4.17. RESEARCHING MODELS WITH AN ULTRASONIC ECHOSCOPE

Purpose of experiment

Determine the main characteristics of ultrasound waves, and the distances and positions of models using an ultrasonic echoscope.

Tasks of experiment

- Determine ultrasound velocities and probe delays in three cylinders.
- Determine the position and size of the discontinuities in the test block making B-scan measurements.
- Determine ultrasound wave periods, frequency and wavelengths using different probes.
- Determine the size of eye model structures (lens, iris and retina).

Theoretical topics

- Sound waves, their velocity, reflection and refraction.
- Ultrasound: generation and detection.
- Ultrasound echography. A-scan (an amplitude modulation scan), B-scan (brightness scan).
- Ultrasound interaction with biological tissues, ultrasound application in medicine.
- Structure of the eye, biometry, principles of eye echoscopy.

Equipment and materials

Ultrasonic echoscope, ultrasonic probes, cylinders, test block, eye model, ultrasonic gel, distilled water, vernier calliper, PC with software.

Theoretical part

Some theoretical topics are presented in lab. work No 4.16A description.

Medical Ultrasonography. Medical ultrasonography is a medical diagnostic technique which can use sound information to construct images for the visualization of the size, structure and lesions of internal organs and other bodily tissues. These images can be used for both diagnostic and treatment purposes (for example enabling a surgeon to visualize an area with a tumor during a biopsy). The most familiar application of this technique is obstetric ultrasonography, which uses the technique to image and monitor the fetus during a pregnancy.

This technique relies on the fact that in different materials the speed of sound and acoustic impedance are different. The acoustic impedance/resistance concept is particularly useful. Consider a sound wave that passes from an initial medium with one resistance into a second medium with a different resistance. If the resistances are identical, all of the sound energy will pass from the first medium into the second across the interface between them. If the resistances of the two media are different, some of the energy will be reflected back into the initial medium. Thus the resistance enables one to characterize the acoustic transmission and reflection at the boundary of the two materials. The difference in $Z$, which leads to some of the energy being reflected back into the initial medium, is often referred to as the resistance mismatch. When the acoustic boundary
conditions apply which require that the particle velocity and pressure be continuous across the interface between the two media, the reflection coefficient can be described by

\[ R = \left( \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \right)^2, \]  

(4.16.B.1)

where \( \rho_1 \) and \( \rho_2 \) are the densities of the two media. The fraction of the energy transmitted into the second medium is given by \( T = 1 - R \).

A collimated beam of high-frequency sound is projected into the body of the person being examined. The frequencies chosen will depend on the application. For example, if the tissue is deeper within the body, the sound must travel over a longer path and attenuation affects can present difficulties. Using a lower ultrasonic frequency reduces attenuation. Alternatively, if a higher resolution is needed, a higher frequency is used. In each position where the density of the tissue changes, there is an acoustic impedance mismatch. Therefore, at each interface between various types of tissues some of the sound is reflected. By measuring the time between echoes, one can determine the spatial position of the various tissues.

If a single, stationary transducer is used; one gets spatial information that lies along a straight line. Typically, the probe contains a phased array of transducers that are used to generate image information from different directions around the area of interest. The different transducers in the probe send out acoustic pulses that are reflected from the various tissues. As the acoustic signals return, the transducers receive them and convert the information into a digital, pictorial representation. One must also match the impedances between the surface of the probe and the body. The head of the probe is usually soft rubber, and the contact between the probe and the body is impedance-matched by a water-based gel.

To construct the image, each transducer measures the strength of the echo. This measurement indicates how much sound has been lost due to attenuation (different tissues have different attenuation values). Additionally, each transducer measures the delay time between echoes, which indicates the distance the sound has travelled before encountering the interface causing the echo (actually since the sound has made a round trip during the echo the actual displacement between the tissues is half of the total distance travelled). With this information a two-dimensional image can be created. In some versions of the technique, computers can be used to generate a three-dimensional image from the information as well.

Another form of ultrasonography, Doppler ultrasonography, is also used. This technique requires separate arrays of transducers, one for broadcasting a continuous-wave acoustic signal and another for receiving it. By measuring a frequency shift caused by the Doppler effect, the probe can detect structures moving towards or away from the probe. For example, as a given volume of blood passes through the heart or some other organ, its velocity and direction can be determined and visualized. More-recent versions of this technique make use of pulses rather than continuous waves and can therefore use a single probe for both broadcast and reception of the signal. This version of the technique requires more-advanced analysis to determine the frequency shift. This technique presents advantages because the timing of the pulses and their echoes can be measured to provide distance information as well.

