07 - 10 September 2009

PROCEEDINGS

54. IWK

Internationales Wissenschaftliches Kolloquium

International Scientific Colloquium

Information Technology and Electrical Engineering - Devices and Systems, Materials and Technologies for the Future

Faculty of Electrical Engineering and Information Technology

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Dr. h. c. Prof. h. c.
Peter Scharff

Redaktion: Referat Marketing
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Univ.-Prof. Dr.-Ing. Frank Berger

Redaktionsschluss: 17. August 2009

Technische Realisierung (USB-Flash-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag: isle
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilmenau

ISBN (USB-Flash-Ausgabe): 978-3-938843-45-1
ISBN (Druckausgabe der Kurzfassungen): 978-3-938843-44-4

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=14089

APPLICATION OF STATISTICAL METHODS FOR SIGNAL EVALUATION IN MFL NONDESTRUCTIVE TESTING

Barat V, Slesarev D.

Moscow, Moscow Power Engineering Institute (TU), Intron Plus

ABSTRACT

This paper presented method for electromagnetic inverse problem solution based on statistical diagnostics model. Statistical estimation model represents a set of regression equations that determine relations between defects' parameters and MFL signals'features. Regression equations are formed based on learning sample that consists of great amount of magnetic signals for various defects – corrosions, cracks, notches, which may be obtained both experimentally and through numerical simulation. Physical regularities of magnetic inspection are considered in the offered model as *a priory* information.

Within the bounds of statistical parameterization model correlation analysis is also applied, allowing significance determination of influencing parameters and factor analysis, for assessment of nuisance factors' influencing.

Index Terms - MFL signal, statistical evaluation, regression analysis

1. INTRODUCTION

Inverse problem of magnetic inspection consists in defection defects depth and linear dimensions on the base of magnetic flux leakage topography. To solve conventional inverse problem one shall establish analytical dependence between magnetic induction measured values and estimated defect parameters. However, existing analytical dependences are applicable only for magnetic field of artificial defects description. Unlike analytical model finite elements simulation allows to consider actual defect shape features and also imperfections of magnetizing and measuring system. Numerical diagnostic model is built on the base of great amount of estimated parameters therefore it loses compactness property. As a result, we obtain data base that includes approximately 10,000 magnetic signals. In this case, special methods capable of large-scale data analysis should be applied, to solve inverse problem. These include statistical analysis methods, genetic algorithms, neural networks.

Each method has its peculiarities, but all of them are implemented in practice. Nevertheless, statistical estimation provides a range of advantages: a possibility of adequacy determination for developed model, reliability assessment for obtained results, factor analysis and significance determination of influencing factors.

2. GENERAL METHOD DESCRIPTION

Statistical method of defects' parameters estimation is based on the linear regression model (1) that allow to relate one dependent variable to several independent variables. In this case, dependent variables are defect's parameters (length, width, depth), while independent variables are features, extracted from magnetic diagnostic signal.

$$defect\_parameter_i = \beta_0 + \beta_1 feat_{1i} + ... + \beta_p feat_{pi} + e_i \quad (1)$$

Equation coefficients are determined on the base of learning sample, corresponding to a great number of diagnostic signals, represented with a set of informative attributes. Learning sample may include data of different nature – signals, obtained through analytical model or FEM simulation, or data, obtained experimentally.

Regression equation is a decent alternative to analytical solution, despite certain degree of formalism of the offered method. Wit correctly used *a priory* information, regression equation represents rather accurate linearization of solution for incorrect inverse problem.

1.1 Accuracy and Reliability of Statistical Estimation

Accuracy and reliability of regression estimation is determined on the base of variance analysis. Full dispersion SS_T may be divided into two components – variance, conditioned by regression, SS_D and variance, conditioned by deviation from regression, SS_R, which determines standard error of dependent variable estimation.

Criteria that determine reliability and effectiveness of the offered statistical estimation model are – error of dependent variable estimation, obtained on learning sample, determination coefficient R^2 and F-criterion.

Determination coefficient R^2 is calculated as ration of a sum of squares, conditioned by regression, to cumulative sum of squares. It represents quality measure for dependent variable determination. The closer to one R^2 value is, the more adequate this model appears to be.

$$R^2 = \frac{SS_D}{SS_T} \quad (2).$$

The correct choice of attributes and reliability of dependent variable determination is determined through F-ratio (3), where p is the number of independent variables; n is the number of observations.

$$F = \frac{SS_D / p}{SS_R / (n - p - 1)} \quad (3).$$

1.2 Method Implementation

Statistical parameterization method is very convenient and easy to implement. This method is not iterative and requires neither adaptation nor pre-adjustment. All the required calculations are performed at preliminary stage whlie analysing of learning sample. Learning stage results in the set of regression equations coefficients $\beta_1, \beta_2, \ldots, \beta_p$ (1), which are used as parameterization procedure parameters.

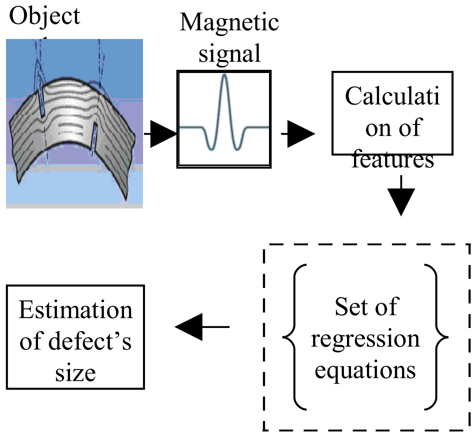

Fig.1 Implementation Scheme of Statistical Estimation Method

To estimate defect's length, width and depth measured magnetic signal is characterised by a set of features, included in regression equation as independent variables. Then calculated features are multiplied by the corresponding coefficients of regression equation so that defect's parameter is calciulated in compliance with regression equation (1).

