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Contents

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Contents

41. Investigation of Acoustic Channel of Flow Rate Meters	101
L. Jakevičius, A. Vladišauskas	
42. Model of Cavitation Cluster in Rotor Impulse Apparatus	107
M.A. Promptov, M.V. Monastirsky	
43. Acoustical Pollutions in Grass Fodder Production When Using Wheeled Tractors	111
A. Spirgys, A. Mioldažys	
44. The Latvian Acoustics Association-Past & Present	115
A. Zabrauskis	
45. Proposals for ImproveMent of Aircraft Noise Calculation Methods and Zonning Around the airports	117
O. Zaporozhets	
46. Noise Levels Assessment Inside Airport Buildings from External Sources	121
A. Zaporozhets, O. Kartyshev, E. Konovalova	
47. Managing Urban Noise in Cites-an Integrated Approach to Mapping, Monitoring, Evaluation and Improvement	125
D. Manvell, L. Winberg, P.-J. Henning, P. Larsen	
48. Use of the TLM Method in Acoustics	131
U. Kristiansen, H. Solvik, N. Brachet, K. Jezzine	
49. Investigation of Speech Privacy in Buildings by Mean of Auralisation	135
M. Vorlander, R. Thaden	
50. Anisotropy of Ultrasound Absorbtion and Viscous Properties of Nematic Liquid Crystal Mixtures	141
A.N. Larionov, N.A. Us, N.N. Larionova, O.V. Volkov	
51. Signal Processing in Sound Fields	145
Y. Yamasaki, Y. Oikawa	
52. The Effect of Noise Annoyance at the Workplace on the Risk of Myocardial Infarction	151
V. Malinauskienė, R. Gražulevičienė	
53. The Hygienic Estimation of Noise Level in the "LITHUANIAN AIRLINES" Airplanes	155
A. Lukauskas, D. Ereminas	
54. Sound Absorbing Building Constructions Produced by Firm KNAUF – are not just Beauty	159
D. Gužas, A. Bundonienė	
55. The Dynamics of a Mechanical System Excited Parametrically by a Travelling Wave	169
K. Ragulskis, M. Ragulskis, L. Ragulskis	
56. The Clasification of Bodies on a Vibrating Plane of a Platform	175
P. Ilgakojs, H. Lundquist, J. Ragulskienė	
57. Signal Enhancement of Acoustic Recording	183
K. Oishi, K. Yamaoka, Y. Oikawa, Y. Yamasaki	
58. Diffraction of Guided Optical Waves by Surface Acoustic Waves in Proton-Exchanged 128⁰ Rotated Y-cut LiNbO₃	185
R. Rimeika, D. Čiplys, S. Balakauskas	
59. The Influence of a Loudspeaker Cabinet's Shape on the Radiated Power	189
U. P. Svensson, K. Wendlandt	
60. Acoustical Studies of the High-Frequency Hopping Conductivity in the Quantum Hall Regime	193
Yu. M. Galperin, I. L. Drichko, A. M. Diakonov, I. Yu. Smirnov, A. I. Toropov	
61. Convex Plasterboard Sound Absorbtion Research	197
Dz. Lasis, A. Zabrauskis, A. Veinbergs	

Investigation of Acoustic Channel of Flow Rate Meters

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ABSTRACT: The report deals with a task of the acoustic channel. The two main tasks are concerned: to eliminate the influence of the recesses for the fluid flow in the pipe and to increase the refraction coefficient of ultrasonic waves. For this the recesses fill up the liquids or jelly which the acoustic impedance change from $0.8 \cdot 10^6 \text{ kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ to $5.0 \cdot 10^6 \text{ kg} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$.

KEYWORDS: acoustic channel, recess, flow rate, angle of refraction, refraction coefficient, acoustic impedance.

