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Ultrasonic Pulse Signal Diffraction from Different Flaws in Elastic Media

Dmitry V. Perov, Anatoly B. Rinkevich, Yakov G. Smorodinsky

Institute of Metal Physics Ural Division of Russian Academy of Sciences;

Ekaterinburg, Russia

Phone: +7 343 3783697, Fax: +7 343 3745244; e-mail: peroff@imp.uran.ru,

rin@imp.uran.ru, sm@imp.uran.ru

Abstract

The analysis of the processes of acoustic wave interaction with the reflectors of different shape located in an isotropic elastic medium has been carried out. To analyze the changes of instantaneous frequency of reflected signals in time, the algorithm based on the use of the continuous wavelet transform was applied. It has been demonstrated that reflected signals can have the frequency modulation different from that in the probe signal. Furthermore, under certain conditions, the central frequency of the spectrum of reflected signal can differ noticeably from the value corresponding to the probe signal.

Keywords: acoustic waves, reflectors, diffraction, instantaneous frequency, wavelets

1. Introduction

The analysis of the processes of acoustic waves interaction with various inhomogenities in an elastic medium is of considerable interest in such applications as, for example, geophysics, non-destructive testing, and medical diagnostics. The widespread scheme of performing the acoustic probing methods in these fields is using the single radiator as well as the single receiver of acoustic waves. Mostly, the same transducer has the functions both radiator and receiver of pulse signals.

As a rule, the main informative parameters of echo-pulse reflected from some inhomogenity of a medium are the delay time of the signal and its amplitude. Such a way does not allow, in all instances, to make definite conclusions about the features of detected object and estimate its sizes. The foremost restriction appeared in the present state of affairs is that the shape of reflector can not be determined. Often such information may be of main interest for researchers.

For the reconstruction of reflector’s shape by acoustic probing of object controlled, the methods of computer tomography are usually applied. To realize them, it is necessary to use a set of transducers. The systems of this kind are available but these are complicated and expensive. In a few cases, however, it is enough to know the class which the reflective object is rated in. Such a problem can be solved, in principle, with the use of single transducer. In such a situation, the question about search of the proper informative characteristics which allow classifying the echo-signals becomes relevant.

2. Definition of instantaneous frequency

One of the possible ways for solving this problem lies in the use of information about the change of the instantaneous frequency of reflected signal in time. The instantaneous frequency $\tilde{f}(t)$ can be founded by the interrelation [1]

$$\tilde{f}(t) = \mathrm{Im}\left[\frac{1}{\dot{z}(t)}\frac{d\dot{z}(t)}{dt}\right] \quad , \tag{1}$$

where $\dot{z}(t)$ is the analytical signal obtained from the analyzed signal $s(t)$ from the formula $\dot{z}(t) = s(t) + iH[s(t)]$; $H[\cdot]$ is the Hilbert transform.

We have mentioned that calculated result depends vastly on the noise existing in an analyzed signal due to the presence of the derivative operator in the formula (1). More steady results can be obtained by using the modification of formula (1) performed with the use of the continuous wavelet transform [1, 2]. By known wavelet spectrum of analytical signal $\dot{W}_z(s,\theta)$, it is possible to find the following expression for the instantaneous frequency:

$$\tilde{f}(\theta, s^*) = \frac{1}{2\pi}\mathrm{Im}\left[\frac{1}{\dot{W}_z(s^*,\theta)}\frac{d\,\dot{W}_z(s^*,\theta)}{d\theta}\right] \tag{2}$$

where $s^* = s^*(\theta)$ is the value of the scaling coefficient s corresponding to the condition: $\left|\dot{W}_z(s^*,\theta)\right| = \max\left\{\left|\dot{W}_z(s,\theta)\right|\right\}$, θ is the translation parameter of wavelet transform, which is similar in meaning to the variable t in the formula (1).

3. Experimental investigations

To carry out the experimental investigations, we used the steel specimen in the shape of parallelepiped. For excitation and reception of ultrasound oscillations, the straight-beam and angle transducers were applied, the resonant frequencies of which were, respectively, 10 and 5 MHz. The diameters of piezoelectric transducers were equal to 5 mm. The radiation of probing signals and reception of echo-signals were carried out by using the PCUS-10 flaw detector.

