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Investigations of excitation of longitudinal surface acoustic waves by piezoelectric grating

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Introduction

Longitudinal surface acoustic waves (LSAW) are usually excited in isotropic solids using angular transducers, when the incidence angle of bulk longitudinal waves is equal to the first critical angle [1-3]. The critical angle depends on a sound velocity both in the prism and in the solid. That is the reason why the prism transducer with constant incidence angle can not be universal, and it can be used to excite LSAW only in solids, where sound velocities are known and matches to the sound velocity in a prism. In order to make LSAW angular transducers more universal, angular transducers with a variable angle are used. Incidence angle of longitudinal waves in the mentioned transducers can be selected from interval [0° - 90°] to obtain the maximum angle of LSAW excitation – the first critical angle in a solid [4]. There are two types of angular transducers with a variable angle: 1) piezoelectric element can be turned around axis, coinciding with a mass center in a transverse plane 2) piezoelectric element can be turned around the axis on the radiating surface of the transducer prism [1]. In the first case introduction point of LSAW changes its position. In the second case introduction point of LSAW does not change its position. The first type angular transducer has another imperfection: when the incidence angle of bulk waves is changed, the length of propagation way changes too. It has the influence on the level of the excited LSAW.

The mentioned drawbacks of angular transducers need to be solved in the other way. Using non-destructive testing efficiency of LSAW excitation becomes very important. LSAW are weaker in comparison to the Rayleigh or transverse SAW (TSAW) [1]. The attention on theoretically described process of excitation of Rayleigh waves was paid using periodical vibratory linear structure [4]. Estimating similarity of LSAW and Rayleigh waves propagation features it could be expected to use piezoelectric gratings for LSAW excitation. This conclusion comes from the latest experiments, when LSAW are excited termoacoustically, using pulse laser to create mechanical strains on the solid surface [5, 6]. Experimental results show that LSAW and Rayleigh waves are excited at the same time efficiently.

Simulation of piezoelectric grating

Strip-shaped piezoelement (Fig. 1), with $l >> h$, $l >> d$ is mechanically attached to the solid surface.

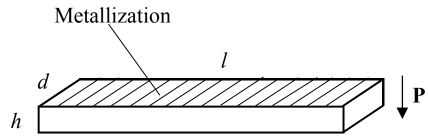


Fig. 1. **Elementary strip-shaped piezoelement**

The piezoelement excited by a thickness mode of vibration emits semispherical bulk wave $a(r, t)$ (Fig. 2), described by Eq. 1:

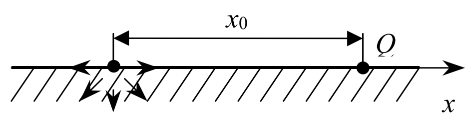


Fig.2. **Spot source of primary acoustic waves on the surface of isotropic solid plane**

$$a(r,t) = A \sin \frac{2\pi}{T}\left(t - \frac{r}{c_L}\right), \tag{1}$$

where A is the wave amplitude, T is the period, t is the time, r is the radius, c_L is the velocity of wave propagation.

If there are m spot sources on the surface (piezoelectric grating, which consists of m elementary strip-shaped piezoelements, arranged at distance Δx), and these spot sources are excited in-phase (Fig. 3), then the wave generated at the surface spot Q, is given by

$$a(x_0,t) = A\sum_{n=1}^{m} \sin \frac{2\pi}{T}\left(t - \frac{x_0 + (n-1)\,\Delta x}{c_L}\right), \tag{2}$$

where x_0 is the distance between the last piezoelement and the surface spot Q.

The piezoelements (Fig. 3) are excited in-phase, when $\Delta x = c_{LSAW}/\omega = \lambda_{LSAW}$, where ω is the angular frequency, $c_{LSAW} \approx c_L$ and $\lambda_{LSAW} \approx \lambda_L$ are the LSAW phase velocity and the length; c_L and λ_L are the phase velocity and the length of longitudinal bulk waves.

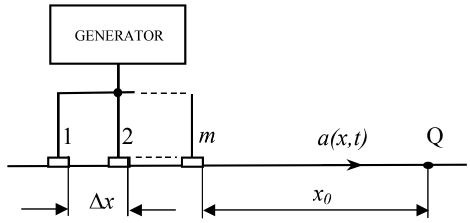


Fig. 3. **In-phase excited grating consisting of *m* piezoelements**

The length of grating can be reduced and quantity of piezoelements is the same when LSAW transducers are operating in a low frequency range. Then piezoelements must be arranged at the distance $\lambda_{LSAW}/2$ between them and excited in phase opposition or excited in phase, but polarization direction is changed contrarily.

