is created by magnetized body. The flux lines of magnetized object do not all cross the defect area directly. It means generally that the longitudinal and radial components of magnetic field are observed.

The described new version of nondestructive device can be characterized in model by the model of yoke. In previous paper we applied this yoke method and the sensitivity condition for geometrical parameters of magnetized element and sensing unit have been specified[8].

The mathematical analysis of nondestructive testing unit is based on Maxwell equations. FEM (Finite Element Method) has been performed in the combination with ANSYS software package. The first models have been realized in the frame of 2D geometry with cylindrical symmetry. In these cases the magnetic field is represented by the vector potencial quantity. As regard the geometrical profile the defectoscope the application of 3D model with scalar potencial formulation has been shown more accuracy[9]. Figure 1 demonstrates the example of 3D magnetized unit model.

3. FUNDAMENTAL PARTS OF DEVICE

The magnetic defectoscope for nondestructive testing of ferromagnetic ropes, wires, pipes and cylindrical bodies is generally completed from the following elements:

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- source of magnetic flux realized by the set of permanent magnets
- incremental measurement unit
- sensing unit completed by two (three) sensor channels
- interface box for data conversion and recording
- PC for signal processing

The magnetic defectoscop REMA 1 is shown on Figure 2. This defectoscope can inspect ropes with diameter from 18 to 60 mm. New defectoscope for testing pipes of power station is special to diameter 35 mm (Fig. 3).
The real testing equipment is presented in Fig. 3. In this figure we can see the magnetization head, twins of permanent magnet holders, and sensing unit.

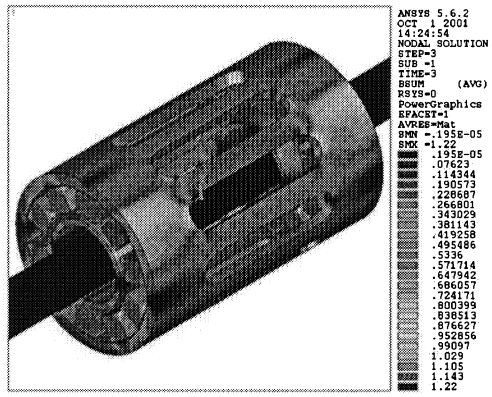


Fig. 1. Model of magnetic nondestructive defectoscope.

Fig. 2. The construction of the defectoscope with optimized level of magnetic flux in inspected body.

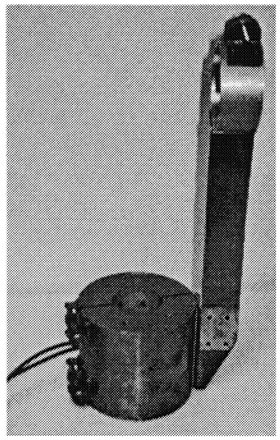


Fig. 3. Magnetic defectoscope for pipe testing with 38 mm diameter.

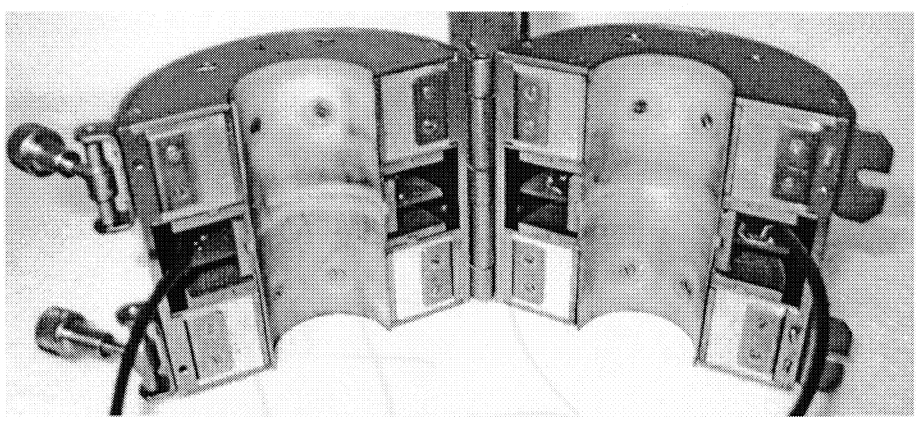


Fig. 4. Detail of magnetic defectoscope for pipe testing

For maximal relationship of output signal/noise during measurement the optimum value of magnetic flux in inspected object has to be generated. This can be solved by the modulation of magnetic resistance in magnetized circuit or by short magnetic circuit. These presented approaches can bring the difficulties as regards the resistance against environment (temperature, humidity and vibrations), linearity, and size. To avoid these difficulties the new construction of external magnetization head part has been suggested.