Regression estimation method is so extent stable and easy to implemet that it allows parameterization in off-line mode after inspection and in on-line mode simultaneously with the inspection.

3. DESIGN OF PARAMETERIZATION EQUATIONS

Key issue for design of regression equations is set of independent variables – features that determine magnetic signal. As an example Fig. 2 shows topography of defects' stray magnetic induction field axial component.

Field topography is characterized with three extreme areas, corresponding to defects' center and edges. Magnetic signal of such shape may be rather completely described by extreme values and their coordinates and extreme areas' width. Nevertheless, relationship between signal parameters and defect's length, width and depth appears to be not only nonlinear but also nonmonotonic. Hence, none of signal individual parameters can be used for defect shape recovery.

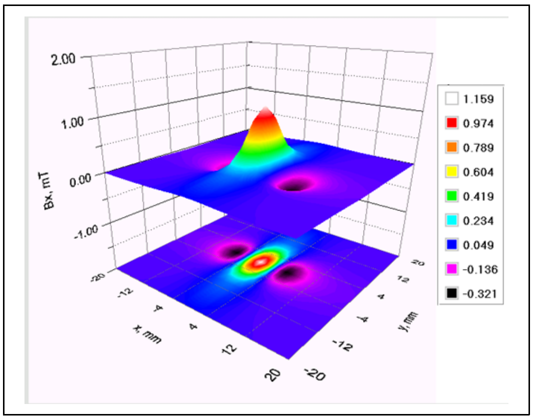

Fig.2 Magnetic field leakage topography of a local pitting corrosion

Two ways of solving this problem using statistical (regression) estimation may be offered. The first is development of multiple linear regression (1). In this case, linearization of relationship takes place due to balanced summarizing of signal features, with different character of dependence from estimated variable.

This parameterization method is described in the work [2]. Linear predictors have been applied for estimation of defects' parameters, corresponding to three different models – "corrosion", "scratch mark", "crack". By application of this estimation scheme a generally acceptable result has been obtained. Disadvantage of the offered method is low interference resistance resulting from parameterization error determination via, primarily, regression model error and weighted sum of each MFL signal features determination errors.

$$param\_error = \sqrt{(\beta_1 \Delta feat_1 + \ldots + \beta_p \Delta feat_p)^2 + SS_D} \quad (4)$$

The second method is more resistant to interference; it provides for parameterization via piecewise linear approximation. For this purpose set of different regression equations should be designed for different ranges of estimated parameters. Therewith model parameters are selected in such a manner that the number of independent variables in regression equation were minimal.

For correct design of piecewise linear approximation it is required to consider principal physics of MFL method. Topography of defects' magnetic flux leakage can be represented as a result of defect's edges fields overlapping. In this connection an assumption can be made that for defects with close linear dimensions, dependence between maximum value of magnetic induction and defect depth will be linear.

Fig. 3 shows correlation coefficient dependence between defect depth and maximum value of azimuthal component of dependence magnetic induction ($B\varphi_{max}$) from length and centering error, characterizing defect elongation in azimuthal direction.

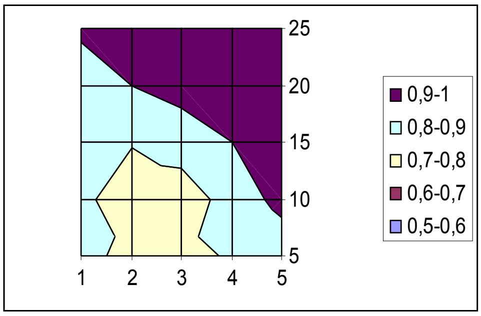

Fig. 3 Correlation coefficient between defect depth and maximum B_φ value as a function of defect length and its eccentricity

At distribution we can find some arias, where it is possible to use only one feature - $B\varphi_{max,}$ to estimate defects depth. It provides sufficient accuracy of the estimation. Defects' propagation analysis allows making a conclusion, that in more than 80% of cases only this one feature ensures depth estimation with accuracy of 10%.

Main disadvantage of this method's is "problem regions", in which coefficient value of correlation between defect depth and signal amplitude is less than 0.7. This is due to the fact that length and width of magnetic signal is not always precisely corresponding to defects' length and width. And for this reason close linear dimensions appear with different defect types, for example, with notch and corrosion. As magnetic flux leakage value of notches appears considerably greater than that of corrosion of similar size, dependence $B\varphi_{max}$(depth) in this range of values appears to be nonlinear.

For defects' parameterization in "problem region" of values, multiple regression model may be applied; therewith the best parameterization results are obtained through use of attributes equal to the ratio of signal amplitude to its width and length.

4. CONCLUSION

The considered statistical method for solution of magnetic inspection inverse problem has been implemented as software model. Efficiency of the offered method has been determined based on test results of sampling of several thousands of artificial and natural defects. Error of corrosions' and notches' depth determination has not exceeded 20%, while that of cracks 15% of tube wall thickness with 95% probability. Error of defects' linear dimensions determination appeared to be less than 20 mm.

5. REFERENCES

[1] Barat V., Lunin V., Seidel H.-U., Bock A. "Signal Processing of Magnetic flux Leakage Data Obtained from Pipeline Inspection", 48th International Scientific Colloquium: Proceedings Ilmenau, Germany, 2003, pp.131-132

[2] Barat V., Slessarev D. „Statistisches algorithmus der Signalklassifizierung in magnetischer zerstörungsfreier Prüfung", 51th International Scientific Colloquium: Proceedings Ilmenau, Germany, 2006