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Influence of the object edge on the efficiency of Lamb wave excitation

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Abstract

One of the main problems in a long-range ultrasonics is effective generation of a desired wave mode. The efficiency of excitation can be affected by object boundaries existing at close distance from the transmitter, especially taking into account the relatively big wavelength of the guided waves. The objective of this paper was to determine the regularities of the influence of the edge on the efficiency of Lamb wave generation. The investigations were carried out on the steel plate having thickness 40 mm using the modelling by the finite difference method. Obtained dependencies of the amplitudes of the excited waves on the distance of the transmitter with respect to the plate edge demonstrated that most optimal distances are $\lambda/8$ and $\lambda/2$, where λ is the wavelength of the excited Lamb wave mode. It was demonstrated, that positioning of the transducer at the distance less then $\lambda/8$ is not recommended due to essential reduction of the amplitude of the generated waves.

Keywords: long-range ultrasonics, ultrasonic guided waves, numerical simulation

Introduction

Non-destructive testing (NDT) of large engineering constructions with a size 10 meters and more is problematic. Such objects are wind power stations, bridge constructions and underground pipes. The guided ultrasonic waves are very attractive for testing of these objects because they propagate long distances inside the object and enable at once to test large segments of the construction. The guided waves are dispersive and multimodal, so the most important question in the application of guided waves is efficient generation of the desired wave mode at the selected frequency. In practice of the inspection of planar objects mainly symmetrical S_0 and asymmetrical A_0 modes of the Lamb wave are used.

The frequency range used in a long-range ultrasonics usually is 20-300 kHz. At these frequencies the wavelengths of guided waves λ are approximately in the range of tens of centimetres.

In real measurements the transducers are very often positioned at close distance from the object boundaries. The efficient excitation can be affected by these boundaries due to interference of the direct and reflected waves [1-2].

The objective of the presented work was to determine influence of the edges of the object on the amplitude of generated Lamb waves and to find out the optimal in the sense of the efficiency distances from the edge.

The model of the object

The investigations were carried out using finite difference method in 2D approach. The excitation of the S_0 Lamb wave modes in a 40 mm unbounded steel plate was analysed. The setup of the numerical experiments is presented in Fig.1.

The length of the plate along the x axis is 7 meters. Such a length along the x axis was selected in order to obtain the best selectivity in the time domain of the A_0 and S_0 Lamb wave modes and to avoid at the receiver position the interference of the direct waves and the reflected by the end of the plate. The plate is infinite in the y axis direction due to the 2D approach. It was assumed that the steel plate is unloaded, e.g. is placed in vacuum. The transducer element was situated along x axis with the different distances d_{Tr} from the edge of the plate. The distance d_{Tr} was changed in the range 0-2λ with the step 10mm. The λ is the wavelength of the S_0 mode. The width of the active element of the transducer was 10 mm.

The excitation was performed using the virtual shear type transducer [3]. The virtual transmitting element was simulated as initial boundary conditions, e.g. a predefined time dependent displacement along x axis (shear type excitation). This means that all spatial discretization nodes inside the area of exciting element „vibrate“, corresponding to the waveform of the excitation signal and are not affected by propagating waves. Therefore, such a virtual element possesses an infinite bandwidth and can excite longitudinal or shear component depending on a selected option. The virtual receiver is placed at 3 meters from the plate edge and can pick up longitudinal and transversal displacement components of ultrasound wave. The virtual receiver is transparent for any type of displacements and does not affect propagating waves, e.g. does not create reflections.

Simulations were carried out using 2 mm step of the sampling in space domain. The integration step in the time domain was 0.2831 μs.

Selection of excitation parameters

The calculated dispersion curves of the phase velocity of the 40 mm thickness steel plate are presented in Fig.2.

From the presented dispersion curves follows that in order to avoid strong effect of dispersion the frequency of the S_0 and the A_0 modes should be selected in the range from 10 kHz to 40 kHz.

