Electromagnetic Field Simulation in Technical Diagnostics

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Abstract. An information diagnostic system is currently being developed. The system is based on electromagnetic non-destructive testing and uses a matrix magnetic converter for revealing flaws and forecasting the reliability of machines and mechanisms. The considered algorithm, which analyses magnetic non-destructive testing results, uses a dynamic type matrix magnetic transducer. To estimate crack parameters topography of magnetic leakage fields were explored. The method of finite elements is used to study the topography of the magnetic leakage field of flaws. A database has been formed for flaw type recognition, i.e. reconstruction of their form, size and position relative to weld seam. The purpose of this work is the creation of algorithm, allowing to obtain information on the topography of a magnetic field, and to optimize the speed of recognition of flaw parameters. New methods and algorithms will be developed to perform magnetic non-destructive testing and estimate the degree of danger caused by flaws to machine usage and design.

A diagnostic information system for non-destructive Magnetic Flux Leakage (MFL) examination is being developed. This system uses a magnetic matrix sensor to detect potential defects and failures of crucial elements of industrial (better than energetic) equipment, as well as to prognosticate their reliability in a cost-effective manner. The developed MFL data analysis algorithm allows to obtain a topography of the magnetic field limited only by the size of the used sensor. Nevertheless the use of specialized algorithms to treat the obtained data removes this restriction and allows testing of surfaces, areas of which exceed the size of sensor without using any special positioning devices. Fig. 1 shows a dynamic magnetic matrix sensor composed of 900 (30x30) (see page 2) magnetotransistors. Its dimensions are 8x10 mm and its resolution is about 300 mkm at a consumed current of 50 to 60 mkA.

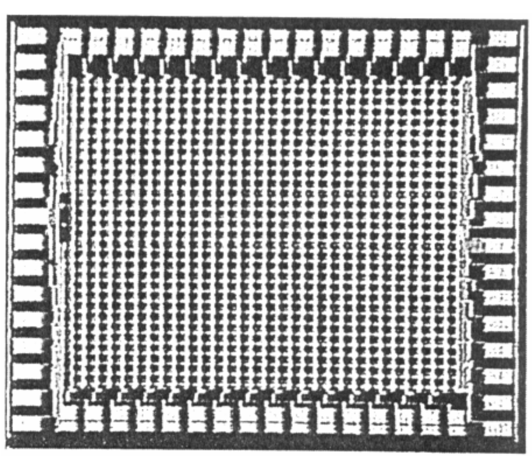

Fig.1. Matrix magnetic sensor

Non-destructive MFL examination is based on the registration of the magnetic flux leakage near a defect. The most common defects revealed by the MFL method are cracks on the surface of a tested object. The magnetic flux ΔΦ, created by a defect (Fig. 2), emerges from the surface and is detected by the magnetic flux sensor. However, the detection alone allows only to establish the presence of a defect. The method proposed in this work is designed to identify the defect parameters required to estimate the usability of the tested object and the dangers associated with its use.

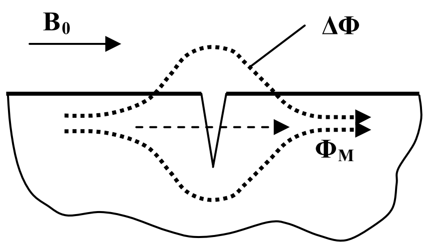

Fig.2. Magnetic flux, measured by a magnetic sensor

From the results of the analysis of the MFL topography, it is possible to draw conclusions about the existence and the type of defect on the surface of the tested object. The algorithm used to treat MFL testing data is demonstrated using the example of a crack detected on the surface of a nut. Fig.3 shows the position of the nut during the examination of one of its sides. The crack on the analyzed surface causes a magnetic field deformation to occur, the normal component of which is detected by the matrix sensor.

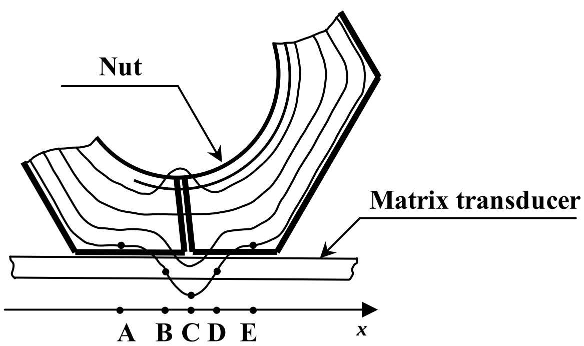

Fig. 3. Position of a nut on the surface of a matrix sensor during examination

To reduce the influence of random signal disturbances, measurements should be taken several times, and the obtained values must be averaged. At the same time, a data analysis is performed to check for the presence of grave errors and/or omissions. False results are excluded from further consideration.