NOTATION

- ρ - density of the medium
- c - the speed of ultrasound
- θ - the angel between the path of the ultrasound and centerline of the pipe
- α - the angle between of the acoustic waves direction and a normal to surface
- D_n - the diameter of the recess
- D_p - the diameter of the transducer
- l_n - the depth of the recess
- t - the size of the gap
- W - the refraction coefficient

1. INTRODUCTION

Ultrasonic methods of the flow rate measurement widespread in the industry and in the life [1,2,3]. The further subsequent development and use of this method are directed attention to decrease of the uncertainty. One of these uncertainty sources of the wetted transducers is the recess between a surface of the transducer and a wall of the pipe. The size and depth of the recesses depend on the diameter of the transducer, the condition of measurement and of an angle between the path of the ultrasound and of the pipe axis. The pipes of the radial-wetted transducers can be different size. In practical lower pipe size limit to this configuration is about five centimetres, with an upper limit in excess of 2 meters. The decrease of the uncertainty it is possible insulating flow from the recesses by means of the grids and films. These also protect the recesses from fill up with hard particles in some cases.

This paper presents the results of investigation transmission of ultrasonic waves through the recesses and evaluation of the size of the recesses in the different measurement path.

2. CALCULATION THE DEPTH

Initially we want to know the exact size of the recesses. If an edge of the transducer (see Fig.1, transducer 2) is

equally with a surface of the pipe wall, the depth of the recess l_n can be calculated

$$l_n = \frac{D_n}{2 \operatorname{tg} \theta}, \quad (1)$$

where D_n – the diameter of the recess, θ - the angle between the path of the ultrasound and centreline of the pipe.

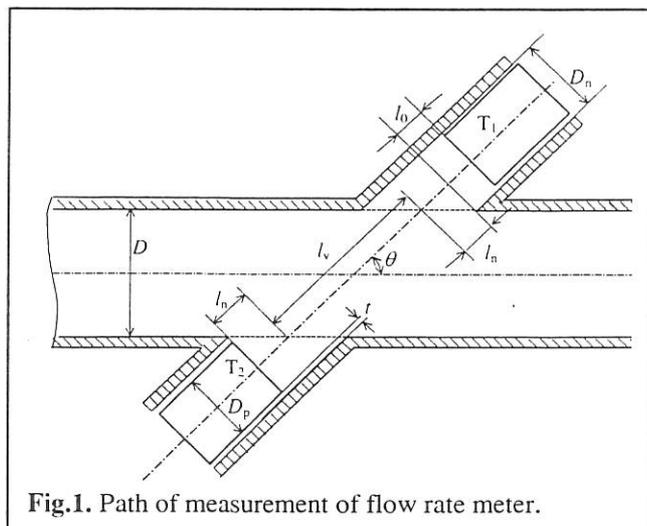


Fig.1. Path of measurement of flow rate meter.

The accepted depth l_n corresponds with a distance of ultrasonic waves spread according to the acoustical axis of the transducer. The diameter of the recess depends on the diameter of the transducer and the gap. If both transducers are situated in the recesses as the transducer T_2 , we have the symmetrical case and the depth of the recesses is equal. When one of the transducer is deeper in the recess (Fig.1, transducer 1), it corresponds the asymmetrical case. Then the depth of both transducer

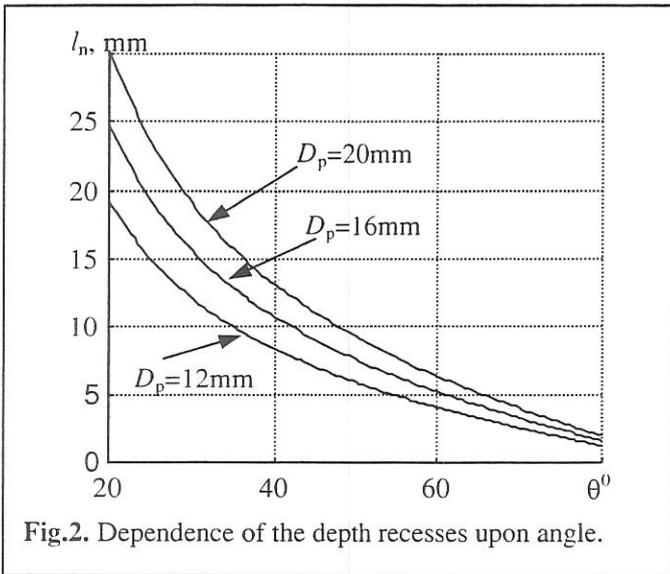
$$l = 2l_n + l_0. \quad (2)$$

The diameter of the recess is

$$D_n = D_p + 2t, \quad (3)$$

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where D_p – the diameter of the transducer, t – the size of the gap.



