Influence of the Viscoelastic Media Properties on the Lowest Lamb Wave Mode Propagation in Pipe

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Abstract. The results of comparative experimental research in influence on torsional *T*(0,1), symmetrical and antisymmetrical Lamb waves attenuation in pipe under the loading conditions on viscoelastic media such as internal fluid (water, glue) and external loose media are presented in this article. The technique and the experimental installation allowing to generate and receive different kinds of Lamb waves with special-purpose electromagnetic-acoustic oscillators and piezoelectric receivers are introduced. The obtained results can be taken into account when equipment and waveguide techniques for pipeline testing being developed with the use of torsional, symmetrical and antisymmetrical waves to estimate sensitivity of methods and distance of extended object scanning.

Keywords: viscoelastic medium, symmetric wave, antisymmetric wave, torsional wave attenuation, long-range guided wave testing, pipe

INTRODUCTION

Long-range guided wave acoustic testing technique based on the use of normal Lamb waves becomes more common in instant testing of pipelines due to an opportunity of normal wave propagation for long distances in pipes covered with insulation and laid under ground or water. It is stated [1–10], that a range of pipe scanning distances can be changed from 1 to 200 meters depending on the used wave mode, a type of transported substance, a type of insulation, operating conditions of pipelines (underwater, ground-surface, underground) and their typical sizes.

The results of experimental research in influence of pipe loading conditions on attenuation of zero-order symmetrical and antisymmetrical Lamb waves and torsional waves are presented in the article.

APPROACHES USED

The guided wave testing technique installation which includes a probe pulse generator, a sync pulse generator, an amplifier, a registration unit (digital oscillograph RIGOL) was used for experimental research. Electromagnetic-acoustic transducers (EMAT) operating on electrodynamic mechanism were used as oscillators. Reception was performed with the use of

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piezoelectric transducer based on shearing piezoceramics labeled as NFI50. Generation and reception of both horizontal polarized (torsional) waves and zero-order symmetrical and antisymmetrical Lamb wave modes is possible depending on locations of oscillators and receivers about a pipe axis (Figure 1).

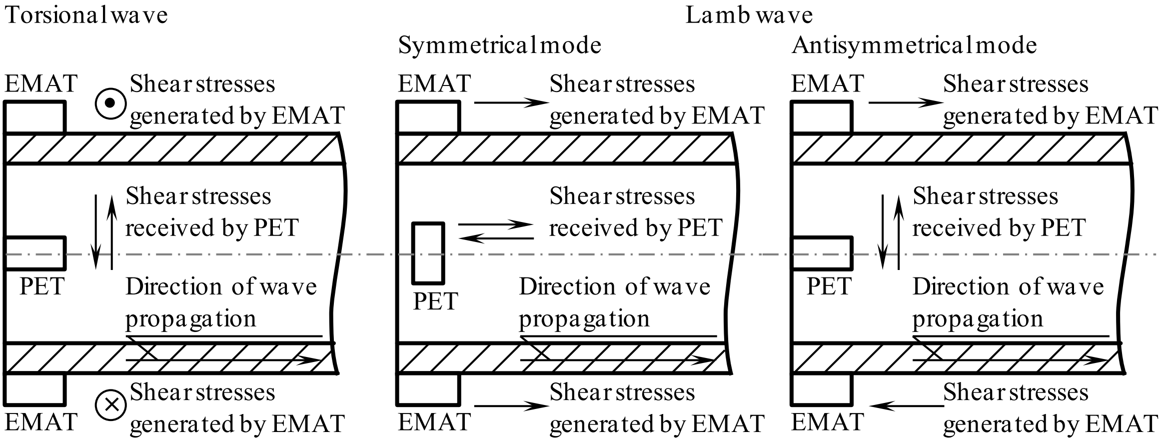

Figure 1. A scheme of different type wave excitation and transducer locations around the pipe end: EMAT – electromagnetic acoustic transducer, PET – piezoelectric transducer