The two-dimensional median filtering method is used to further data treatment. The filtering is realized by means of motion of a certain aperture along the sequence of (discrete?) measured values, and of replacement of the one in the centre of the aperture by a median of original values inside of the aperture. The above mentioned value sequence in reality represents a two-dimensional matrix, the dimensions of which are 30x30, i.e., they are equal to those of the used matrix sensor. The dimensions of the aperture are 3x3 everywhere except at the edge of the value sequence.

As can be seen from example shown on Fig. 4, using the two-dimensional median filtering has allows to correct and improve the obtained data, further reducing the influence of single pulse disturbances (random noise surges and omissions). After carrying out these operations, it is still necessary to dispose of the general background of the magnetic field by subtracting the permanent component from the filtered data.

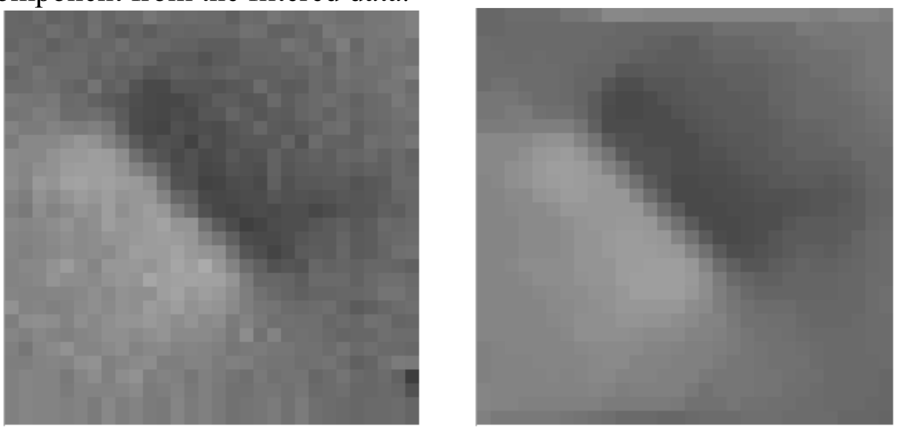

Fig. 4. Data before and after the two-dimensional median filtering

Next, data are screened for the occurrence of extrema. In the case of presence of a defect, it is expected that there will be two domains of extrema, of which one is located in the positive half-space, and the other in the negative. Fig. 5. shows the two found extremes domains after the inspection of the defected nut. When no extremes are detected, it can be concluded that the surface does not contain any defect; otherwise, it is necessary to analyze these areas and to investigate the form of the supposed defect.

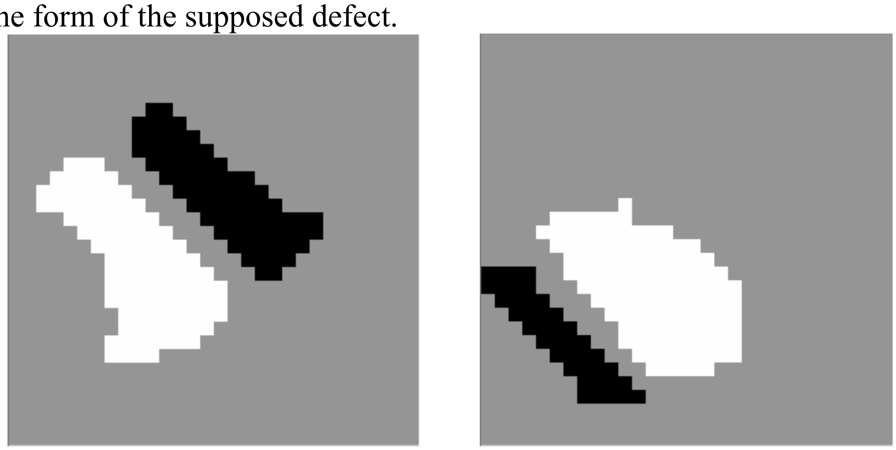

Fig. 5. The illustration of the domains of extremes

When analyzing the revealed domains, it is necessary to find the turning points, where signals change signs. Having identified these points, and by joining them, the outline of the defect is obtained, shown in red dots on Fig. 6.