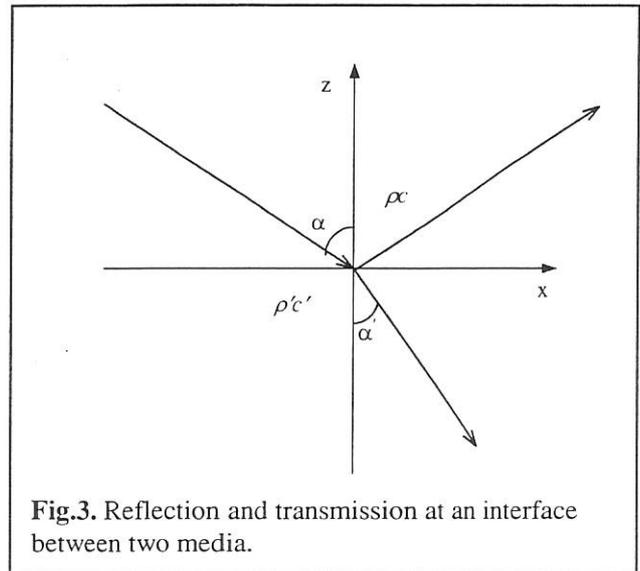
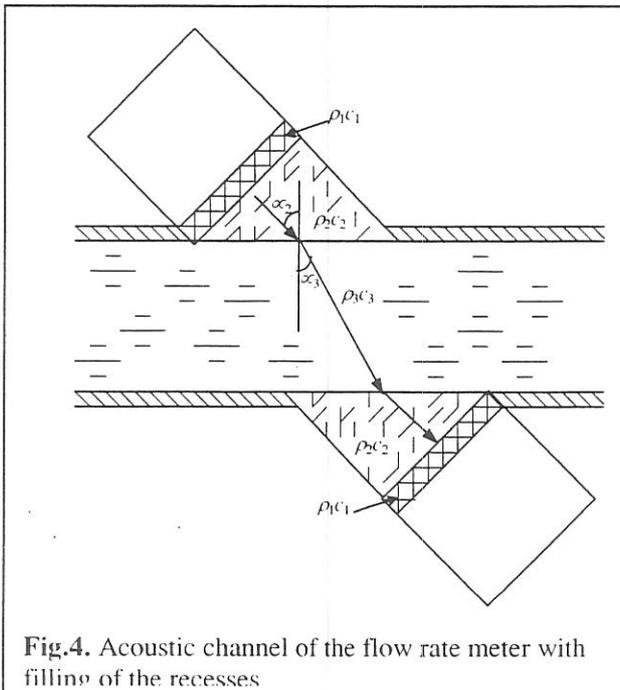
The depth of one recess for the symmetrical case

$$l_n = \frac{D_p + 2t}{2tg\theta}, \quad (4)$$

and for the asymmetrical case

$$l_n = \frac{D_p + 2t}{2tg\theta} + l_o. \quad (5)$$

For calculation (4) accept the diameter of the transducers used in the flow rate meter are 12 mm, 16 mm, 20 mm, the gap – 1 mm and the angles change from 20° to 80°. The data obtained show (Fig. 2), that 45° angle



presented the depth of recess roughly equal to the radius of transducers. The absolute depth of the recess appreciably depend on the angle, especially in the range small angle and less depend on the diameter of the transducer. Hence, the large angle will gives small depth of the recess, but it unfitness for ensuring high accuracy of the flow meters and vice versa.

