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Verification of the acoustic computer model for the case of two tilted planar reflectors

E. Jasiūnienė, R. Šliteris, L. Mažeika, R. Kažys

Ultrasound Institute, Kaunas University of Technology,
Studentu 50, LT-51368 Kaunas, Lithuania
E-mail: elena.jasiuniene@ktu.lt

Abstract:

The modelling of the ultrasonic signals reflected from complex curved surfaces is a very complicated task. In order to simplify this task the reflectors are decomposed into multiple planar elements. Then the signals reflected by the planar areas and the areas between two planar elements oriented under some angle can be analysed separately.

The objective of this study was verification of the acoustic computer model by simulation and experimentally for the region containing boundary between two planar areas. The used model enables calculation of the signals, reflected by components of complicated geometry decomposed into triangles. Verification of the computer model was carried out comparing the C-scan images obtained experimentally and by simulation. The reflectors were composed of two triangles with different tilt angles to each other.

The simulations show, that a shape of the reflector can be recognised only in the case of the specular or close to the specular reflection. The edges of the reflectors can be seen only when they are parallel to the transducer surface. Comparison of the experimental and simulated results shows that the model enables to obtain adequate reflected signals. The good coincidence of the simulated and the experimental signals has been obtained.

Keywords: 3D modelling, scattering of ultrasonic waves, ultrasonic fields, Huygens principle.

Introduction

There are very different formats in which the components of complicated geometry can be approximated and presented. Different modelling approaches for approximation of objects using various facets (rectangular, circular and triangular) are available [1 - 3].

For the approximation of the inspected objects planar triangular facets were used, because in a widely used CAD models "STL" format describes all surfaces decomposed into triangles. In such 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].

The acoustic computer model developed by us enables calculation of the ultrasonic signals, reflected by the components of complicated geometry, approximated by triangles [4 - 6]. The reflected signal according to this approach is calculated as a sum of the signals reflected by elementary segments of the part of a triangle which is in the intersection zone of the directivity patterns of the transmitter and the receiver. However, the common case is that in the directivity pattern there is more then one triangle available and each of them is oriented with different angles with respect to the transducer.

The objective of this study was experimental verification of the acoustic computer model [4] for the region containing boundary between two planar areas defined by triangles. The model used enables calculation of the signals reflected by the objects having a complicated geometry and approximated by triangles. Verification of the computer model was carried out comparing the experimental and simulated C-scan images obtained on the reflectors possessing the same geometry.

Main steps of the modelling method

For calculations of reflected signals the computer model, which exploits the Huygens's principle was used [4]. In the model the signals are calculated for the separate triangle reflectors, from which the investigated object is composed. 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 [4]:

- The triangle is moved to the origin of the used coordinate system and rotated in such a way, that after the rotation it would be located in one plane (z=0);
- In order to keep the position of the transducers with respect to the triangle unchanged the transducers are moved and rotated in the same way as the triangle;
- The signal amplitude at each point of the triangle plane according to the directivity patterns of the transmitter and receiver is found:

$$A = \left(\exp\left(K_{dir} \cdot \alpha_a^2\right)\right)^2, \tag{1}$$

where $K_{dir} = \log(0.5)/\alpha_r^2$; α_a is the angle from the transducer axis, α_r is the limiting angle of the transducer;

- The zone of the triangle is found, which is overlapped by the directivity patterns of the transmitter and receiver;
- This zone is divided into elementary segments with a step, smaller than the half of the wavelength;
- The signal propagation time from the transmitter to each elementary segment in the triangle and back to the receiver is calculated:

$$t_e = \frac{d_{et} + d_{er}}{c}, \tag{2}$$

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;

- The total received signal is calculated as the sum of reflections from the elementary segments

$$u(t)=\sum_{k=1}^{N_e} u_t(t)\otimes h_k(t-t_{e,k}), \qquad (3)$$

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 and N_e is the total number of elementary segments.

Modelling of 3D reflections from two tilted triangle reflectors

In order to test the developed model, simulation of ultrasonic signals reflected by the object, composed of two triangles possessing different orientation was carried out. Verification of the developed model was performed in the case when the ultrasonic beam is reflected by objects, reflecting surfaces of which are inclined with respect to the symmetry axis of the directivity pattern of the transducers. Therefore the signals which are picked up are not specularly reflected by the object. For this purpose the reflector composed of two triangles with different tilt angles (0° - 3°) was used. The geometry of the object used in modeling is given in Fig. 1.

