ISSN 1392-2114 ULTRAGARSAS, Nr.2(35). 2000.

Application of the wavelet transform for enhancement of B-type ultrasonic images

R. Kažys, G. Čeplys

Prof. K. Baršauskas Ultrasound Institute
Kaunas University of Technology

Introduction

Ultrasonic imaging systems nowadays are widely used in non-destructive testing for detection and evaluation of defects, determination their dimensions, location, etc. Quality of the images obtained is not high enough due to diffraction and refraction phenomena of ultrasonic waves, structural and electronic noise and restrictions imposed by the imaging technique and instrumentation. Therefore the acoustic image significantly differs from the optical image of the intrinsic structure of the object under investigation. Quality of ultrasonic images may be significantly improved by means of various signal processing techniques [1-4].

In this paper for enhancement of a quality of the images obtained by ultrasonic imaging systems a novel approach is proposed. In this approach a B-type image of the object is obtained by means of fusion of compression and shear wave signals, caused by sharp inhomogenuities. Such inhomogenuities are reflecting an incident longitudinal wave and also transforming it into a diffracted shear wave. These two waves are propagating with different velocities back to the receiver of ultrasonic waves and, depending on the type of ultrasonic transducers used, both may be separately observed. Such a technique is known as the time-of the flight diffraction (TOFD) technique and is widely used for estimation of dimensions of cracks inside solids [1].

In the proposed approach compression and shear wave signals are detected and separated by means of the one-dimensional Wavelet transform. After that time scales of the signals corresponding to compression and shear waves are transformed in such a way that they are overlapping in the time domain and they fused together into one compound B-type image.

Problem statement

In imaging systems both types of waves- compression and shear waves may be exploited. After interaction of the particular wave with a non-uniformity in the object, a part of the wave is reflected , part of it diffracted and part of it is converted into other types of waves. For example, if the incident wave is compression wave, part of it is converted by sharp tips of a crack into a diffracted shear wave, which may be picked up by an ultrasonic receiver. These waves are propagating with different velocities and arriving to the receiver at different instants. It is necessary to keep in mind, that both waves possess longitudinal and transversal components, amplitudes of which depend on the type of reflector and the angle of incidence (Fig.1.). The time of arrival of the particular wave is determined as the instant of the maximal amplitude of the received impulse:

$$\tau_L = \frac{2L}{c_L}, \tag{1}$$

$$\tau_S = \frac{L}{c_L} + \frac{L}{c_S}, \tag{2}$$

where τ_L is the delay time of the reflected compression wave, τ_S is the instant of the arrival of the diffracted shear wave, L is the distance between ultrasonic transducer and reflector, c_L, c_S are the velocities of the compression and shear waves in the sample correspondingly. The distance between the ultrasonic transducer and the crack may be found from both delay times:

$$l_L = \frac{\tau_L c_L}{2}, \tag{3}$$

$$l_S = \frac{\tau_S c_S c_L}{c_S + c_L}. \tag{4}$$

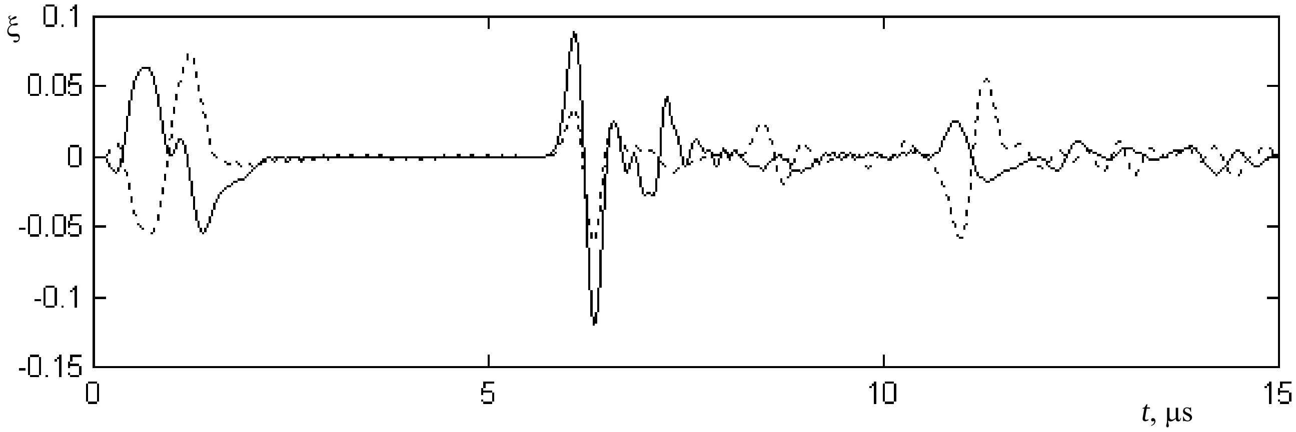


Fig.1. **Compression and shear waves, reflected and diffracted by a crack in steel: the solid line – longitudinal component, the dashed line – transversal component. The time waveforms were calculated by the software Wave2000, based on the finite difference method.**

If the distances found from the reflected compression and the diffracted shear wave impulses are the same, then these signals are caused by the same reflector. In this case the following condition must be fulfilled:

$$l=\tau_L c_L=\tau_S c_S\,. \tag{5}$$

The difference in the delays of different types of waves may be characterized by the ratio

$$K=\frac{\tau_L}{\tau_S}=\frac{2c_S}{c_S+c_L}\,. \tag{6}$$

Most receivers of ultrasonic waves used in non-destructive testing, such as piezoelectric transducers, respond to the particle velocity *v* or related to it pressure *p*:

$$p=\rho c v=\rho c\frac{d\xi}{dt}, \tag{7}$$

where ρ is the density and ξ is the displacement. The particle velocity *v* possesses two orthogonal components – longitudinal v_z and lateral v_x. In most general case the ultrasonic receiver is sensitive to both components. In this case the electric signal at the output of the transducer is given by