The shape of oscillations, generated by piezoelectric grating, was simulated using the mathematical packet *MathCAD 2001 Professional*. There are m=4 piezoelements in the grating. It is assumed that piezoelements are made of piezoceramics CTS-19, h=0.5 mm, l=15 mm >> h. The resonant frequency f_0=3.3 MHz, when the piezoelement oscillates along thickness, because the velocity of longitudinal waves in the piezoceramics CTS-19 is c_L=3300 m/s. The LSAW are excited in duralumin, where the velocity of longitudinal bulk waves is c_L=6320 m/s and $\lambda_L \approx \lambda_{LSAW}$=1.92 mm.

Each piezoelement is excited using burst with the duration of 10T, where T is the period of an excitation voltage. The normalized amplitude of the pulse is 1 (Fig. 4a). The acoustic wave, generated at the surface spot Q (Fig. 4, b) was calculated accepting, that damping of wave is deniably small. The distance between the spot Q and the piezoelement m is $x_0 = 5\lambda_{LSAW}$.

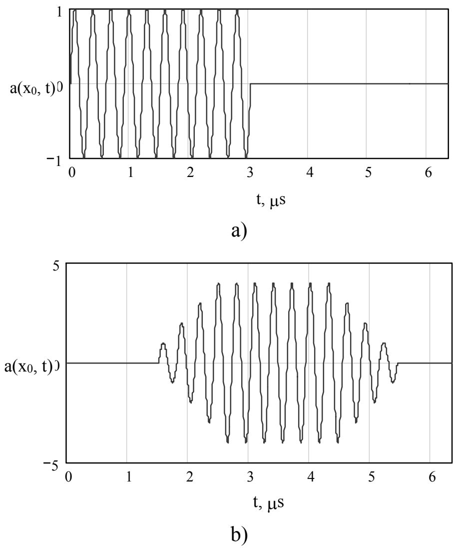


Fig. 4. **Finite duration excitation pulse (a) and acoustic wave on the surface spot *Q* (b)**

If can be seen that the acoustic wave is amplified, delayed and with ramp-up and ramp-down fronts. The shape of acoustic wave may be restored (Fig. 5b) if the shift circuits (Fig. 5a) with a delay duration equal to the period T=0.33 µs are used.

The acoustic wave fronts are sharp. The fronts of the excited signal are nearly linear (Fig 6, b), when exciting pulses are not delayed and the piezoelectric grating is excited using the pulse with the exponent ramp-up and ramp-down fronts (Fig 6, a). The excited signal has almost the same waveform, when the exciting pulses are delayed (Fig 6c) using the shift circuit shown in Fig. 5 a.

Comparing Fig. 6b and Fig 6c, we see that the waveform and amplitude are similar, but delay time differs notably.

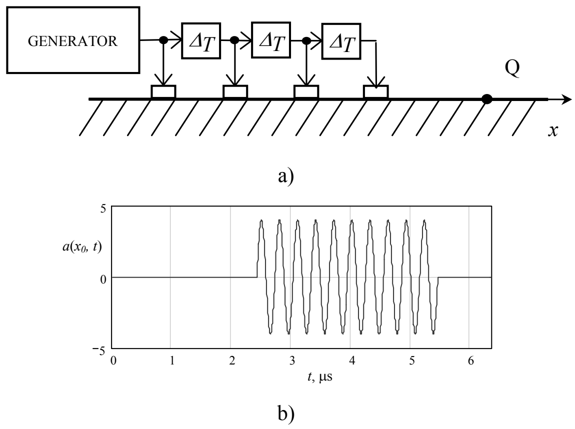


Fig.5. **Excitation of piezoelectric grating using shift elements (a), waveform (b)**

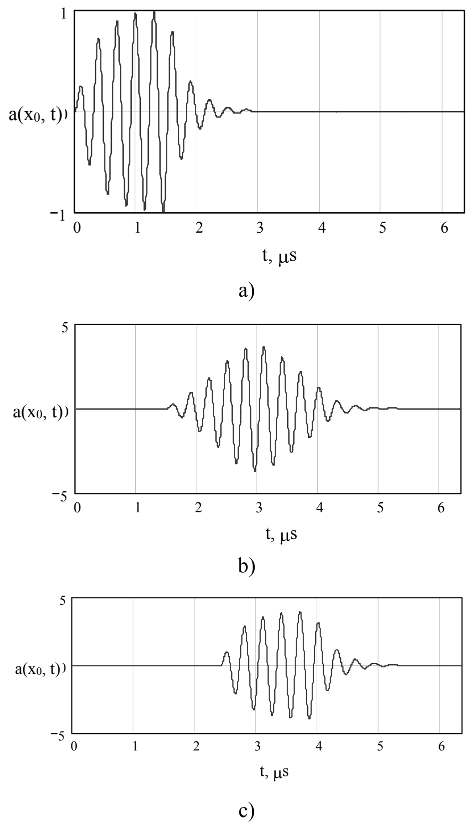
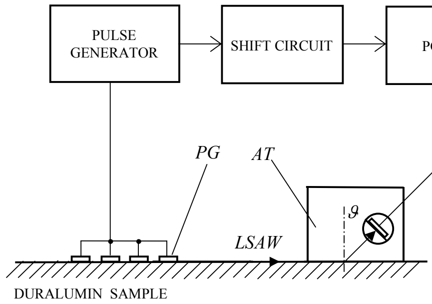


