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Investigation of interaction of surface acoustic waves with liquid in the ultrasonic range

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Abstract

In the paper experimental results of investigation of interaction between transversal surface acoustic waves (TSAW, Rayleigh waves), longitudinal surface acoustic waves (LSAW) and liquid in the ultrasonic range (2 MHz) are presented. It was determined, that TSAW amplitude is particularly sensitive to contact of solid body and liquid (drops, thin layer, thick layer) and rapidly decreases with increase of liquid layer thickness. When the thickness of the liquid layer $h < \Lambda$ (Λ – length of acoustic wave in liquid), TSAW amplitude decreases in interferential manner with increase of propagation distance *d*. When $h >> \Lambda$, the TSAW amplitude level stabilizes and is determined by mechanical surface dampening, which depends on the acoustic impedance of liquid.

Experiment results show that when TSAW propagate along the surface covered by liquid layer, intense bulk longitudinal waves are excited in it and for this reason TSAW are attenuated. Meanwhile, liquid influence on the attenuation of LSAW waves is marginal.

It was shown, that investigation of surface acoustic waves in the ultrasonic range allows creation of physical models of the Earth seismic phenomena, also could be useful to investigate tsunami formation and its properties.
Keywords: ultrasound, transversal surface acoustic waves, longitudinal surface acousticc waves, Earth modeling

Introduction

During research of propagation properties of two types of surface acoustic waves (SAW) – transversal surface acoustic waves (TSAW) and longitudinal surface acoustic waves (LSAW) – it was determined, that attenuation of STW is especially sensitive to the states of solid body surface (roughness, irregularities) [1, 2]. Contrarily, LSAW weakly reacts to surface quality parameters and perfectly propagates even under crudely mechanically processed surfaces, including threads. That allowed to make the conclusion that LSAW waves propagate not along the very surface of a solid body, but along the near-surface layer and weakly interacts with the surface.

Interaction of SAW with a thin liquid layer situated on the surface of vibrating solid body was analysed in [3]. It was experimentally determined in this work that during propagation of STW along the surface the liquid particles are forced to move and due to this reason side bulk longitudinal waves (SBLW) are excited. Thus surface waves lose most part of their mechanical energy and are attenuated.

The surface seismic waves are the most common occurrence of SAW in nature. These waves propagate the longest distance along the bottom of ocean, because the significant area of the Earth surface is covered by oceans. Natural investigations of seismic phenomena are often limited to observations of earthquakes and analysis of their consequences, and investigation of excitation and propagation of artificially generated seismic waves is very expensive. Meanwhile research of surface acoustic waves in the ultrasonic range may be useful not only for theoretical, but also for experimental investigations under laboratory conditions. Research results may be applied in non-destructive product control using surface acoustic waves [4].

The aim of this work is to model experimentally and to investigate the mechanism of interaction between surface acoustic waves and liquid layer.

Investigation method and equipment

Investigations were performed with both types of surface acoustic waves (TSAW and LSAW) by exciting their pulses in the special duralumin test samples placed into water tank (Fig. 1). 2 MHz variable angle SAW transducers [5] and the equipment described in [1] were used in investigations. The experimental sample was made of the aluminum alloy 6063-T6 (Sweden), and its dimensions were 240 x 120 x 60 mm.

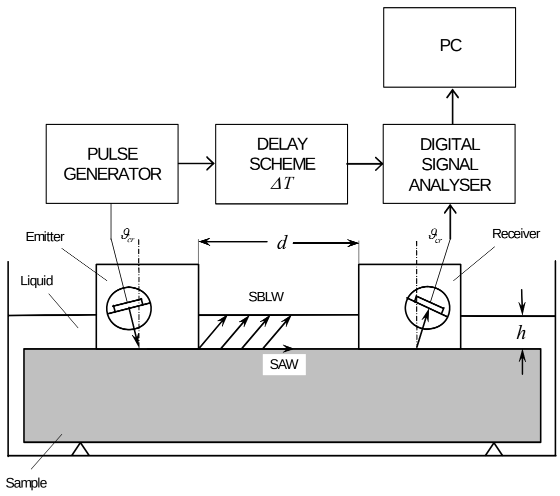


Fig. 1. **The scheme of experimental investigations**

Planar ultrasonic model of seismic surface waves was assumed in order to increase the reliability of investigations.