**Methodology**

A short mechanical wave is produced by a short voltage pulse applied to a piezoelectric ceramic which expand and contract with the amplitude proportional to the electric field amplitude. If this wave is coupled to solid state material it propagates in a linear way and will be reflected on interfaces where acoustic impedance changes (boundaries).
From the known distance \((s)\), between the ultrasonic probe and the boundary of a solid, and the measured time of propagation \((t)\), the sound velocity \((c)\) can be determined for perpendicular sound incidence and measuring in the reflection mode, in the following way:

\[
c = \frac{2s}{t}.
\]  
\[\text{(4.17.2)}\]

Nearly all ultrasonic probes are covered with a protective layer on the active surface (ceramics). The thickness of the protective layer can vary. In the current system, the protective layer of a 1 MHz probe (probe with a blue tip) is larger than the layer of a 2 MHz probe (probe with a red tip). The time needed by the ultrasound waves to pass through this layer is added to the time of propagation measured for the sample. This additional time causes errors in sound velocity measurements. The measured time of propagation \((t)\) is composed of the time of propagation through the protective layer \((t_{2L})\) and the time of propagation through the sample \((t_{2s})\) (Fig. 4.17.1).

\[t = t_{2s1} + t_{2L} = (t - t_{2s1}).\]  
\[t_{2L} = (t - \frac{2s}{c}).\]  
\[\text{(4.17.6)}\]

The influence of ultrasound propagation through the protective layer (thickness \(L\)) can be diminished if sound velocity \((c)\) is determined measuring two different times of ultrasound propagation \((t_1\) and \(t_2)\) in samples of two different thickness \((s_1\) and \(s_2)\). The time of ultrasound propagation in the first sample:

\[
t_1 = \frac{2(L+s_1)}{c}.
\]  
\[\text{(4.17.3)}\]

The time of ultrasound propagation in the second sample can be written analogically and from current formula the thickness of the protective layer can be determined:

\[
t_2 = \frac{2(L+s_2)}{c}; \quad L = \frac{t_2 c}{2} - s_2.
\]  
\[\text{(4.17.4)}\]

Using the formulas (4.17.3) and (4.17.4), the ultrasound velocity can be determined:

\[
c = \frac{2(s_1 - s_2)}{t_1 - t_2}.
\]  
\[\text{(4.17.5)}\]

For different probes, the thickness of the protective layers is different, therefore the probe delays \(t_{2L}\) are different. The time of ultrasound propagation through the protective layer can be calculated:

\[
t = (t_{2s1} + t_{2L});
\]
\[
t_{2L} = (t - t_{2s1});
\]
\[
t_{2L} = (t - \frac{2s}{c}).
\]  
\[\text{(4.17.6)}\]

If ultrasound velocity \((c)\) and probe delay are known, the sample thickness can be measured using the following formula:
\[ s = \frac{(t - t_2)c}{2}. \quad (4.17.7) \]

If we have a solid glass block with discontinuities, diameter \( d \) of discontinuity can be calculated with the measured distances from the discontinuity to the sides of the test block (Fig. 4.17.2):

\[ d = BS_1 - S_1 - S_2 = BS_2 - S_3 - S_4; \quad (4.17.8) \]

here \( BS_1 \) – height, \( BS_2 \) – length of the test block, \( S_1, S_2, S_3 \) and \( S_4 \) – distances from every side of the block to the particular discontinuity (Fig. 4.17.2 a).

In a sectional object image (B-scan), the echo amplitude is displayed as a colour value and the time of propagation as the penetration depth. In a sectional object image (Fig. 4.17.2 b) the vertical axis shows the depth of penetration, and the horizontal axis – time value. The local resolution along this scanning line results from the position of the probe or its speed of movement. A simple way to produce a sectional image is to move the probe slowly by hand (compound scan). However, in this case, a precise lateral resolution is only possible with the aid of additional coordinate acquisition systems, such as linear scanners. On the other hand, due to the low scanning speed, high-quality images can be produced over extended examination areas.

The image quality is determined by the following parameters:
- Precise, coordinate-based image point transmission which is made possible by the scanner system
- Axial resolution which depends on ultrasound frequency
- Lateral resolution which depends on sound frequency, sound field geometry, and focus
- Colour scale resolution which depends on transmission power, gain, and TGC (time gain control)
- Scanning speed
- Aberrations, acoustic shadows, multiple reflections, and movement artefacts.