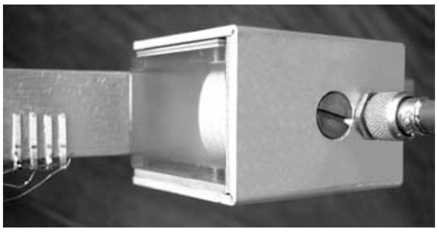
Fig.6. **Finite duration excitation pulse (a) and the waveforms of signal at the surface spot *Q*, when the exciting signals are not delayed (b) and are delayed (c).**

Results of experimental investigations

Piezoelectric gratings (m=1, 2, 3, 4) were made in order to perform the research. Strip-shaped piezoelements (made of the piezoceramics CTS-19, l=15 mm, h=1.0 mm, d=1.5 mm) were glued to the duralumin sample using an epoxy resin. The piezoelements were excited at the resonant frequency of the thickness mode. The emitted LSAW pulse signal was received using the angular transducer with a variable angle, when the angle matched the maximal received signal amplitude (the first critical angle). The piezoelement, used in the angular transducer, was made of the piezoceramics CTS-19 (l=11 mm, h=1,0 mm, d=8 mm), the prism – of plexiglas. Signals were registered using the digital signal analyzer PCS64i (Great Britain). Experimental set-up is shown in Fig. 7a.

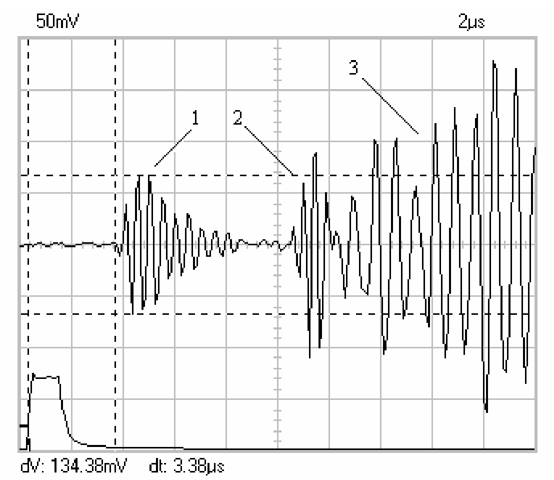


a)

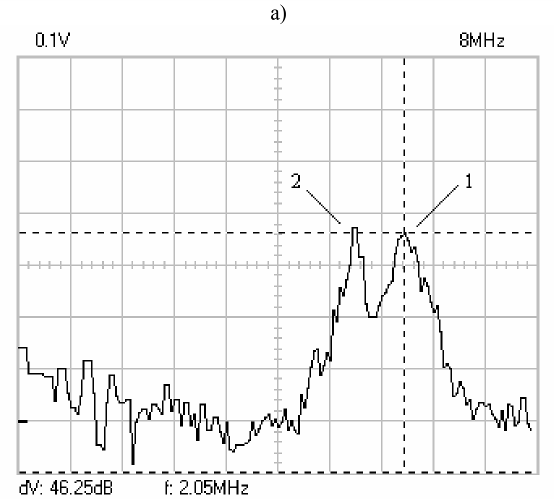


b)

Fig.7. **Piezoelectric grating investigation scheme (a) and top view of piezoelectric grating together with the angular transducer (b). PG is the piezoelectric grating, AT is the angular transducer**



a)

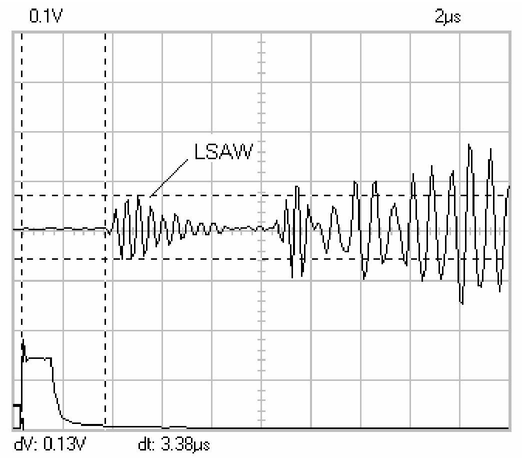


b)