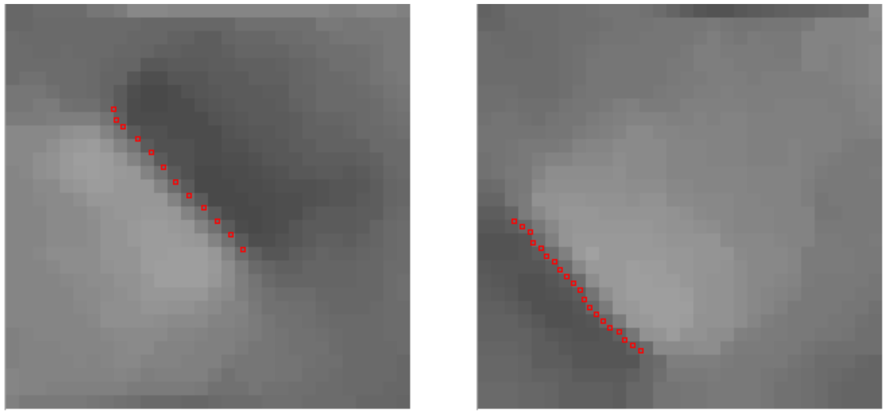

Fig.6. Result of defect analysis in the tested sample

In the case of the surface examination using a single Hall transducer, it is only possible to detect one point of the position of the crack, while using the matrix sensor, it is possible to not only ascertain the existence of the crack, but to also determine its length. The use of this type of sensor simplifies the non-destructive MFL examination procedure and increases the accuracy of the obtained results.

To evaluate the conditions for using the considered matrix sensor, a numerical modeling (?, simulation?)of the MFL topographies of cracks was carried out. The study of the topography of a straight crack on a flat surface of a steel 20 sheet is performed using the ANSYS software package. The calculations were carried out for a two-dimensional case. The investigated area (Fig. 7), including the steel plate with a crack and its surrounding area, is discretized using a local adaptive mesh refinement technique: a finer grid is overlayed on a coarse one in the area containing the defect to obtain a more exact distribution of the magnetic field intensity.

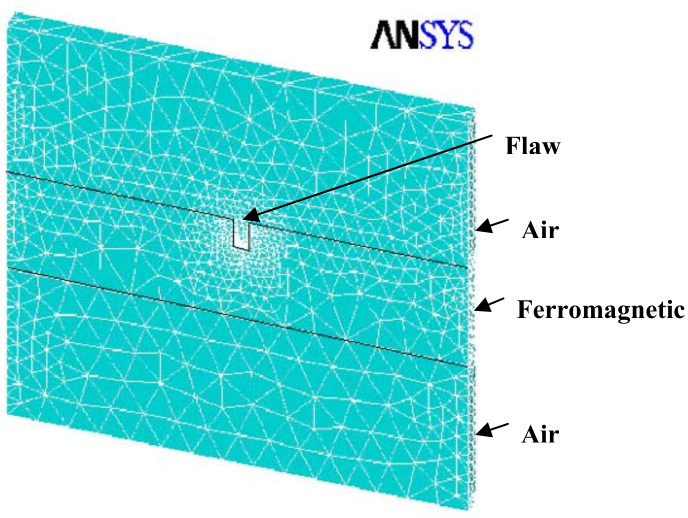

Fig. 7. Calculation area for the modeling of the crack

The calculations were carried out on a surface area large enough so that the influence of the crack on the area edges was practically insignificant. Empirically, an area length of 100 mm was chosen, so in all further figures, the position of the crack corresponds to 50 mm.

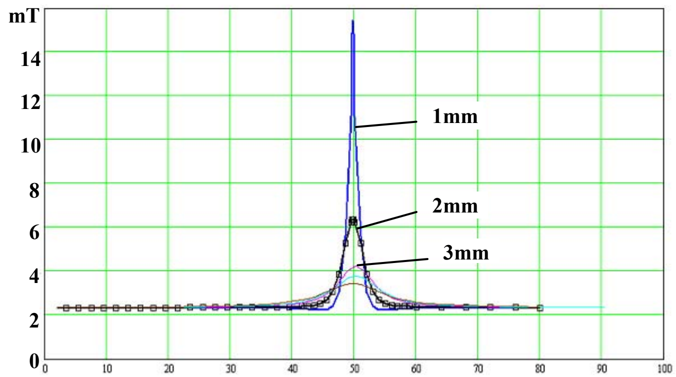

Fig. 8. Tangential component distribution of magnetic induction at different distances from surface

Calculations were made for a crack, the width and depth of which vary between 0,1 and 0,5 mm, and 1 and 5 mm, respectively. The tangential component distribution of the magnetic induction was calculated at different distances from surface. Fig. 8 shows the tangential component distribution at different distances. However, the minimum distance was equal to 1 mm as this is the minimum distance required to place the matrix sensor. As seen, there is no reason to locate the matrix sensor at a distance further than 2 mm from the surface since besides a significant reduction of the magnetic induction, a kind of smoothing of the distribution also occurs. In such close to uniform field, signal values of all elements of the matrix will be very close to each other and it will be nearly impossible to locate the crack.

