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Experimental verification of the acoustic computer model using triangle reflector

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Abstract:

Objective of this study was experimental verification of the acoustic computer model, which enables calculation of the signals reflected by triangles arbitrally oriented in space. Verification of the computer model was carried out comparing the C-scan images of triangle reflectors, obtained experimentally and by simulation in the case when ultrasonic beam is reflected by triangle reflectors, reflecting surfaces of which are perpendicular and inclined with respect to the symmetry axis of the directivity pattern.

Comparison of the experimental and simulated results of the inclined triangle reflector revealed some discrepancies. In order to find out the reason of these discrepancies the assumption was made that during rotation of the triangle reflector, the rotation axis was not strictly perpendicular to the incident ultrasonic beam, but that it was slightly deflected. In order to check this hypothesis modelling was also performed at different transducer deflection angles from its supposed position for each triangle angle. The simulation results clearly show that this assumption was correct and correspondence between experimental and simulation results in this case (0.75° deflection) is obtained much better.

Keywords: 3D modelling, ultrasonic, Huygens, experimental.

Introduction

The main objective of the developed acoustic computer model is calculation of the ultrasonic signals, reflected by the components of complicated geometry [1, 2]. The objects, having complicated geometry, often are approximated by triangles, because of co-planar property the plane triangular facet [3]. Also in a widely used CAD models all surfaces are given in terms of triangles. In these computer models each facet in the three-dimensional space is represented by its vertex points and the unit surface normal vector pointing out of the body [3].

Objective of this study was experimental verification of the acoustic computer model, which enables calculation of the signals reflected by triangles arbitrally oriented in space. Verification of the computer model was carried out comparing the C-scan images of triangles, obtained experimentally and by simulation. Also the influence of the transducer positioning angle deviation from its supposed position on the 3D reflections from triangle was investigated.

Main steps of the used method

In the used acoustic computer model, which exploits the Huygen's principle [1] it is assumed that a triangle reflector is arbitrally oriented in 3D space. The calculations in 3D space are very complicated and require a lot of computer resources; therefore the main advantage of the model is that this approach reduces the amount of the data, and, consequently, increases the speed of calculations.

The modelling of 3D reflections from triangles using the proposed approach is performed as follows [1]:

- The triangle is moved to the origin of the coordinate system and rotated in such a way, that after the rotation it would be located in one plane (z=0);
- The transducers are translated and rotated in the same way as the triangle in order to keep the position of the transducers with respect to the triangle unchanged;
- The zone of the triangle, which is completely in the intersection zone of the directivity patterns of the transducers is found and divided into elementary segments with a step, smaller than the half of the wavelength;
- The signal propagation time from the transmitter to the elementary segment in the triangle and back to the receiver is calculated, because all elements according to the Huygen's principle are assumed to be the sources of ultrasonic waves:

$$t_e = \frac{d_{et} + d_{er}}{c}, \qquad (1)$$

where d_{et} is the distance from the elementary segment of the triangle to the centre of the transmitter, d_{er} is the distance from the elementary segment of the triangle to the centre of the receiver, c is the ultrasound velocity.

- According to the Huygens's principle the total received signal is calculated as the sum of reflections from elementary segments as

$$u(t) = \sum_{k=1}^{N_e} u_t(t) \otimes h_k(t - t_{e,k}), \qquad (2)$$

where the $u_t(t)$ is the transmitted ultrasonic signal, $h_k(t)$ is the pulse response of k-th elementary segment, $\otimes$ denotes convolution.

Experimental verification of the computer model

Verification of the computer model was carried out comparing the C-scan images of a triangle, obtained experimentally and by simulation. Experiments were performed using specially developed and manufactured at the Ultrasound institute test sample, imitating triangle shape reflector. The geometry of the triangle reflector is given in Fig. 1. The triangle reflector was immersed in a water tank.

