Simulation of the Lamb waves propagation on the plate which contacts with gas containing iron ore pulp in Waveform Revealer toolbox

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Abstract
A method for the effective control of the pulp gas phase composition in the flotation process using dynamic effects of high energy ultrasound on the base of phased array technology and determination of its parameters are described.
Key words: ULTRASOUND, PULP, CONTROL, LAMB WAVES

Lamb waves are elastic perturbations propagating in a solid plate (layer), which has a displacement in the direction of wave propagation and perpendicular to the plane of the plate [1].

Various methods and devices of ultrasonic testing, which found application in process automation in [2-13] are discussed. It is noted the advantages of these methods, such as high accuracy and reliability in aggressive media parameters measuring. Thus, the use of these methods is one of the most promising approaches in the development of measurement systems for the process automation.

The ultrasonic measurement methods in the practice of minerals beneficiation have been used primarily for determining the parameters of the pulp, as well as for liquid and lumpy materials level monitoring in process vessels.

In [2,3] it is shown that the intensity measurement of high-frequency ultrasonic oscillations passing through a controlled volume of pulp, as well as surface ultrasonic Lamb waves passed a fixed distance on the surface which contacts with the investigated medium during high-energy ultrasound exposure. The ultrasound intensity which varies on the well-known law, allow us to estimate the pulp reducted ore particle size distribution function, ie its particle size distribution of the solid phase.

The purpose is to investigate the features of Lamb waves propagation on the steel plate which contacts within a randomly heterogeneous medium (gas containing iron ore pulp) in the process of its natural and specially organized movement.

Let's consider a plane harmonic Lamb wave which propagates in the plate with thickness 2d in the positive direction of the axis X. Let's introduce the scalar φ and vector ψ displacement potentials, describing longitudinal and transverse waves respectively for the region occupied by the plate. Values of φ and ψ can be represented in the following form[1]

$$\phi = A_S chqze^{ikx} + B_a shqze^{ikx}, \qquad (1)$$

$$\psi = D_S shsze^{ikx} + C_a chsze^{ikx}, \qquad (2)$$

A_S, B_a, C_a, D_S - are the arbitrary constants; k – is the wave number of the Lamb waves;

$q = \sqrt{k^2 - k_l^2}$; $s = \sqrt{k^2 - k_t^2}$

The values of the wave number k are determined from the characteristic equations

$$\left(k^2 + s^2\right)^2 ch \cdot qh \cdot sh \cdot sd - -4k^2 qs \cdot sh \cdot qd \cdot ch \cdot sd = 0, \qquad (3)$$

$$\left(k^2 + s^2\right)^2 sh \cdot qd \cdot ch \cdot sd - -4k^2 qs \cdot ch \cdot qd \cdot sh \cdot sd = 0, \qquad (4)$$

After some simple mathematical transformations the expressions for calculation of desired potentials can be obtained by

$$\phi = A_S ch \cdot q_s ze^{ik_s x} + B_a sh \cdot q_a ze^{ik_a x}, \qquad (5)$$

$$\psi = \frac{2ik_s q_s sh \cdot q_s d}{\left(k_s^2 + s_s^2\right) shs_s d} A_S sh \cdot s_s ze^{ik_s x} + \frac{2ik_a q_a ch_a \cdot q_a d}{\left(k_a^2 + s_a^2\right) ch \cdot s_a d} B_a chs_a ze^{ik_a x} \qquad (6)$$

where $q_{s,a} = \sqrt{k_{s,a}^2 - k_l^2}$; $S_{s,a} = \sqrt{k_{s,a}^2 - k_t^2}$.

Expressions (5) and (6) allows to calculate the displacement components U and W [1]

$$U = U_S + U_a, \qquad (7)$$

$$W = W_S + W_a, \qquad (8)$$

$$U_S = Ak_s \left(\frac{ch \cdot q_s z}{sh \cdot q_s d} - \frac{2q_s s_s}{k_s^2 + s_s^2} \frac{sh \cdot s_a z}{ch \cdot s_a d} \right) \times \times e^{i\left(k_s x - \omega t - \frac{\pi}{2}\right)}, \qquad (9)$$

$$U_a = Bk_a \left(\frac{sh \cdot q_a z}{ch \cdot q_a d} - \frac{2q_a s_a}{k_a^2 + s_a^2} \frac{sh \cdot s_a z}{ch \cdot s_a d} \right) \times \times e^{i\left(k_a x - \omega t - \frac{\pi}{2}\right)}, \qquad (10)$$

$$W_S = -Aq_s \left(\frac{sh \cdot q_s z}{sh \cdot q_s d} - \frac{2k_s^2}{k_s^2 + s_s^2} \frac{sh \cdot s_s z}{sh \cdot s_s d} \right) \times \times e^{i\left(k_s x - \omega t - \frac{\pi}{2}\right)}, \quad (11)$$

$$W_a = -Bq_a \left(\frac{ch \cdot q_a z}{ch \cdot q_a d} - \frac{2k_a^2}{k_a^2 + s_a^2} \frac{ch \cdot s_a z}{ch \cdot s_a d} \right) \times \times e^{i\left(k_a x - \omega t - \frac{\pi}{2}\right)} \quad (12)$$

where *A* and *B* – constants.