The angular emitter tuned for the first ϑ_{cr}^{I} or second ϑ_{cr}^{II} critical angle is excited using pulse generator and in the first case generates TSAW (Rayleigh waves), and LSAW in the second case. When interacting with liquid (H_2O) SAW emit bulk longitudinal waves BLW, which are received using the angular receiver of analogous construction. The received signals are processed using the digital spectrum analyzer PCS64i, and their waveform and parameters are stored into a computer memory. The signal amplitude measurement absolute errors did not exceed ± 10 mV.

Experimental investigations of interaction between surface acoustic waves and liquid

When the angular emitter was excited using short electrical pulse and by changing visually the inductance of correcting coils, the Gaussian TSAW pulse of maximal amplitude and several periods length (Fig. 2) was received. Due to insufficiently big dimensions of the transducer wedge the lateral reflections are also received in it, which in turn create additional pulses of the same waveform delayed in respect to the main (first) signal. Since the lateral signals are of considerably less amplitude, they do not influence investigations when measuring amplitude of the main TSAW signal.

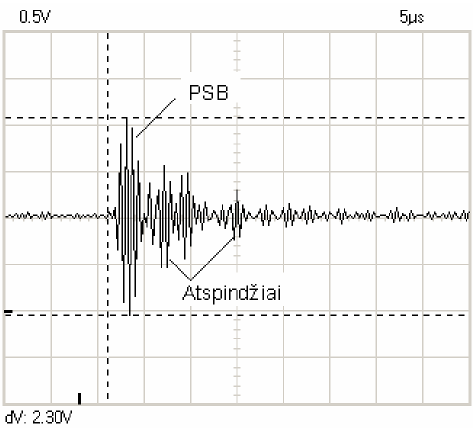


Fig. 2. **TSAW signal, when distance between transducers *d* = 0, and the sample surface is clear**

When a layer of liquid (water) is placed on the sample‘s surface, reflected from the liquid surface side BLW return at particular sharp angle to the surface of the sample and interfere with TSAW, which results in the variations of signal amplitude depending on the liquid layer thickness *h*. When the liquid layer thickness $h \leq \Lambda_{PAB}$ (here $\Lambda_{PAB} \approx$ 0,75 mm – length of the acoustic wave in liquid), interference effect is strong, but it also doesn't completely disappear in the cases when liquid layers are thicker. Fig. 3 illustrates the measured dependence of the double amplitude of TSAW signal (Fig. 2) on the liquid layer thickness *h*.

As it is shown in Fig. 2, even a thin layer of liquid on the surface of a solid body considerably increases attenuation of TSAW signals, but when $h > \Lambda_{PAB}$, the attenuation marginally decreases when increasing *h*. At the same time the nature of signal attenuation remains weakly interferential.

Super-sensitivity of TSAW to the state of surface of the sample is illustrated by results of the experiment with drops of technical oil applied on the surface of the sample along the symmetry axis between the emitter and the receiver. These results are presented in Fig. 4.