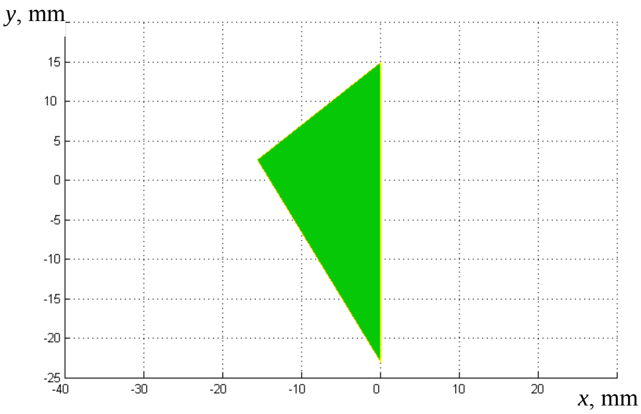

Fig. 1. **Geometry of the simulated triangle**

Experiments and simulations were performed at the 300 mm distance between the ultrasonic transducer and the planar (reflecting) surface of the triangle. The set-up for experimental verification of the computer model in the pulse-echo mode is presented in Fig. 2. In order to get C-scan images, scanning was performed in the plane, parallel to the flat surface of the sample. The scanning step was 0.5 mm. The experiment was carried out using the single 5 MHz transducer operating in a pulse-echo mode.

Modelling and experimental measurements of the 3D reflections from the triangle were performed in the case when an ultrasonic beam is reflected by a planar surface and by triangle, reflecting surface of which is inclined with respect to the symmetry axis of the directivity pattern. Therefore the signals, which are picked up, are not only specularly reflected by the object. For this purpose the single triangle was rotated around the longest leg (Fig. 3).

The experimentally obtained and simulated ultrasonic images of the triangle reflector obtained under different orientation angles (0°, 1°, 2° and 5°) are presented respectively in Fig. 4 - 7 and Fig. 8 - 11. It is necessary to take into account that the true value of the maximal amplitude in each image differs essentially.

