Classification of Mixed Indications in the Defectoscopy by Eddy-Current

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Abstract. *The contribution treats the topic of classification of indications in the field of non-destructive defectoscopy by eddy-currents. One of the fields is classification of mixed indications into classes that are characterized by the signal shape, eventually by the signatures relating to the signal shape. The contribution concentrates on the choice of transformation of mixed indications into representation suitable for classification.*

Keywords: defectoscopy, classification, mixed indications

1. Introduction

Presented paper describes experiments with output signal from testing heat-exchanger tubing by a differential probe. It is non-destructive testing method based on eddy-current. The shape of output signal from the probe reflects properties of tested material. Potential locations of the defect in the signal are called indications. In our previous work we presented several algorithms for localisation and classification of indications. Different transformations of indications info vectors of signatures were presented too [1][2][3].

This paper is focused to classification of mixed indications. These indications are result of composition of two or more signals influenced by tube structure changes (defects or construction elements). The most common signal compositions are mixes of support plate and defects of different type. We identify six basic classes of mixed indications in our reference database of indications (Table 1.).

Table 1. Classes of mixed indications

Class ID	Class name	Dominant indication
17	Defect 100% near support plate edge	Defect
18	Defect 100% under support plate	Support
19	Defect 48% near support plate edge	Defect
20	Defect 48% under support plate	Support
21	Outer groove 20% near support plate edge	Defect
22	Outer groove 20% under support plate	Support

2. Data representations

At the experiments whose results have been published, the indication characteristics were calculated by different methods. Analysis in this paper will be specifically focused on mixed indications. Transformations were compared for ability of classification of mixed indications using different criteria. In the next section we try to briefly summarize calculation and basic properties of these representations. Representation peak-angle-peak is intuitive and was inspiration for design of representation std-cov-std. Fourier based signatures were inspired by [4] and wavelet coefficients by [5] and localization algorithm [1].

Table 2. Survey of indications transformations to signature vectors R

Transformation	Calculation
Peak-angle-peak 3components	$dist(\tilde{s},m,n)=\sqrt{((x(m)-x(n))^2+((y(m)-y(n))^2}$; $(\bar{m},\bar{n})=\underset{m,n}{\arg\max}(dist(\tilde{s},m,n))$ $\Delta x(\bar{m},\bar{n})=\lvert x(\bar{m})-x(\bar{n})\rvert$; $\Delta y(\bar{m},\bar{n})=\lvert y(\bar{m})-y(\bar{n})\rvert$; $\phi(\tilde{s}(t))=\arctan\left(\frac{\Delta y(\bar{m},\bar{n})}{\Delta x(\bar{m},\bar{n})}\right)$ $R=[\Delta x(\bar{m},\bar{n}),\Delta y(\bar{m},\bar{n}),\phi(\tilde{s}(t))]$
Std-cov-std 3components	$E(x)=\frac{1}{L}\sum_{k=1}^{L}x(k)$; $E(y)=\frac{1}{L}\sum_{k=1}^{L}y(k)$; $D(x)=E[(x-E(x))^2]$; $D(y)=E[(y-E(y))^2]$ $\mathrm{cov}(x,y)=E[(x-E(x)).(y-E(y))]$; $R=[\sqrt{D(x)},\sqrt{D(y)},\mathrm{cov}(x,y)]$
Fourier transf. 30components	$\tilde{X}[k]=\sum_{n=0}^{N-1}\tilde{x}[n]e^{-i\frac{2\pi}{N}nk},k=0,1,...N-1;\ \tilde{x}[n]=\frac{1}{N}\sum_{k=0}^{N-1}\tilde{X}[k]e^{i\frac{2\pi}{N}nk},n=0,1,...N-1$ $R=[\tilde{x}[0],\tilde{x}[1],...,\tilde{x}[15]]$
Wavelet transf. 3components	$C_{x(t)}(s,p)=\int_{-\infty}^{\infty}x(t).\psi(s,p,t)dt$; where $\psi(s,p,t)$ is wavelet function $M(s,p)=\sqrt{C_x^2(s,p)+C_y^2(s,p)}$; $(\bar{s},\bar{p})=\underset{s,p}{\arg\max}(M(s,p))$; $\alpha=\arctan(C_{y(t)}(\bar{s},\bar{p}),C_{x(t)}(\bar{s},\bar{p}))$; $R=[M(\bar{s},\bar{p}),\bar{s},\alpha]$

3. Experiments

Using reference database of mixed indications we were able to calculate reference vectors of signatures. Then we analyzed separability of signature vectors into subspaces corresponding to six selected classes from table 1. Figure 1 shows projections of calculated signature vectors for transformations peak-angle-peak and std-cov-std. It's easy to see that classes 21 and 22 can't be separated using peak-angle-peak, but using std-cov-std method we are able to classify all indications into proper classes.

