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On the pipe's investigation by means of the asymmetric radiated/received Lamb waves

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Introduction

The determination of the thickness of sediment layer in pipelines or tanks is one of the biggest problems of non-destructive testing. The anti-symmetric Lamb waves (flexural) were successfully used for this purpose. Waves were excited by longitudinal wave transducer lodged to the wall of the pipe and received by the other transducer on the opposite side of the pipe [1, 2]. Such an excitation is effective in wide range of frequencies, does not need the preparation of the pipe and allow assembling or removing the transducers easily. The amplitude frequency response (AFCh) is registered when the frequency of continuous signal is changed. The quasi-periodic resonant peaks are observed when the perimeter of the pipe is equal to the integer of wavelengths. Those peaks are very deformed and this does not allow using classical methods for quality (and sediment thickness also) assessment. The method for estimation of sediment layer thickness and based on determination of biggest sharpness of the autocorrelation function is quite efficient [3,4]. The requirement that transducers must be located against each other makes the use of method more complicated when the pipe is accessed only from one side.

From the technologic point of view the possibility to measure with the transducers fastened asymmetrically (at one side) would be very request. But it must be examined how the excitation – receiving geometry will influence the AFCh. It must also be known how AFCh is formed analyzing the transient processes in the pipe shape waveguide [5]. Only the case with the transducers at one side on the line parallel to cylinder axle is slightly studied [6].

The object and the method

The transducers are fixed at the points 1 and 2 (Fig. 1). The perimeter of the pipe is L, the distance between transducers is l. The standing waves appear in the wall and the resonance peak is registered when the condition

$$L=n\lambda, \tag{1}$$

where n=1,2,3,…, is fullfilled.

When the transducer 1 radiates the waves, the other transducer 2 receives them, the latter transducer will catch the antinodes of the standing wave when

$$L(1-s)=p_1\lambda, \tag{2}$$

where p_1=1,2,3...n-1; $s=2l/L$.

It will occur in the node, when

$$L(1-s)=(p_2-0.5)\lambda, \quad \text{or} \quad Ls=(m+0.5)\lambda, \tag{3}$$

where p_2 =1,2,3...n; $m=n-p_2$.

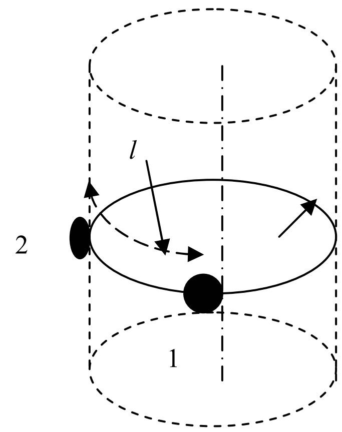

Fig. 1. **The arrangement of transducers on the pipe under test**

The waves in the case of Eq. 2 arriving to the receiving point clockwise will have the same phase, and in the case of Eq. 3 – the opposite. The received signal is formed by the series of decreasing waves, showing them as turning phasors - the chain of vectors. This chain is stretched when the conditions given to Eq. 1 and 2 are fulfilled and when the frequency is detuned, they spin smoothly. So, the resonance peak is formed. The waves are almost fully eliminated in the case of Eq. 3. In the every other case the wave propagating to the left from the point 1 (Fig. 1) will reach the point 2 earlier then that propagating to the right. The superposition of all waves can be written as

$$U=\sum_{i=1}^{2N}\frac{a_1}{\sqrt{r_i}}\cos(\omega t-k_W r_i)\exp(-\alpha r_i), \tag{4}$$

where U is the received signal, a_1 is the amplitude of foremost arrived waves at the receiving point, r_i is the path of the wave (for odd i means $r_i=(i-1+s)L/2$, even - $r_i=(i-s)L/2$), ω is the angular frequency, k_w is the wave number, α is the coefficient of attenuation, $2N$ is the number of waves involved in superposition; odd i correspond the waves propagating from the transmitter to the left, and the even – to the right.

The receiving time and the phase of the waves that came from the left and from the right to the receiving point coincide when the transducers are set against each other (s=1), and they are not separated by the transducer, receiving from all directions (in our case). Their receiving time and phase will be different in all the other cases, but their average will satisfy the case when s=1. Such vectors will form a Z-bend chain (Fig.2).

