ISSN 1392-2114 ULTRAGARSAS, Nr.3(52). 2004.

Investigation of mechanical tension in sheet products by symmetrical Lamb waves

S. Sajauskas, A. Valinevičius, D. Klimavičius

Department of electronic engineering, Kaunas University of Technology

K.Donelaičio str. 73, LT – 44029

Introduction

Longitudinal surface acoustic waves (LSAW) excited on the surface of isotropic solid surfaces by the first critical angle are characterized by the bigger longitudinal component of surface vibration than the transversal component [1]. This determines their property to propagate with phase velocity close to the bulk longitudinal wave phase velocity depending also on the Poisson's ratio of the solid. The prediction that the LSAW phase velocity must depend on a solid surface layer mechanical state can be made. It was theoretically proved that in sheet products with the thickness $h << \lambda_{LE}$ (λ_{LE} is the length of the Lamb wave) the dispersal symmetric s_0 and antisymmetric α_0 Lamb waves of the zero order can be excited [2]. Experimentally it was found that in sheet products, the wave excited by the angle transducer matched for the first critical angle (LSAW wave) is symmetric Lamb wave s_0 of a zero order.

The purpose of this work is to investigate experimentally the properties and the dependence on the mechanical stress of the sheet of symmetric s_0 Lamb waves excited by the LSAW transducer.

Theory

When the longitudinal surface acoustic wave is excited by the first critical angle. The material particles moves in the trajectory of the ellipse (Fig. 1) with the longitudinal component $\xi_x > \xi_z$ (where ξ_z is the normal component, λ_L - bulk longitudinal wave length).

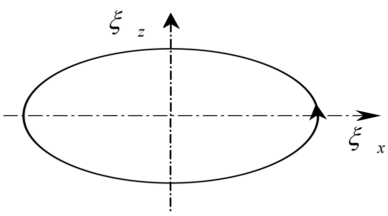


Fig. 1. **The LSAW trajectory of surface point movement**

The tangential ξ_x and the normal ξ_z oscillation components in the symmetric wave are described by [3]:

$$\xi_{Sz} = -A_S q_S \left(\frac{\sinh q_S z}{\sinh q_S \frac{h}{2}} - \frac{2k_S^2}{k_S^2 + s_S^2} \cdot \frac{\sinh s_S z}{\sinh s_S \frac{h}{2}} \right) e^{i(k_S x - \omega t)},$$

$$\xi_{Sx} = A_S k_S \left(\frac{\cosh q_S z}{\sinh q_S \frac{h}{2}} - \frac{2q_S s_S}{k_S^2 + s_S^2} \cdot \frac{\cosh s_S z}{\sinh 2s_S \frac{h}{2}} \right) e^{i(k_S x - \omega t - \pi/2)},$$

where: A_S = const; $q_S = \sqrt{k_S^2 - k_L^2}$; $s_S = \sqrt{k_S^2 - k_T^2}$; $k_S = \omega h / 2c_S$ is the number of symmetric Lamb wave, k_L and k_T are the numbers of bulk longitudinal and transversal waves; h is the thickness of the plate; $\omega = 2\pi f$, f is the frequency; c_s is the phase velocity of symmetric Lamb wave.

Symmetric Lamb waves are dispersal and their phase velocity c_s depends not only on the thickness of the sheet h, but also on the sound velocity in a sheet material and changes from $\sqrt{E/\rho(1-\sigma^2)}$ to the c_R (Fig.2); where E is Young module; ρ is the density; σ is Poisson's ratio; c_R is the phase velocity of Rayleigh waves [2].

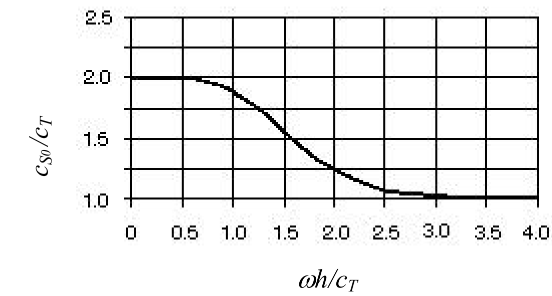


Fig. 2**. Theoretical dependence of symmetrical Lamb wave s_0 phase velocity on bulk transversal wave velocity [2]**

It excites the symmetric Lamb wave s_0, with dominating longitudinal component in acoustically thin sheets ($h << \lambda_L$) because of LSAW interaction with both free sheet surfaces. Physical origin of such a wave determines that the features of s_0 wave more depend on factors determining propagation of the longitudinal component, but not the transversal components. One of such factors is the mechanical tension of the material, influencing the material density and the Poisson's ratio σ.

