The Examination of Frequency Dependences of Elastic Waves Velocities and Their Attenuation in Heterogeneous Mediums

P.P.Turchin[1,2], A.A.Parfenov[1], V.V.Beletsky jun.[1], A.A.Volzhentcev[1], V.M.Ruzanov[1], K.S.Aleksandrov[1,2]
1 - Siberian Federal University
Svobodny av. 79, Krasnoyarsk, 660041 Russia
2 - Kirensky Institute of Physics, Siberian Division, Russian Academy of Sciences
Akademgorodok, Krasnoyarsk, 660036 Russia
E-mail: pavelpturchin@lan.krasu.ru

***Abstract*— The pulse - phase method for examination of ultrasonic waves propagation in materials, including mediums with high attenuation of a sou nd was designed. By automation methods of measurings the opportunity of determination the elastic waves velocities with an frequency range 100 kHz - 30 MHz with the resolution on frequency of 10^{-6} Hz is implemented. The phase method and a method of the frequency strobing for recording impulses are realized. These methods allow to define with precision not worse than 10^{-9} second the time of ultrasonic waves propagation. Requirements to the minimum linear dimensions of samples are restricted by the method sensitivity only. Velocities of elastic waves and their signal attenuation in ceramic and composites are measured.**

Keywords - automation of measurings, physical acoustics, elastic properties, composites, ceramics, sound signal attenuation

I. INTRODUCTION

Ultrasonic methods are widely used for study of the material properties of crystals [1-2], rocks [3,4], composite and other materials. Such examinations are based on measuring of velocities of acoustic waves and their changes as a result of external actions [5,6] or structural singularities of explored mediums. Such measurings do not create the especial difficulties in the long-wave limit when signal attenuation of a sound is small. In a case when the acoustic wave length is comparable with inhomogeneities size or strongly inhomogeneous materials are explored, application of the additional experimental possibilities related to amplification of an direct impulse and sensitivity of devices registrating signal should be above.

Possibilities realisation of monofrequency measurings in the broad frequency range what is not always accessible within the limits of known experimental methods are important in the latter case.

Such measurings essentially become simpler in the presence of a measurings possibility not only on a resonant frequency or harmonicses of the piezoelectric transducer but also in its neighbourhood when it is necessary take into account effect of "tightening" of registered signal in resonant frequency field.

The indicated singularities can be considered by means of the modern methods of automation and a digital processing of explored signals which are taken as a principle of the computerised pulse - phase method for examination of acoustic waves propagation in materials with high attenuation of sound signal.

II. THE EXPERIMENTAL METHOD

The experimental method (fig.1) is based on developed earlier [7] by authors the computerised device for examinations of solids by acoustic and acoustic-luminescense methods. In the method digital control by a frequency synthesizer CH6-31 and registrating of signals in the CAMAC standard of data exchange of devices with the personal computer (PC) are implemented. In this case, the two-channel analogue-digital converter (ADC) AD9288 is used for automatic recording of signal. Both ADC channels are connected to a separate chip of fast memory of static type (SRAM) K6R4008V10-JI10. Synthesizer CH6-31 sets the clock rate of ADC in the range 50 Hz - 40 MHz with the

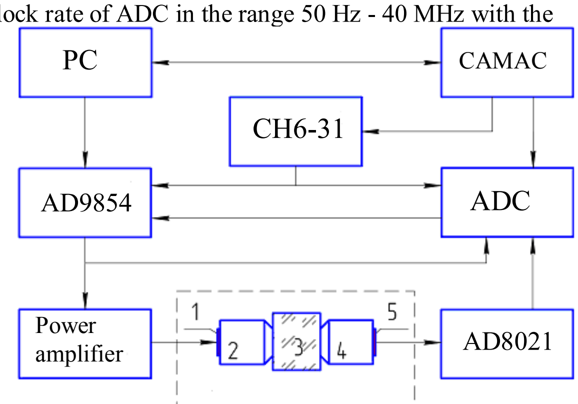

Figure 1. The block-scheme of automation pulse-phase method for acoustic measurings. 1, 5 - input and output piezoelectric transducers; 2, 4 - buffers; 3 – sample

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resolution of 10^{-2} Hz. Data from ADC channels are synchronously noted in SRAM and after reading are accessible to mathematical handling on PC.