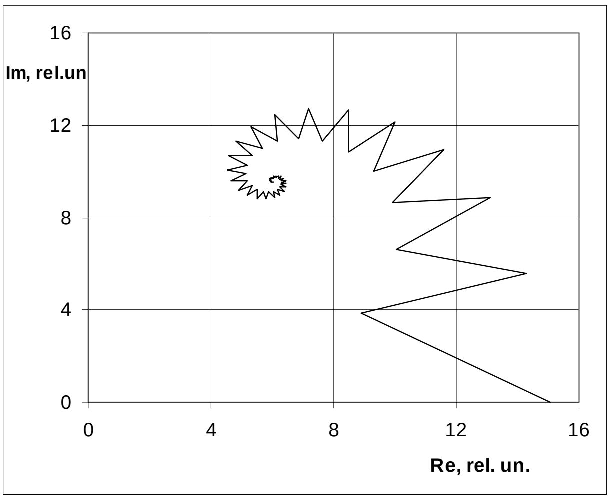

Fig. 2. **The chain of vectors in a general case. L/λ=12.95, s=0.414, αL=0.1**

The results of experiment and modeling

a) The surrounding of the antinodes. Eq. 1 estimates the frequencies of resonance peaks. The chain in the surrounding of peak has a weak Z-bond shape and the formation of the signal does not differ from the classical case of interference if Eq. 2 suits the same frequency. The phases of received waves differ over $2\pi L(1\text{-}s)/\lambda$ if the quantity p_1 in Eq. 2 differs from the integer number significantly (when n in Eq. 1 is an integer number). Assuming that amplitudes of both waves are equal, their contribution into the whole wave is equal 2 $a_i\cos[\pi L(1\text{-}s)/\lambda]$. Such a Z-bond chain gives smaller total vector and the obtained peak is also smaller. The phase varies a little and has no influence on the form of the peak, though it decreases when the frequency is detuned. The presumption about equality of amplitudes at least fits to the first waves (because of the influence of the coefficient $r_i^{-0.5}$ and influence of the attenuation), but the peak is formed by many waves.

AFCh for the case of symmetric excitation - receiving (transducers are against each other) is shown in Fig. 3. The amplitudes of the peaks are not equal because the transmission coefficient of both transducers depends on a frequency. The AFCh, obtained experimentally in the same cross-section without moving of one transducer and simulated by asymmetric transmition - reception, is shown in Fig. 4a and 4b respectively. The peaks with n=14 and 15 are slightly reduced, and the peaks with n=13 and 16 are significantly reduced. The results of experiment and modeling coincide adequate enough.

b) The surrounding of the nodes. In this case Eq. 1 and 3 are satisfied. The members of the vectors chain (Fig. 2) are directed to opposite directions, and their sum gives a small vector depending slightly on a frequency (i.e. peak disappears fully). Experimental and modelled AFCh of the same pipe as in Fig. 3 and Fig. 4 in the same interval of frequencies are shown in Fig. 5a and Fig. 5b respectively. In this case Eq. 2 is approximately satisfied and the peaks with n = 11, 13, 15, and 17 almost disappear. This equality is fully satisfied when s = 0,5. The sharp minimum of the corresponding peak size in modelled curve and broader minimum in the experimental curve are seen in Fig. 5 also. The inadequacy of modelling and experiment has several reasons:

1. The real contact between the transducer and the wall is closer to the line than to the point and evaluating the “pillow” of the contact liquid is closer to ellipse;
2. Due to such surface contact, the amplitude of the first waves at the receiving point decreases irregularly and approximately slower than $r^{-0.5}$ (the near field zone);
3. The law $r^{-0.5}$ fits to the further waves also only approximately.

The dependence of the wave amplitude on the distance can be corrected for more precise of modelling.

Conclusions

The arrangement of transducers on one side of the pipe is desirable from the technological point, but it must be kept in mind that by unsuccessful choice of the transducer mounting point the resonance peaks disappear. The below mentioned procedure for the measurement must be recommended:

- the wave velocity and their attenuation in the pipe must be evaluated tentatively;
- the frequency where Eq. 2 and 3 are fulfilled must be checked;
- the frequency intervals near the solutions of Eq. 3 are skipped off from the measurement program.