There is amplitude modulation of magnetic flux in measured corpus by the geometrical forming of external mantle of equipment (see Figure 2). The continuous envelope of the cylindrical magnetized body has been reconstructed on the base of mathematical modelling. The shape of the mantle can be characterized as the cage geometry with air window stripe areas. This approach enables us to modify the magnetic resistance of the magnetic field generator and in consequence of this to optimize the value of magnetic flux in diagnostic body. The discussed modulation of the magnetic flux can be amplified by the application of different ferromagnetic cartridges in air windows.

The sensing module is located inside between the poles of the magnetization head. The sensing is divided to two independent channels. One of them is used for the detection of slow decay in the cross-section of the rope (corrosion channel). The second magnetic yoke is placed inside the previous circuit (breakage channel). In the both sensing yokes are fixed Hall plates (Siemens KSY 14), which transform the magnetic field to electric voltage. The electrical signal is amplified by microamplifiers in sensing module to ensure the maximal signal/noise ratio and after is transmitted to the interface box (A-D conversion) and measuring card of PC.

The magnetic exciting circuit is equipped with rare earth permanent magnets (SmCo version), which are as the source of magnetic flux. Their coercivity is high enough to prevent demagnetization event in very strong negative magnetic fields. Using permanent magnet materials with high level of B_sH_c enables to reduce weight and volume parameters of the magnetization corpus. This process of weight reducing is supported by the new type of head mantle configuration too. The basic body of the magnetization head is made from magnetic circuit steel (AREMA).

4. EXPERIMENTAL TESTS

The sensing tests of new pipe defectoscope have been realized through the experiments with pipe etalon. This reference sample of steel pipe has been prepared with aim to confirm the indication limits the magnetic nondestructive diagnostics to internal defects. The analyzed object is completed from five welded equivalent parts of pipe where each pipe segment is characterized by six different artificial damages. The geometrical distribution of defects and completed etalon are depicted in Fig. 5, 6.

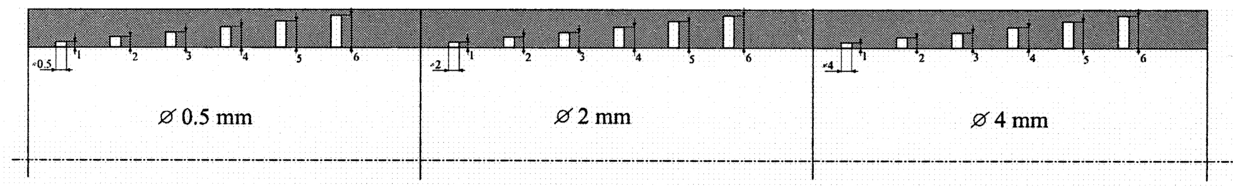


Fig. 5. The measuring etalon for the limit specification of the presented kind of defectoscope. The geometrical description (from left to right): 1-st part – 6 nicks, 0.5 mm diameter each, the depth from 1 to 6 mm, respectively, equivalent 100 mm distance between nicks; 2-nd part – the same, 2 mm diameters of nicks; 3-rd part – the same, 4 mm diameters of nicks. The thickness of pipe envelope is 7 mm.

