FACTOR ANALYSIS INFLUENCING THE RESULTS OF WHEELSET AXLE TESTING BY ULTRASONIC THROUGH TRANSMISSION METHOD

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KEYWORDS: Wheelset Axle, Ultrasonic Through Transmission Method, Interfering Factors, Surface Roughness, Frequency Deviation, Beam Spread, Grain Size

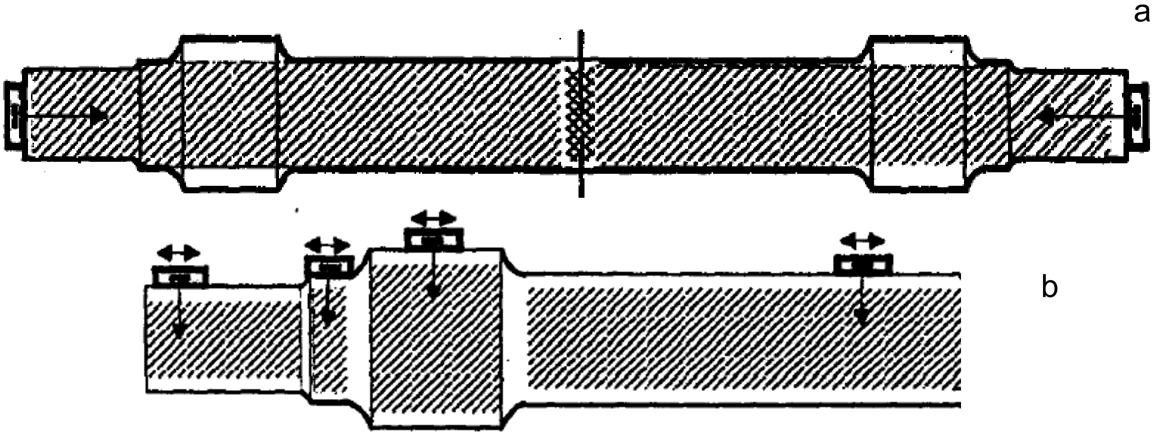
INTRODUCTION

A number of articles of railway, metal and mechanical engineering industries is tested by ultrasonic testing using through transmission and reflection through transmission techniques. In particular these techniques are recommended to apply for forged pieces, plates, railway rails, car wheelset axle and other articles.

The method is based on the analysis of decreasing the echo amplitude propagated through testing object due to defect presence. Despite of low sensitivity in comparison with pulse–echo method used traditionally, through transmission technique hasn't the dead zone и allow to detect the defects with random orientation.

The schemes of this method realization for car wheelset axle are presented on Fig.1.

a



b

Fig.1. The schemes of ultrasonic through transmission method of wheelset axle testing: a – longitudinal sounding from the face of Wheelset Axle, b – radial sounding from lateral surface.

The potential causes of signal amplitude decreasing are metallurgical flaws (voids, abscesses, nonmetallic inclusions, flakes, Widmanstatten pattern, fluctuations of grain sizes) and operational defects (developed fatigue cracks etc.) and also methodical and technological factors (surface roughness and constructional peculiarities of input and reflecting surface, acoustic properties of coupling liquid, transducer sizes and operating frequency, fluctuations of acoustic attenuation of standard sample properties).

According to the specified factors signal attenuation, using through transmission techniques can be described by following formula

$$N, dB = (N_1 + N_2 + N_3 + N_4 + N_5) - N_{st}\ , \tag{1}$$

where N_1 - attenuation caused by the limited transparency of a couplant layer; N_2 - attenuation caused by of ultrasound beam spread during propagation; N_3 - the damping caused by ultrasound absorption and scattering; N_4 - attenuation caused by constructional peculiarities of the reflecting surface; N_5 - attenuation due to defect availability, N_{st} – attenuation due to dumping and beam spread from back reflection signal on standard sample. The values of some disturbing factors influencing on the results of reflection through transmission techniques are estimated for longitudinal and radial directions of weellset axles.