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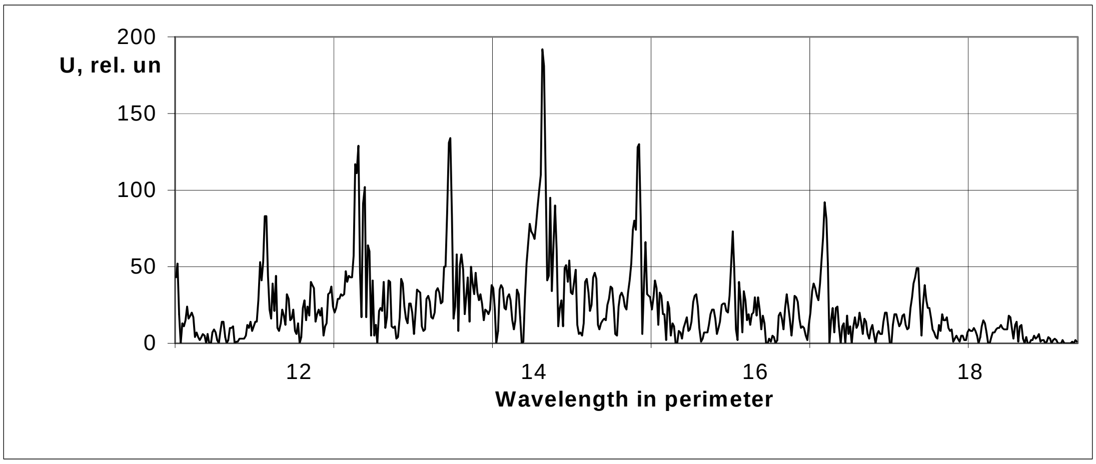
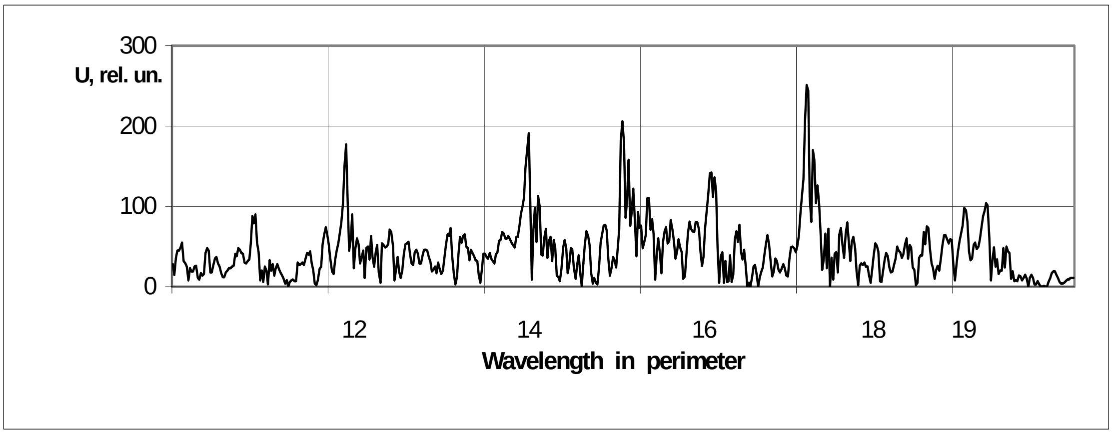


Fig. 3. **Frequency response of the empty and rather corroded steel pipe (diameter *D*=148, thickness of the wall *t*=8 mm), when the transducers are against each other (*s*=1). The frequencies are 96-142 kHz**.



