Work F3. Damping of ultrasound in solid bodies

Aim of the work:

Studying damping of ultrasound waves in solid bodies depending on their frequency and the thickness of the sample.

Safety notes

1. The apparatus is connected to the 220 V power mains.
2. Do not cover openings on the apparatus which are necessary for ventilation.
3. Do not thrust any things into the apparatus: it can lead to short circuit.
4. Before using the ultrasonic probe, ascertain its integrity. If the sensor is broken, replace it.
5. Unplug the sensors by holding the socket. Do not pull the wire!
6. Peak voltage on the sensor's contacts can achieve 300 V. Do not touch the sockets while the apparatus is in work!
7. Do not apply the apparatus to people or other objects except special test samples used in this work.

Experimental setup

1. Ultrasonic echoscope GS200 (see figure 1)
2. Ultrasonic probes (1 MHz, blue; 2 MHz, red; 4 MHz, green)
3. Objects to study (a set of acrylic cylinders)
4. Ultrasound transmission gel
5. Laptop
6. Ruler or calipers

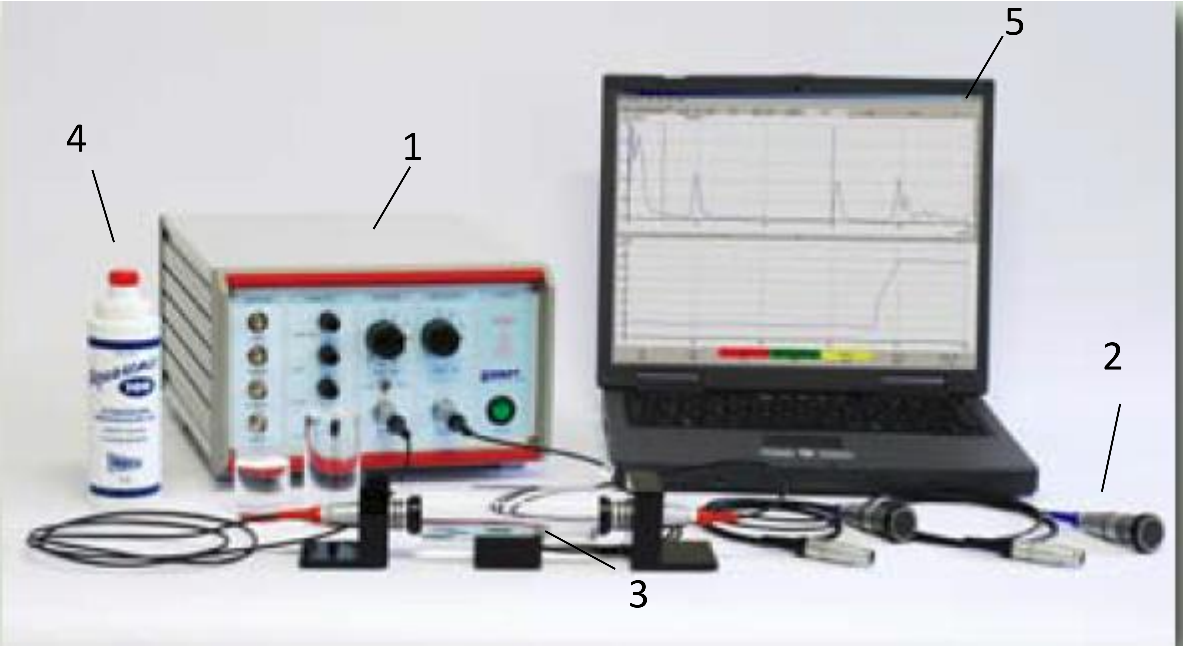


Figure 1. Laboratory setup for studying ultrasound decay in solid objects. (1) Ultrasonic echoscope GS200; (2) probes (blue, 1 MHz; red, 2 MHz; green, 4 MHz); (3) object to study; (4) gel; (5) laptop.

Tasks to solve:

1. Determine attenuation factor of ultrasonic waves and the speed of sound in solids at three different frequencies in regimes of signal reflection and transmission.
2. Build the speed of sound in solids at three different frequencies.

Brief theory

While a sound wave propagates through a material, it loses the energy due to various processes (scattering, absorption, reflection). In general, this process is called damping or attenuation. The intensity of the wave I decreases according to the following law of attenuation:

$$I = I_0 \exp(-\mu x)\,, \qquad (1)$$

where I_0 is the intensity of the incident wave, x is the path of the wave in the medium, and μ is the attenuation factor.