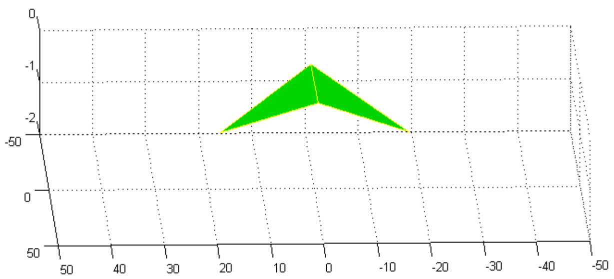

Fig. 1. **Geometry of the reflector**

The tilt between two triangles α was changed during the modeling (Fig. 2). The projection of the reflector into *xOy* plane possesses a rectangular shape.

The simulation was performed using the two 5 MHz transducers – the transmitter and the receiver with partially overlapping directivity patterns (Fig.3). Both transducers were simultaneously shifted in a plane (z=300 mm), and the simulated reflected signals in the time domain were used to construct a C-scan type image of the triangle. The scanning step was 0.5 mm. It was assumed, that the object is immersed in water.

The simulated ultrasonic image of the triangles with 0° angle tilt (both triangle in the same plane) is presented in Fig. 4. The simulated ultrasonic images of the reflector with the triangles tilt angles α (Fig. 3) of 1°, 2° and 3° degrees are presented respectively in Fig. 5 - 7.

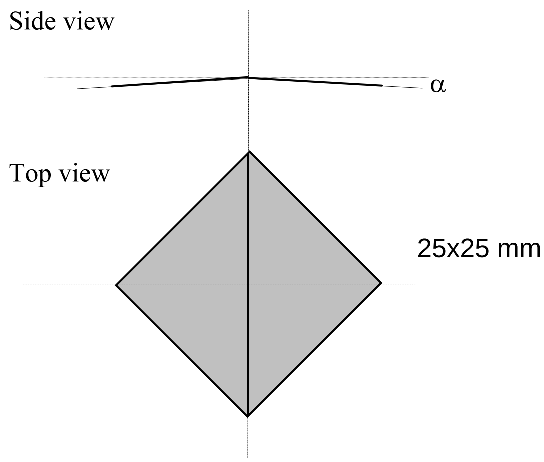

Fig. 2**. Top and side view of the reflector**

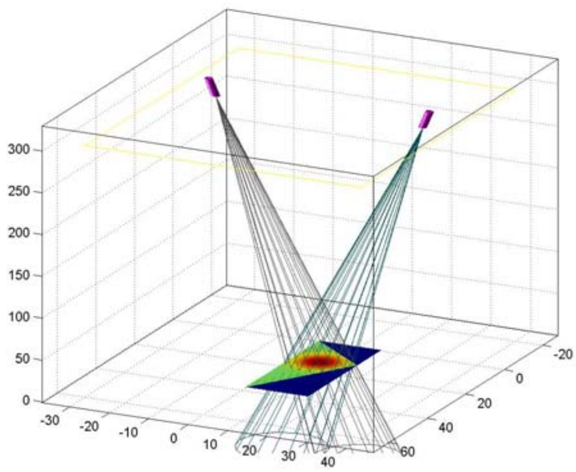

Fig. 3. **Simulation and measurement scheme using two transducers**

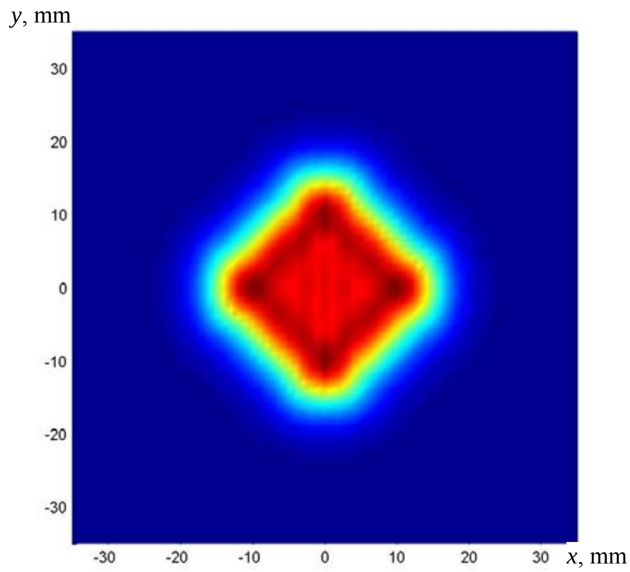

Fig.4. **The simulated C-scan image of the reflector when the triangles are tilted by the angle of 0°**