a

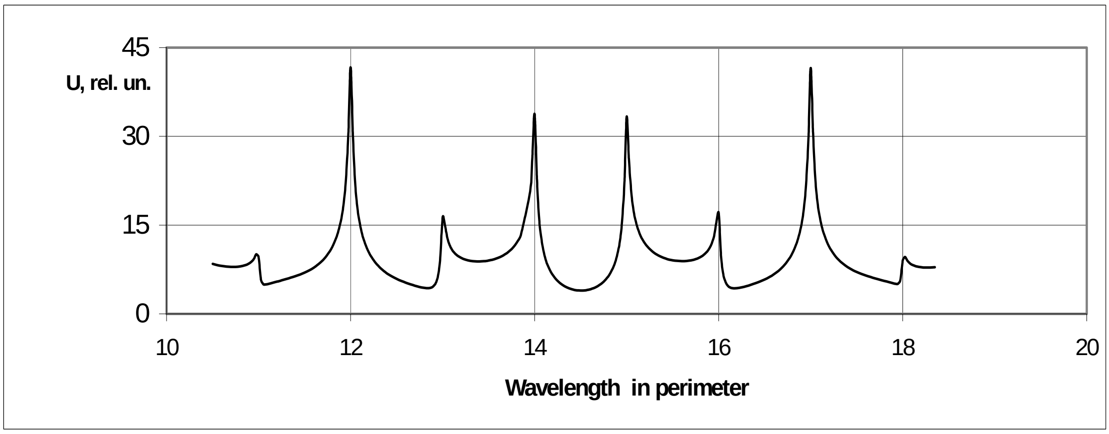


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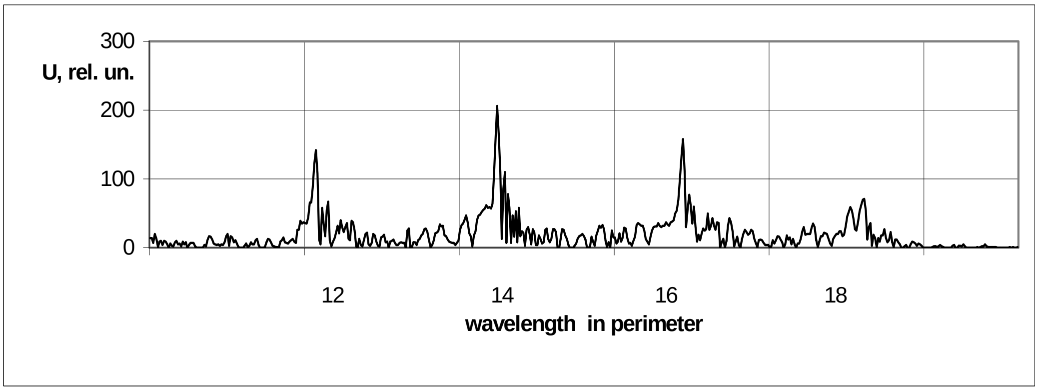
Fig. 4. **Measured (a) and simulated (b) frequency responses of the same pipe as in Fig. 3, *s*=0.414**



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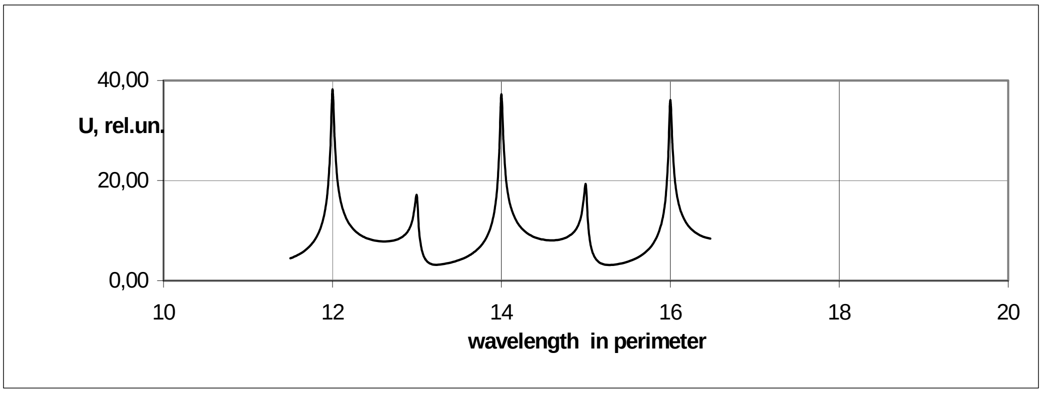

b

Fig. 5. **Measured (a) and simulated (b) frequency responses. The pipe and frequencies as in Fig. 3-4, *s*=0.51**

V. Sukackas

Vamzdžių tyrimas nesimetriškai sužadinant ir priimant Lembo bangas

Reziumė

Aprašomas metodas vamzdžiams tirti Lembo bangomis sužadinant ir priimant jas išilginių bangų keitikliais, priglaustais prie sienelės. Jų kontaktinis plotelis gali būti traktuojamas kaip taškas. Nagrinėjami dažninės amplitudės charakteristikos pokyčiai, kai žadinimo ir priėmimo keitikliai išdėstyti viename pjūvyje, bet ne priešpriešiais. Parodyta, kad, kai ėmiklis yra mazgo aplinkoje, kai kurie pikai išnyksta arba labai sumažėja. Jei ėmiklis yra pūpsnio aplinkoje, pikai sumažėja, bet jų forma nepasikeičia. Siūloma dažnių, kuriems esant keitiklis patenka į mazgą, aplinkos į matavimus neįtraukti. Modeliuota vektoriškai sumuojant bangų, atėjusių į ėmiklį iš kairės arba iš dešinės ir daug kartų apibėgančių vamzdį, kompleksines amplitudes. Modeliavimo ir eksperimentų rezultatai gerai sutampa.

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