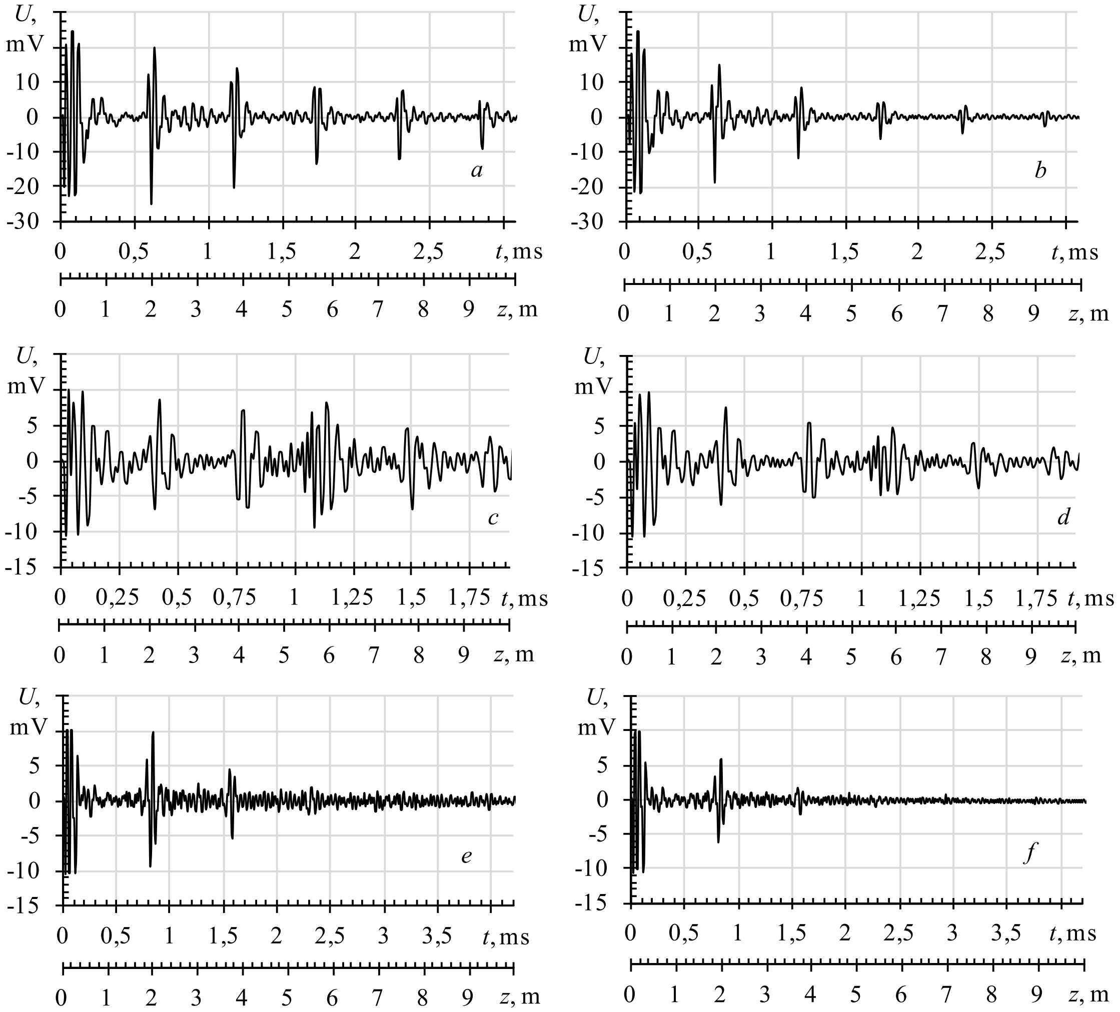

Figure 2. Pulse echo ultrasound torsional, symmetrical, antisymmetrical wave images for unloaded pipe (*a*, *c*, *e* respectively) and pipe buried in sand (*b*, *d*, *f* respectively)

Experiments were carried out for steel pipe with diameter 33.7 mm, wall thickness $h = 4.2$ mm and length $l = 100$ mm under operating frequency 30 kHz. The pipe was located in plastic container and loaded on contact external and internal media. Air, water and dextrin (oil simulation) were used as internal media, and damp sand, arid ground and clay were used as external media. The result of echo-pulse series registration of torsional, symmetrical and antisymmetrical waves repeatedly reflected from free pipe edges and the same waves under loading conditions on damp sand is represented in Figure 2.