**Principles of eye echoscopy.**

![Fig. 4.17.2 a) Setup of test block. 1-11: discontinuities number, S₁, S₂, S₃, S₄ – distances from the sides of test block to the discontinuity and BS₁ – height of test block, b) sectional object image (B-scan).](image)

Diagnostic ultrasound is now used routinely in the investigation of patients with opacification of the ocular media or with orbital problems. Ultrasonic frequencies within the range 5-20 MHz are generally used for ophthalmic diagnosis. In order to couple the high-frequency sound to the eye, a gel can be applied to the anaesthetized eye or to the closed eyelids or the coupling can be realised by means of a saline bath.
Ultrasound is mostly used in ophthalmology in the area of biometry, to measure distances in the eye. The distance between the cornea and the retina has to be known to calculate the characteristics of an artificial lens, which can be implanted into patients with a cataract. Sonography is necessary in this case since the cornea or the lens is too cloudy to be inspected with optical methods.

The measured time of propagation, determined in the A-scan, cannot be transformed directly into distances using “time to depth” button, because the ultrasound velocity is different in the cornea, lens and vitreous humour. Therefore when measuring the separate distances of the eye model it is necessary to use different velocities of ultrasound in the different structures of the eye model. The thickness of each eye model structure can be calculated according to the ultrasound time of propagation measurement:

\[
s = \frac{v \Delta t}{2}
\]  

(4.17.9)

In medical diagnostics average values are often used. Average ultrasound velocity in the eye model is:

\[
v = \frac{v_1(t_1+(t_3-t_2))+v_2(t_2-t_1)}{t_3};
\]  

(4.17.10)

here (Fig. 4.17.3) \( t_1 \) – ultrasound time of propagation up to the front of lens, \( t_2 \) – up to the back layer of lens, \( t_3 \) – up to retina, \( v_1 \) – ultrasound velocity in vitreous humour (for this model - 1410 m/s), \( v_2 \) – ultrasound velocity in lens (for this model - 2500 m/s).
Procedures

Caution!
Pay close attention to the special operation and safety instructions in the manual of the ultrasonic echoscope.

This is not medical equipment, do not apply to the human body.

Attention:
Wipe the ultrasound cylinders, test block and the ultrasonic probes clean immediately after they have been used in combination with ultrasound gel. Then clean them with water or a soap solution. Do not use alcohol or liquids with solvents for cleaning the equipment. Avoid any mechanical damage to the surface (scratches etc.) since it would have a negative effect on the sound contact.

Do not use too much water for coupling since it might flow under the block and change the reflection signal of the bottom echo (sound will be coupled out to the surface underneath the block (table)).

1. Determination of ultrasound velocity in transparent cylinders

![Fig. 4.17.4. Experimental setup for the ultrasound velocity measurement.]

1. Measure the thickness of the three cylinders \( (s_1, s_2 \text{ and } s_3) \) with a calliper gauge.
2. Prepare the experimental setup (Fig. 4.17.4). Connect the ultrasound probe with blue tip (1 MHz) to the echoscope (1, Fig. 4.17.4) "Probe (Reflexion)" plug (5, Fig. 4.17.10), switch the selection knob to the "Reflexion" position (4, Fig. 4.17.10) and connect the echoscope to the PC (2, Fig. 4.17.4) via USB cable.
3. Switch on the echoscope, open the program “measure Ultra Echo” (Fig. 4.17.5).
4. Couple a probe (3, Fig. 4.17.4) to the test cylinders using a gel or a water film. When using water as coupling make sure it does not run under the cylinder. It could produce ghost echoes.
5. Find the reflection signal from the cylinder back wall. The “measure Ultra Echo” program (Fig. 4.17.5) shows the reflected wave as a peak.
6. Adjust the transmitter (6, Fig. 4.17.10) and receiver amplifier (3, Fig. 4.17.10) settings until the peak is well distinguishable, has a bell shape and is not made from several peaks. The peak shape can be optimised adjusting the time-TGC (Time Gain Control) parameters (D block, Fig. 4.17.10).
7. Measure the time of propagation from the input and first reflected signal. The time of propagation can be read out directly using the software cursors (red and green lines); their position can be changed dragging cursors with the mouse or using arrow keys on the keyboard: ←, →, ↑, ↓ for the beginning cursor, ↑, ↓ for the end cursor). The positions of cursors and the difference between
them are shown at the bottom of the main software window below coloured tags (red tag –
beginning cursor, green – end cursor, yellow – difference between cursors values).
8. Measurements are repeated with different thickness cylinders ($t_1$, $t_2$...).
9. All measurements and calculations are repeated (4-8 procedures) with the 2 MHz probe (probe
with red tip).
10. Calculate ultrasound velocity (4.17.5 formula) and probe delay (4.17.6 formula) for both
probes.
11. In order to measure cylinder thickness directly, the following parameters are set in the program
“measure Ultra Echo” main window: in “Sound velocity (m/s)” the calculated ultrasound velocity is
written; menu “options” → “parameter” calculated probe delays are written (timeshift) for both
probes (1 MHz and 2 MHz).
12. In the program “measure Ultra Echo” main window (Fig. 4.17.5) switch “Time” button to
“Depth” and calculate 3 different cylinder thickness directly using cursors (red and green lines). On
the abscissa of the graph which is displayed in the main program window depth (not time) values
will be shown.
13. Compare thickness of cylinders measured in two different ways (with a calliper gauge and
software).