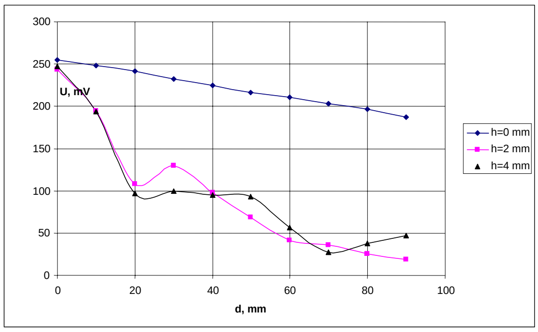
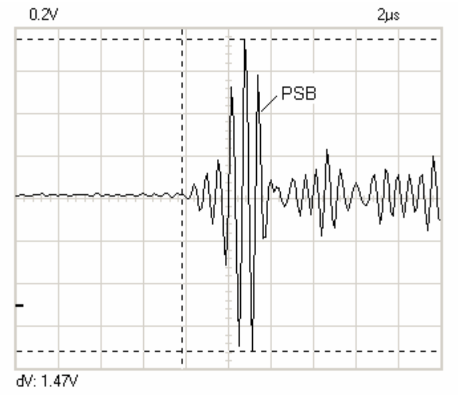


Fig. 3. **TSAW pulse amplitude dependencies on the distance *d* between emitter and receiver when different liquid layer thicknesses are present**

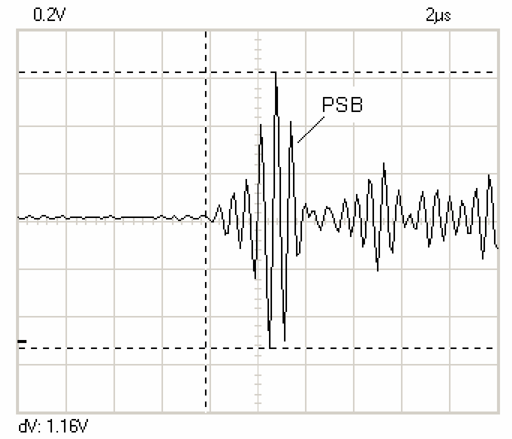
Attenuation measurements of LSAW waves have shown that a layer of water of several millimeters thick practically does not influence amplitude of the received signal. Therefore an experiment of investigated test sample submersion into water was conducted in order to compare TSAW and LSAW in a quantifiable manner. Changes of TSAW and LSAW signal waveforms and amplitudes were observed before sample submersion (h = 0) and after submersion into water (h = 15 mm), when the distance between the emitter and the receiver d = 60 mm (Fig. 5 and 6). After sample submersion, TSAW signal was reduced by 12 dB and attenuation stabilised after reaching depth *h*, which is related to the fixed mechanical dampening of surface with increase of the depth *h*.

Charactersitic change of the signal waveform can be observed in Fig. 5, b and is related to the construction of the wedge of the angular transducer, due to which piezoelement also reacts to bulk longitudinal waves (BLW), propagating in the liquid in the area between the emitter and the receiver. This part of the signal practically completely vanishes after placing the wave-absorbing barrier between the transducers (Fig. 5,c).

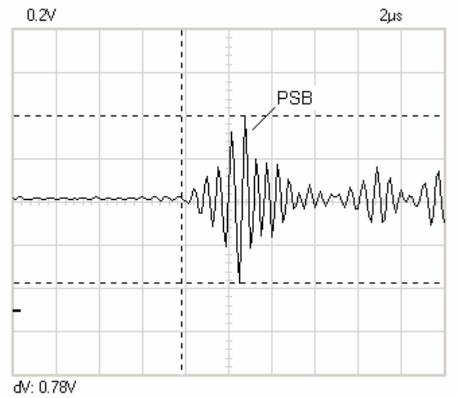
Results of analogous experiments with LSAW are shown in Fig. 6. It is obvious, that fluid influence on the signal amplitude is minimal in the case of thick layers also (h/Λ_{PIB} >>1). Clear decrease of lateral oscillations of the piezoelement resonant frequency in the water layer impact area can be noticed from the waveform of the signal shown in Fig. 6 c. This fact points out that lateral TSAW reflections formed on the surface of the sample are the physical nature of these disturbances.