3. TRANSMISSION OF ULTRASONIC WAVES

Let's analyse possibility to improve the refraction coefficient of pressure in the acoustic channel. Two medium are divided by a plane $Z=0$ (Fig. 3). The densities of medium ρ in ρ' and the speed of the acoustic waves in them – c and c' , respectively. The plane acoustic wave incident at the angle on a plane $Z=0$. The part of this wave reflects from an interface and leaves in the first medium. The another part refracts from an interface between two mediums and change the direction. It is known from general acoustic [4], the refraction coefficient from gases or liquid to another media consist of gases or liquid is expressed

$$W = \frac{2\rho'c' / \cos \alpha'}{\rho'c' / \cos \alpha' + \rho c / \cos \alpha}. \quad (6)$$

The recess between a surface of the transducer and a wall of the pipe can be fill up with the liquid or the composite jelly. These mediums should be separated with a film or a membrane. Then the acoustic waves must pass two boundary: a) transducer – the media of the recess; b) the media of the recess – the investigation liquid (see Fig.4). The first boundary is between solid and liquid. The acoustic wave of the transducer is perpendicular to the first boundary and the longitudinal waves are radiated in the both media. The refraction coefficient can be calculated from the transducer to the investigation liquid

$$W_{13} = W_{12}W_{23}, \quad (7)$$

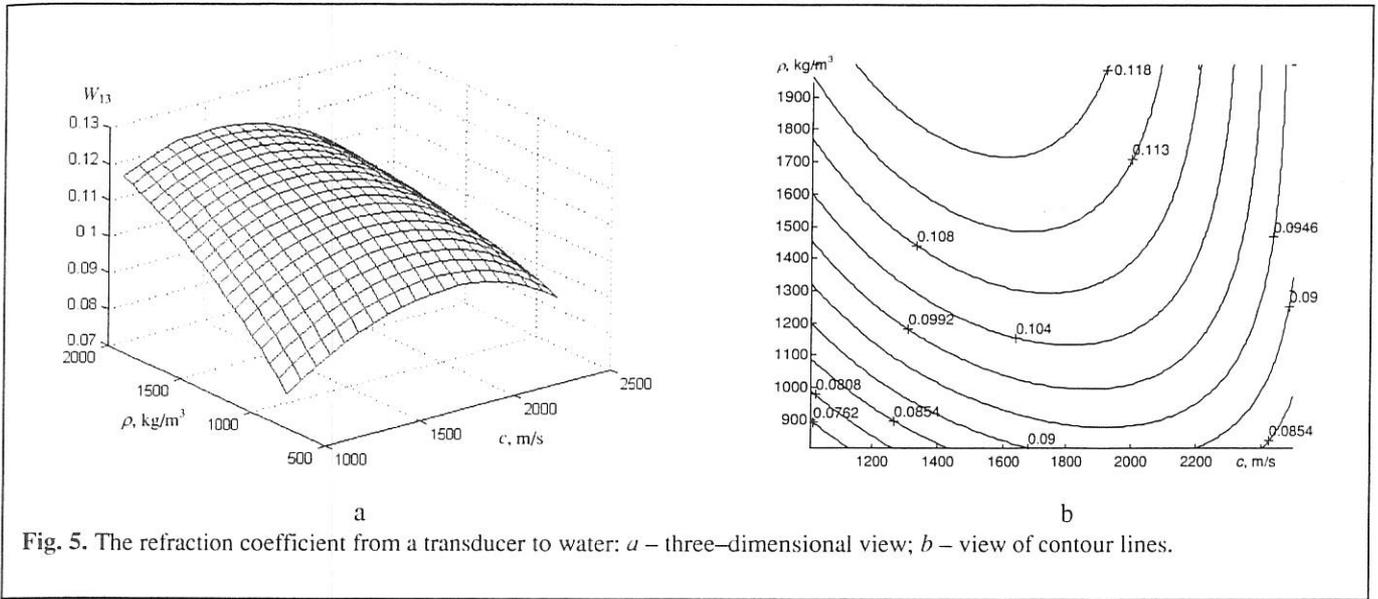


Fig. 5. The refraction coefficient from a transducer to water: *a* – three-dimensional view; *b* – view of contour lines.