The direct signal from a synthesizer AD9854 (fig. 1) comes to the first channel of the ADC and on a power amplifier. The signal from exit of a power amplifier goes on the input piezoelectric transducer of an acoustic line, then is registrated by the output piezoelectric transducer. After amplification by amplifier AD8021 the signal comes on the second channel of the ADC. Frequency, initial phase and amplitude of a sound signal are set by a command from PC and spotted by parametres of chip AD9854 which is plugged through parallel port of PC. The AD9854 frequency range is 0-100 MHz with the resolution of 10^{-6} Hz; phases - 0^0-360^0 with the resolution of 0.01^0. The entry of signals on both channels of the ADC begins simultaneously. Sync of synthesizer AD9854 and the ADC is ensured with their starting up on front of a clock impulse with frequency f_t.

The wide-band amplifier of power made with use of broad-band transformers is applied to amplification of a sound signal. The amplifier input potential is over the range 0.5-1 V. Amplification constant 40 db over the range frequencies 100 kHz - 50 MHz with the maximum passband ripple 6 db. On value of an input potential of the amplifier is adapted with synthesizer AD9854.

III. Registrating of a signal and velocity measuring

In a metering circuit acoustic line (fig. 1) the sample is arranged between two buffers from the fused silica with length near 25 mm. Piezoelectric transducers are bonded on to butts of the buffer and actuate in a frequency band Δf in a resonant frequency neighbourhood f_0 ($\Delta f/f_0 \approx 0.1 \div 0.2$). The time of duration of a sound signal t is set by a control program in a limits

$$t<\tau_1, \qquad (1)$$

where τ_1 is a time of propagation of signal in acoustic line without reflections.

The example of observed data on frequency $f=f_0=4.4$ MHz with $f_r=32$ MHz is given on fig. 2 where are shown the direct signal registrated by the first the ADC channel, and delayed in an acoustic line, registrated by the second the ADC. On fig. 3, “with the incremented scan”, the effect of signal tightening in field of a resonant frequency [3] is shown at measurings on the frequency which different from a resonant frequency of oscillations of the output piezoelectric transducer. Such effect is related to a oscillations frequency shift to f_0 when the vibration amplitude is small, and it should be considered at investigations on frequencies distinct from f_0 which are based on analyses of first area of registrated signal.

In this method (fig. 1) measuring of elastic wave velocities is made by comparing the delay time of signal in an acoustic line with the sample t_1 and without the sample t_2:

$$V = \frac{\ell}{\Delta t} = \frac{\ell}{t_1 - t_2}, \qquad (2)$$

where ℓ is length of sample. Times t_1 and t_2 can be determined by direct comparison of identical fragments (maximums, "nulls") direct signal beginning and the signal delayed in acoustic line. Such fragment is chosen before reflected signals registration.

