Ultrasonic testing of pulp solid phase concentration and particle size distribution considering dispersion and dissipation influence

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Abstract
The work is devoted to theoretical basis of ultrasonic testing of mineral disclosure degree, solid phase concentration and particle size distribution of crushed material in the pulp flow on the basis of Lamb waves parameters measurements considering the influence of dispersion and dissipation effects.

Key words: ULTRASOUND, PULP, CONTROL, LAMB WAVES

In [1-11] and other various methods and devices of ultrasonic testing, which have been used in the automation of technological processes were described. The known methods of pulp parameters ultrasonic testing allow to define two main characteristics – the density and the particle size distribution [7].

In [12] a method of determining solid phase concentration and the crushed material particle content of particle size several classes based on the ratio of the Lamb waves signals, which characterizes the particle size distribution of the controlled medium (Fig. 1) is described.

$$S = \frac{S_1}{S_2} = \frac{Z\rho}{lC_v \aleph(\rho_т - \rho_в)} \int_0^{r_m} \sigma(v,r)F(r)dr \qquad (1)$$

The value of the signal S_1 is determined by the concentration of the solid phase and its particle size distribution, the signal S_2 is proportional to the volume fraction of the solid in the pulp. The S value depends only on the solid particles size distribution, and hence uniquely determine the concentration of the solid phase particle size control class.

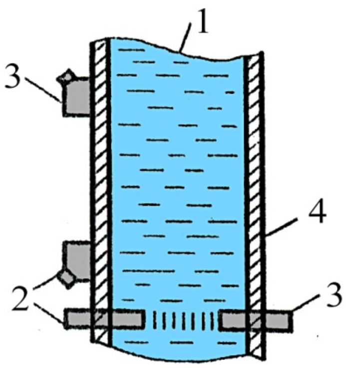

Figure 1. The measurement of pulp solid phase particle size distribution:
1 –controlled environment; *2, 3* –transmitter and receiver of ultrasonic oscillations; *4* –measuring container

Wave solutions for classical elastic medium are the simplest and therefore the most illustrative. However, the behavior of real media is much more complex and this is due to the presence of interrelated processes of dissipation and dispersion of waves [13]. The presence of dispersion leads to a distortion of the wave packet during its propagation. This distortion the stronger the more spaced apart the velocities of $C_t^{(1)}$ and $C_t^{(2)}$, as well as the greater the distance from the source [14].

The solution of the dispersion relation $\det\left[R\left(k,\omega\right)\right]=0$ are the two complex-valued functions $k_A(\omega)$ and $k_B(\omega)$. In this case, to calculate the phase and group velocities, we use only real parts of the wave numbers

$$C_p\left(\omega\right) = \omega / \Re k\left(\omega\right)$$
$$C_g\left(\omega\right) = \frac{1}{\Re k'\left(\omega\right)} \quad , \qquad (2)$$

The velocity data depending on the physical frequency is shown in Fig. 2a and Fig. 2b, where the velocities for the first wave mode are shown in solid lines, and the second – in dashed. The dependences of the speed on frequency indicates that there is a wave dispersion. The presence of dispersion leads to a distortion of the wave consisting of harmonics with different frequencies.

The presence of dissipation for each wave mode is determined by conditions

$$\wp k_A\left(\omega\right) > 0, \ \wp k_B\left(\omega\right) > 0, \qquad (3)$$

This also leads to a change in the amplitude of the wave packets according to the distance (Fig. 2c) [14].

In *Mode shape v2* and *Waveform Revealer toolboxes* [15] in MATLAB the simulation of Lamb wave propagation in a dispersion medium was performed under the following conditions: the 1st- mode wave with a frequency f_d=1000 kHz, d=1mm, f=1MHz, c/c_S =2,8379. The dispersion curves, the displacement vector, the stress graphs $\sigma_{xx}, \sigma_{yy}, \sigma_{xy}, \sigma_{xx-yy}$, as well as the parameters of the antisymmetric Lamb wave are shown in Fig. 3 – 5.