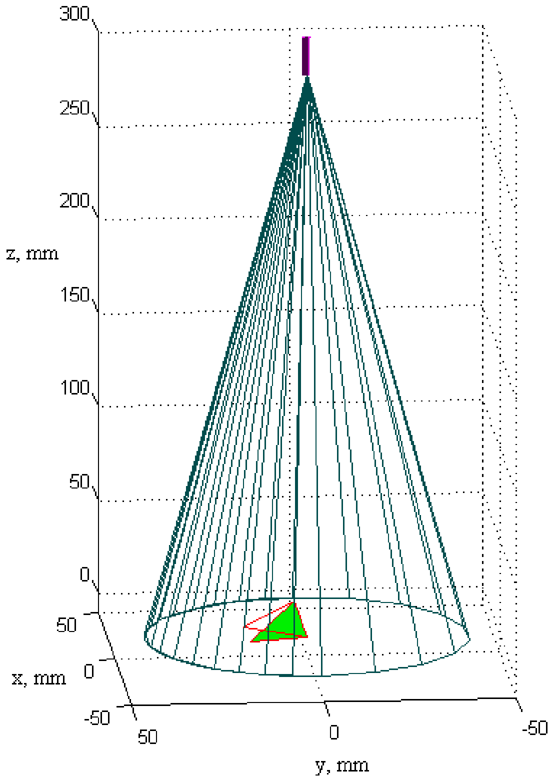

Fig. 3. **Rotation of the single triangle around the longest leg**

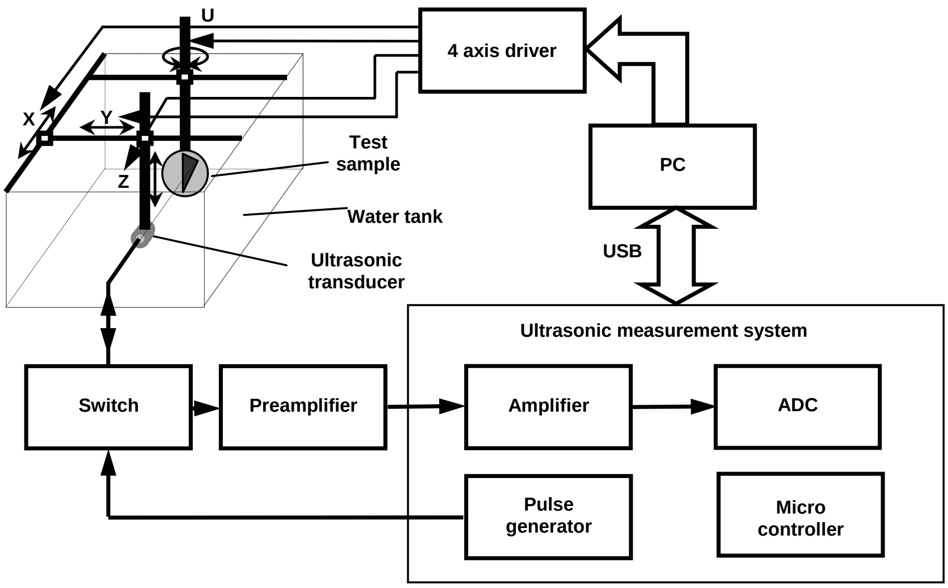

Fig. 2. **Experimental set-up for experimental verification of the computer model in the pulse-echo mode**