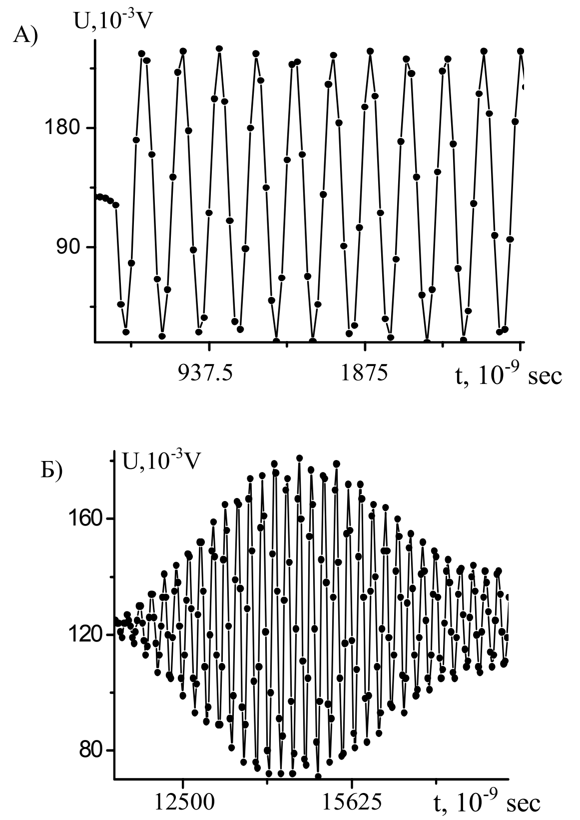

Figure 2. Example of a sound signal. (A) - registered by the first ADC channel; (B) - delaying in acoustic line and registered by the second ADC channel. Points mark out values of signal amplitude recorded in SRAM

Comparison of identical fragments of registrated by the output piezoelectric transducer signals in an acoustic line with the sample and without the sample allows to define at once value Δt. Necessary requirements for reaching of demanded precision of measurings delay (10^{-9} sec), expelling effect of "tightening", is the identical amplitude of signals and comparison of the same fragments for line with the sample and without the sample. The indicated precision of delay time definition on the developed experimental method can be gained by two ways at the expense of the higher resolution of a signal, than the resolution recieved on the given clock rate.

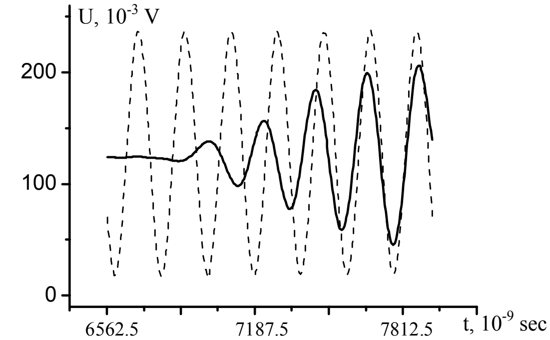

Figure 3. Effect of "signal tightening". The full curve - the delayed signal, the dashed - direct. Frequency of measuring is 5.1 MHz. The modification of frequency of the delayed signal is visible

In first case (a phase method) delay times t_1 and t_2 are determined from a phase comparison φ_1 and φ_2 points of the second channel ADC in line with the sample and without the sample with a phase φ_0 same points in beginning of a direct signal as it is shown on fig. 4. For determination φ_0 (φ_1, φ_2) of the point the signal is repeating many times with a modification of its initial phase (with the given resolution) within half of period. Quantities t_1 and t_2 are found by a known number of the whole periods p which laid between two points and the gained value $\Delta\varphi_{1(2)} = \varphi_0 - \varphi_{1(2)}$ of a relation

$$t_{1(2)} = pT + \frac{1}{2\pi}\frac{\Delta\varphi_{1(2)}}{f} = \left(p + \frac{\Delta\varphi_{1(2)}}{2\pi}\right)\cdot T, \qquad (3)$$

where T, f is period and frequency of a sound signal.

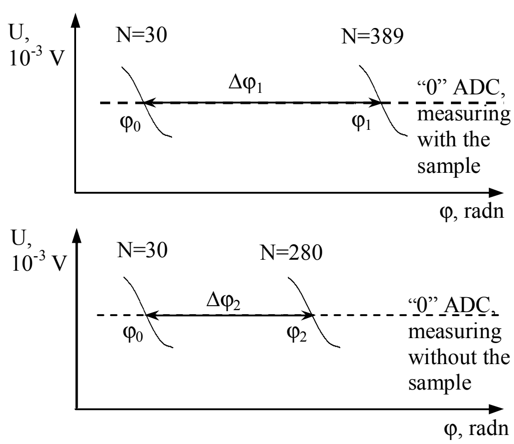

Figure 4. Definition of sound delay by the phase method

It is necessary to point out, that a phase method of the signal resolution, applied in the experimental scheme, is more effective at the relative measurings of sound velocity changes. The higher resolution of a sound signal in the viewed experimental scheme (fig. 1) has been gained by strobing of sound signal by modification of clock frequency of synthesizer CH6-31 (a method of strobing by frequency). In this case the clock rate modification f_{kt} is set at each recurring of a sound signal within one step f_t by formula