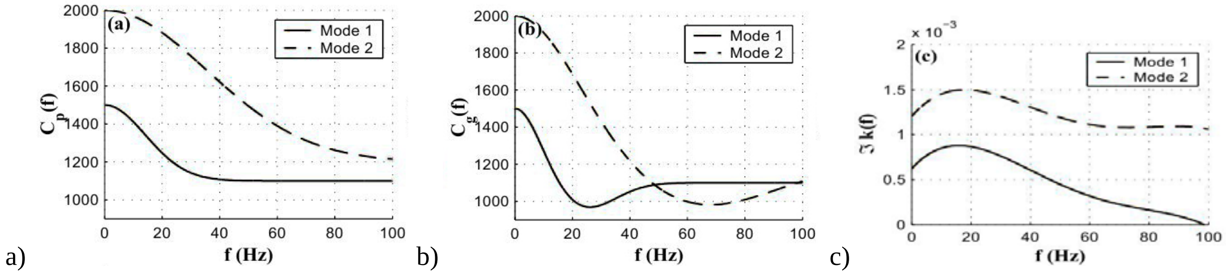

Figure 2. The two modes- wave propagation with dispersion and dissipation

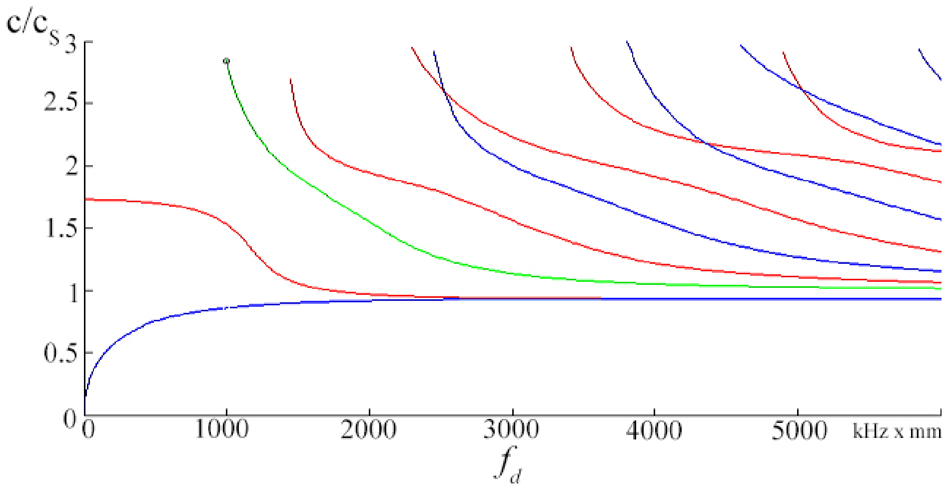

Figure 3. The dispersion curves of the antisymmetric 1st- mode Lamb wave

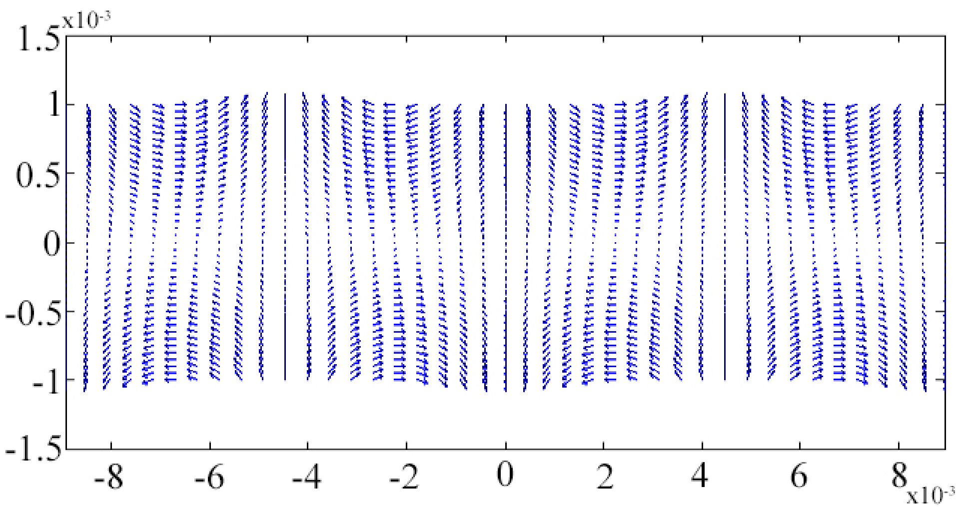

Figure 4. The displacement vector of the antisymmetric Lamb wave

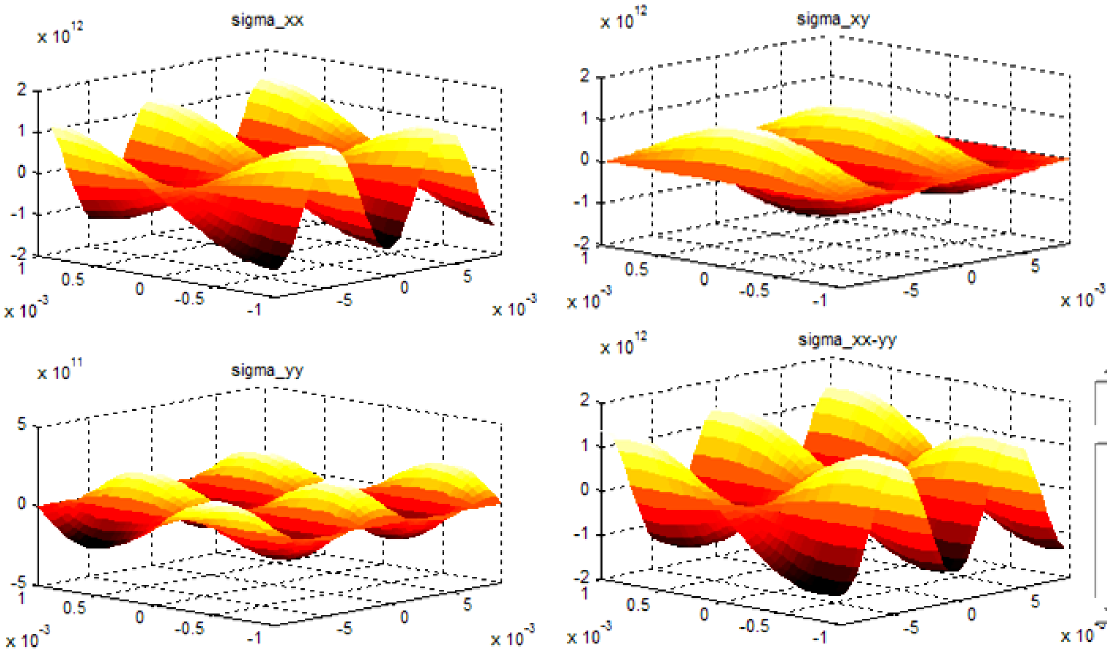

Figure 5. The stress graphs $\sigma_{xx}, \sigma_{yy}, \sigma_{xy}, \sigma_{xx-yy}$ of the antisymmetric Lamb wave

Conclusions

Thus, the above-described ultrasonic testing method allows us to determine the mineral disclosure degree, the solid phase concentration and the particle size distribution of the crushed material in the pulp flow based on the measurements of the Lamb waves parameters considering the influence of the dispersion and dissipation effects.

References

1. Lamb H. (1917). On waves in an elastic plate. *Royal Society of London*, No93(648), p.p.114-128.
2. Brajnikov N. *Ultrazvukovyye metody* [Ultrasonic methods], Moscow: Energy, 1975
3. Ultrazvuk: Malenkaya entsiklopediya [Ultrasound: A small encyclopedia], Moscow: Soviet Encyclopedia, 1979.
4. Brajnikov N., Shavykina N., Gordeev, A., Skripalov V. (1975). *Ispolzovaniye voln Lemba dlya signalizatsii urovnya zhidkikh sred* [The use of Lamb waves for level detection of liquid media], Pribory i sistemy upravleniya, No9,: p.p. 31-32.
5. Gumanyuk M. *Ultrasound in mining automation*. Kiev, Tehnika, 1970.
6. Bergman L. *Ultrazvuk i yego primeneniye v nauke i tekhnike* [Ultrasound and its application in science and technology], Moscow, Izdatelstvo inostran. lit., 1957.