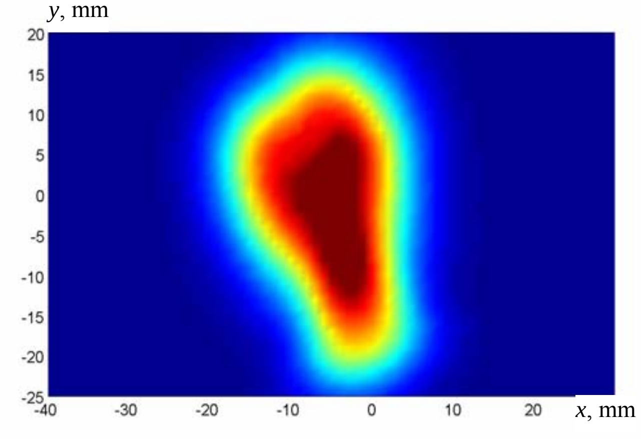

Fig. 4. **The experimental C scan of the triangle at the angle 0°**

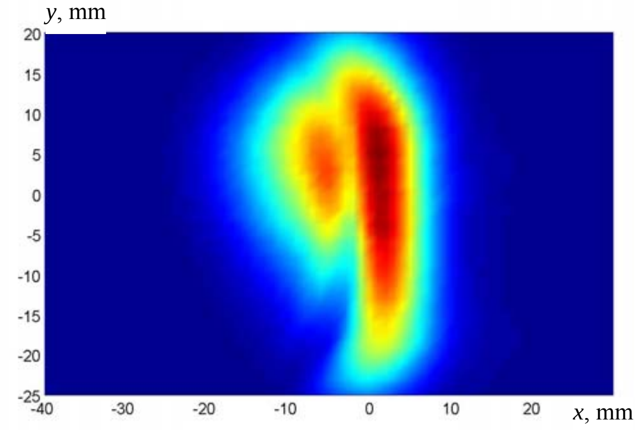

Fig. 5. **The experimental C scan of the triangle at the angle 1°**

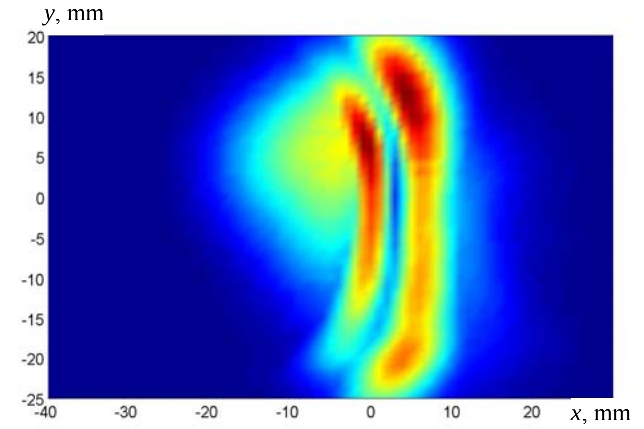

Fig. 6. **The experimental C scan of the triangle at the angle 2°**

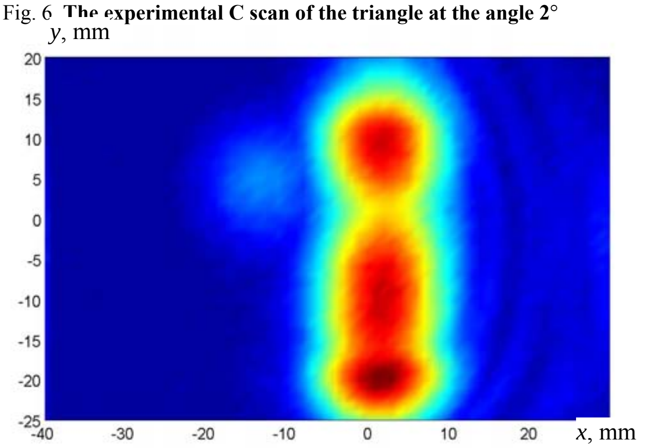

Fig. 7. **The experimental C scan of the triangle at the angle 5°**

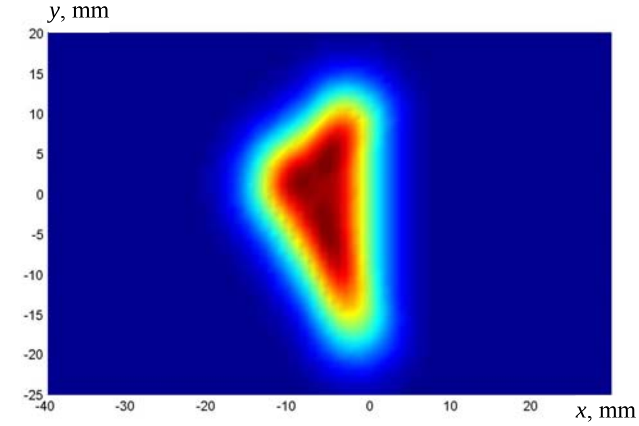

Fig.8. **The simulated C-scan image of the triangle at the angle 0°**

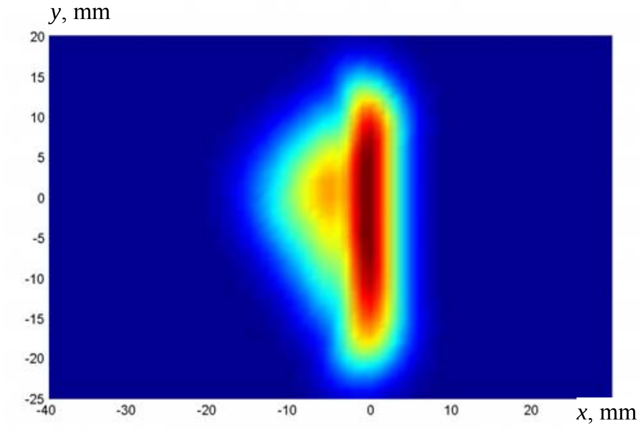

Fig.9. **The simulated C-scan image of the triangle at the angle 1°**

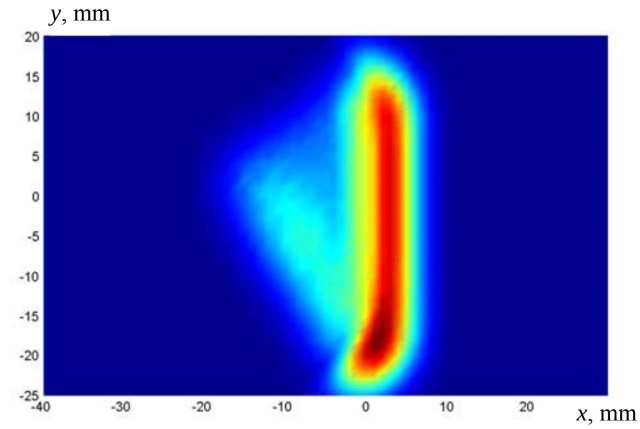

Fig.10. **The simulated C-scan image of the triangle at the angle 2°**

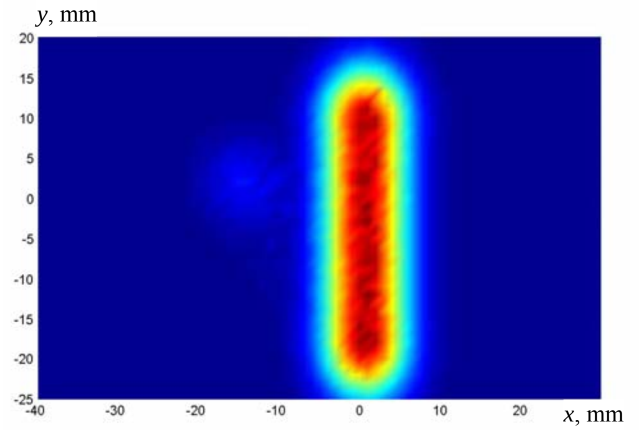

Fig.11. **The simulated C-scan image of the triangle at the angle 5°**

The following conclusions can be made from the presented results:

- The shape of a triangle reflector as such can be recognized only under angles close to the perpendicular to the triangle surface (<±1°);
- The edges of the triangle parallel to the transducer surface can be seen in a wide range of angles. If the edge is sharp enough, there is no essential difference how the edge is oriented with respect to the transducer;