If the intensity of the incident wave is known and its intensity after passing different ways x in the solid bodies (made of the same material) is measured, the factor μ for the given material can be calculated using Eq. (1).

The attenuation factor is expressed in units of 1/cm or, more often, in dB/cm. Translating between different units is made as

$$\mu\ [1/\text{cm}] = \mu\ [\text{dB/cm}]\ \frac{1}{20\lg(\text{e})} = \mu\ [\text{dB/cm}]\ \frac{1}{8.686}\,. \qquad (2)$$

A change in power by a factor of 10 corresponds to a 10 dB change in level. The factor of 20 in the denominator in expression (2) allows for the fat that the intensity (energy) of the wave I is proportional to the square of its amplitude A. Thus, if the amplitudes of the sound wave at the entrance in the object and after passing the way x in the medium are A_0 and A, respectively, then the attenuation factor can be calculated as

$$\mu = \frac{8.686 \ln(A_0 / A)}{x}\,. \qquad (3)$$

Algorithm of measurements

Preparations (connecting and tuning)

- Connect the echoscope GS200 to the computer.
- Connect the 1-MHz sensor (blue) to the socket “Probe1” (see figure 2).
- Launch the program GS-EchoView on the desktop of the laptop.
- In the window “A-mode” find the tab “params” and set the parameters “begin” and “end” to 0 and 100, respectively (see figure 3).

- In the “params” tab tick the radiobutton “µs” for the “measurement length” (this will set the regime when the echo appearing time is measured).
- Press the button “Start A-scan.”
- Get the TGC profile like that shown in figures 3–4 (tune the time gain) using the handwheels 7–10 of the block C (figure 2). Initial settings of the switchers 3 and 5 (figure 2) of the block B should be “Gain” = 10, “Output” = 10. If necessary, change these numbers (depending on the studied model).

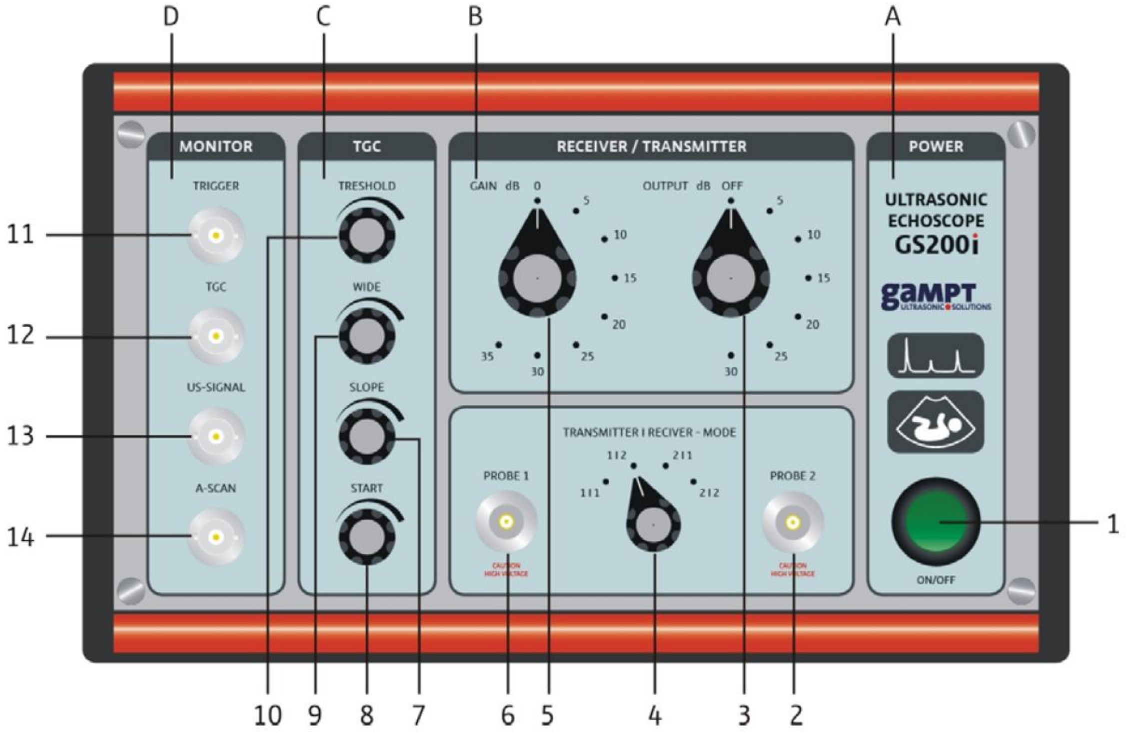


Figure 2. Front panel of the echoscope GS200.