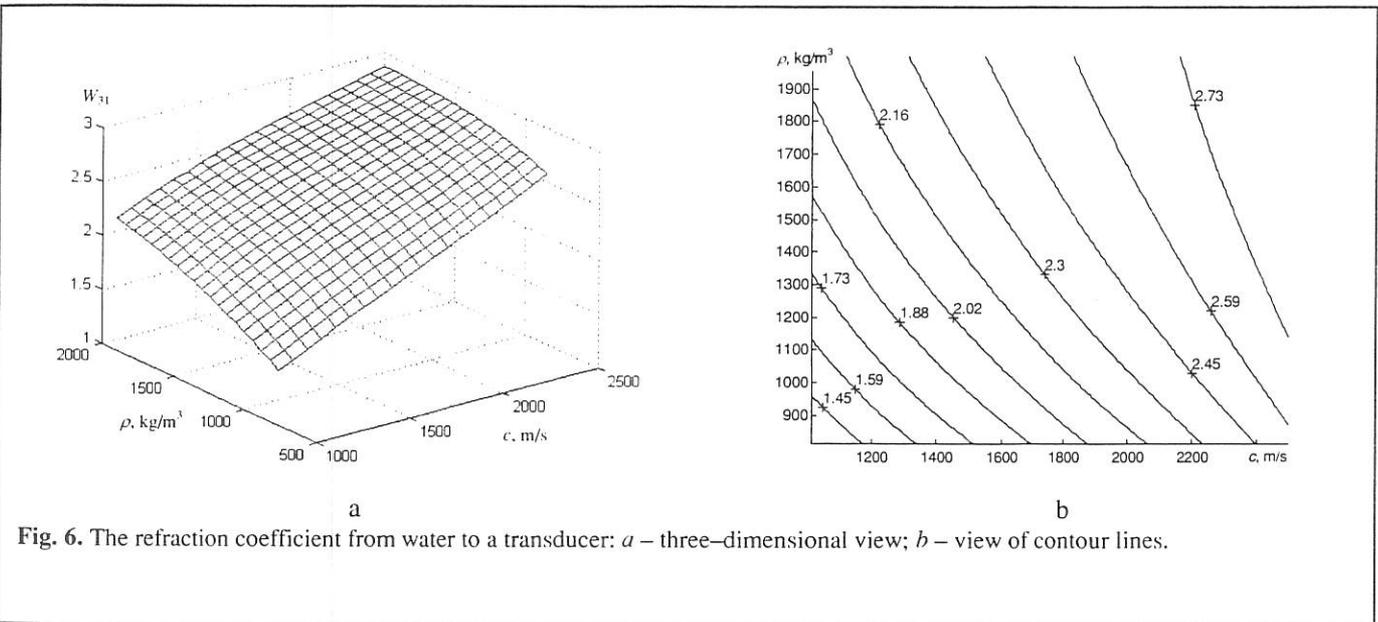


Fig. 6. The refraction coefficient from water to a transducer: *a* – three-dimensional view; *b* – view of contour lines.