Factor N_5 is caused availability of metal defect of metallurgical and operational origin. It's determined by detectability coefficient of reflection through transmission techniques as ratio of reflected signal amplitude when defect presents U_d to reflected signal amplitude when defect absences U_0:

$$K_{3T} = \frac{U_\partial}{U_0}\ . \tag{2}$$

In the paper the influence of different factors on the results of ultrasonic through transmission method are presented.

THE INFLUENCE OF CONTACT LAYER (FACTOR N_2)

Ultrasound wave reflection and transparency trough the contact layer with the width h and wave resistance Z_2, placed between two mediums with wave resistances Z_1 and Z_3 for normal incidence can be described by the expressions for reflection coefficient R and transparency coefficient D, received by Brehovskih [1]:

$$R = \frac{(Z_1 + Z_2)(Z_2 - Z_3)exp(-2i\varphi) + (Z_1 - Z_2)(Z_2 + Z_3)}{(Z_1 + Z_2)(Z_2 + Z_3)exp(-2i\varphi) + (Z_1 - Z_2)(Z_2 - Z_3)}\ , \tag{3}$$

$$D = \frac{4Z_1 Z_2}{(Z_1 - Z_2)(Z_2 - Z_3)exp(i\varphi) + (Z_1 + Z_2)(Z_2 + Z_3)exp(-i\varphi)}\ , \tag{4}$$

where $\varphi = k_2 h = \omega h / C_2$ - wave phase with frequency ω during propagation trough layer, C_2 – longitudinal wave velocity in the contact layer.

The calculation results of transparency coefficient D according to the thin layer theory are presented on Fig.2 for the cases of uniform and non-uniform thickness contact layer caused by surface roughness. The variations fh from zero up to value 0,34 mm·MHz (correspond transparency maximum h=135 microns on the frequency f=2,5 MHz) leads to changing N_1=24 dB for non-uniform clearance. The account of factor N_1 leads to transparency decreasing on ~4-6 dB under surface roughness changing from 20 up to 40 microns depending on coupling liquid and transducer protector material properties.

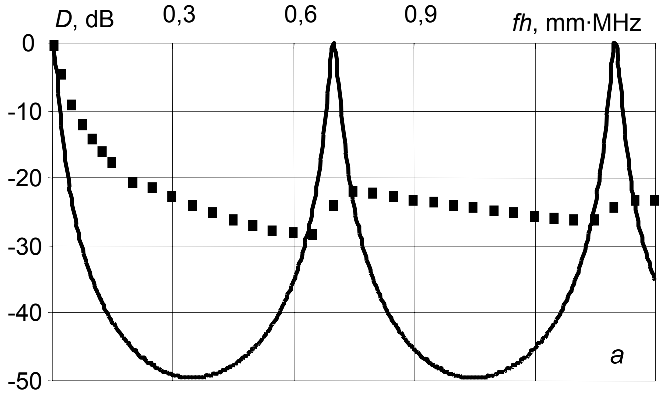


Fig.2. Transparency coefficient *D* for the cases of uniform (—) and non-uniform (- - -) thickness contact layer

Layer transparency essentially depends on the acoustical properties of coupling liquid and transducer protector. For example the transparence coefficient changes from 8 dB for glycerine up to 16 dB for diesel oil at fixed roughness Rz40. Modification of protector material from the steel on the plexiglass leads to essential stabilization of transparency coefficient dependence. Working frequency and its deviation from nominal (±10%) influences on the transparency value insignificantly.

ATTENUATION CAUSED BY OF ULTRASOUND BEAM SPREAD (FACTOR N_2)

Besides the metal structural heterogeneity damping the beam spread influence on signal attenuation and therefore on the results of reflection through transmission technique.

The calculations of main parameters of different piezotransducer acoustic fields and amplitude attenuation on various distances 2*r* are presented in Table 1.

Main parameters of piezotransducer acoustic fields Table 1

The piezo transducer type	Near zone length, mm	First minimum angle of directivity diagram θ_{1min}, degree	Amplitude attenuation *due to ultrasound* beam spread N_2, dB on the distance 2*r*		
			200 mm	1000 mm	2000 mm
1,8MHz, ∅18mm	25	12,7	18	31	37
2,5MHz, ∅12mm	15,4	13,8	18	32	38
5,0MHz, ∅8mm	13,7	10,3	16	30	36
10MHz, ∅6mm	15,4	6,8	13	26	31

The estimations of specified factor make N_2=16 dB for the frequency 2,5 MHz and the length of testing objects L=100 mm and N_2=36 dB at L=1000 mm.