$$u_{out}=K_0\sqrt{v_z^2+(kv_x)^2}\,, \tag{8}$$

where K_0 is the constant and *k* is the coefficient indicating difference in a sensitivity of the transducer to the orthogonal components. As it was mentioned above, compression and shear waves possess both components, which propagate with different velocities. For this reason both- compression and shear waves produce electric signal at the output of the transducer, thus creating artifacts in the B-scan image, obtained from individual A-scans.

In the proposed aproach the signals caused by different types of waves are separated using the Wavelet transform and afterwards fused together in a new compound B-type image.

Wavelet transform

Wavelets are spatial variable scale basis functions, which are obtained from the mother wavelet by means of dilations and translations. Efficient way to perform the wavelet transform has been proposed by S. Mllat [5, 6]. The discrete wavelet transform (DWT) may be performed only in $m\in 2^n$ scales and positions.

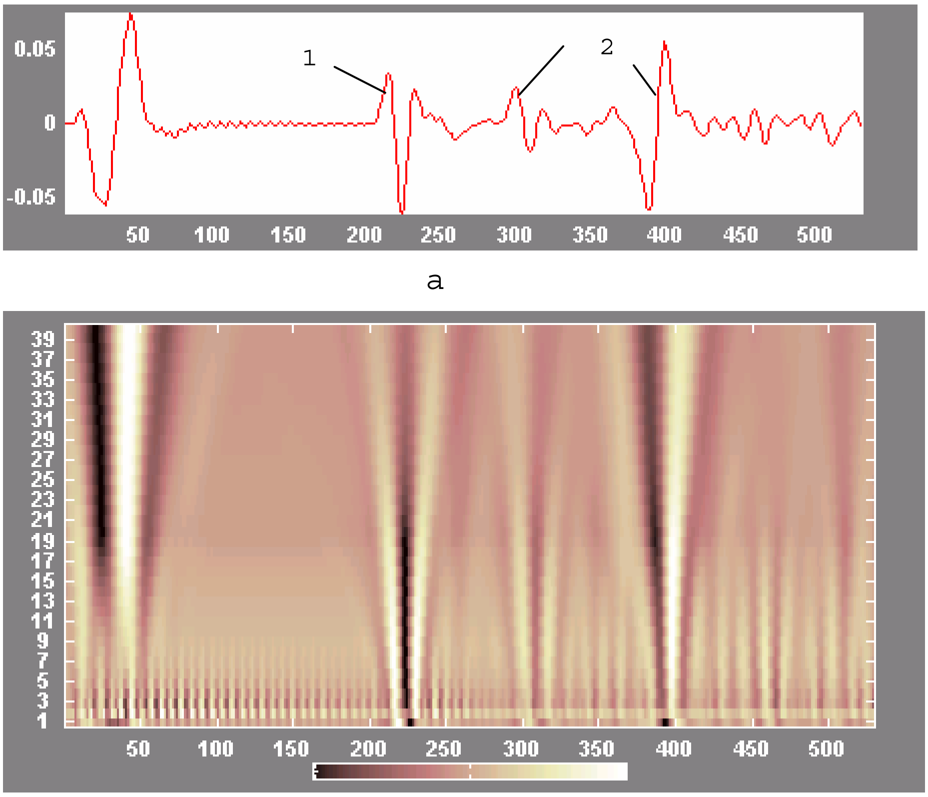
Continuos wavelet transform (CWT) enables to perform not discrete but continuos translation of wavelets [5, 6] and, hence, is more suitable for our purposes. The CWT may be carried out in any scale $m\in N$. The wavelet coefficients are given by [7, 8]:

$$C(a,b)=\int_{-\infty}^{+\infty} f(t)\psi(a,b,t)dt\,, \tag{9}$$

where

$$\psi_{a,b}(t)=\frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right), a,b\in R,\quad a\neq 0\,, \tag{10}$$

where the continuous variables *a* and *b* are the dilation and translation parameters. An example of the CWT of the ultrasonic signal, consisting of compression (Fig2a, impulse 1) and shear (Fig 2a, impulse 2) waves with different delays is presented in Fig.2b. The CWT is presented as 2D image, in which the horizontal axis corresponds to the time and the vertical axis to the number



a

b

Fig.2. **Ultrasonic signal (a) and corresponding CWT (b).**

of the wavelet coefficient $C(a,b)$. The amplitude values of the coefficients are shown in a grey scale.

Processing algorithm

The fusion of the signals caused by compression and shear waves consists of the following steps:

- detection of the impulses of compression and shear waves by means of CWT;
- separation of the compression and shear wave signals;
- transformation of the different time scales into one scale;
- fusion of the transformed signals into a new compound B-scan image.

The more detailed explanation of these steps is presented below:

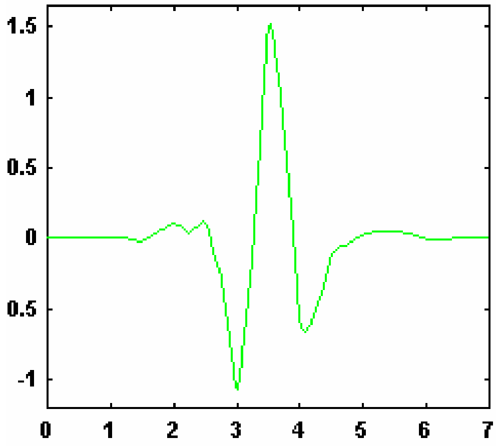


Fig.3. **Orthogonal Sym-4 - mother wavelet $\psi(t)$**

1. For detection and separation of the compression and shear wave signals the CWT is used. For this purpose the orthogonal continuos Sym-4 wavelet has been selected (Fig.3). The position of the detected impulse corresponds to the local maximum of the wavelet, e.g., where the first derivative of the wavelet is equal to zero. Transformation depth is determined according to the ratio

$$n = \left\lfloor {}^{f_s}\!/\!_{f_c} \right\rfloor \qquad (11)$$

where f_c is the center frequency of the ultrasonic impulse, f_s is the sampling frequency in the time domain. The coefficients of the wavelet Sym-4 are given in Table 1.

The next processing steps are carried out only for those impulses, for which the condition (6) holds. The position of the impulse is found as the instant of a local maximum of the wavelet coefficient function.

2. In the vicinity of each detected impulse the time interval $(t_{i+1} - t_i)$ is selected, which is claimed that belongs to this particular impulse. This interval is found as the interval in which the impulse amplitude is higher then some given value, e.g. :

$$u(t)_{t=t_i,t_{i+1}} = \gamma\left[\max\{\, u(t)\}\right], \qquad (12)$$

where γ defines the threshold level. If it has been determined that there is a shear wave impulse corresponding to the detected compression wave impulse, then the time – amplitude scale of this impulse is compressed according to

$$u_{tr}(t) = k_w K u_s\left(\frac{t}{K}\right), \qquad (13)$$

where the dilation factor K is given by Eq.6 and k_w is the weight coefficient. Necessity of the weight coefficient is caused by a rather low amplitude of the diffracted shear waves in comparison to the directly reflected compression wave. Influence of this coefficient on a quality of the ultrasonic image will be illustrated by experimental results. The transformed signal is fused with the signal corresponding to the compression wave. The fusion is adding operation , during which is checked if the polarity of the fused signal at the instant of maximal value is the same. If polarities are opposite, then polarity of one signal is changed to opposite.