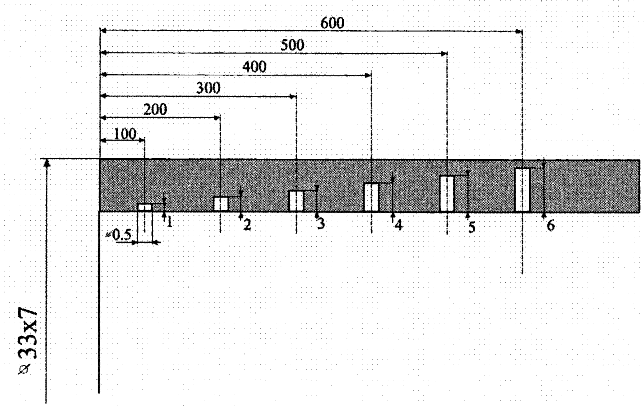
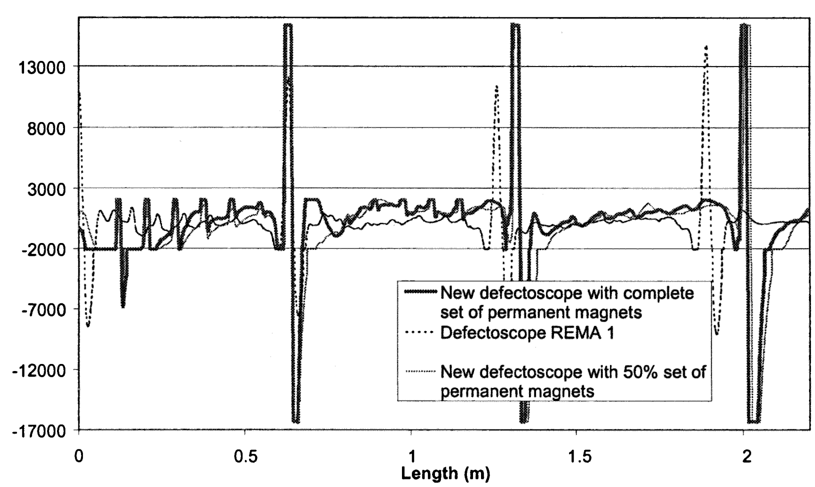


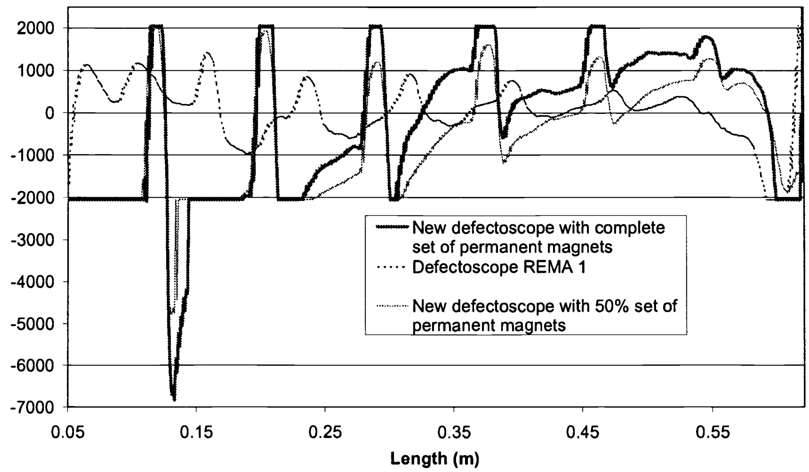
Fig. 6. Detail of the 1-st part of measuring etalon

The holes have been produced inside radially from axis to have the sample with internal cracks, which are invisible from outside by eye. After preparation of breakages in each sample segment the pipe parts have been axially welded.
The experimental arrangements have been concentrated on the comparison of the original magnetic diagnostic unit and new equipment, which was developed at Institute of Physics, TU Ostrava. The concrete results are collected in Fig. 7.

a)



b)



c)