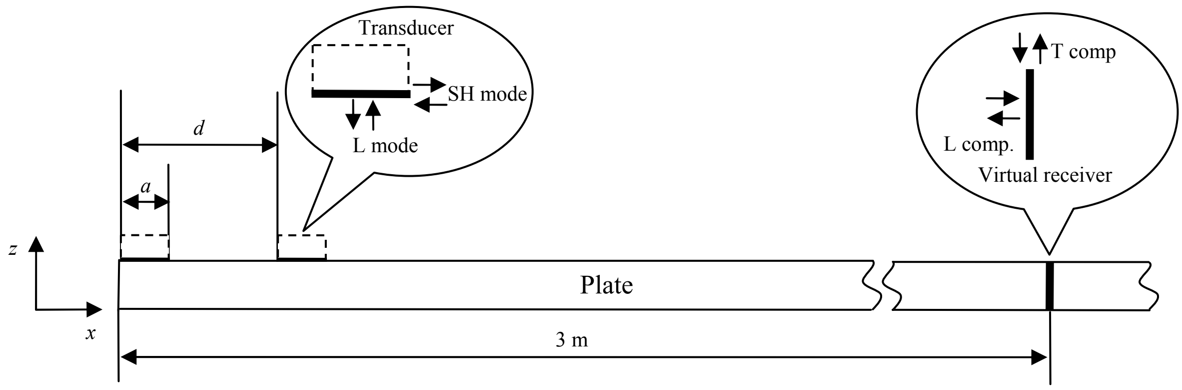

Fig 1. **The set up of the numerical experiment**

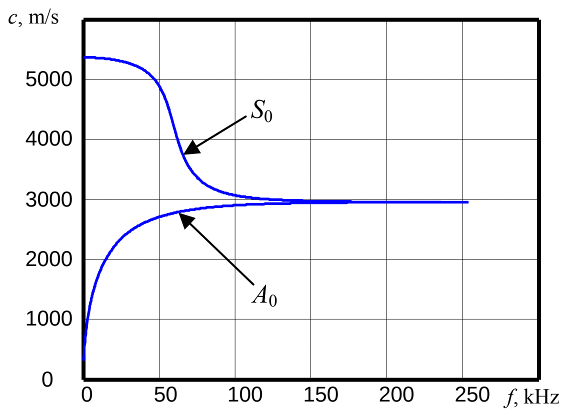

Fig.2. **The dispersion curves of the phase velocity of the Lamb waves in the 40 mm thickness steel plate**

Also, in this frequency range the signals of the propagating S_0 and A_0 Lamb wave modes can be simply separated in the time domain due to the essential difference in propagation velocities. So, the numerical simulations were performed at the frequency 30 kHz. The ultrasound velocity of longitudinal waves in steel was 5900 m/s. The phase velocity of the S_0 Lamb wave mode in a steel plate with the thickness 40 mm at 30 kHz according to dispersion curves is 5272 m/s.

The wavelength of the S_0 mode at this frequency is $\lambda = 0.176$ m. The excitation has been performed using 5 periods burst with the Gaussian envelope. The waveform of the excitation signal is presented in Fig.3

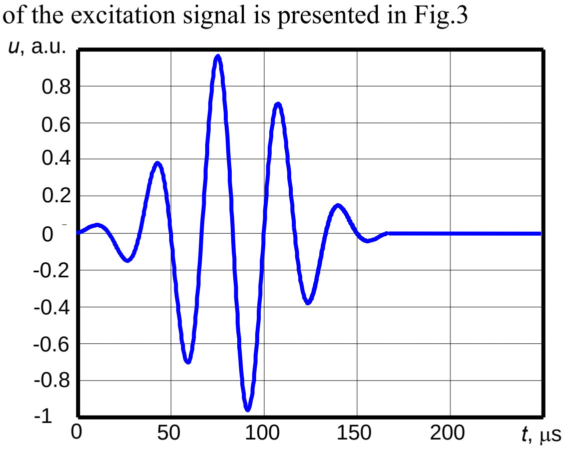

Fig.3. **30 kHz excitation impulse with the Gaussian envelope**

Simulation and results

The simple estimation of the expected results was made before the start of the experiments. The estimation is based on the assumption that the total generated wave signal is the result of the direct signal and the signals reflected by the edge of the plate (Fig.4):