- The edges not parallel to the transducer surface can be seen only under angles close to the perpendicular to the triangle surface (±1°).

Comparison of the experimental and simulated results of the inclined triangle reflector revealed some discrepancies. In order to find out reason of these discrepancies the assumption was made that during rotation of the triangle reflector, the rotation axis was not strictly perpendicular to the incident ultrasonic beam, but that it was slightly deflected. In order to check this hypothesis simulation was carried out at different deflection angles of the rotation axis of the triangle [2]. The simulation results show that this assumption may be correct and the best correspondence between experimental and simulation results was obtained in the case of 0.75° deflection (Fig. 12 –15). It is necessary to point out that these deflection angles, at which a good correspondence is obtained, are quite small, e.g. <1°. In experiments it was impossible to carry out adjustments with such high accuracy.

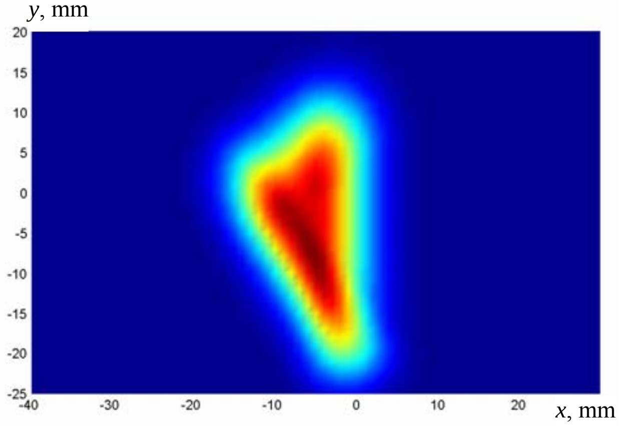

Fig.12. **The simulated C-scan image of the triangle at the angle 0°, transducer deflected by 0,75°**

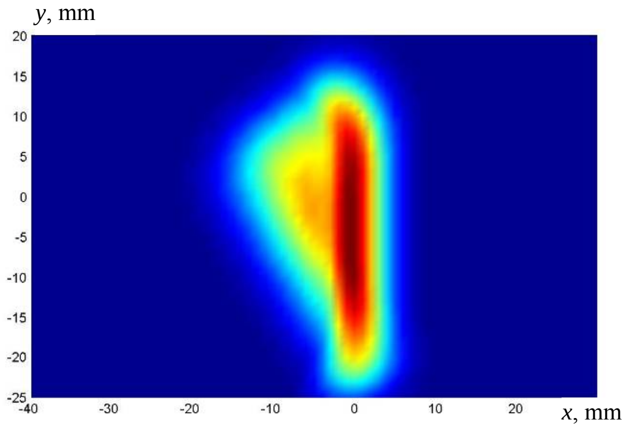

Fig.13 **The simulated C-scan image of the triangle at the angle 1°, transducer deflected by 0,75°**

