APPLICATION OF WAVELET TRANSFORMATION IN EDDY CURRENT TESTING

Grman J.

Department of Measurement, Slovak University of Technology
Ilkovičova 3, 812 19 Bratislava, Slovakia

Phone: +421 7 654 29 600 Email: janog@pluto.elf.stuba.sk

Fast localization of indications of defects and structure elements in the defectoscopy of steam generator tubes is the field where application of wavelet transformation is very perspective. Our prmary task is to find positions of potential indications within signal and secondary task is to calculate optimal boundaries of indications with respect to their future use in process of classification.

The contribution concentrates on the choice of suitable wavelet function and parameters of localization algorithm. Basic result of this algorithm is vector of positions of indications within signal. Use of multiresolution wavelet analysis implies a possibility to calculate optimal boundaries of found indications. Selected algorithm and his parameters were compared using real records of steam generator tubes and artificial defects and imitations of construction elements as well.

1. Introduction

The assessment of data records obtained from the measurement on tube is based on the knowledge of the evaluation record structure, whose parts correspond to the indications of constrution elements of the tested object (support, collector, transition between tested and measured tube). Every record contains also signals from the same tube containing artificial defects with well-known parameters.

For automated assessment of records it is necessary to assure the reliable detection of all parts of signals which can be potential locations of indication occurrence responding to selected construction elements of steam generator such as support plate and especially to the location of defects. The contribution treats the topic of utilization of wavelet transform for the localization of mentioned indications.

Continuous wavelet transform (CWT) [1] is defined as the sum over all time of the signal f(t) multiplied by scaled, shifted versions of the wavelet function Ψ (a,b,t):

$$C(a,b) = \int_{-\infty}^{+\infty} f(t).\psi(a,b,t)dt \qquad (1)$$

where *a* is scale, *b* is location.

A wavelet is a waveform of effectively limited duration that has an average value of zero. The result of the CWT are many wavelet coefficients C (a, b), which are a function of scale and position. Implementation of the continuous wavelet transform (*CWT* command from *MATLAB® Wavelet Toolbox*) was used for described application.

2. Algorithm of localization

For each measured frequency (in the case of multifrequency method) couple of one another orthogonal voltages designated as x- and y- channel carrying information on the change of measured probe impedance is recorded. Using (1) we can calculate wavelet coefficients for every channel [2]. An absolute value for all coefficients of one frequency is calculated. Formally, we take couple of coefficients as the element of two component vector

$$C(a,b) = \left[C_x(a,b), C_y(a,b)\right] \qquad (2)$$

$$|C(a,b)| = \sqrt{C_x^2(a,b) + C_y^2(a,b)} \quad (3)$$

where C_x (C_y) is matrix of coefficients calculated from x-channel (y-channel), a is the scale of wavelet and b is location in record.

An example of result calculation of calibration tube signal is in fig. 1. The tube contains artificial defects, support plate and other elements. Areas with highest level of shade (black colour) represent the high absolute values of complex coefficients of wavelet transform, that means the high correlation of chosen wavelet function with the part of analysed signal.

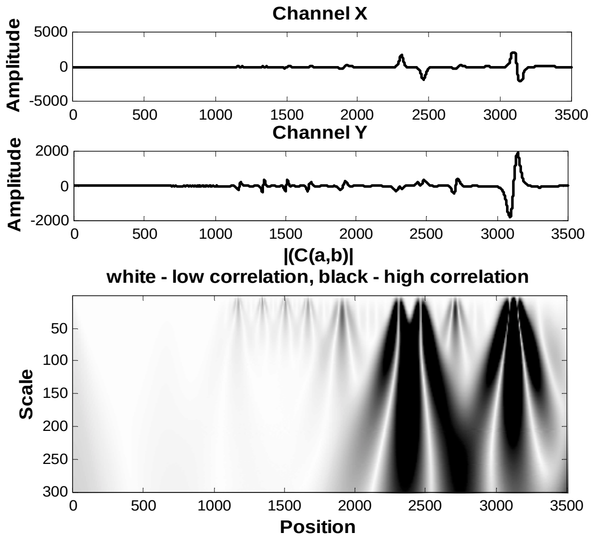

Figure 1. Arrangement of construction elements of steam generator

Localization algorithm is based on the analysis of result coefficients in both directions. Location (index) of maximum value in vertical direction indicates level of wavelet decomposition (scale) with the highest correlation. It means that for each position in tested signal we can calculate scale in which wavelet the most similar to underlaying signal is used. Experiments show that it is possible to assess approximately location and optimal boundaries of potential indications by analysis of coefficients in horizontal direction and using the best level of decomposition for each position.

The first task in our experiments was to choose siutable wavelet function. Understanding continuous wavelet transform way of computation we decided to choose wavelet which is similar (gives the best correlation results) to typical shape of the most common indications (support plate, defect).