$$f_{kt} = \frac{f_t \cdot N \cdot n}{N \cdot n + k}, \qquad (4)$$

where n is a number of one clock dissection interval, k is the point number of a scanned interval (k=1÷n) within clock. As a result of the modification of a clock rate the point N is shifted on a time interval $\frac{1}{f_t \cdot n}$.

Application of strobing method by frequency allow to registrate a signal with the resolution not less 10^{-2} nanoseconds in all frequency band.

The result of recording strobing by frequency signal at measurings the velocities of longitudinal volume acoustic waves (BAW) in single crystal $La_3Ga_5SiO_{14}$ is given on fig. 5. Measuring is fulfilled on frequency f=4.3 MHz with the resolution on time ~0.3 nanoseconds (n=100). Values t_1 and t_2 were spotted on intersection points of a signal with a line of a zero level of the ADC. Paired comparison of corresponding points of a signal at definition Δt in an acoustic line with the sample and without the sample gives equal values of velocity BAW (2) under condition of coincidence of amplitudes of registrated signals in both cases. Correspondence of amplitudes is installed by the programm modification of amplitude value for sound signal on synthesizer AD9854 with initial phase constant. It allows to avoid any phase shift.

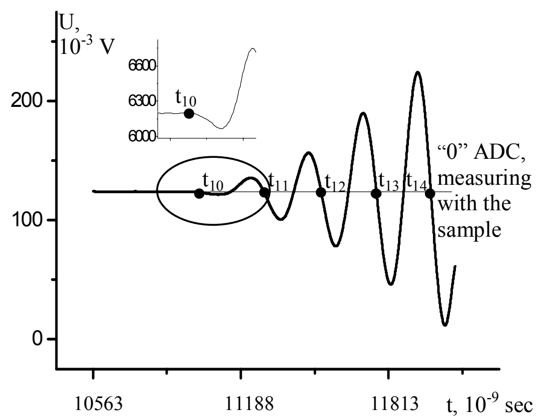

Figure 5. Measuring of sound delay by the method of the frequency strobing. Indicated time points t_{1i} which are taken for evaluation V. On parenthesizing - isolated the fragment of signal recorded with storage

The delay time can be discovered direct measurement of time start of signal t_{10} (fig. 5). There by limitations on the minimum sizes of explored samples are eliminated. They are spotted in this case only by precision of delay time determination.

In the given article by authors the problem of sound delay in contact stratum of lubrication the buffer-sample separately is not considered. It is sufficiently explored earlier.

On some experimental estimates such delay can to accept values of 1-2 nanoseconds.

IV. EXAMINATIONS OF VELOCITIES AND SOUND SIGNAL ATTENUATION

Observed data of velocities longitudinal BAW and the experimental estimates of sound signal attenuation in materials with the strong absorption are given in tab. 1. Measurings were led for samples with linear dimensions from 1 mm to 10 centimeters. In all cases in single crystals $La_3Ga_5SiO_{14}$ (langasit) for crystallographicly equivalent directions equal values V within the experimental error are gained. For determination of signal attenuation in a line with the sample and without the sample were adjusted by modification of signals amplitudes on exit AD9854.

Value of signal attenuation α was spotted from relation

$$\alpha = \frac{1}{\ell} \cdot 20 \cdot \lg \frac{U_1}{U_2}, \qquad (5)$$

where U_1 and U_2 - amplitudes of a signal on exit AD9854 at measurings in an acoustic line with the sample and without the sample accordingly.

TABLE I.