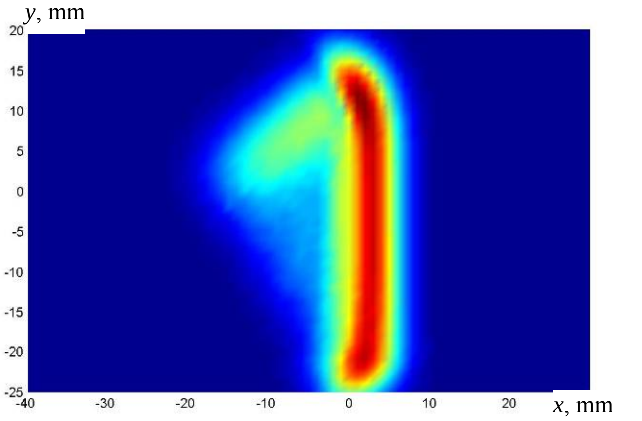

Fig.14. **The simulated C-scan image of the triangle at the angle 2°, transducer deflected by 0,75°**

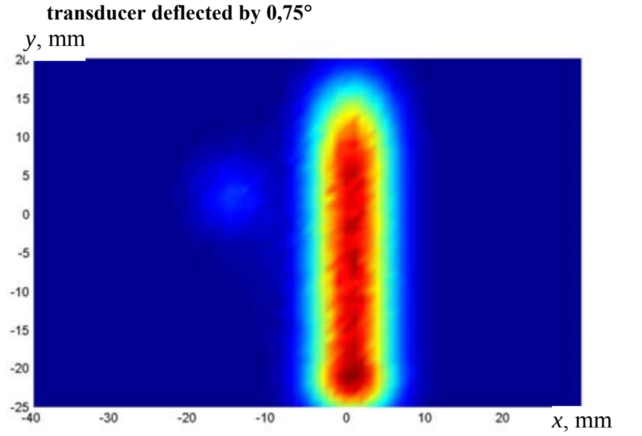

Fig.14. **The simulated C-scan image of the triangle at the angle 5°, transducer deflected by 0,75°**

Conclusions

The developed acoustic model using the Huygens's approach enables to calculate the signals reflected by triangle reflectors in 3D space. The simulations and experimental measurements of the 3D reflections from triangle at different angles show, that a triangle as a shape can be recognised only in the case of a specular reflection. The edges of the triangle can be seen when they are parallel to the transducer surface.

The model has been verified comparing the simulated signals and images with experimental ones. The comparison has been performed using a simple triangle reflector. The comparison has shown that the model enables to obtain adequate reflected signals. The good coincidence of the simulated and the experimental signals has been obtained.

Investigation of the influence of the transducer positioning angle deviation from its supposed position on the 3D reflections from a triangle reflector was performed. The simulated ultrasonic images of the triangle reflector obtained under different orientation angles when transducer was deflected only by 0,75° from its supposed position show, that even small deflection of the transducer (<1°) deteriorates the obtained image of the object and if more complicated structures are inspected it can considerably affect the recognition of the inspected object.

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Akustinio kompiuterinio modelio eksperimentinis patikrinimas trikampiais atspindėtuvais

Reziumė

Šio darbo tikslas buvo patikrinti akustinį kompiuterinį modelį, kuris leidžia modeliuoti ultragarso signalo atspindžius nuo bet kaip orientuotų trikampių trimatėje erdvėje. Atspindžių nuo trikampio modeliavimo ir eksperimentinių matavimų palyginimas esant įvairiems jo pasukimo kampams parodė, kad trikampio forma gali būti atpažinta tik tuomet, kai trikampio plokštuma yra lygiagreti su keitiklio plokštuma. Be to, matomos tik lygiagrečios su keitiklio plokštuma trikampio kraštinės.

Buvo ištirta ir keitiklio kampinio pozicionavimo nuokrypio įtaka atspindžiams nuo trikampių trimatėje erdvėje. Palyginus modeliavimo ir eksperimentinius rezultatus nustatyta, kad net ir maži kampiniai keitiklio nuokrypiai turi įtakos gaunamam vaizdui.

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