Table 1 **Coefficients of the. wavelet Sym-4**

C_0	-0.07576571478927
C_1	-0.02963552764600
C_2	0.49761866763202
C_3	0.80373875180592
C_4	0.29785779560528
C_5	-0.09921954357685
C_6	-0.01260396726204
C_7	0.03222310060404

3. From the fused 1D ultrasonic signals B-scan image of the object is produced in a conventional way, except that instead of two types of waves only one compaund image of each non-uniformity is left.

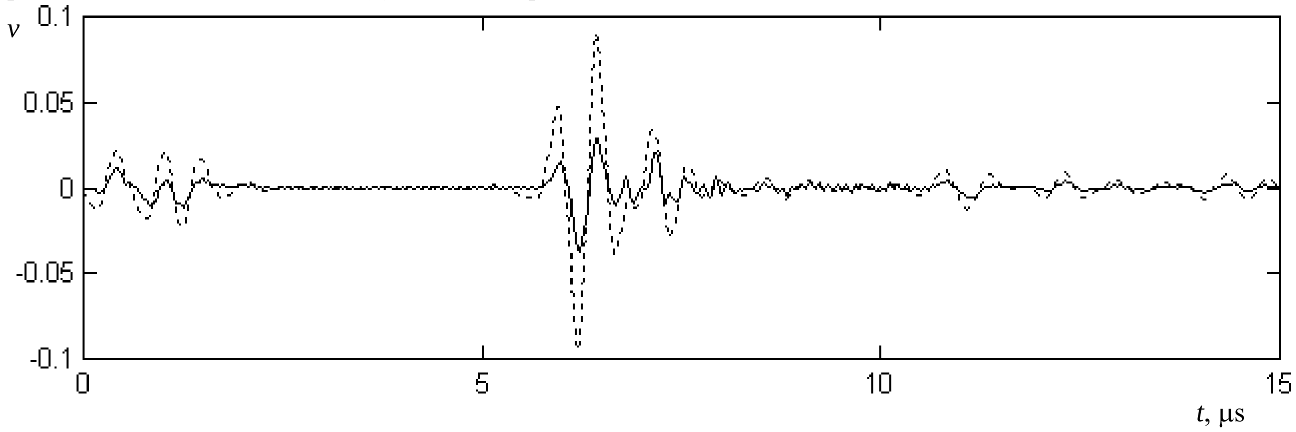
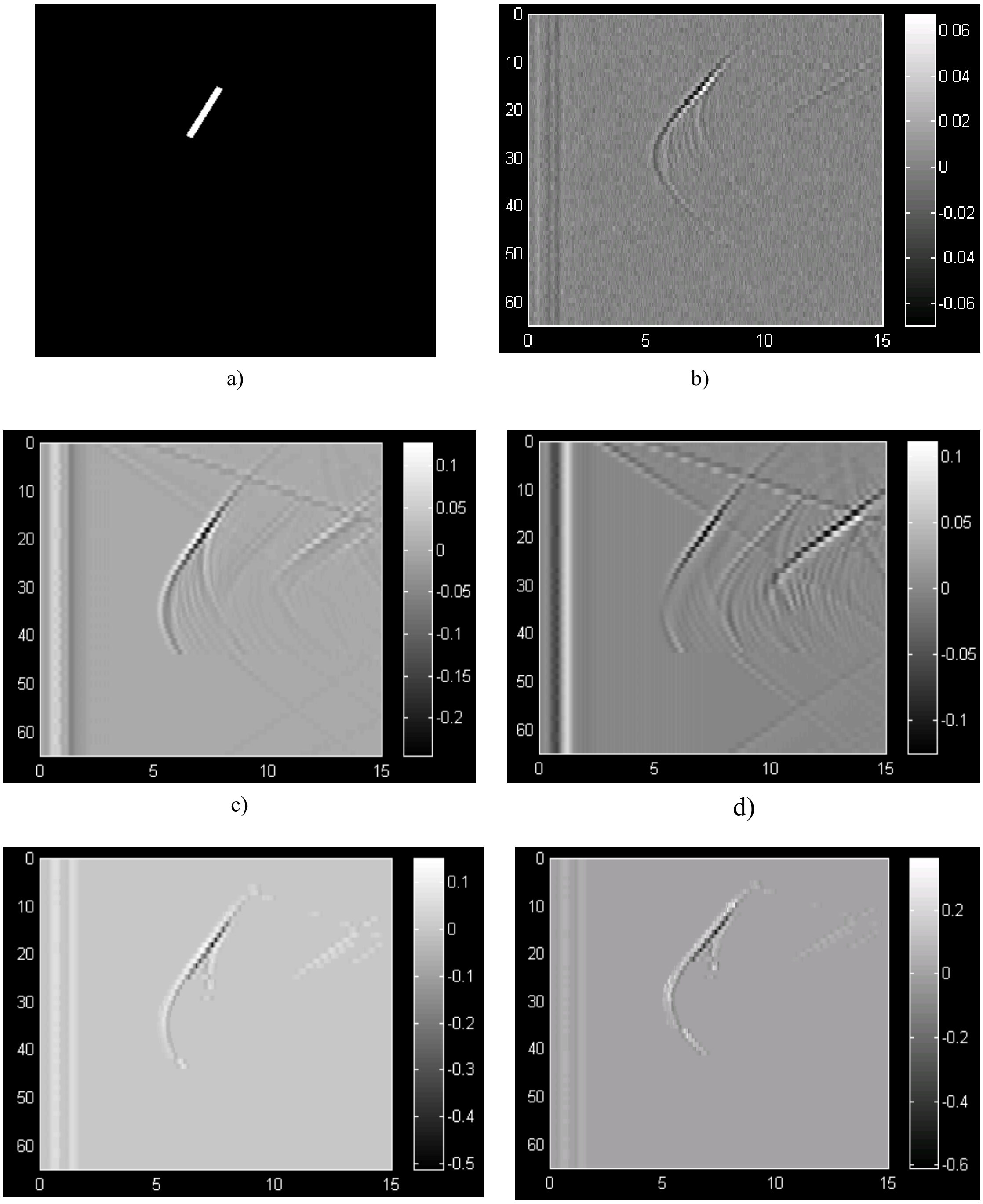