Fig. 9 shows changes of tangential and normal components of magnetic field as a function of the width of the defect. It is clear that the tangential component amplitude can realistically be used to evaluate the width of the defect using the matrix sensor since the dimensions of the area, where the magnetic field variation occurs simultaneously with the change of the width of the defect, correspond to the size of the sensor.

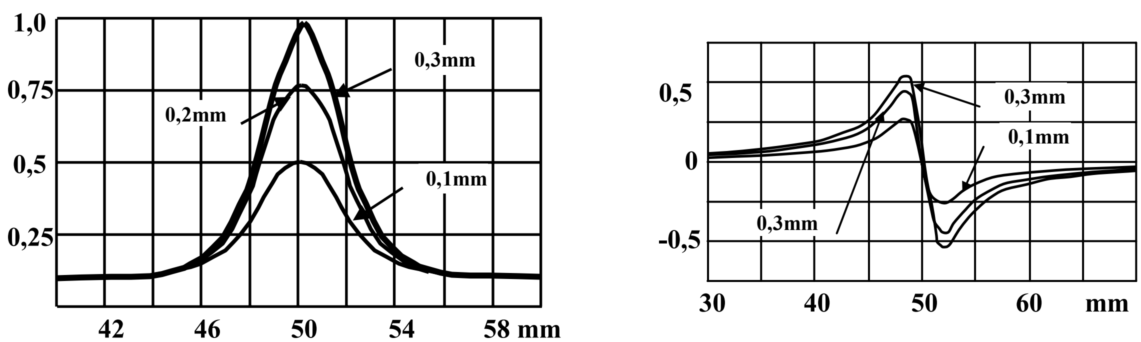

Fig. 9. Tangential and normal components of magnetic field as a function of the width of the defect

The normal component is more suitable for determination of the position of the defect since it changes signs exactly at the place of the location of the defect. It can be seen that the size of the area of the normal component variation is greater than that of the tangential one since it exceeds the size of the matrix sensor.

The topography of a defect in the form of an inclined slot was also carried out. This case is closer to typical defectometry problems. The calculation is also carried out using the ANSYS software, with the calculation area configuration shown on Fig. 10.

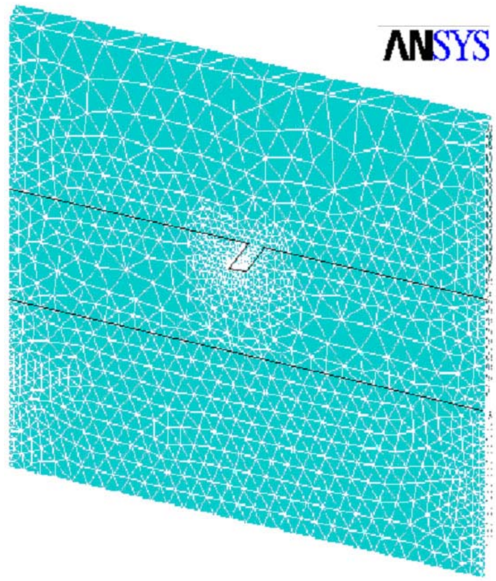

Fig. 10. Calculation area for the modeling of the inclined slot

The angle of inclination mainly affects the tangential component of the magnetic field. Fig. 11 illustrates that the angle of inclination of the defect creates an asymmetry in the tangential component curve.

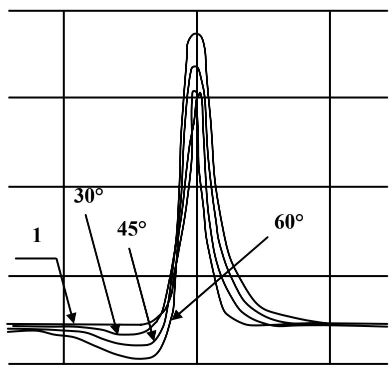

Fig. 11. Tangential component of the magnetic field as a function of the angle of inclination of the crack

In this figure, the curve for a defect without incline is marked by 1 and it is symmetric. The following three lines correspond to inclines of 30, 45 and 60 degrees, respectively. The size of the area of the topography distortion and the value of these distortions allow the matrix sensor to be used to estimate the value of the incline of the defect. Meanwhile, the use of a single Hall sensor would have required the use of a scanning device.

References

[1] 17th Russian science and technical conference "Nondestructive testing and diagnostics.
[2] A. Mamajev, A. Pokrovskiy, N. Meleshko, A. Khvostov. Matrix magnetic transducer in nondestructive testing. Paper 106. Ekaterinburg, 2005.