RESULTS AND DISCUSSION

The propagation velocities of symmetrical, antisymmetrical and torsional waves are defined by the following formula:

$$C = \frac{nl}{\Delta t}, \tag{1}$$

where C is a velocity of certain type Lamb wave, n is a number of analyzed reflections, Δt is time between probe impulse and the n^{th} impulse of certain type Lamb wave.

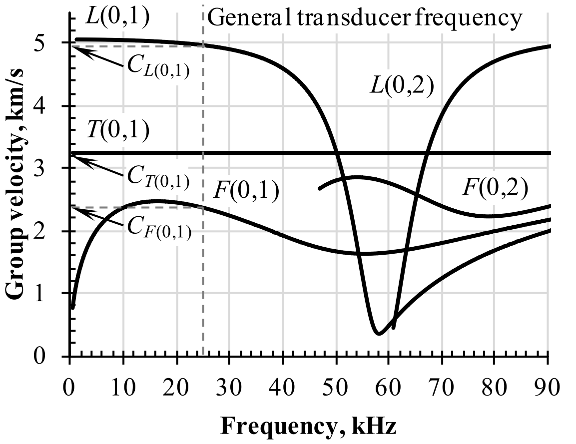

Figure 3. Dispersion curves for pipe: diameter 32 mm, wall thickness 4.2

Velocities calculated according to the obtained oscillograms are $C_{L(0,1)} = 5225$ m/s for Lamb wave symmetrical mode $L(0,1)$, $C_{F(0,1)} = 2375$ m/s for Lamb wave antisymmetrical mode $F(0,1)$, $C_{T(0,1)} = 3250$ m/s for torsional mode $T(0,1)$. It's worth mentioning, that the given values are in agreement with the values calculated by Lamb wave dispersion curves, built in special-purpose software (Figure 3).

Figure 2 shows that values of attenuation are different by distance of different Lamb waves, even for unloaded pipe, that is caused by influence of dispersion. The attenuation has the lowest

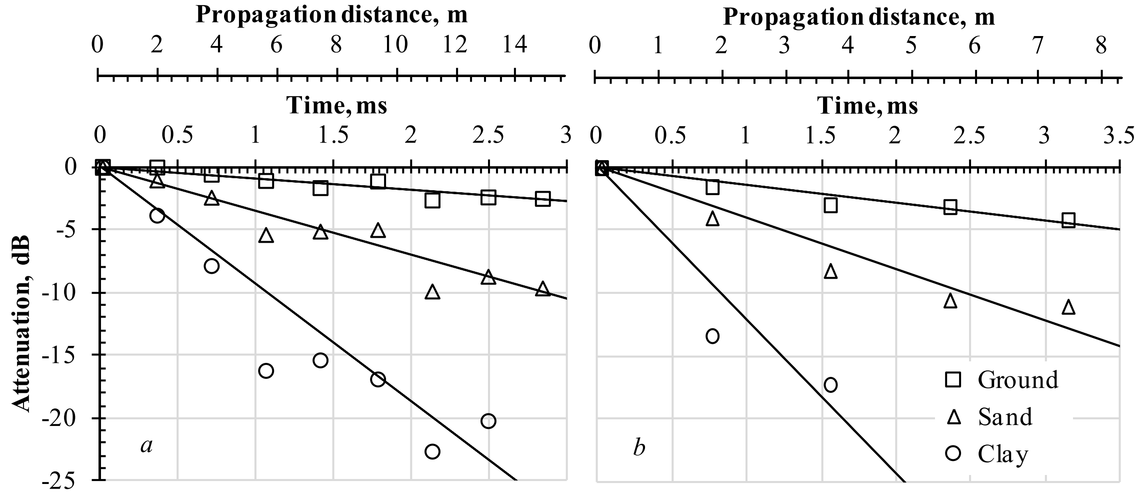

Figure 4. Generalized dependences of pulse echo symmetrical (*a*) and antisymmetrical (*b*) wave attenuation in dB for pipe loading on ground, sand or clay compared to unloaded pipe

value for torsional waves *T*(0,1) where dispersion is absent (Figure 3) and attenuation is caused by internal viscous losses and scattering from surface inhomogeneity; the highest value of attenuation is observed for the mode *F*(0,1) with the highest value of dispersion. Reradiation of vertical, horizontal (in the cases of modes *L*(0,1) and *F*(0,1)) and angular (in the case of mode *T*(0,1)) displacement components in surrounding media influence more on attenuation for the pipe loaded on contact media.