By analyzing (5) - (12) it can be noticed that in the first wave group, which marked with index *s*, the motion is symmetrical relative to the plane *Z* = 0 (i.e., in the upper and lower plate halves the displacement *U* has the same sign and the displacement *W* is opposite). In the second group of waves marked with index *a*, the motion is anti-symmetric relative to the plane *Z* = 0 (i.e., in the upper and lower plate halves the displacement *U* has opposite signs, and the displacement *W* has the same sign).

The first group waves are symmetric Lamb waves and the second group waves are anti-symmetric. The finite number of symmetric and anti-symmetric Lamb waves which differ from each other by phase and group velocities, as well as the distribution of displacements and plate thickness stresses in the plate with thickness of 2d at frequency ω can be defined.

To simulate Lamb wave phase and group velocity, wavelength and tuning for the stainless steel we use the software tools of Waveform Revealer package in Matlab (Fig.1–4 [14]).

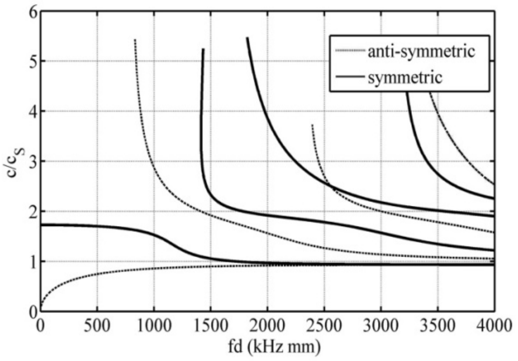

Figure 1 Lamb wave phase velocity of Steel

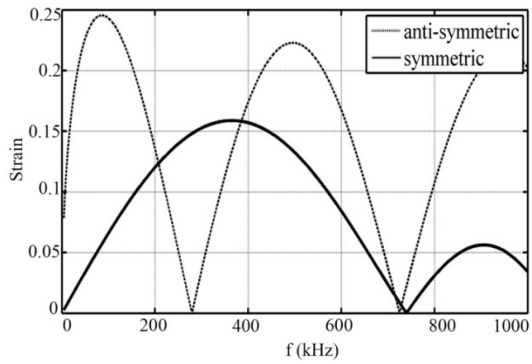

Figure 2 Tuning of Steel: Strain

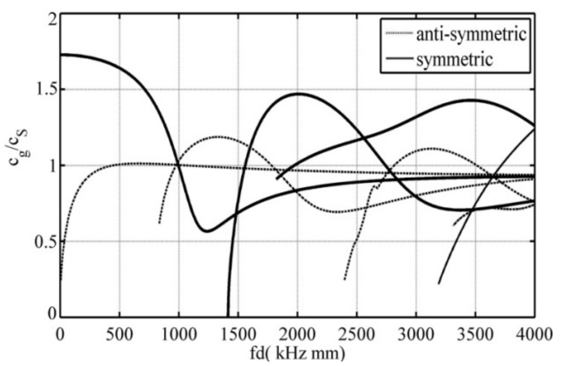

Figure 3 Lamb wave group velocity of Steel

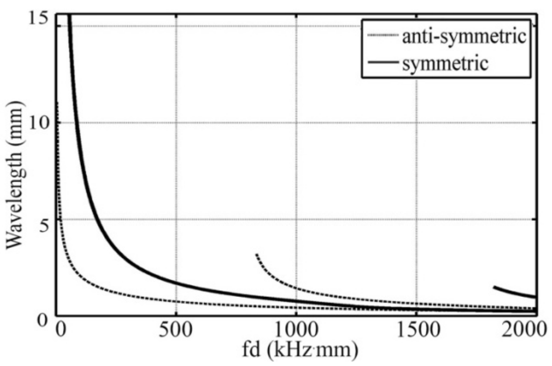

Figure 4 Lamb wavelength of Steel

Conclusions

The experimental results confirm the effectiveness of the above approach, and the Waveform Revealer package is useful and effective tool for simulation of Lamb waves propagation in different materials

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