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ON THE POSSIBILITY OF IMPROVEMENT OF ACOUSTIC MICROSCOPE RESOLUTION BY SPHERICAL TRANSFORMER[1]

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The wavefront transformation on the supplementary boundary for the improvement of acoustic microscope resolution inside the solid specimens is suggested. It is shown that such transformation can be realized by bonding the stainless demisphere on the front surface of the sample. The possibilities of using the spherical transformer in quantitative acoustic microscopy are demonstrated.

The application of reflective acoustic microscope for the investigation of thick specimens is complicated due to decreasing its resolution inside the sample [1-3]. The refraction of the converging spherical wave on the flat sample surface leads to the noteable aberration inside the sample the acoustic velocity of which is higher than the velocity inside the coupling medium. The resolution loss due to aberration can be compensated by use of an additional element (a "transformer" TR) acoustically connected with the sample (S in fig.1.). This element transforms the spherical wave from lens with focus F into the spherical wave with the new focus F' inside the sample.

The proper shape of the front transformer surface T can be determined using the following procedure. Let us suppose that there is a source of spherical wave inside the investigated object, at the point F'. The wave from this source becomes aspherical in the transformer due to refraction on the flat sample-transformer boundary. Its wavefronts $\Phi(x, y, z)$ may be simply evaluated provided the sound velocities both in the sample and in the transformer are known.

It is evident that a wave with the same wavefronts $\Phi(x, y, z)$ but with opposite wavevector will be focused (passing into the sample) at the point F'. It means that the refraction on the front transformer surface should change the wave from the lens with spherical wavefronts $\Psi(x, y, z)$ into the wave with the wavefronts $\Phi(x, y, z)$. The phase of refracted wave is equal to the phase of impinging wave on the refraction surface (if the angles of incidence are not too big). So the front transformer surface $T(x, y, z)$ can be found from the equation

$$\Phi(x_T, y_T, z_T) = \Psi(x_T, y_T, z_T)$$

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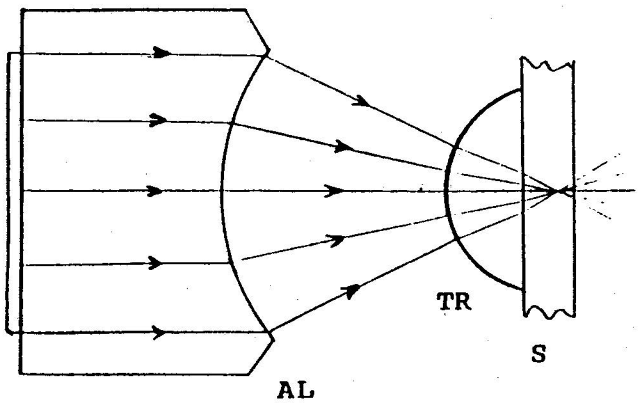

Fig.1. Ray diagram of the system consisting of the acoustical lens (AL), transformer (TR) and the sample (S).

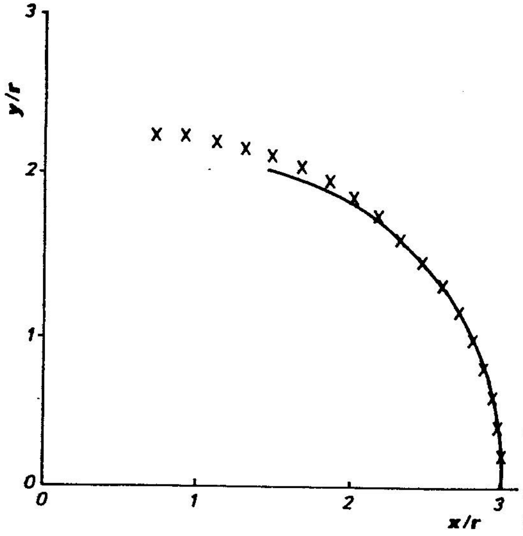

Fig.2. Calculated cut curve of the surface T (full line) and the cut curve of the sphere (+ points). Sound velocities are taken to be 1500 m/s in liquid, 3000 m/s in transformer, and 6000 m/s in the sample.

i.e. $T(x, y, z)$ is the surface where the phase of these two waves are equal each other.