Generalized dependences of echo-pulse amplitude attenuation for the modes *F*(0,1) and *L*(0,1) in dB compared to unloaded pipe (level of 0 dB) by the distance for different contact media are represented as an example in Figure 4. It follows from the given dependences, that in the case of pipe loading on ground echo-impulse amplitude attenuation compared to unloaded pipe is the lowest for the mode *T*(0,1) and it is equal to 2 dB at the distance of 10 m for this mode, 2 dB at the distance of 10 m for the mode *L*(0,1), 6 dB at the distance of 10 m for the mode *F*(0,1). The pipe loading on clay causes more essential wave attenuation: 30 dB at the distance of 10 m for the mode *T*(0,1), 18 dB at the distance of 10 m for the mode *L*(0,1), approximately 50 dB at the distance of 10 m for the mode *F*(0,1). It should be noted, that in the cases of loading on water and dextrin both from external and internal sides of pipe, essential echo-impulse amplitude variation for the mode *T*(0,1) isn't observed that is caused by the absence of torsional wave reradiation effect in fluid media due to impossibility of shear displacement generation in latter waves. Whereas, influence of these media is enough essential for the mode *F*(0,1).

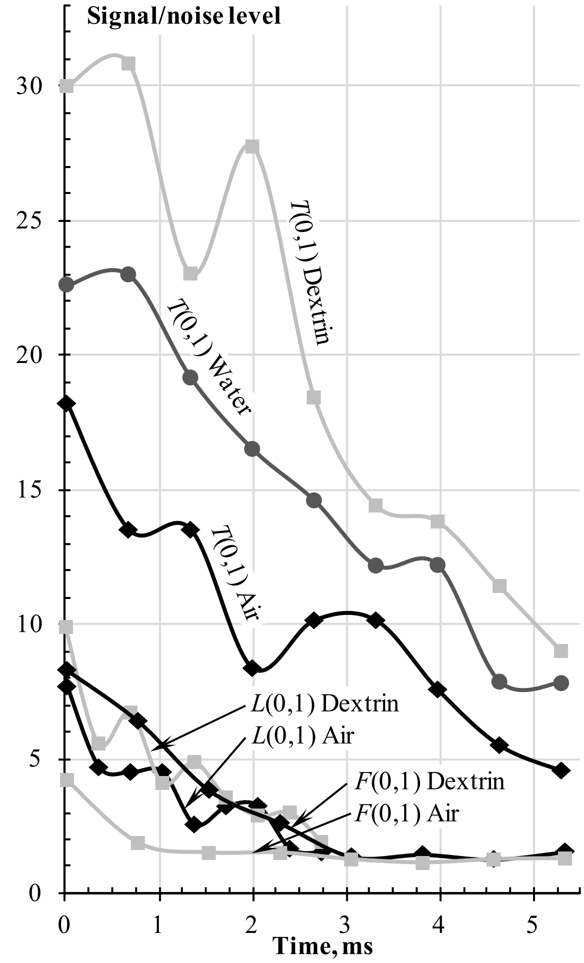

Figure 5. Signal/noise level dependences on the pipe end reflections for different types of wave propagation in pipe loaded on air, dextrin and water (for torsional wave)

Obstructive waves, which are basically acoustic noise restricting the sensitivity to defects, can appear together with the main Lamb wave modes during generation (reception). It is essential, that in the case of the mode *T*(0,1) the level of acoustic noise, caused by radiation of obstructive mode oscillation (symmetrical and antisymmetrical), decreases essentially under loading on fluid media (by 1.3 times under loading on water, by 1.8 times under loading on dextrin) compared to unloaded pipe, that is caused by absence of torsional wave reradiation effect in fluid media due to impossibility of shear displacement generation in latter waves.

The obtained results can be taken into account when equipment and waveguide techniques for pipeline testing are being developed with the use of torsional, symmetrical and antisymmetrical waves to estimate sensitivity of methods and scanning range.

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