Fig.4. **The ultrasonic signal picked up by an ultrasonic transducer (solid line) and the corresponding 14 level coefficient vector of the CWT (dotted line)**

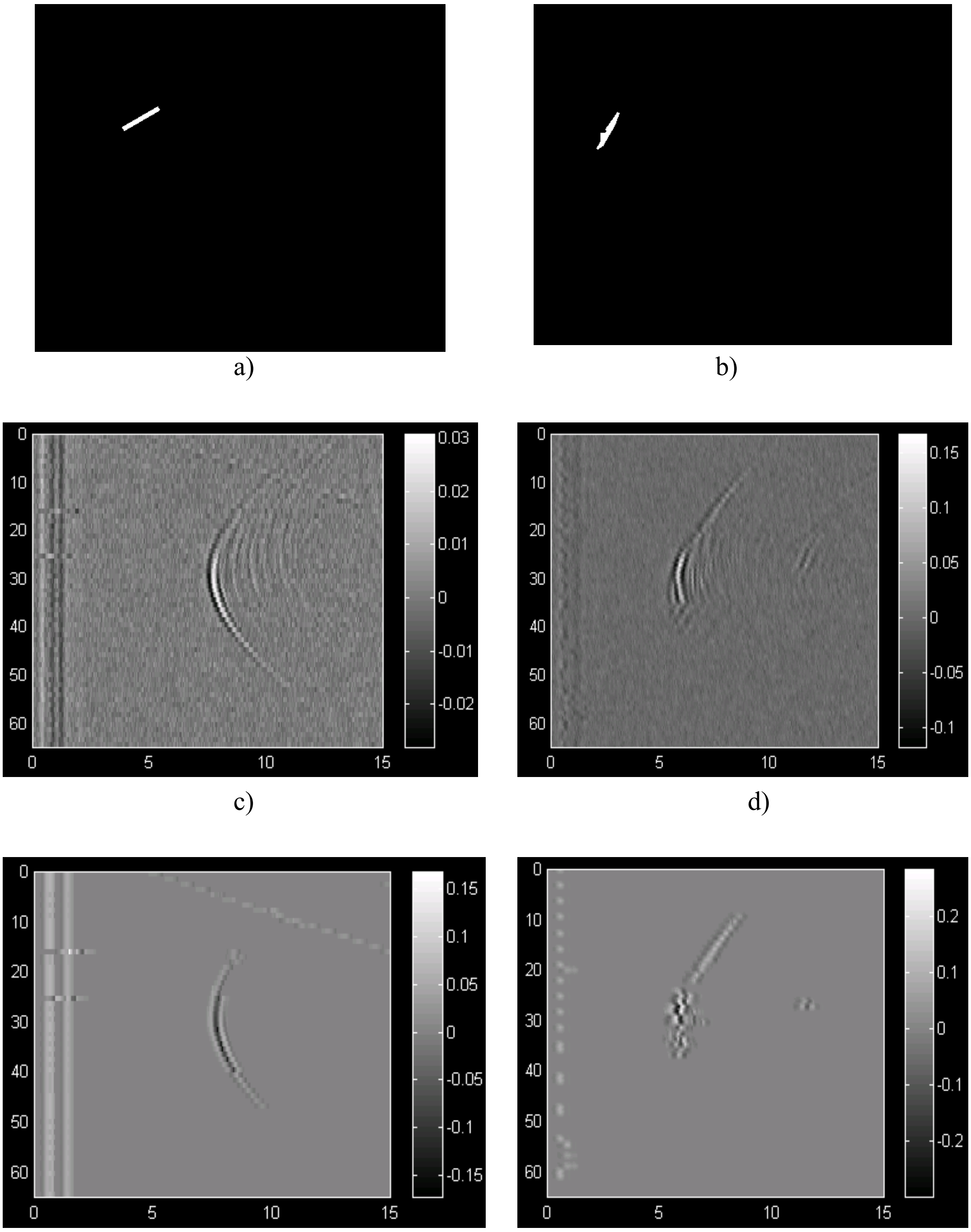


a) b)

c) d)

e) f)

Fig.5. **Lay-out of the sample with a smooth crack (a) and B-scan images: b- the complete unprocessed image; c- B-scan image obtained only from the longitudinal components; d- B-scan image obtained only from the transversal components; e- B-scan image obtained after fusion of the transformed signals, the weight coefficient k_w=1; e – the same as in Fig.5e except that k_w>1.**



a) b) c) d) e) f)

Fig.6**. Lay-outs of the sample with a smooth 30º crack (a) and rough 60º crack (b) and corresponding B-scan images: c, d- the unprocessed images; e, f- B-scan images obtained after fusion of the transformed signals**

Analysis of the results

The developed image processing procedure was tested using simulated data. Simulations were performed by means of the WAVE2000 software. The corresponding B-scans were obtained by the developed graphic interface. For simulations steel sample with cracks oriented at different angles was selected. The frequency of the ultrasonic waves was chosen 2 MHz, the sampling frequency f_s=35MHz. In order to obtain data for the B-scan image, the ultrasonic transducers used for transmission and reception of ultrasonic waves were shifted along the surface of the sample with the step 1mm. Each image was produced from 65 scans. For the CWT the Sym-4 wavelet was used. Results of the computer experiments are presented in Fig.5-7.

The software package WAVE2000 enables to obtain separately signals corresponding to longitudinal or shear particle velocity components. Please, note that such unprocessed ultrasonic images are given in Fig.5c and d. The image after fusion of the transformed particular images is presented in Fig.5e. This image was obtained when the weight factor k_w=1. In Fig.5f the amplitude of the diffracted shear wave was signifcantly increased ($k_w > 1$). It is possible to see that the level of artifacts in this case is lower and the actual dimensions of the crack may be determined more precisely.

Results presented in Fig.6 illustrate the performance of the processing algorithm at different orientation angles of the crack. Note, that in Fig.6b,d and f not a smooth but rough crack was simulated. Surface roughness was 1mm. It is necessary to point out, that only the waves diffracted by the nearest crack tip were exploited. The waves diffracted by the futher crack tip were too weak and were not used for processing.