The shape of the surface T calculated according previous algorithm is shown in the figure 2. As it is seen from this figure, the surface T is close to the spherical one. Notable differences occur only for aperture greater than 40 degrees. So we could realize such transformer using a part of steel bearing ball.

The advantages and difficulties connected with using of such transformer are illustrated on the echo-diagrams of low frequency reflective acoustic microscope. Our system consisted of a silicium lens (radius of curvature $R = 6$ mm, aperture $\phi/2 = 22°$), mercury as an immersion liquid, a half of steel bearing ball as a transformer (the radius of curvature $r = 3.36$ mm and the velocity of the longitudinal sound waves $C_{TL} = 5.91 \times 10^3$m/s) and a glass plate (thickness $h = 5.68$ mm, the velocity of longitudinal waves $C_{SL} = 5.76 \times 10^3$m/s, the velocity of shear waves $C_{ST} = 3.40 \times 10^3$m/s) bonded on the flat surface of the transformer by salol. The signal pulse time was 0.5 μs at working frequency 13.5 MHz. The maximal aberration in the sample calculated for this system is 200 μm (less than half of wavelenght). Echo-diagrams presented in the

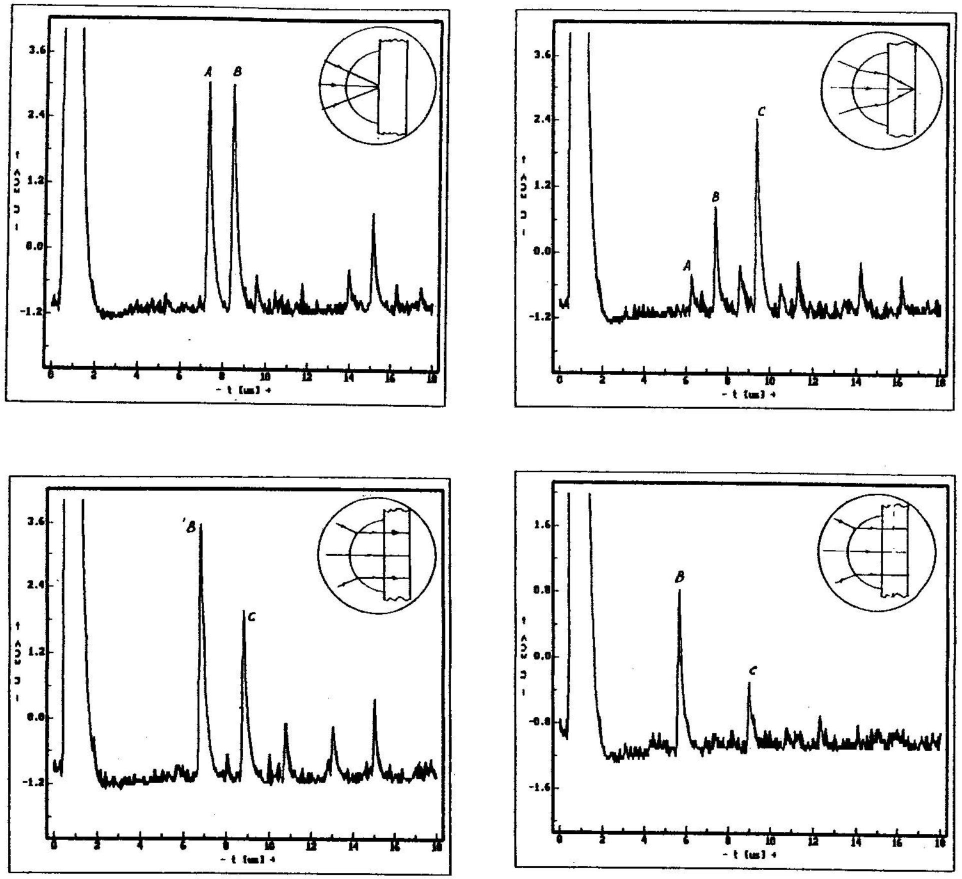

Fig.3. Echo-diagrams at different positions of the lens corresponding to the cases: a - the focus is on the flat interface transformer-sample; b - the focus is on the back side of the sample; c - collinear beam of longitudinal waves in the sample , d - collinear beam of shear waves in the sample.

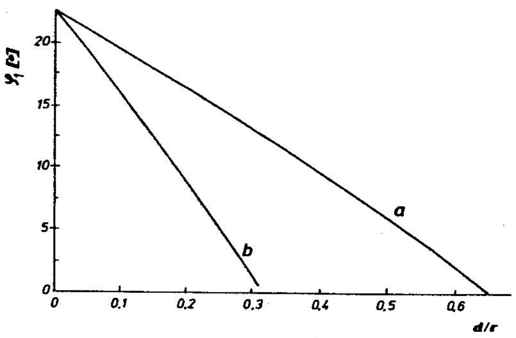

Fig.4. Shift dependences of aperture angle of the beam in transformer for longitudinal (a) and for shear (b) waves.

fig.3 contain the echo A given by the reflection from spherical surface of TR, the echo B produced through reflection of longitudinal waves from the flat transformer-sample interface end the echo C corresponding to the sound reflection from the back side of the sample. Changing the distance between the lens and the transformer we can find a position which corresponds to the focusing the beam on the flat transformer-sample interface. The second echo (echo B on fig.3.a) has its maximum at this position. As the transformer is half of the sphere, the echo A given by the reflection on the spherical surface has a maximal value at the same position as well because the incident rays are perpendicular to the transformer surface. These echoes are separated by time distance