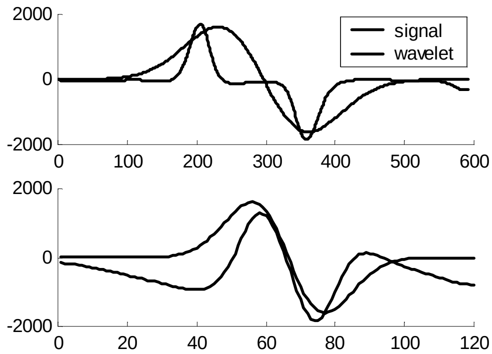

Figure 2. Correspondence between Gaussian wavelet and typical signal of indications (support plate, defect-hole)

Experimental results show, that Gaussian wavelet seems to be a good choice. Gaussian wavelets are derivatives of the Gaussian probability density function

$$Gaus(x,n) = C_n * diff(\exp(-x^2), n) \tag{4}$$

where *diff* denotes the symbolic derivative, and where C_n is such that the 2-norm of *Gaus(x, n)=1*. This wavelet has effective support on interval [-5, 5] and infinite support width. We are using symmetric Gaussian wavelet *Gaus(x, **1**)* (fig. 2).

Positions of indications are computed using both channels of single measurement frequency. A matrix of correlation coefficients is calculated for each channel. These matrixes are using (2) connected and transformed to one complex matrix and using (3) absolute values of matrix coefficients are calculated. Let us name result real matrix as *M(s, p),* where *s* is scale and *p* position.

$$s \in <1, ScaleDim>, p \in <1, SignalSize> \tag{5}$$

SignalSize is size of tested signal. Optimal value of parameter *ScaleDim* will be discused later.

The next logical step in algorithm is to calculate maximal values of matrix *M* in scale direction. As result of the calculation we are able to obtain two vectors (6)(7):

$$Ampl(p) = \max_{s \in <1, ScaleDim>} (M(s,p)) \tag{6}$$

$$Index(p) = \arg\max_{s \in <1, ScaleDim>} (M(s,p)) \tag{7}$$

where $p \in <1, \mathrm{SignalSize}>$.

We must define what the local maximum in vector *ampl* is. It can be difficult, because there are big differences in vector values. Local maximum is global maximum on some smaller interval. Every static condition for interval size that we used had wrong results for some type of indications. We decided to define variable size of interval for every tested position. Idea of optimal local maximum interval is based on one of already mentioned results. Vector *index* holds scale of wavelet for which maximal correlation with signal was reached. There is dependence between wavelet scale and size. Using this fact we are able to mark local maximums using formula (8).

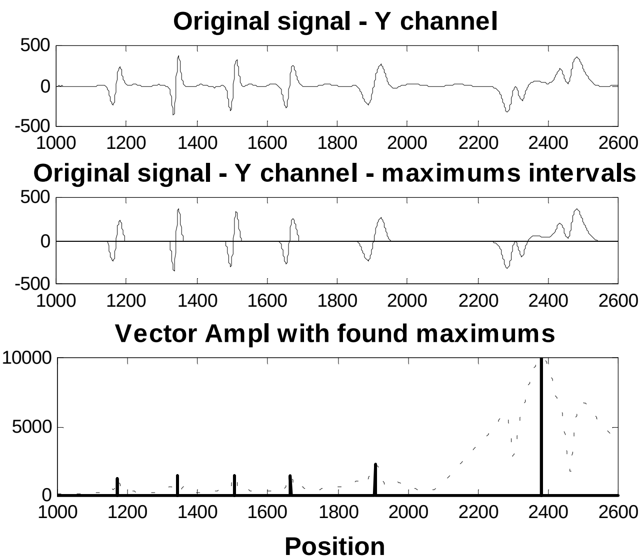

Figure 3. Local maximums (positions, sizes and corresponding intervals)

$$IsMax\ (p) = \left[\max_{r \in <p-S(p),\, p+S(p)>} (Ampl\ (r)) = Ampl\ (p) \right] \tag{8}$$

where S is function of calculated wavelet scale defined as

$$S(p) = SConst * Index(p) \tag{9}$$

and *SConst* is experimentally determined real constant (in our experiments for Gauss1 wavelet *SConst* was equal to 7/4).

Fig. 3 shows indications of five different defects and one support plate at the end. There is an example of use (8) and (9) to determine "good" local maximums in vector *ampl*. It is easy to see that there are differences between values of vectors *ampl* and *index*. Indication of support plate was found using higher level (wavelet scale) and higher correlation than indications of defects. There are also differences between defects. Calculated values of wavelet scale and correlation with indication can be used as a part of signature vector usually used as input of some classification algorithm (for example in neural classifier [3],[4],[5]).

3. Conclusion

We hope that we are able to use these results not only to find positions of indication but also to obtain the first approximation of indication type (class). Every type of indications has it's own specific shape, angle and size. These properties can be used to define limitations for result values with the highest probability. Indication of support plate is usually detected at higher level (wavelet scale) as any defect indication.

This means that using calibration part of measured signal we are able to calculate approximate values of characteristic scales for different types of indications in the tested signal. Every found indication then has a scale in the neighbourhood of one of the calculated scales.

In the contribution, described method doesn't use contrary to [1] complex coefficients, but the module of complex coefficient as result of the continuous multiresolution wavelet approximation. An attention is paid to the suitable (compromise) selection of the wavelet function shape, in order to use minimal, in ideal case one type of wavelet function for detection and for the establishment of indication location in record. The presented process can be a fundamental step for automatic inspection and determination of location of indications that can be then classified by selected suitable methods (e.g using classifiers based on neural network).

Experiments show that multiresolution wavelet analysis is very perspective topic for science research especially for problems of automatic localization, but we hope that also for classification of indications in the field of defectoscopy by eddy-currents.

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