The measurements results of velocities longitudinal BAW and sound signal attenuations

Material	**Frecuency, MHz**	**Velocities V, m/sec**		**Attenuation α*, db/ centimeter**
		This work	***[6] (30 MHz)***	***This work***
Langasit, x-cut	4.0÷5.0	5748±5	5748.7±0,5	
Langasit, y-cut	4.0÷5.0	5755±5	5755.3±0,5	
Langasit, z-cut	4.0÷5.0	6749±5	6746.7±0,5	
BZT** №1	4.4	4094±10		33.9
BZT** №2	4.4	3915±10		58.2
BZT** №3	4.4	4448±10		42.2
Acrylic plastic	4.4	2719±10		12.4
Wood compo-site	4.4	960±20		256

* The definition error α does not exceed 10 %;

** BZT - ceramics Ba $(Zn_x, Ta_{1-x}) O_3$, gained under various requirements solid-state synthesis.

In table 2 observed data of values of isotropic velocities $\overline{V}$ and signal attenuation of longitudinal BAW in composite of fractal type (fig. 6) are presented. Values of velocities calculated according to relation (2).

TABLE II.

The measurements of velocities and sound signal attenuations in composite of fractal type

Frecuency, MHz	0,65	1,5	2	4,4
Velocities $\overline{V}$, m/sec	7612	5549	5018	6247
Attenuation α, db/ centimeter	41,4	160,4	127,3	209,7

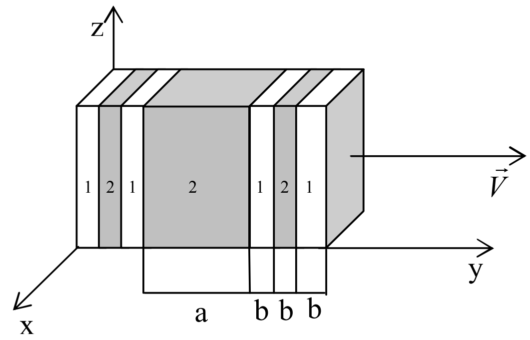

Figure 6. Structure of fractal type: 1 - acrylic plastic; 2 - Si. a = 3 mm, b = 1mm

The gained frequency dependences for this structure are not monotonous.

CONCLUSION

The viewed computerised scheme of ultrasonic measurings, it is padding to the featured possibilities, can be used and for embodying of the majority ultrasonic methods for examinations of materials.

REFERENCES

[1] Physical acoustics. Prinsiples and methods, Edited by W. P. Mason, vol. I, Methods and devices, Part A, Academic press, New York and London, 1964.

[2] R. Truell, Ch. Elbaum, B. B. Chick, Ultrasonics methods in solid state physics, Academic press, New York and London, 1969.

[3] K. S. Aleksandrov, G. T. Prodaivoda, Elasic of minerals and rocks, publishers SB RAS, 2000.

[4] B. P. Belikov, K. S. Aleksandrov, T.F.Ryshgeva Elastic properties of Rock-forming mineralses and rocks, Moscow, Nauka, 1970.

[5] K. S. Aleksandrov, B. P. Sorokin, P. P. Turchin, D. A. Glushkov, «Non-linear piezoelectricity in $La_3Ga_5SiO_{14}$ piezoelectric single crystal», Ferroelectrics Letters., 1992, v.14, №5-6, p.115-126.

[6] B. P. Sorokin, P. P. Turchin, D. A. Glushkov, «The elastic nonlinearity and pecularities of bulk acoustic waves propagation under the influence of homogeneous mechanical pressure in $La_3Ga_5SiO_{14}$», Fizika tverdogo tela (Rus.), 1994, vol. 36, N10, pp. 2907-2916.

[7] P. P. Turchin, A.A.Parfenov, V.V.Beletsky jun., N.A.Tokarev, K. S. Aleksandrov, «Automation of acoustic methods for solids examinations», Vestnik KrasGU, ser. phys. math. sci., 2006, vol.1, pp. 34-41.