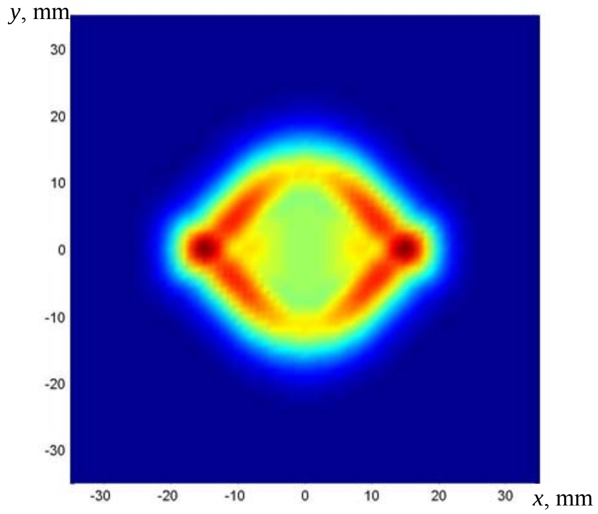

Fig.5. **The simulated C-scan image of the reflector when the triangles are tilted by the angle of 1°**

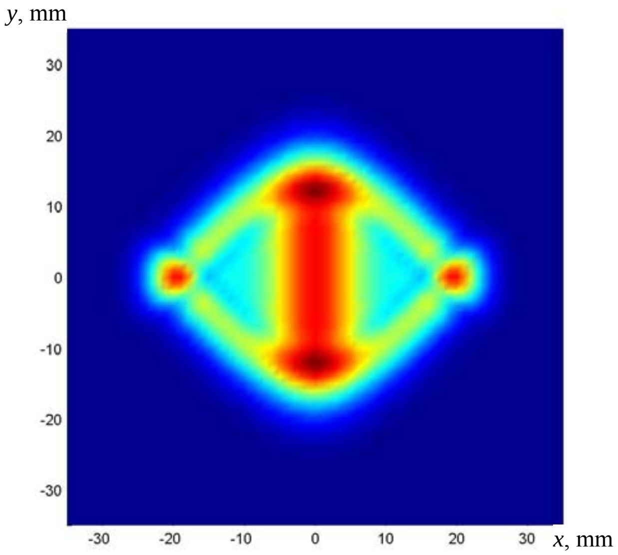

Fig.6. **The simulated C-scan image of the reflector when the triangles are tilted by the angle of 2°**

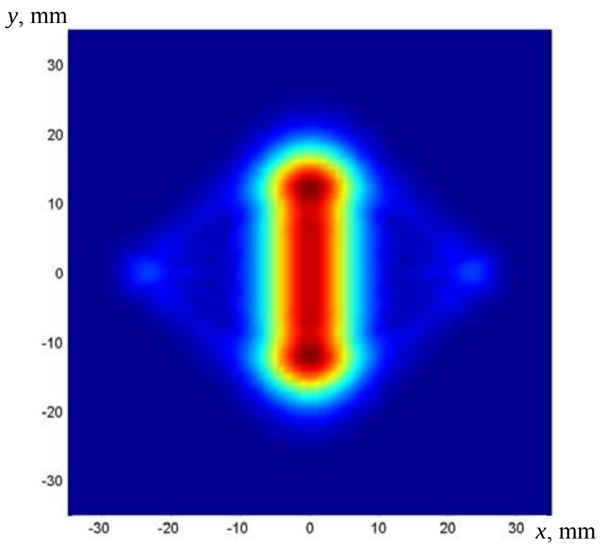

Fig.7. **The simulated C-scan image of the reflector when the triangles are tilted by the angle of 2°**

As can be seen only in the case of zero angle tilt the rectangular shape of the reflector can be easily recognized. In other cases more complicated ultrasonic images were obtained. However the edge between two triangles can be seen in the case 2° and 3° angle of the tilt. It is necessary to take into account that the true value of the maximal amplitude in each image differs essentially.