The acoustic wave reflectors of the next shapes were taken into consideration: the through cylindrical hole with diameter of 6 mm drilled on the width plane of the specimen (*cylinder*), the bottom surface of the specimen (*flat surface*), and the *dihedral angle* formed by a pair of specimen's planes which were perpendicular to each other. All these are shown in Fig. 1a. Moreover, another specimen with the reflecting side in the form of the *concave surface* was also used; see Fig. 1b.

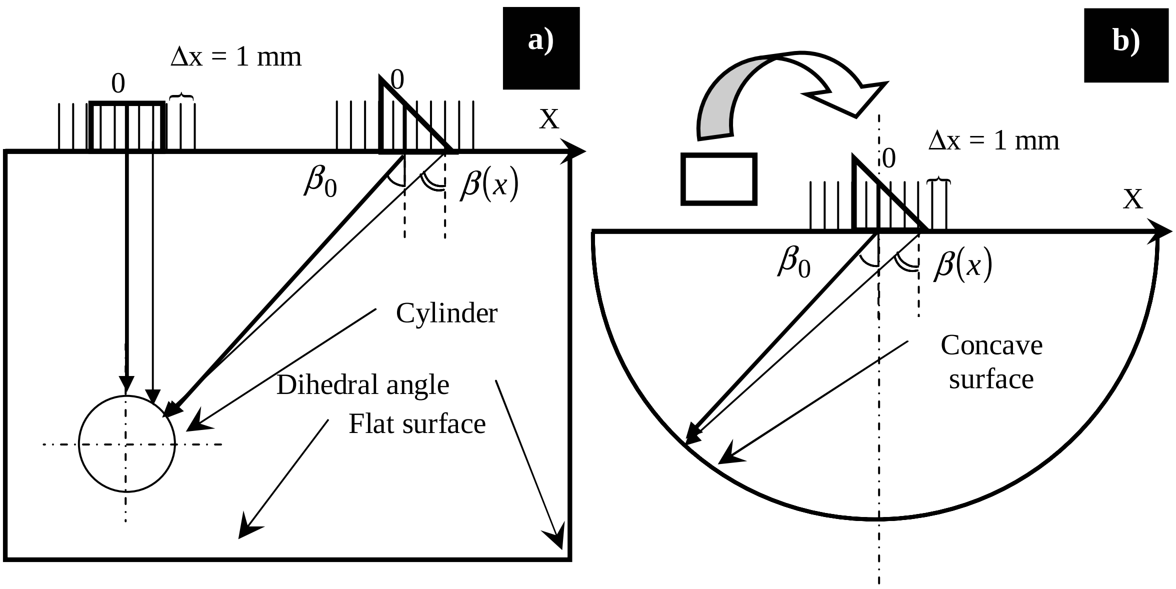

Figure 1. The scheme of experiment: the investigated specimens;
the disposition of piezoelectric transducers; the reflectors of acoustic waves.

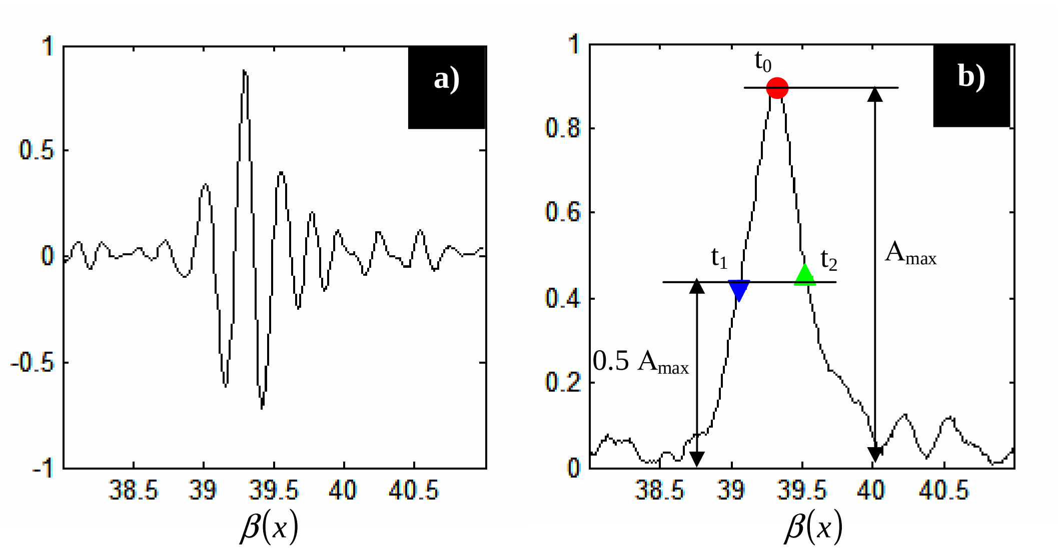

Figure 2. An example of reflected signal (a) and its envelope (b).
The instantaneous frequency of reflected signal is to be evaluated at the points t_0, t_1, and t_2.
The β_0 angle is equal to 40°