$$u_R(t,d_{Tr}) = u_D(t) + u_R(t,d_{Tr}) = u_D(t) + u_D(t-\Delta t_D)\,, \quad (1)$$

where $u_R(t,d_{Tr})$ is the total signal received by the receiver, $u_D(t)$ is the directly propagating wave, $u_D(t)$ is the signal reflected by the edge of the plate, $\Delta t_D = 2d_{Tr}/c_L$ is the delay time of the wave propagating to the edge and back to the position of the transmitter, c_L is the phase velocity of the S_0 mode Lamb wave.

Then the variations of the peak to peak amplitude caused by the interference of these two signals can be calculated according

$$U_{PP}(d_{Tr}) = \max_t\left[u_R(t,d_{Tr})\right] - \min_t\left[u_R(t,d_{Tr})\right]. \quad (2)$$

The obtained dependency of the amplitude of the received signal versus distance of the transducer with respect of the plate edge was normalized according to

$$U_{PP,n}(d_{Tr}) = u_{PP}(d_{Tr}) / \max\left[u_{PP}(d_{Tr})\right]$$

and is presented in Fig.6 by the solid line, where the distance is denoted by the wave number *k*. As can be seen the dependency possess the wavy, decaying character. It demonstrates that the best positions according theoretical estimation are completely on the edge (zero distance) and the distance λ/2.

In the case of the numerical modeling, the distributions of the acoustic field at different time instants were obtained. The acoustic fields in the cross-section of the front part of the plate at the time instants 65 μs, 120 μs, 250μs are presented in Fig.5. The received signals were recorded at each transmitter position. The examples of the measured signals for most typical positions are presented in Fig.8-10. As can be seen each signal contains two bursts, first of which corresponds to the propagating faster S_0 mode, the second one to the A_0 mode of the Lemb wave.

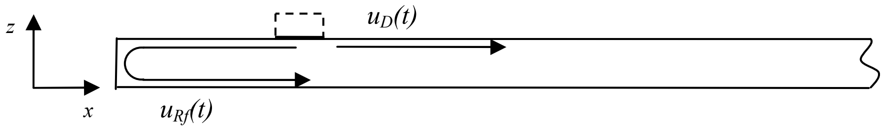

Fig.4. **Basic principle of the signal reflection used in the estimation of expected results**

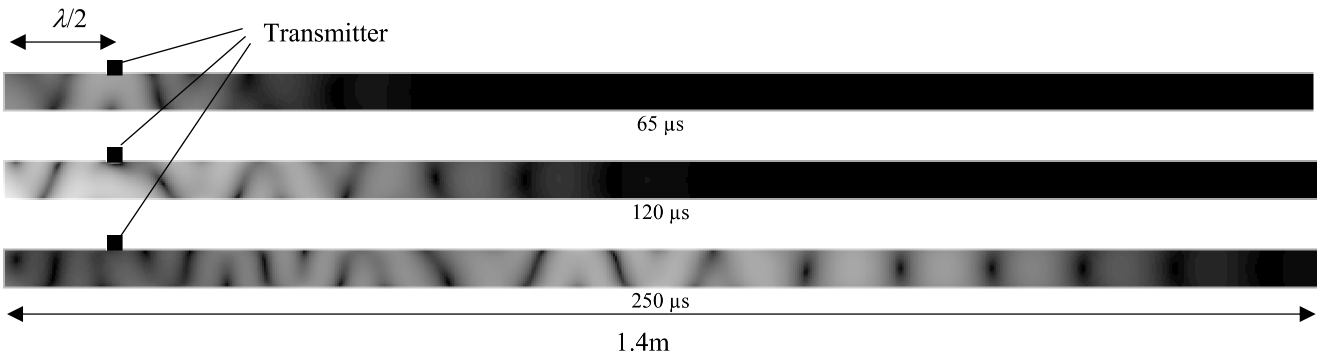

Fig.5. **The acoustic fields in the cross-section of the front part of the plate at different time instants**