![Software „measure Ultra Echo“ main window.](image.png)

**Fig. 4.17.5.** Software „measure Ultra Echo“ main window.
2. Analysis of the test block

![Fig. 4.17.6. Experimental setup for the test block analysis](image)

1. Prepare the experimental setup (Fig. 4.17.6). Connect the ultrasound probe with red tip (2 MHz) to the echoscope (1, Fig. 4.17.6) "Probe (Reflexion)" plug (5, Fig. 4.17.10), switch the selection knob to "Reflexion" position (4, Fig. 4.17.10) and connect echoscope to the PC (2, Fig. 4.17.6) via USB cable.
2. Switch on the echoscope, and open the program “measure Ultra Echo” (Fig. 4.17.5).
3. Set the “measure Ultra Echo” software parameters: in "Options" → "Parameter" add the calculated probe delays (in "Time Shift" window) with cylinders, also check the "Time shift enabled" window.
4. Couple a probe to the test block (on the short side to measure the long side length) using a gel or a water film. Search the back wall reflection.
5. Switch the measuring range (in the “measure Ultra Echo” software) from “Half” to “Full” because the time of propagation of the reflected pulse is longer than 100 µs.

![Fig. 4.17.7. Engineering drawing of the test block](image)

6. The “measure Ultra Echo” software (Fig. 4.17.5) shows the reflected wave as a peak. Adjust the transmitter (6, Fig. 4.17.10) and receiver amplifier (3, Fig. 4.17.10) settings until the reflected peaks are clearly distinguishable.
7. Measure the time of propagation through the whole block. The time of propagation can be read out directly using the software cursors (red and green lines); their position can be changed by
dragging the cursors with the mouse or by using the arrow keys on the keyboard: ←, →, ↑, ↓ for the beginning cursor, ↑, ↓ - for the end cursor.

8. Calculate ultrasound velocity (4.17.2 formula) and adjust the value in the “measure Ultra Echo” program. Switch the display to “Depth”. Now, the distance to the defect can be measured directly.

9. Distances $S_1$, $S_2$, $S_3$, $S_4$ for each hole (Fig. 4.17.2 a) are measured. Defects in deeper areas of the block do not yield a signal of the same strength. Hence, the echoscope is equipped with an amplifier. The strength of the signal can be adjusted with the knobs Threshold, Wide, Slope and Start. Calculate the thicknesses of the discontinuities (4.17.8 formula).

10. In the program “measure Ultra Echo” toolbar, HF mode is chosen. In this mode the signal is spread in time in such a way that ultrasound vibrations are clearly seen. At the bottom of the newly opened window are arrows with which the signal can be spread in time.

11. Measure the ultrasound period and calculate frequency and wavelength.

12. Press the “Amp” button in the program “measure Ultra Echo” toolbar and detect reflections from the double hole (1 and 2 holes in Fig. 4.17.2 a). Distances between the reflections of both holes are measured in two different ways – taking measurements between the beginning of holes and between the peaks of holes.

13. Procedures 10-12 are repeated with the 1 MHz probe (probe with blue tip). Probe resolutions are evaluated (the probe's ability to distinguish each hole in a double hole).

14. Press the “B-Mode” button in order to start the program “measure Ultra Echo” or recording a 2D brightness image (B-scan, Fig. 4.17.8).