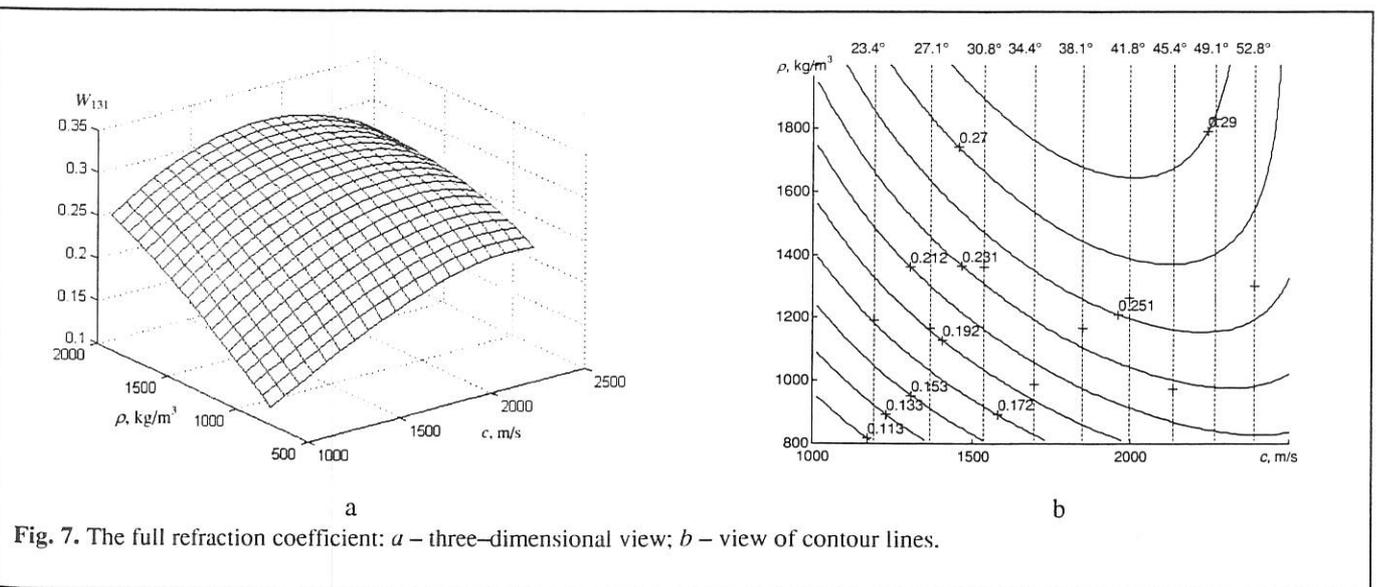


Fig. 7. The full refraction coefficient: *a* – three-dimensional view; *b* – view of contour lines.

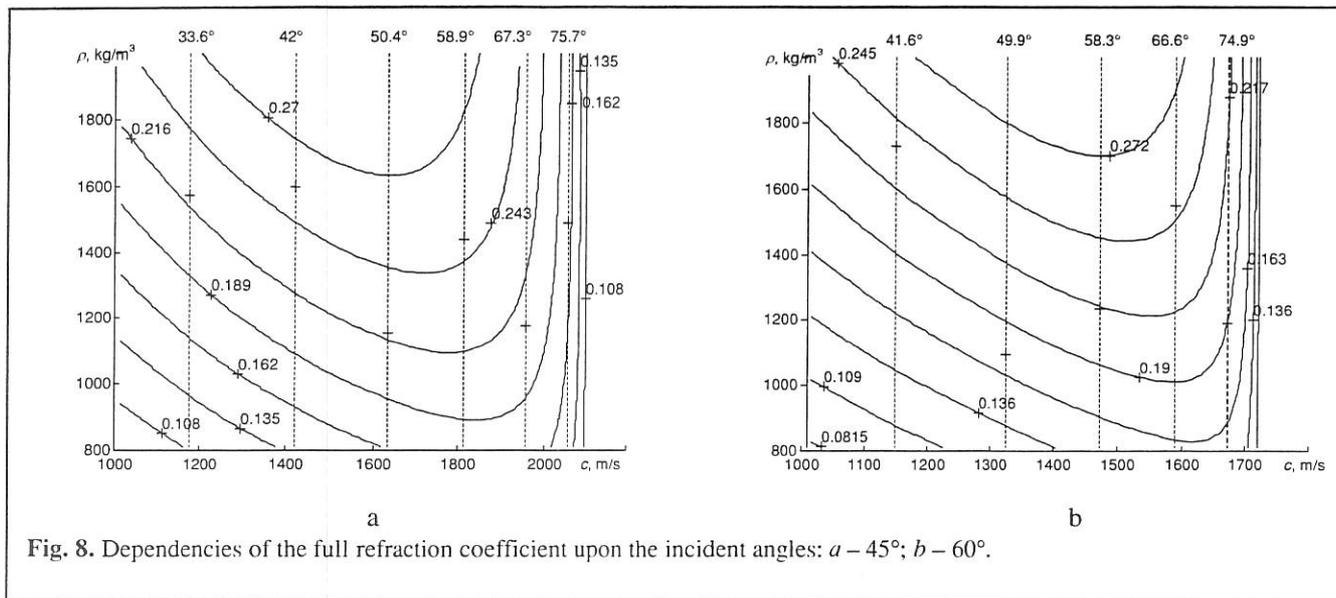


Fig. 8. Dependencies of the full refraction coefficient upon the incident angles: $a - 45^\circ$; $b - 60^\circ$.

where W_{12} and W_{23} - the refraction coefficient of the first and the second boundary.

