Detection and correction of measurement data errors in magnetic and electromagnetic non-destructive testing of materials

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1 INTRODUCTION

Structural integrity and reliability of construction elements in power engineering systems depend to a considerable extend from state and characteristics of there material. This can be obtained by means of different methods of non-destructive testing, which for metallic materials in most cases means – electromagnetic or acoustic methods. In this cases material is exposed to external electromagnetic or acoustic excitation and the distribution of resulting reaction over the surface is to be measured. In the case of electromagnetic testing this means distribution of electromagnetic field. Estimation of material characteristics is to be made by means of inverse problem solution. In many cases, material discontinuities should be detected and their size be estimated, for example pipe wall continuousness faults. Modern instruments, which enable solution of this problem, consist mostly of sensor lattices and arrays and data processing units. Application of sensor arrays (lattices) enables high degree of data processing automation and raises test feasibility. With increasing of element number in sensor arrays increases also a probability of sensor faults and consequently errors and failure in measurement data. Such failures can be especially critical for solution of inverse problem because of its instability. In this connection detection and correction of sensor malfunction has great importance in measurement systems with sensor arrays (in particular high resolution sensor arrays).

2 PROBLEM ANALYSIS

Detection sensor malfunction and correction of measurement errors will be shown on an example of magnetic non-destructive testing of steel plates or pipes. To detect sensor malfunction different criteria are applied, which assume correct calibration of measurement system relative recorded values. In this case permissible variations of measured value should not exceed dynamic range of measurement system at a given system sensitivity. So a prolonged saturation of sensor signal can be used as a first criterion of sensor malfunction. The second sensor malfunction criteria is based on the assumption, that random influence factors effects all sensors to the same extend, consequently a standard deviation of sensor measured value should not differ significantly from an average standard deviation of the sensor array:

$$\sigma_i^2 < \sigma_{mean}^2 / k_2$$

where σ_i^2 - variance of the *i*-th sensor, σ_{cp}^2 - average variance of the sensor array, k_2 – some coefficient (k_2>1). Coefficient k_2 is to be chosen with a consideration of characteristics of measurement system and measured. Often more complicated criteria are applied to detect sensor malfunction. To detect missed scans scan numeration is applied.

Correction of detected measurement errors, caused by sensor malfunction is based on the model of expected signals. This model can be built with helps of a priori information about inspected objects, which often enables parameterization of the model. As an example Figure 1 shows typical signal, obtained by the measurement of magnetic field distribution above a pitting corrosion on the pipe wall in the applied magnetic field (B_z - axial component of magnetic field). Such signals appear in magnetic non-destructive testing [1]. Parameter of this signal carries information about defects size.

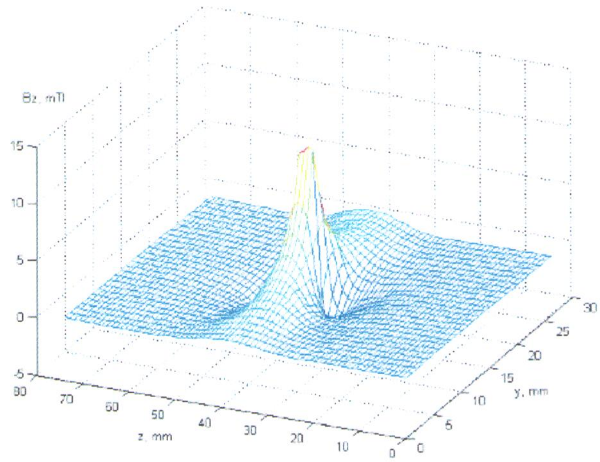


Figure 1. Typical signal of magnetic field distribution above a pitting corrosion on the pipe wall

Malfunction of sensors leads to a mistake in the estimation of material discontinuities. For example estimation of the corrosion depth made by regression method [1] for a pitting corrosion with diameter of 24 mm gives as a result 1.8 mm (real depth 1.6 mm) with no sensor malfunction and 2.6 mm with a malfunction of one sensor block in sensor array. The measurement signal for this situation is shown on Figure 2. Estimation error for the signal with malfunction sensors makes up 0.13T instead of 0.03 T (where T – wall thickness, is 8 mm), which is 4 time more, than in normal case.

Error correction is based on the redundancy of measurement data, which means in the case of non-destructive testing a certain margin of sensitivity and resolution relative minimal detectable defect.