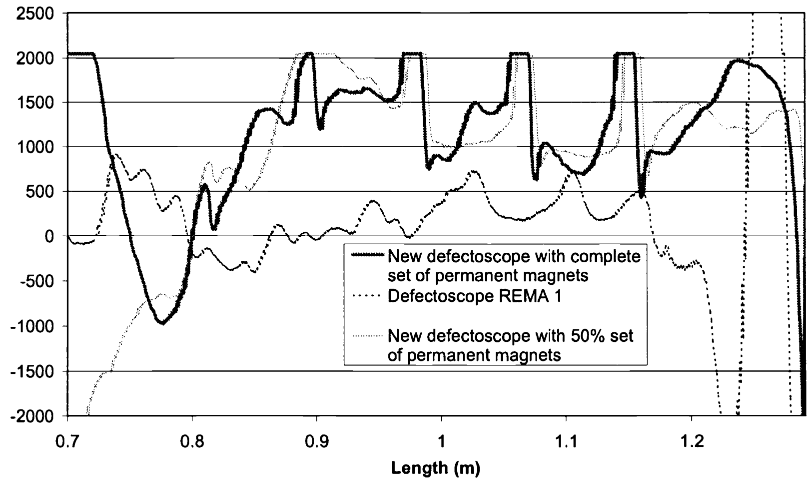


Fig. 7. Output signal from magnetic defectoscope

The solid line describes the measurement realized by the newest version of magnetic defectoscope with complete set of permanent magnets, the dot one specifies the sensitivity of the same version of defectoscope but only 50% of permanent magnets have been used to generate magnetic flux. For the comparison the signal output from REMA 1 defectoscope is demonstrated by dashed line. The three sharp high peaks (Fig. 7a) represent the welded area. The modulation of output signal between welded areas characterizes the effects of the artificial damages. The signal differences in the frame of compared discussed diagnostic units are expressive. The detail of signal output from left side and middle one of pipe etalon are shown in Figs. 7b), 7c).

5. CONCLUSIONS

From Fig. 7. we can clearly observe that the output signal of magnetic sensing unit depends on the level of inspected body magnetization. This property can be easy document by Fig. 7b). For the same sample of pipe with artificial defects the solid line curve present the results related to the newest magnetic defectoscope in which the magnetization head has been occupied by the complete set of permanent magnets . The dot line demonstrates the situation when only one half of permanent magnets inside of magnetization head is used for magnetization process. From Fig. 7b) (last peak on the right side) and Fig. 7c) (last peak on left side) we can deduct that the magnetization level of inspected body is more important for deep internal damages. The geometry of sensing units has to be in relation ship to damage size. In our case the longitudinal distance of magnetic sensing yoke has been chosen 20 mm. It means that the magnetic field which is

generated by the defect of magnetized body is approximately recorded in the frame of this length. In the case of microdefects detection for the mentioned yoke geometry we observe that the output signal amplitude is decreasing. This effect can be presented by the comparison of the right part and left one of Fig. 7a). As results we have to be very carefully during the preparation of sensing geometry and specify the axial sensor yoke distance following the defect sizes.

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REFERENCES

1. Pištora, J. M. Lesňák, J. Vlček & J. Foukal 1999. Magnetic defectoscope with permanent magnets. *J. Mag. Mag. Mat*. 196-197:283-285.
2. Kruusing, A. 2001. Optimizing magnetization orientation of permanent magnets for maximal gradient force. *J. Mag. Mag. Mat.* 234:545-555.
3. Ripka, P. & G. Vertesy 2000. Sensors based on soft magnetic materials. Panel discussion. *J. Mag. Mag. Mat.* 215-216:795-799.
4. Oka, M., M. Enokizono, T. Todaka, M. Akita, T. Chady, Y. Tsuchida, R. Sikora & S. Gratkowski 1999. High sensitive rotational magnetic flux sensing. *J. Mag. Mag. Mat.* 196-197:369-371.
5. Kreutzbruck, M. V., K. Allweins, G. Gierelt, H.-J. Krause, S. Gartner & W. Wolf 2002. Defect detection in thick aircraft samples using HTS SQUID magnetometers. *Physica* C 368: 85-90.
6. Minkov, D., J. Lee & T. Shoji 2000. Study of crack inversions utilizing dipole model of a crack and Hall element measurements. *J. Mag. Mag. Mat.* 217:207-215.
7. Tumanski S. & T. Bakon 2001. Measuring system for two-dimansional testing of electrical steel. *J. Mag. Mag. Mat.* 223:315-325.
8. Pištora, J., M. Lesňák, M. Janík & J. Foukal 2001. The short detector for magnetic testing. *Mat. Sci. Forum* 373-376 :465-468.
9. Janík, M., M. Lesňák, J. Pištora & J. Foukal 1999. Computer techniques in magnetic defectoscopy of steel wire ropes. *J. El. Eng.* 50:50-52.
10. Pištora, J., Lesňák, M., Vlček, J., Foukal, J.: Magnetic defectoscope with permanent magnets. Journal of Magnetism and Magnetic Materials, ISSN 0304-8853, vol. 196-197, 1999, pp. 283-285
11. Pištora, J., Lesňák, M., Janík, M., Foukal, J.: The Short Detector for Magnetic Testing. Materials Science Forum, ISSN 0255-5476, Vols. 373-376, 2001, pp. 465 – 468
12. ANSYS, Inc., Southpoint, 275 Technology Drive, Canonsburg, PA 15317, USA