Experimental verification of the computer model

Verification of the computer model was carried out experimentally also. The experimental investigations were performed in a transmitter-receiver mode using two ultrasonic transducers. The positioning of the ultrasonic transducers for experimental verification of the model is presented in Fig. 8. The transducers were placed at the distance of 52 mm from each other and tilted by ±5° (Fig. 8). Due to overlap of the inclined directivity patterns quasi-focusing is obtained at the distance of 300 mm.

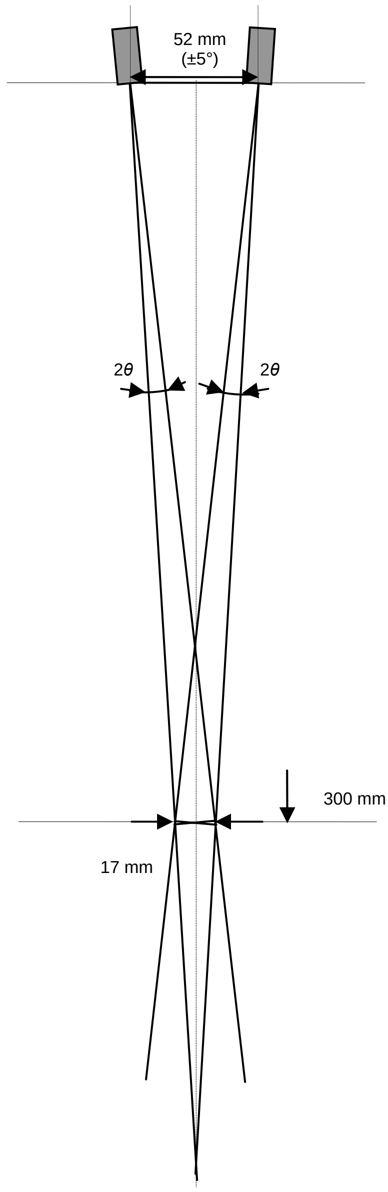

Fig. 8. **Positioning of the ultrasonic transducers for experimental verification in the "transmitter-receiver" mode**

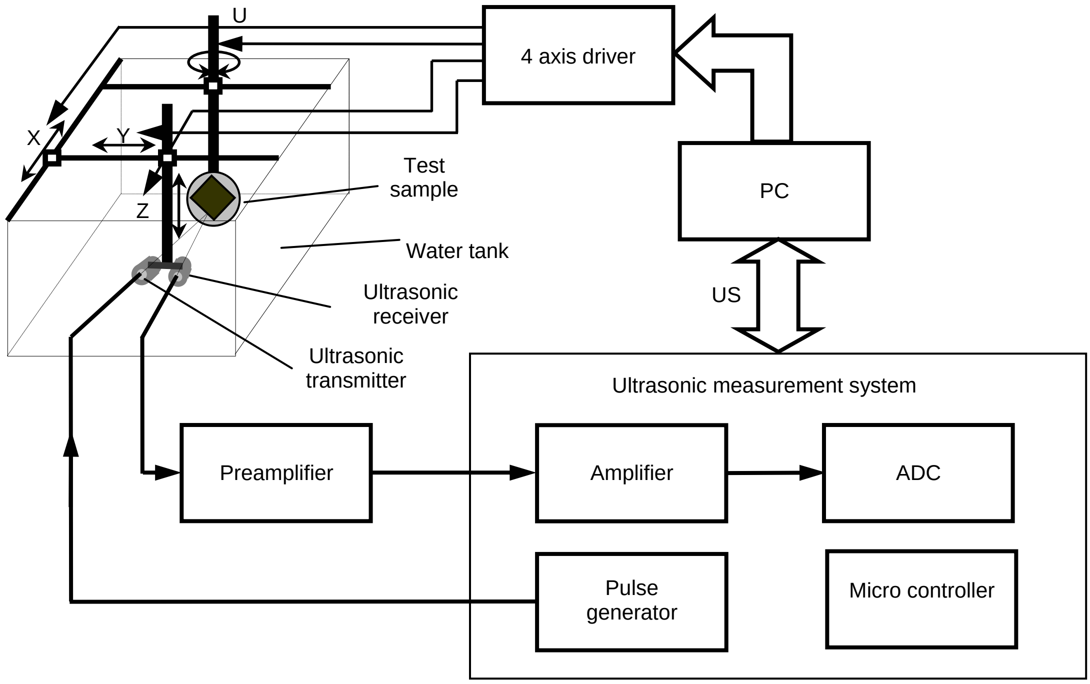

Fig. 9. **Experimental set-up for experimental verification of the computer model in the pulse-echo mode**