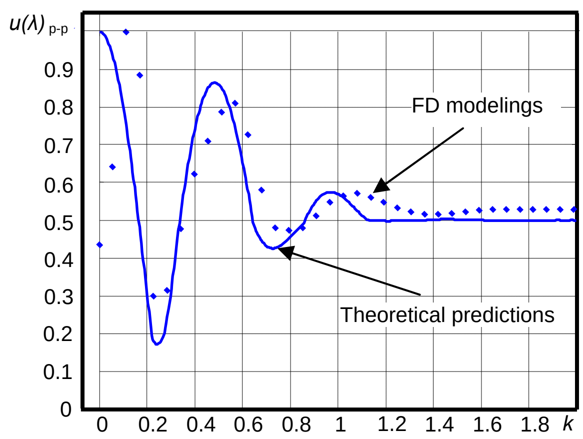

Fig.6. **The normalized amplitudes of the received signal versus distance of the transmitter with respect to the edge of the plate: FD- modeling by the finite difference method**

The peak to peak amplitudes of the S_0 mode signal obtained from the numerical modeling are denoted in Fig.6 by dots. In general, obtained dependency coincides with prediction and possesses the similar character, but there are some differences. At first, there is a small mismatch of the phase of the wavy character. The second one, more essential, is quite different behavior at distances close to the edge. It can be seen that the dependency obtained by the numerical modelling demonstrates contrarily to the prediction an essential reduction of the amplitude completely on the edge. This can be explained by the fact that attachment of the transducer at the edge changes boundary conditions, so, the whole wave generation process can not be approximated simply by the interference of two waves.

Conclusions

The investigation carried out using modelling has demonstrated that the distance of the transducer with respect to the edge or boundary of the object essentially affects the efficiency of the excitation, mainly due to the interference of the direct waves and the waves reflected by the boundary.

It was find out by the numerical modelling of the steel plate that most optimal distances for the generation of the S_0 mode of Lamb waves in the case of the shear type transducers are λ/8 and λ/2.

It is necessary to state that investigations were carried out for steel plate and the shear type transducer, so in the case of different type of the transducer or different object or different wave reflections conditions the regularities can be different from the obtained ones.

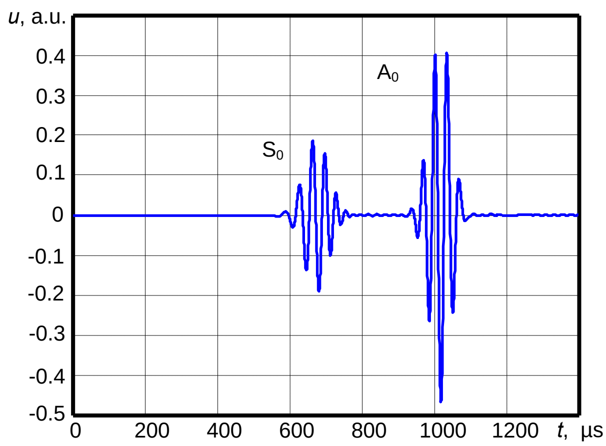

Fig.7. **The waveforms of the ultrasonic guided waves received at 3 meters from the transducer placed on a free edge**

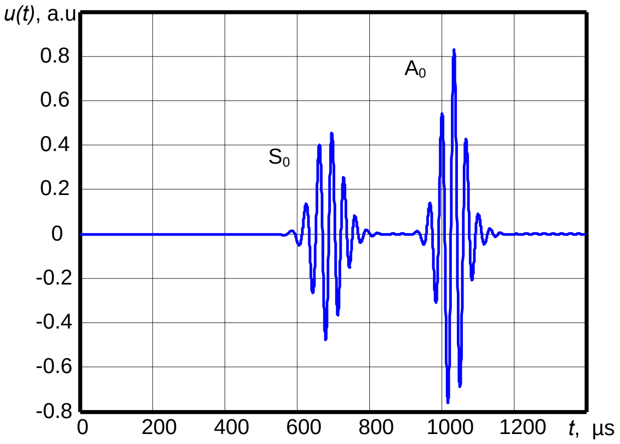

Fig.8. **The waveforms of the ultrasonic guided waves received at 3 meters from the transducer placed from the edge at the distance λ/8**