The specified loses can be realized completely if the cross sizes of the object are more then ultrasound beam width (forgings, sheets). The waveguide effect can take place for the number of articles (for example longitudinal sounding from the face of wheelset axle). Thus summed signal is the result of interference of the beams over reflected from the axle cylinder surfaces and therefore depends on transducer position on the face. When sounding from cylinder surface it is possible additional effect of wave divergence. Cylinder form of reflected surface can result to as increasing and decreasing the spread loses depending on object diameter to transducer sizes ratio.

ATTENUATION CAUSED BY DAMPING (FACTOR N_3**)**

Dumping factor N_3 caused by ultrasound absorption and scattering can be find by formulas:

$$N_4, \partial Б = \left\langle \frac{U}{U_0} \right\rangle = \left\langle \exp(-2\delta r) \right\rangle . \quad (5)$$

where δ - damping coefficient.

Damping coefficient is determined by the frequency, grain sizes, anisotropy properties of object material. In particular for lowcarbon steel under condition $\lambda > 10D$ (λ - wave length, D – medium grain diameter) the following formulas can be used for calculations [2]:

$$\delta = a_1 f + a_2 f^4 D_3^3 , \quad (6)$$

where a_1=0,12 [microsecond/m], a_2=20 [microsecond ^{4}/m·mm^3], δ [1/m], f [MHz], D [mm].

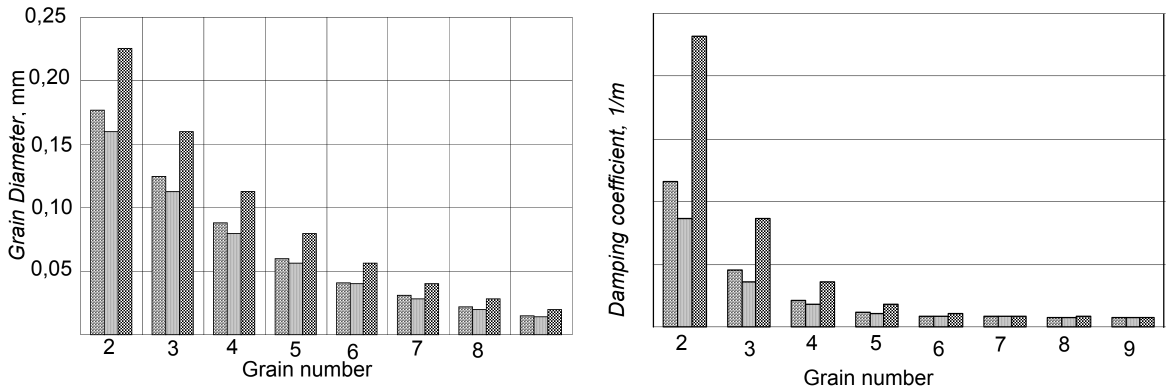


Fig.3. Variations in grain sizes (a) and damping coefficients (b) for different grain numbers

Fig.3 shows the influence of grain number and its variations relative to medium value diameter on the damping coefficient deviations. The fluctuations of grain sizes from average even within one grain number result in essential amplitude decreasing and consequently to wrong rejection of the article on its structure. The calculations show that the diameter grain changing from 4 up 7 numbers (88-31 microns) result in attenuation decreasing on N3=20 dB at the distance L=150 mm.

The deviations the operating frequency from nominal value even within the tolerance limit (±10%) can change the amplitude signal considerably on account of the sharp frequency dependence of attenuation factor. For example excess of the frequency f=2,5 MHz above nominal on 10% reduces amplitude back reflection signal on N_3=10 dB at the length L=2000 mm. The deviation from frequency of 5 MHz leads to more essential signal decreasing.