15. Place the block on its long side and couple the 1 MHz probe (probe with blue tip) with a water film to one of the edges of the block. Now apply a thin water film along the entire surface of the block.

16. Press the “Start” button in the software and move the probe steadily over the block. When the other end of the block is reached, stop the program (“Stop” button). The contrast and brightness of the recorded B-scan image can be changed with the aid of the image processing features.

17. The distances between the holes and the upper edge are measured in the image with the aid of the cursor (computer mouse).

18. Compare the measured results with real block values (Fig. 4.17.7).

19. Repeat B-scan measurements (15-17 procedures) with the 2 MHz probe (probe with red tip) and compare the quality of the images.
**Note:**

The cornea of the eye model is made of a sensitive ultrasonic phantom material. The surface can be deformed easily when pushing the probe on the surface. Some pressure on the probe can increase the coupling between the probe and the bent cornea but too strong a pressure can lead to cracks in the material and damage the model. Do not touch the model with sharp objects. Clean the cornea with a wet, soft cloth. Do not use any cleaning agents or hot water, as they could destroy the model.

### 3. Analysis of the eye model

![Fig. 4.17.9. Experimental setup for the eye dummy analysis](image)

1. Prepare the experimental setup (Fig. 4.17.9). Connect the ultrasound probe with red tip (2 MHz) to the echoscope (1, Fig. 4.17.9) "Probe (Reflexion)" plug (5, Fig. 4.17.10), switch the selection knob to the "Reflexion" position (4, Fig. 4.17.10) and connect the echoscope to the PC (2, Fig. 4.17.9) via USB cable.
2. Switch on the echoscope, open the program “measure Ultra Echo” (Fig. 4.17.5). In the main window choose “A-scan” mode and time measurement mode (“Time”). Choose average transmitter (Gain (6, Fig. 4.17.10)) and receiver (Output (3, Fig. 4.17.10)) values.
3. Couple the probe in the middle of the cornea to the test model using sufficient coupling gel to get a good ultrasonic contact between the probe and the model.
4. Slowly move the probe over the cornea, without any pressure, observing the A scan image. Change the position until the two large echoes of the front and the back of the lens and the smaller echo of the retina can be seen (Fig. 4.17.3). Adjust the transmitter and receiver amplifier settings until the peak position, corresponding to the lens and the retina can be clearly determined. The respective peak amplitudes can also be optimized adjusting the time-TGC (Time Gain Control) parameters (D block in Appendix 1). Often, the small echo of the iris appears in front of the first lens signal peak. The two echoes of the lens and the retina echo are seen as clear peaks, without any supplementary structure. Only in this condition is the incident sound angle perpendicular to the lens. If the direction of the ultrasonic wave is not perpendicular to the lens surface, the peaks will appear larger and small additional peaks can appear. Do not interpret these artefacts as additional boundary surfaces in the model.
5. The obtained image is stopped by pressing the “Stop” button on the toolbar of the program “measure Ultra Echo”.
6. Measure the time of propagation in the different parts of the model: at the front side of the lens ($t_1$), at the back side of the lens ($t_2$) and at the retina ($t_3$) (Fig. 4.17.3). The time of propagation can be read out directly using the software cursors (red and green lines).
7. Calculate the dimension of the lens and vitreous humour assuming the following velocity values: aqueous/vitreous humour 1410 m/s, lens 2500 m/s.
8. Calculate the average ultrasound velocity (4.17.9 formula).
9. In the program “measure Ultra Echo” toolbox “Sound Velocity (m/s)” window set the average ultrasound velocity value, toggle the button from “Time” to “Depth” and measure the lens thickness and the distance from the lens to the retina again directly using cursors (red and green lines). On the abscissa of the graph, which is displayed in the main software window, depth (not time) values are shown.

10. Compare the dimension of the lens and the vitreous humour measured in two different ways.

References:

**Echoscope front panel**

A block - power supply
1. on/off LED

B block - transmitter
2. probe connector: transmission mode
3. emitting signal power

C block - receiver
4. knob for mode switching (reflection / transmission mode)
5. probe connector reflection mode or receiver in transmission mode
6. receiver amplifier

D block - Time Gain Control (TGC)
7. Time Gain Control start point
8. Time Gain Control slope
9. Time Gain Control width
10. amplification threshold

E block - oscilloscope outlets
11. TGC signal
12. Trigger signal
13. high frequency signal
14. high frequency signal

F block - PC interface
15. USB plug

---

*Fig. 4.17.10. Echoscope front panel*