The results obtained indicated that in the case of cracks with sharp tips, application of the developed procedure enables improve quality of the B-scan ultrasonic images. Particlularly, it becomes possible to determine a length of cracks more precisely.

Conclusions

The presented novel algorithm for enhancement quality of the B-scan images is based on a fusion of compression and shear wave signals into one compaund B-scan image. For detection of the compression and shear wave impulses one-dimesional continuos wavelet transform has been applied. That enables to reveal changes of the signal at different detail levels what is essential for detection of low amplitude diffracted shear waves. The detected compression and shear wave signals are fused into one A-scan compound signal by means of the time-amplitude transformation. The B-scan image is produced from the set of A-scans in a conventional way. The results of simulations show that the method is most efficient in the case of sharp cracks, creating diffracted waves.

References

1. Интроскопия и автоматизация неразрушающего контроля //В. Сухоруков, Е. Вайнберг, Р. Кажис, А. Абакумов. Москва, 1993.
2. Multiscale Analysis of Ultrasonic Image /Xiaojun Zhou, Yueming Sun, Guosheng Hu, Zhongfang Tong //Acoustical Imaging. 1993, Volume 20.
3. Identification and Synthesis of Acoustic Scattering Components via Wavelet Transform / D. M. Drumheller, D. H. Hughes, B. T. O.Connor, C. F. Gaumond // Acoustic Society. 1995, No. 6.
4. **Murthy R**. Detection of Ultrasonic Anomaly Signals Using Wavelet Decomposition / Rashmi Murthy, Nihat M. Bilgutay, O. Kagan Kaya // Drexler University, Signal Processing Laboratory
5. **Meyer R.** Wavelets: Algorithms & Application. Philadelphia, 1993. 133 p.
6. **Coifman R. R.** Wavelet Analysis and Signal Processing / Ronald R. Coifman, Yves Meyer, M. Victor Wickerhauser // Publication's by M. Victor Wickerhauser, 1992, Washington University, Department of Mathematics.
7. **Wickerhauser M. V.** Time Localization Techniques for Wavelet Transforms. Publication's by M. Victor Wickerhauser, 1995, Washington University, Department of Mathematics
8. **Coifman R. R.** Wavelets, Adapted Waveforms, and De-Noising/ Ronald R. Coifman, M. Victor Wickerhauser // Publication's by M. Victor Wickerhauser, 1996, Washington University, Department of Mathematics

R.Kažys, G.Čeplys

Bangelių tipo transformacijos taikymas B tipo ultragarsinių vaizdų kokybei pagerinti

Reziumė

Neardomuosiuose bandymuose naudojamos automatizuotos ultragarsinės vizualizavimo sistemos turi pavaizduoti aptiktus defektus ir nevienalytiškumus, nustatyti jų dydį ir vietą. Vaizdai, gaunami tiesioginio vizualizavimo metodais, esti nepakankamos kokybės dėl difrakcijos, interferencijos reiškinių, dėl struktūrinių triukšmų, naudojamos aparatūros ribotų galimybių, baltojo triukšmo. Siūloma nauja idėja ir algoritmas akustiniams B skenavimo vaizdams sintezuoti iš transformuotų išilginių ir skersinių bangų. Idėja grindžiama tuo, kad difraguotos skersinės bangos sklinda beveik dvigubai mažesniu greičiu negu išilginės bangos. Jos yra mažesnės amplitudės ir vizualizavimo sistemose atmetamos kaip struktūrinis triukšmas. Šią informaciją galima panaudoti akustiniam vaizdui gerinti. Staigūs bangų amplitudės pakitimai aptinkami taikant vienmatę bangelių transformaciją. Jei aptikti bangų impulsai tenkina atstumo sąlygas, kurios skaičiuojamos pagal skirtingo tipo bangų sklidimo greitį, priimamas sprendimas, kad jie yra sukelti to paties defekto. Signalai transformuojami ir suliejami į vienodo mastelio skalę. Algoritmui patikrinti atliktas kompiuterinis eksperimentas, patvirtinantis pasiūlyto metodo efektyvumą.

Pateikta spaudai: 2000 06 17

DOI: 10.5755/j01.u.35.2.7970