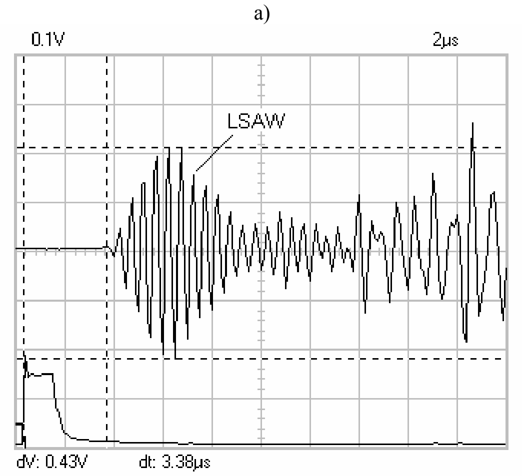
Fig. 8. **Typical acoustic signal (m=4) (a) and signal spectrum (b)**

The piezoelectric grating consisting of four piezoelements (m=4) was excited using a shock voltage. Acoustic signal was received at the distance x_0 = 20 mm. The received pulse signal and its spectrum are shown in Fig. 8.

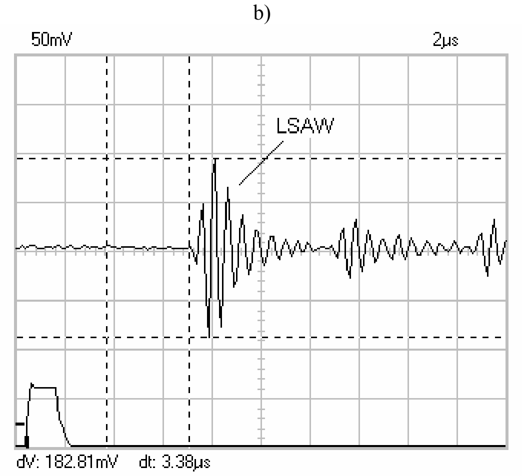
The acoustic signal generated by the piezoelectric grating (Fig. 8a) consists of LSAW corresponding to the thickness mode of vibration (1). There are two different frequency pulses of TSAW that match thickness (2) and transverse modes of vibration (3).



a)



b)



c)

Fig.9. **LSAW signals, generated using one piezoelement (a), grating when m=4 (b), and the angular transducer (c)**

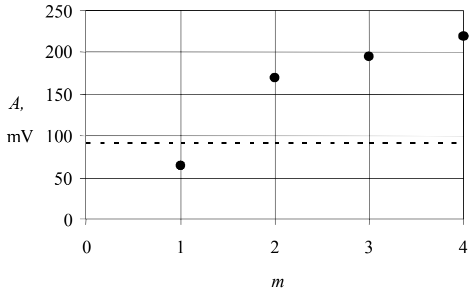


Fig.10. **Dependence of signal amplitude on quantity of piezoelements in the grating. Dotted line shows the pulse amplitude, generated using the angular transducer.**

The thickness mode resonant frequency in the signal spectrum is 2.05 MHz and the transverse mode resonant frequency is 1.24 MHz.

Other generated LSAW signals are shown in Fig. 9. The LSAW, generated by an elementary piezoelement (m=1) is shown in Fig. 9a (x_0=20 mm). LSAW, generated by the piezoelectric grating of four elements (m=4) is shown in Fig 9b (x_0=20 mm). The obtained results can be compared with the generated signal using the angular transducer (Fig. 9c). The signal amplitude dependence upon quantity of piezoelements is shown in Fig. 10. The dependence shows that sensitivity of the angular transducer is less than sensitivity of the two piezoelements (m=2) grating.

Conclusions

Experimental investigations show that a piezoelectric grating is more sensitive than the angular transducer, when grating consists of $m \geq 2$ piezoelements. Piezoelectric gratings generate the LSAW together with the TSAW or the Rayleigh waves. That does not interfere to carry out measurements and non-destructive testing using the LSAW, because the velocity of the LSAW is the fastest.

Acknowledgments

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Paviršinių išilginių bangų sužadinimo pjezoelektrine gardele tyrimai

Reziumė

Aprašomi paviršinių išilginių bangų sužadinimo pjezoelektrine gardele eksperimentiniai tyrimai. Jų rezultatai parodė, kad pjezoelektrine gardele galima sužadinti paviršines išilgines bangas megahercų dažnių diapazone, be to, sužadinimo pjezogardele efektyvumas yra didesnis nei standartiniais kampiniais keitikliais.

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