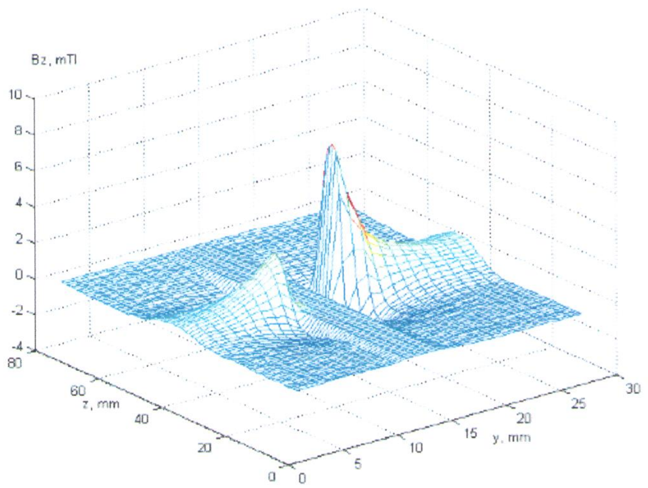
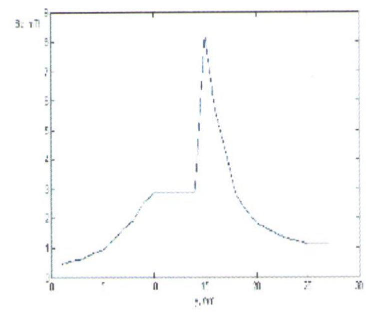


Figure 2. Signal of magnetic field distribution of pitting corrosion with a malfunction of one sensor block.

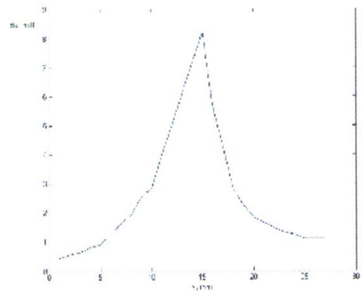
When detecting sensor malfunction, its reading should be substituted by a value, calculated on the base of neighbouring sensors reading. In most of cases these values are calculated by means of interpolation. Different types of interpolation can be applied, but the mostly widespread are piecewise constant, piecewise linear and spline interpolation. These three types are compared below on the example of the signal, shown on the Figure 2.

3 Results

Figure 3 depicts application of piecewise constant (a), piecewise linear (b) and spline (c) interpolation to a central profile of the signal in the Figure 2.



a



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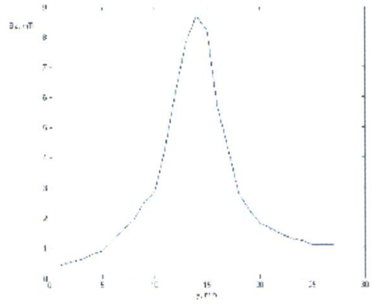

c

Figure 3
Piecewise constant, piecewise linear and spline interpolation of malfunction sensor block.

Piecewise linear interpolation consists in substitution of faulty sensors reading with ones, calculates as linear approximation of corresponding samples on the base of the neighbouring good sensors. Correct realization of this type of interpolation assumes additionally analysis of faulty sensors location – at signal extremum or in monotonous region. In the first case interpolation region should be divided into two parts – each should be calculated separately. This type of interpolation presumes 2 multiplications for each erroneous sample.

Spline interpolation consists in the calculation of faulty sensors reading on the base of the neighbouring good sensors with helps of spline functions – mostly cubic splines. Number of supporting sensors depend on the degree of spline, it is necessary at least 2 supporting sensors from each side of faulty sensors. This type of interpolation is most resource-demanding and complicated in realization. An appropriate algorithm demands 12 multiplications for each erroneous sample in within several consequent cycles.

This three interpolation methods were compared at the sampling of material discontinuities of different size [2]. The sampling consisted of artificial defects of round and square shape with characteristic size from 12 mm to 36 mm and depth of

1.5 mm to 6 mm (wall thickness – 8 mm). Sensor malfunction was simulated in two different regions of signal – at signal extremum and in monotonous region. Average error of defects depth estimation for different types of interpolation is given in the table 1. One can see that for sensor malfunction at the edge even piecewise constant interpolation allows reducing estimation error to 0.03 T. For sensor malfunction in the centre of the signal defect depth estimation with piecewise constant interpolation has rather big error – 0.14 T. With help of spline interpolation this error can be reduced to 0.08 T.

Table 1. Average error of defects depth estimation for different types of interpolation

	Interpolation type		
	piecewise constant	piecewise linear	spline
Sensor malfunction at the edge	0.2 мм	0.16 мм	0.15 мм
Sensor malfunction in the center	1.1 мм	1.0 мм	0.69 мм

4 CONCLUSIONS

Thus best results of measurement errors correction can be achieved with help of spline interpolation and it enables to reduce the error of material discontinuities depth estimation for the case of central sensors malfunction to 0.08 T. This method is nevertheless significantly more resource-demanding than piecewise constant or piecewise linear interpolation. In many cases it is sufficient to apply piecewise linear interpolation.

Acknowledgements

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Literature

[1] Slesarev D.A., Barat V.A. Statistical diagnostic model for Defect parameters reconstruction in MFL nondestructive testing. 10-th European Conference on Non-Destructive Testing - Moscow, 2010. p. 50.

[2] Slesarev D.A. DETECTION AND CORRECTION OF MEASUREMENT DATA FAILURE IN MFL NON-DESTRUCTIVE TESTING. Kontrol. Diagnostika, 2012, №5.