Methodology and results of experimental investigation

Strip-shaped samples of a special shape with the broadened ends for better fixing in a stretch mechanism were made from a bronze sheet for investigation of the excited LSAW s_0 mode symmetric Lamb wave (Fig. 3). The thickness of the sheet was h = 0.09 mm.

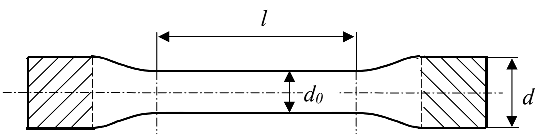


Fig. 3. **The form of the sample**

The sample is fixed in the stretch mechanism and the signal of symmetric Lamb wave is excited in its narrowed part by the LSAW angle transmitter, picked up by the LSAW receiver situated at the distance l_0 from the transmitter (Fig.4).

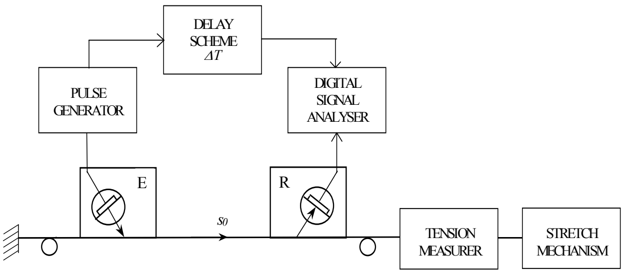


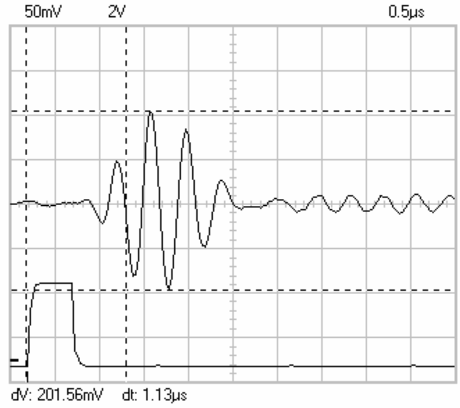
Fig. 4. **The investigation scheme: E and R are the emitter and receiver of ultrasound pulses; S_0 is the symmetric Lamb wave**

The received s_0 Lamb wave ultrasound signal is indicated by the digital signal analyzer (DSA) synchronized by the delayed pulses of the electric pulse oscillator (Fig. 5). Its amplitude and the position in the time domain are measured at the same instant. As it is seen from the theoretical dependence (Fig. 2), the phase velocity of the symmetric s_0 mode Lamb wave quickly changes in the limits $c_R < c_s < 2c_R$, when $\omega h/2c_T$ changes from 2.5 to 1. The strip-shaped sample is in the range of strong symmetric Lamb wave dispersion, when the ultrasound signal frequency f = 2 MHz, the bronze sheet thickness h = 0.09 mm, and the parameter $\omega h/2c_T \approx 1.88$ ($c_T \approx 3000$ m/s). The s_0 mode dispersal Lamb wave phase velocity is calculated having changed the distance between the transducer by Δl_0 = 32 mm and having measured the shift of the received signal in the time domain $\Delta\tau$ = 7.69 µs, when the mechanical stress W = 0 ($c_s = \Delta l_0/\Delta\tau$ = 4160 m/s).

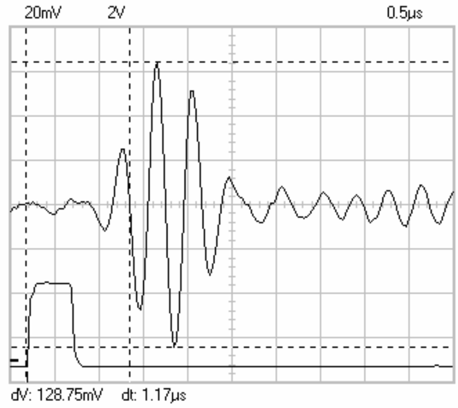
The dependencies $\Delta A_S(W)$ and $\Delta\tau(W)$ were measured changing the mechanical tension $W = F/dh$ (in our case F is the sample dragging power in the direction x (Fig. 3)) and recording the change of the received ultrasound amplitude ΔA_S and the time shift $\Delta\tau_s$.

The ultrasound signals, propagating in the bronze strip-shaped sample, and registered by the digital spectrum analyzer PCS64i discreetly changing the mechanical tension W, are shown in Fig. 5.