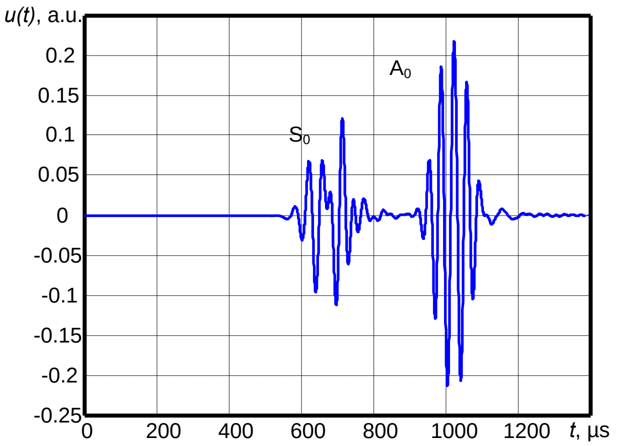

Fig.9. **The waveforms of the ultrasonic guided waves received at 3 meters from the transducer placed from the edge at the distance λ/4**

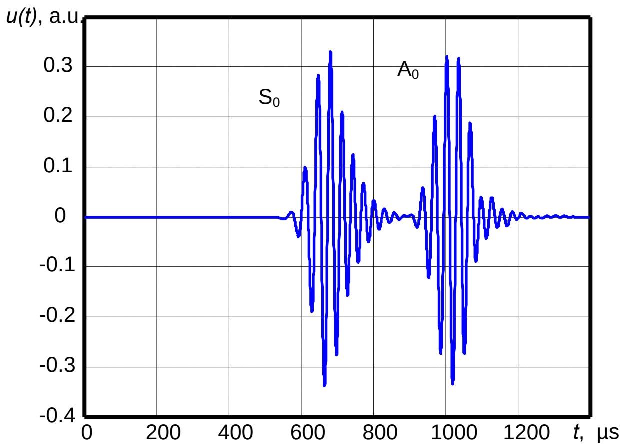

Fig.10. **The waveforms of the ultrasonic guided waves received at 3 meters from the transducer placed from the edge at the distance λ/2**

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Objekto krašto įtaka Lembo bangų žadinimo efektyvumui

Reziumė

Didelių inžinerinių konstrukcijų neardomiesiems bandymams naudojant nukreiptąsias ultragarso bangas yra labai svarbu efektyviai sužadinti pasirinktą modą. Ultragarso bangos modos sužadinimą lemia daugelis veiksnių, tokių kaip keitiklio tipas, jo pritvirtinimo būdas ir vietos parinkimas ant testuojamo objekto. Žadinant Lembo bangas plokščiuose objektuose labai svarbu krašto įtaka. Šio darbo tikslas buvo ištirti Lembo bangų žadinimo efektyvumo priklausomybę nuo keitiklio padėties plokštės krašto atžvilgiu.

Tyrimas buvo atliekamas baigtinių skirtumų metodu dvimatėje erdvėje. Rezultatai parodė, kad, tolstant keitikliui nuo krašto, signalo amplitudė kinta pagal harmoninį slopimo dėsnį. Tai sąlygota tiesiogiai sklindančios ir nuo plokštės krašto atspindėtos bangų tarpusavio interferencijos. Esant keitikliui arti plokštės krašto, buvo pastebėti skirtumai tarp tikėtino interferencijos rezultato ir rezultatų, gautų modeliavimo būdu. Tai rodo ženklų signalo amplitudės padidėjimą keitikliui esant λ/8 atstumu nuo plokštės krašto (λ – pasirinktos modos bangos ilgis). Keitikliui esant toliau nuo krašto abiejų metodų rezultatai sutapo ir parodė, kad optimalūs žadinimo atstumai yra λ/2 kartotiniai.

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