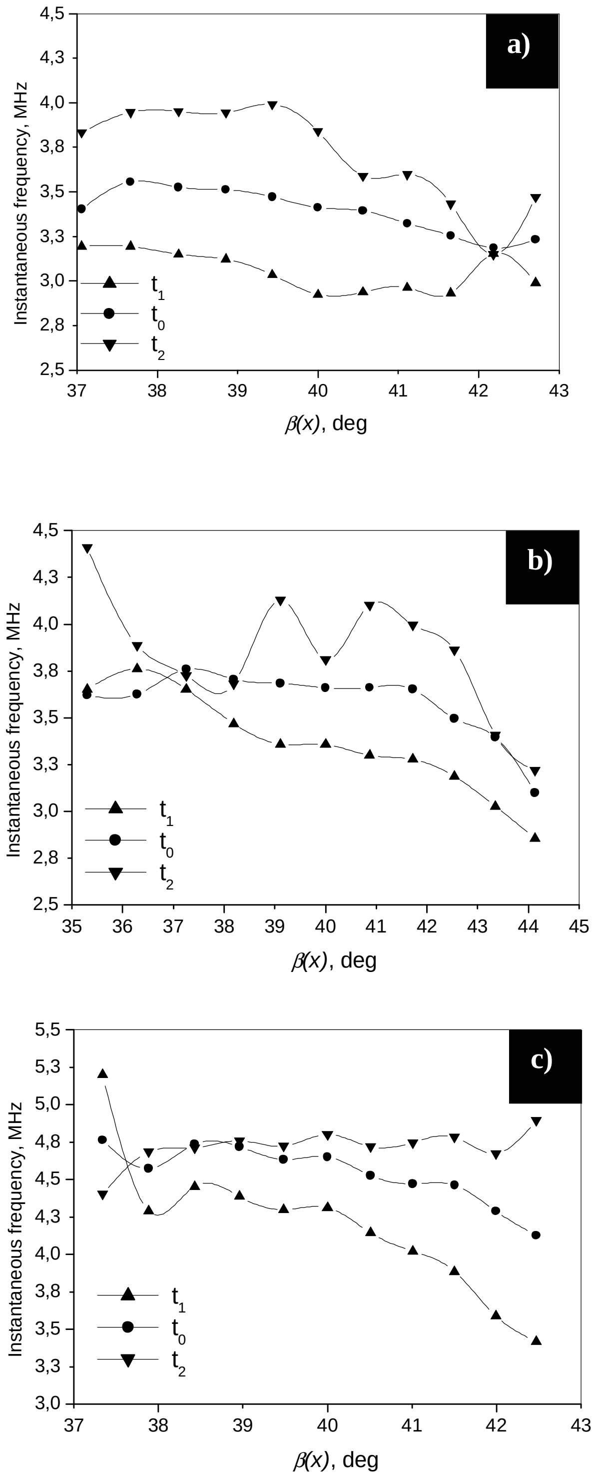

Figure 3. The angle transducer; the β angle dependence of instantaneous frequency for the reflector of the form: dihedral angle (a), cylinder (b), and concave surface (c). The β_0 angle is equal to 40°.

First of all, let us consider the results obtained by using the angle transducer. In Fig. 2 the signal reflected from the cylinder on condition that $\beta(x) = \beta_0$ and its envelope are shown. By using the formula (2), we find the values of the instantaneous frequency of signal at the instants of time corresponding to the points t_0, t_1, and t_2. The β angle dependences of frequency, which have been obtained, are shown in Fig. 3. Notice that the β angle dependences, where the β is the angle between the normal to the surface and straight line connecting the center of ultrasonic beam projection on this surface with the geometrical center of reflector, are plotted here.

The transducer's relative coordinate dependences of frequency, which have been obtained for the straight-beam transducer, are shown in Fig. 4.