Substituting expression (7) into (6) and using Snell's law we shall obtain

$$W_{13} = \frac{4\rho_2 c_2}{(\rho_1 c_1 + \rho_2 c_2) \left(1 + \frac{\rho_2 c_2 \cos \alpha_3}{\rho_3 \sqrt{c_3^2 - c_2^2 \sin^2 \alpha_3}} \right)}, \quad (8)$$

where ρ_1 - the density of a radiating surface of the transducer; c_1 - the speed of ultrasound in the transducer; ρ_2, c_2 - the same parameters of the recess; ρ_3, c_3 - the same parameters of the investigate liquid, α_3 - the angle between of the acoustic waves direction and of a normal to surface. The refraction coefficient to the contrary side (from the investigation liquid to the transducer) will be

$$W_{31} = \frac{4\rho_1 c_1}{(\rho_1 c_1 + \rho_2 c_2) \left(1 + \frac{\rho_3 \sqrt{c_3^2 - c_2^2 \sin^2 \alpha_3}}{\rho_2 c_2 \cos \alpha_3} \right)}, \quad (9)$$

The refraction coefficient of all the acoustic channel from the transmitting transducer to the receiving transducer

$$W_{131} = W_{13} W_{31}. \quad (10)$$

Substituting (8) and (9) into (10) we shall obtain

$$W_{131} = \frac{16\rho_2^2 c_2^2 \rho_1 c_1 \rho_3 \sqrt{c_3^2 - c_2^2 \sin^2 \alpha_3} \cos \alpha_3}{(\rho_1 c_1 + \rho_2 c_2)^2 \left(\rho_2 c_2 \cos \alpha_3 + \rho_3 \sqrt{c_3^2 - c_2^2 \sin^2 \alpha_3} \right)^2}. \quad (11)$$

Table.

	Medium	Density	Speed of ultrasound
1	1 (piezoceramic)	7000 kg/m ³	4250 m/s
2	2 (recess filling)	800÷2000 kg/m ³	1000÷2500 m/s
3	3 (water)	1000 kg/m ³	1500 m/s

The refraction coefficient (8), (9) and (11) were calculated. In the calculation was accepted, that the longitudinal wave without transformation pass from the transmitting transducer to the receiving transducer. The parameters of the acoustic channel presented in the Table.

The data of calculation are depicted in Figs. 5, 6, 7 and 8. The dependencies of the refraction coefficient from the transducer to the water at an angle $\alpha = 30^\circ$ presented Fig. 5. The increasing of the density in the recess filling improve the refraction coefficient from 0,07 to 0,118 in the middle range of the ultrasound speed. The maximum value of the refraction coefficient moves to side of the larger speed. The refraction coefficient W_{31} (Fig. 6) increase sufficiently smoothly when the density and the speed of ultrasound rise. The full refraction coefficient of acoustic waves through the acoustic channel has the maximum value 0,29 at the angle $41,8^\circ$ (Fig. 7). Therefore, the refraction coefficient depends on the longitudinal waves of the refraction angle (Fig. 8). The big angles need less the speed of ultrasound in filling medium. The speed of ultrasound of the recess filling media at the refraction angle = 60° can be no more 1700 m/s.

CONCLUSIONS

The depth of recess at an angle 45° roughly equal to the radius of transducer. The large angle will gives small depth of the recess, but it unfitness for ensuring high accuracy of measurement.

The increasing of the density in the recess filling improve the refraction of the acoustic waves, but the increasing of the refraction angle needs the media of the recesses filling having less values of the ultrasound speed.

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