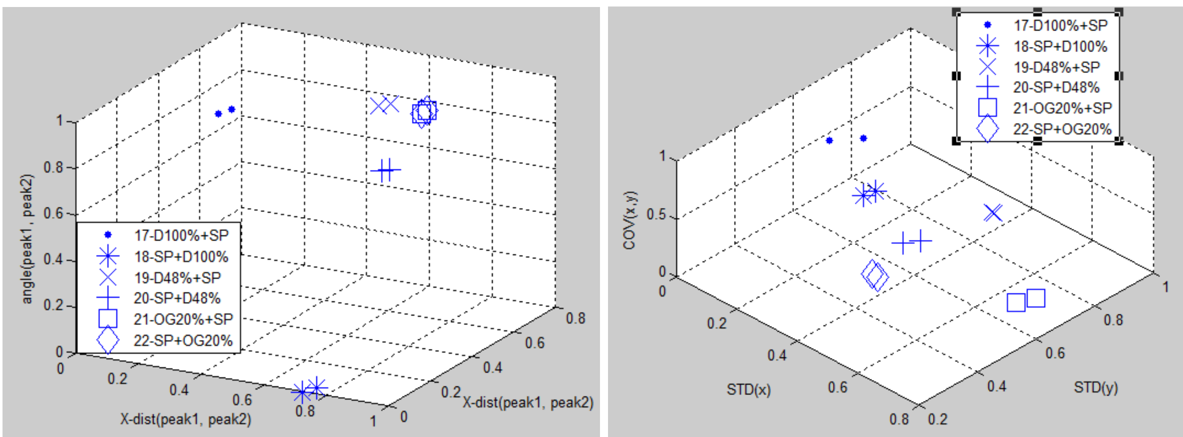

Fig. 1. Projection of signature vectors for peak-angle-peak (left) and std-cov-std (right) transformations calculated from 25kHz signal

Table 3 present results for all transformations. These results were calculated for indications from signal measured using 25 kHz frequency. It is important for interpretation of results. Low frequencies better describe changes on outer side of the tube. It means that influence of support plate outer groove is dominant.

Table 3. Description of classification errors for 25 kHz measuring signal

Transformation	Classification errors	Description
Peak-angle-peak	21/22	No separation for outer groove near or under support plate
Std-cov-std		
Fourier transf.	19/20	No separation for defect 48% near and under support plate
Wavelet transf.	19/21, 18/20, 21/22	No separation for defect 48% and outer groove near support plate edge No separation for defect 100% and 48% under support plate

Our next experiments was done using 700 kHz measuring signal. High frequencies better maps tube internal structure and changes. Signal influence by inner defects is higher. Figure 2 again presents projections of indications using peak-angle-peak and std-cov-std.

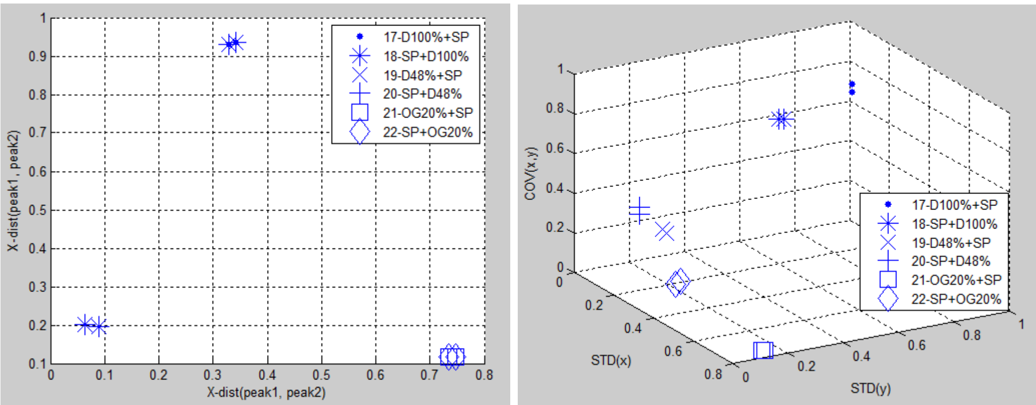

Fig. 2. Projection of signature vectors for peak-angle-peak (left) and std-cov-std (right) transformations calculated from 700kHz signal

Table 4 describes classification errors. Representation std-cov-std has again 100% success. It is interesting that representation based on Fourier transformation with dimension 30 succeed too.

Table 4. Description of classification errors for 700 kHz measuring signal

Transformation	Classification errors	Description
Peak-angle-peak	17/18,19/20,21/22	No difference if defect is near or under support plate
Std-cov-std	--	
Fourier transf.	--	
Wavelet transf.	17/18, 20/22	Defect 48% and outer groove near support plate edge Defect 100% and 48% under support plate

Presented (and omitted because of limited paper range) results indicate std-cov-std as universal transformation of mixed indications into signatures suitable for classification. But it is important to analyze other transformations. When using different frequencies, different transformations are able to produce good results.

Very good example is peak-angle-peak transformation used on 700 kHz signal. For the first look mentioned transformation produce a lot of classification errors. Bud detailed analysis shows that using this representation we are able to separate indications into very good and clear clusters (figure 2, left image). These clusters represent type of defect mixed with support plate without respect to their relative position.

4. Conclusions

Classification of mixed indications is very complicated but very important. Contact of support plate with tube is very often source of corrosion process. Experiments show that mixed indications can be successfully identified. All transformations use original signal from measurement probe. Using presented transformations we are able to omit signal mixes (linear compositions of signals in different frequencies used to suppress indications of support plate). Not each transformation is suitable for classification of mixed indications, but some of them can be used in specific signal frequencies to increase classification success, stability and reliability.

Acknowledgements

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