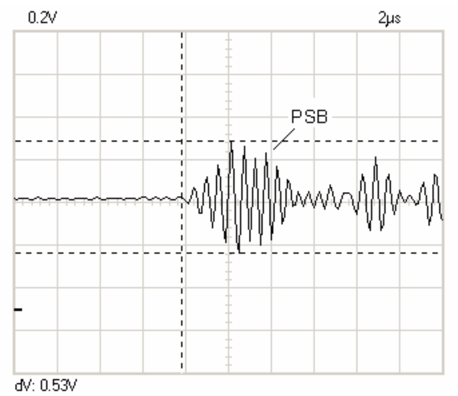
a



b

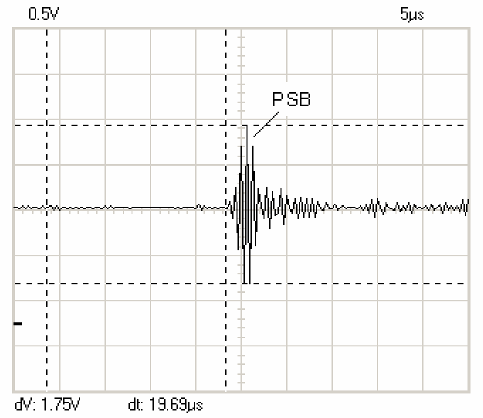


c

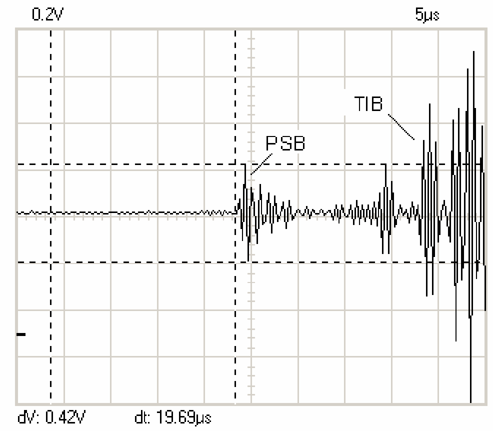


d

Fig. 4. **Technical oil effect on the TSAW signal, when *d* = 90 mm: *a* – 1 drop; *b* – 2 drops; *c* – 3 drops; *d* – 4 drops**



a



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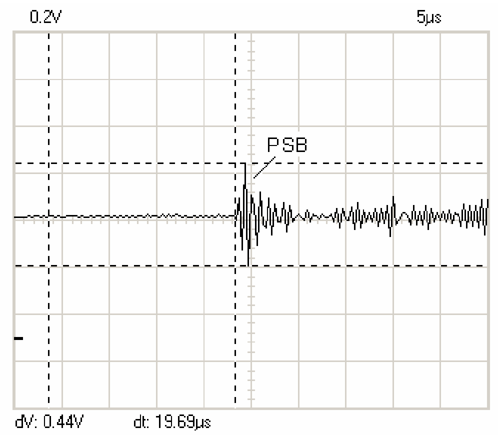

c

Fig. 5. **TSAW signal, received when the distance between transducers *d* = 60 mm: *a* – *h* = 0; *b, c* – *h* = 15 mm**

Conclusions

1. Attenuation of TSAW signals is particularly sensitive to the state of oscillating surface and even one liquid drop placed on the surface decreases the signal amplitude by –3,5 dB.
2. Attenuation of TSAW signal due to the thickness of a surface liquid layer h = const < Λ has interferential character. When the liquid layer thicknesses $h > 20\Lambda$, amplitude of TSAW signal is U = const.
3. During propagation of TSAW along the liquid layer above the surface, intense lateral bulk longitudinal