The set-up for experimental verification of the computer model is presented in Fig. 9. The experiments were performed using specially developed and manufactured at the Ultrasound institute test sample, imitating the simulated reflector. The reflector possessing the same geometry and tilt angle as in the simulation was investigated. The test sample consisted of two triangles, tilted by α=2° to the scanning plane. The reflector was immersed in a water tank. In order to get C-scan images, scanning was performed in *x*O*y* plane. The scanning step was 0.5 mm. The experimentally obtained image of the test sample is presented in Fig. 10.

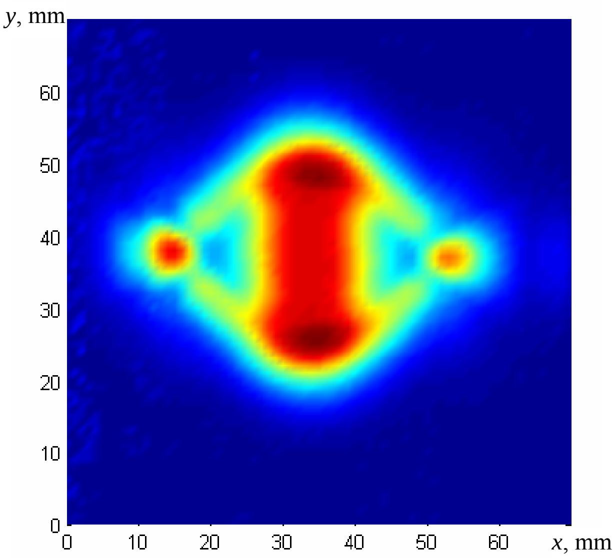

Fig.10. **The experimentally obtained C-scan image of the reflector when the triangles are tilted with the angle of 2°**

The rectangular shape of the reflector is masked by some stronger signals at the edges and corners of the triangles. The strong signals over the boundary between two tilted triangles can be observed also. Comparison of the experimental image (Fig. 10) with simulated one (Fig. 6) demonstrates a good coincidence.

Conclusions

The developed acoustic model using the Huygens's approach enables to calculate the signals in 3D space reflected by objects of complicated geometry, which are decomposed into triangle reflectors.

The investigation results showed that even small tilt angles between neighbouring planar surfaces distort the image of the reflector and only a week signal from the edges and corners can be observed. The shape of the investigated object can be recognised only in the case of a specular reflection. The edges of the reflectors can be seen when they are parallel to the transducer surface.

The comparison of the experimental and simulated results has shown that the developed computer model based on the application of the Huygens's approach enables to obtain adequate reflected signals in 3D space reflected by objects of complicated geometry. The good coincidence of the simulated and the experimental signals has been obtained.

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E. Jasiūnienė, R. Šliteris, L. Mažeika, R. Kažys

Hiuigenso akustinio kompiuterinio modelio eksperimentinis patikrinimas naudojant keturkampius atspindėtuvus

Reziumė

Darbo tikslas buvo patikrinti sukurtą akustinį kompiuterinį modelį naudojant keturkampius atspindėtuvus. Šis modelis leidžia modeliuoti ultragarso signalo atspindžius nuo bet kokios formos objektų trimatėje erdvėje. Įvairios formos objektai sudaromi iš trikampių ir modeliuojami trikampių atspindėtuvų atspindėti signalai. Atspindžių nuo keturkampių modeliavimo ir eksperimentinių matavimų palyginimas parodė, kad keturkampio forma gali būti atpažinta tik tada, kai keturkampio plokštuma yra lygiagreti su keitiklio plokštuma. Be to, matomos tik tos objekto kraštinės, kurios yra lygiagrečios su keitiklio plokštuma.

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