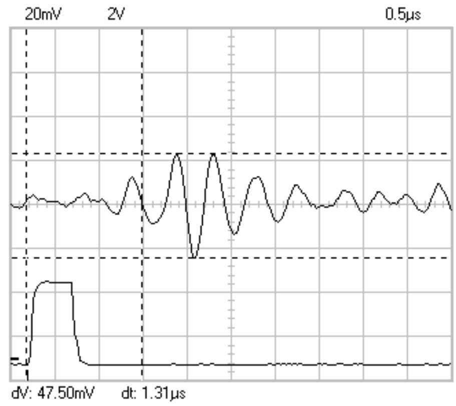
It was noticed that when the mechanical tension increases, the s_0 mode Lamb wave signal amplitude A_s and phase propagation velocity c_s decrease.



a)



b)



c)

Fig. 5. **Ultrasound impulse s_0 mode Lamb wave signals excited and received by the angle LSAW transducer, when a) W = 0; b) W = 55.6 N/mm^2; c) W = 92.6 N/mm^2**

The calculated according to the measurement results dependencies $A_S/(A_S)_{max}(W)$ and $c_S(W)$ of the s_0 mode Lamb wave attenuation are shown in Fig. 6 and Fig. 7.

Stretching of the strip-shaped sample changes the amplitude of the signal (attenuation) as well as the phase velocity, but the dependence c_s is comparatively weak, so it is recommended to control the mechanical tension and the state of the strip-shaped construction measuring attenuation of the s_0 Lamb wave.

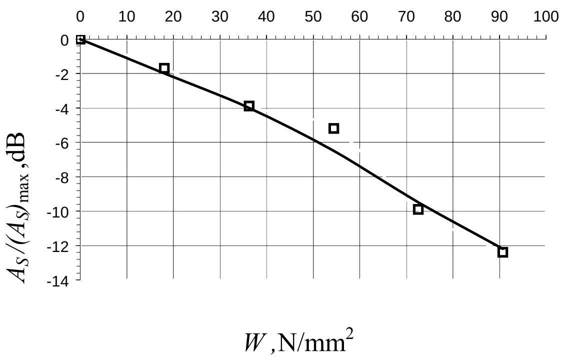


Fig. 6. **The s_0 mode Lamb wave signal amplitude versus mechanical tension**

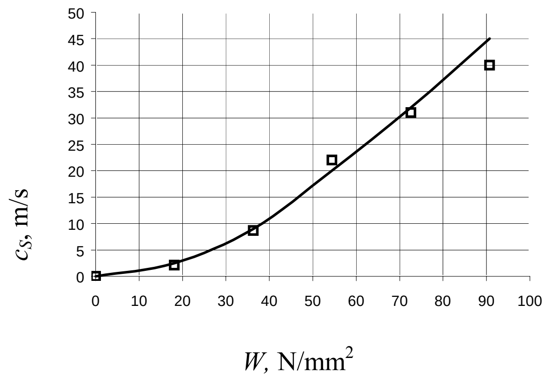


Fig. 7. The **s_0 mode Lamb wave phase velocity versus mechanical tension**

The angle transducers in this case are not the best because the measurements of the signal amplitude (attenuation) are sensitive to the stability of acoustic contact. The strip-shaped piezoelements or their gratings would be more promising for excitation and reception of the s_0 Lamb wave [3].

Conclusions

It was theoretically and experimentally shown that symmetric Lamb waves can be excited effectively in acoustically thin sheet by the angular ultrasound angle matched for the first critical angle. The attenuation of those waves strongly depends on the mechanical stress of the sheet and the measurements of the attenuation of symmetric waves can be effectively used for the mechanical state research of sheet materials by non-destructive method.

References

1. **Sajauskas S.** Longitudinal surface acoustic waves. Kaunas: Technologija. 2002. 160 p. (in Lithuanian).
2. **Викторов В. А.** Звуковые поверхностные волны в твердых телах. Москва: Наука. 1981. C. 101 (In Russian).
3. **Sajauskas S., Vilpišauskas A.** Investigation of excitation of longitudinal surface acoustic waves by piezoelectric grating. Kaunas: Technologija. 2004. P. 13-16.

S. Sajauskas, A. Valinevičius, D. Klimavičius

Lakštinių gaminių mechaninio įtempio tyrimas simetrinėmis Lembo bangomis

Reziumė

Aprašomi simetrinių Lembo bangų lakštuose dispersijos ir slopinimo tyrimai. Simetrinės megahercinio dažnio Lembo bangos akustiškai plonuose lakštuose sužadinamos ir priimamos kampiniais pjezokeitikliais, suderintais pirmajam kritiniam kampui. Eksperimentiniais matavimais nustatyta, kad simetrinių Lembo bangų slopinimas tiesiškai priklauso nuo lakšto mechaninio įtempio. Siūloma šią priklausomybę panaudoti lakštinių gaminių mechaninei būsenai tirti neardomuoju būdu.

Pateikta spaudai 2004 09 14