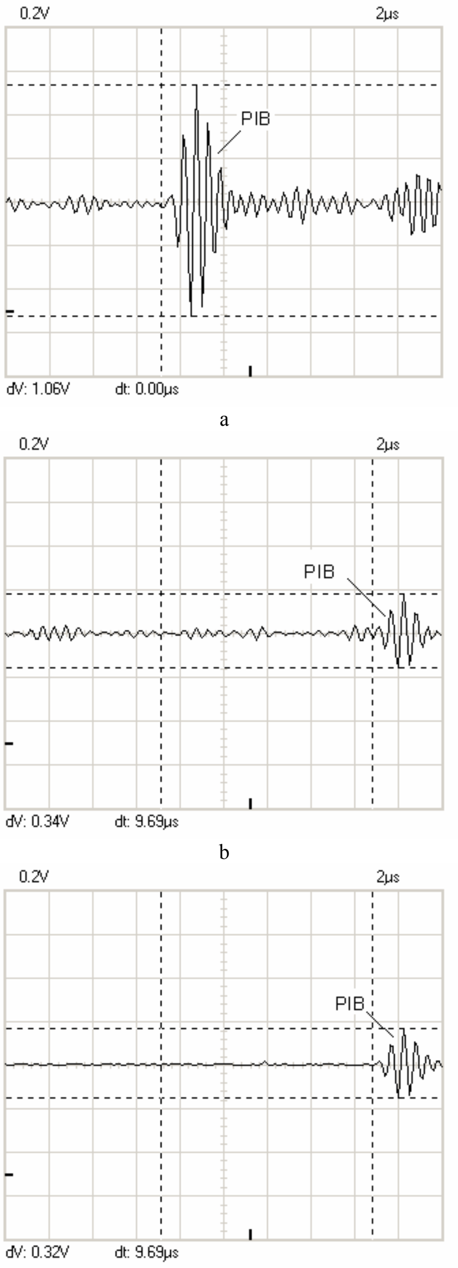

Fig. 6. **The received LSAW signal, when: *a* – *d* = 0, *h* = 0; *b* – *d*= 60 mm, *h* = 0; *c* – *d* = 60 mm, *h* = 15 mm**

waves are excited, which propagate in the liquid layer as in the waveguide.

4. The layer of liquid above the surface of solid body is an effective damper of lateral TSAW signals and allows increasing sensitivity and reliability of tests involving use of longitudinal surface waves. Liquid influence on LSAW signals is in allowable error range, therefore it is not considered.
5. By using SAW experiments in the ultrasonic range under laboratory conditions, Earth surface seismic processes can be modeled, influence of Earth crust fluctuations on deep and surface water mass movement can be investigated, tsunami formation process can be modeled and investigated.

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Ultragarsiniai paviršinių akustinių bangų sąveikos su skysčiu tyrimai

Reziumė

Pateikti paviršinių skersinių (PSB, Reilėjaus) ir paviršinių išilginių bangų (PIB) sąveikos su skysčiu eksperimentinių tyrimų ultragarso diapazone (2 MHz) rezultatai. Nustatyta, kad PSB amplitudė yra ypač jautri kietojo kūno paviršiaus sąlyčiui su skysčiu (lašai, plonas sluoksnis, storas sluoksnis) ir sparčiai slopsta didinant skysčio sluoksnio storį. Esant skysčio sluoksnio storiui $h < \Lambda$ (Λ – akustinės bangos ilgis skystyje), didėjant sklidimo atstumui *d,* PSB signalo amplitudė mažėja interferenciškai. Kai $h >> \Lambda$, PSB amplitudės lygis stabilizuojasi ir sąlygojamas mechaniniu paviršiaus slopinimu, priklausančiu nuo skysčio akustinės pilnutinės varžos.

Eksperimento rezultatai rodo, kad PSB sklindant paviršiumi, padengtu skysčio sluoksniu, jame sužadinamos intensyvios tūrinės išilginės bangos, dėl ko PSB slopsta. Tuo tarpu PIB bangų slopimui skysčio įtaka yra nykstamai maža. Teigiama, kad paviršinių akustinių bangų tyrimai ultragarso diapazone leidžia kurti Žemės seisminių reiškinių fizikinius modelius, gali būti naudingas cunamio atsiradimui ir savybėms tirti.

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