7. Morkun V.S., Potapov V.N. *Sovremennyye metody ultrazvukovoy granulometrii* [The modern methods of ultrasonic granulometry], Moscow, The Institute of Chermetinformatsiya, 1999.
8. Morkun V., Morkun N., Pikilnyak A. (2015). The study of volume ultrasonic waves propagation in the gas-containing iron ore pulp, *Ultrasonics*, No 56C, p.p.340-343.
9. Morkun V., Morkun N., Pikilnyak A. (2014). The gas bubble size distribution control formation in the flotation process, *Metallurgical and Mining Industry*, No4, p.p.42-45: http://www.metaljournal.com.ua/assets/Journal/9.2014.pdf.
10. Morkun V., Morkun N., Pikilnyak A. (2014). Simulation of the Lamb waves propagation on the plate which contacts with gas containing iron ore pulp in Waveform Revealer toolbox, *Metallurgical and Mining Industry*, No5, p.p.16-19: http://www.metaljournal.com.ua/assets/Journal/4-Pikilnyak.pdf.
11. Morkun V., Morkun N., Pikilnyak A. (2014). Modeling of ultrasonic waves propagation in inhomogeneous medium using fibered spaces method (k-space), *Metallurgical and Mining Industry*, No2,

p.p. 43-48: http://www.metaljournal.com.ua/assets/Journal/a8.pdf

12. Morkun V. S. Ultrasonic control for technological characteristics of the crushed materials and adaptive regulation of the grinding and classification processes on its basis ScD diss., Kryvyi Rih, 1999.
13. Kulesh M.A. The development of time-frequency analysis methods of polarization and dispersion properties of wave processes: ScD diss., Perm, 2008
14. Kulesh M.A., Shardakov I.N. Wave dynamics of elastic media: methodical material for the course "Additional chapters of elasticity theory ", Perm, Perm. Univ., 2007.
15. LAMSS. Available at: http://www.me.sc.edu/Research/lamss/