Generalizing dependences of the factors N_2 (due to beam spreading) and N_3 (due to damping) on distance 2r for different transducers and grain numbers are presented on Fig.4.

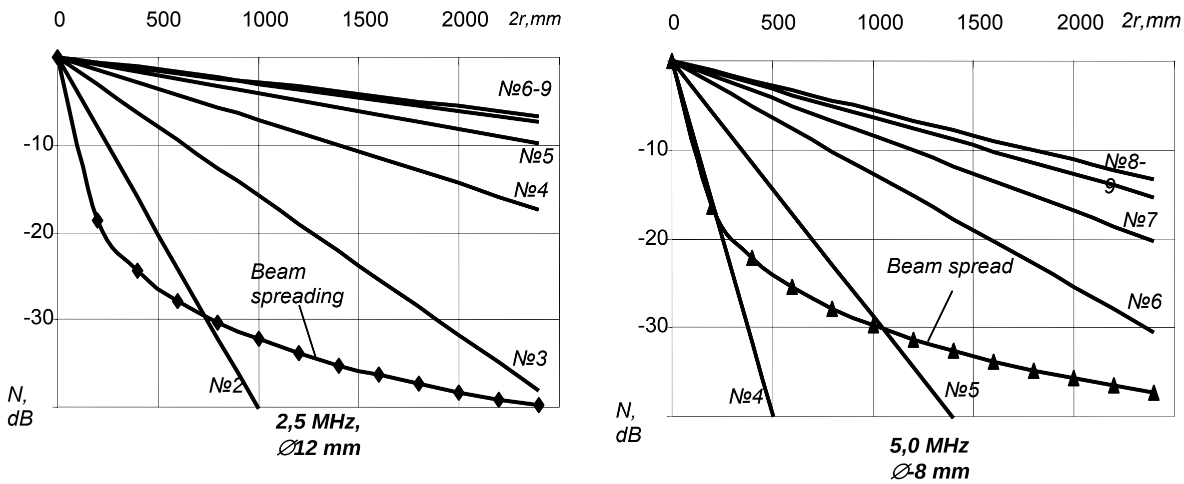


Fig.4. Variations in grain sizes (a) and damping coefficients (b) for different grain numbers

The quality and technological peculiarities of reflection surface (FACTOR N_4) can influence essentially on the signal amplitude especially for the articles with stamped surface, subjected contact-cyclic actions and with complicated form of face surface. For example for the wheelset axles the factor N_4 can reach the value of 20 dB.

LOSES N_{ST} on dumping and beam spread from back reflection signal of standard sample SO-2. Considering that standard sample is made of different steel quality (St20, St3, GOST 14782), possible deviations in chemical composition and property anisotropy, factor N_{st} can change *on* 2,1 dB on the frequency 2,5 MHz, *on* 5 dB on the frequency 5 MHz, *on* 11 dB on the frequency 10 MHz as experimental investigations show.

CONCLUSIONS

1. The following methodical, structure and technological factors influences on the results of reflection through transmission techniques

- acoustic contact instability determined basically by the thickness of contact layer, surface roughness, transducer protector material;
- deviations of grain sizes from medium value even in the limits of the same number can leads to essential attenuation increasing in view of sharp dependence of damping coefficient from grain size $\delta \sim D_3^{\,3}$, therefore it's possible the mistake article reject;
- deviations of transducer frequency from nominal can change significantly the signal amplitude in view of sharp dependence of damping coefficient from the frequency $\delta \sim f^4$, that demands the application of transducers with repeatable frequency characteristics;
- roughness and constructive features of reflected surface;

- the deviations of standard sample on acoustical properties.

2. The influence of disturbing factors is considerable for testing large dimension object, gross-grained and high attenuation materials and using high frequencies.

3. Beam spread effect is determining in signal attenuation on the small distances and fine grain. The damping effect is determining on the large distances and large grain. Beam spread effect is constant when the articles with plane-parallel surfaces tested. Any variations of transducer position for the articles with cylinder surface or limited the beam width leads to changing spread factor.

4. The results obtained can be used for the estimation of the different factors influence on the results of reflection through transmission techniques for articles with arbitrary sizes and arbitrary grain sizes.

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