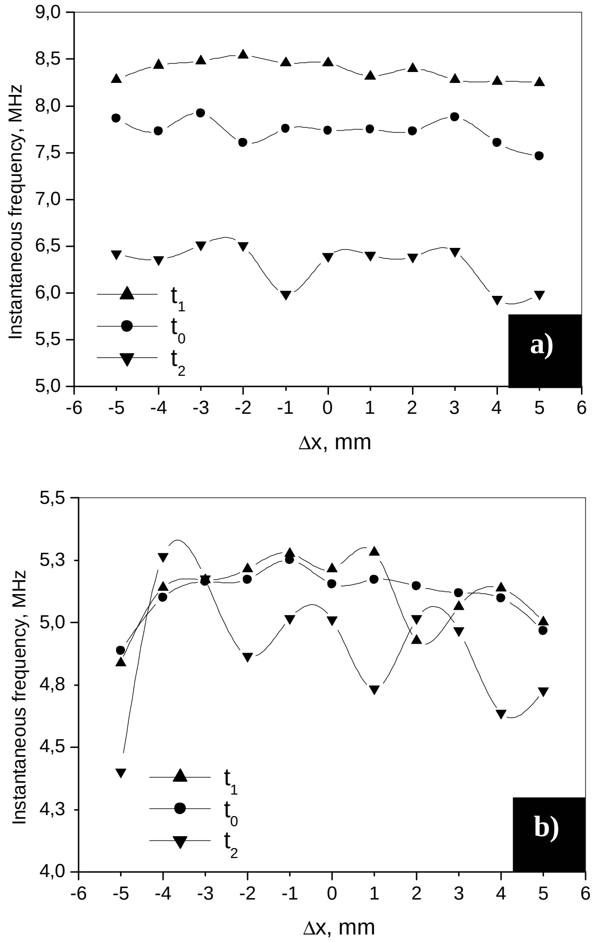

Figure 4. The straight-beam transducer; the relative coordinate dependence of instantaneous frequency for the reflector of the form: flat surface (a) and cylinder (b).

4. Conclusion

(1) The results shown in Figs. 3 and 4 are the evidence that instantaneous frequency of echo-signal can significantly vary in accordance to which part of pulse envelope the instant of measuring corresponds to. The character of this dependence is defined by the shape of acoustic wave reflector. The value of instantaneous frequency is close to the resonant frequency of transducer only if the conditions of interaction between the wave and reflector do not change when the transducer is moved over the surface

of specimen – Fig. 3a. Otherwise, different components of the spatial spectrum of ultrasound beam interact with reflectors variously. It is the reason of appearance of frequency modulation in echo-signals, which is absent in the probing signal. Furthermore, the central frequency of the spectrum of reflected signal can differ noticeably from the value corresponding to the probe signal.

(2) In Fig. 5 the reflector's shape dependence of instantaneous frequency for the initial positions of straight-beam and angle transducers is shown. It follows from the results obtained that the set of values of instantaneous frequency, which are measured at various instants of time, may be chosen as an informative criterion. By using it we can determine, in principle, the shape of reflector with the use of single transducer.

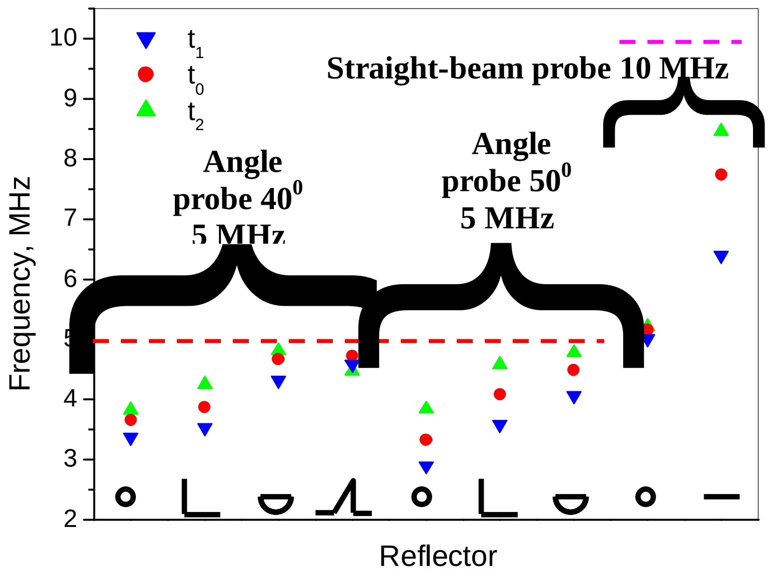

Figure 4. The reflector's shape dependence of instantaneous frequency for different transducers.

References

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