$$t_1 = 2.r \;/\; C_{TL}.$$

Further shifting the lens towards the transformer leads to the focussing the beam on the back side of the sample what gives maximal value of the echo C (fig.3b). Echo C is delayed from the echo B by the time

$$t_2 = 2.h \;/\; C_{SL}.$$

The axial resolution was evaluated by the shift of the lens towards the transformer at which the echo C decreased twicely from its maximal value. It was less than 1.5λ in our case (λ is the wavelenght in the sample). This value of the resolution means that the negative influence of aberration was fully taken off. Measuring t_2 allows us to evaluate the thickness of the sample (or the sound velocity provided the thickness h is known).

Beside the resolution improvement the application of the spherical transformer gives an interesting possibility for sound velocity measurement. Further shortening the distance between the lens and the transformer gives another series of the echoes with time delay t_2. This series is produced through reflections of the longitudinal waves in the plane-parallel sample if the microscope objective and the transformer create a "telescopic system" (fig. 3.c.). Moreover we observed such series for the shear waves arising on the front transformer surface (fig.3.d). The refraction of the convergent beam

on the spherical surface shifted towards the lens decreases the angular aperture of the penetrated beam. Fig.4. presents the dependences of the beam aperture for both longitudinal and shear waves on transformer shift d, calculated on the base of beam-optics representation. The beam of longitudinal waves is collinear in transformer at the shift $d = 0.65\ r$ and the shift $d = 0.31\ r$ gives the collinear beam of shear waves (the velocity of shear waves in transformer was taken to be $3.5 \cdot 10^3$ m/s). These values are in good agreement with the distances given by the experiment.

The mentioned "telescopic system" provides a beam with a diameter smaller than the diameter of the transducer, therefore it may be useful for determination of velocity in small samples. We verified experimentally that the described system allows us to measure the sound velocity in specimens with the thickness of 1 mm and the transversal size 1.5 mm with the accuracy which is analogous to the accuracy of the usual pulse-echo method.

References

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