Description of the echoscope’s front panel:

A – Power supple

(1) Power on/off

B – Transmitter/Receiver block

(2) Socket for the probe 2

(3) Control of the output signal level

(4) Switcher of receive/transmit regimes

(5) Control of the receiver gain level

(6) Socket for the probe 1

C – Time-dependent amplification block

(7) Slope control

(8) Starting point control

(9) Control for the amplification time range width

(10) Control for the gain threshold level

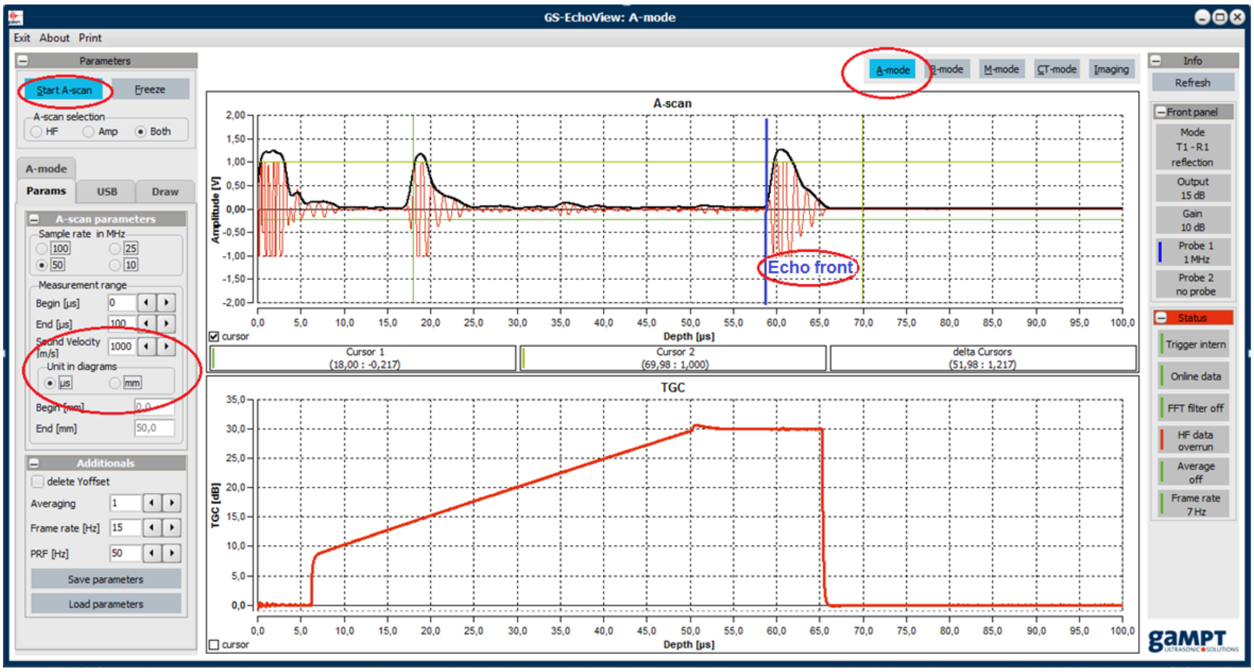
D – Sockets for connecting an oscilloscope

(11) Trigger signal

(12) Time gain control

(13) Ultrasonic signal

(14) Echo signal



A-scan selection: ○ HF ○ Amp ● Both

Sample rate in MHz: ○ 100 ○ 25 ● 50 ○ 10

Measurement range

Begin [µs] 0

End [µs] 100

Sound Velocity [m/s] 1000

Unit in diagrams: ● µs ○ mm

Begin [mm] 0,0

End [mm] 50,0

☐ delete Yoffset

Averaging 1

Frame rate [Hz] 15

PRF [Hz] 50

☑ cursor

Cursor 1 (18,00 : -0,217)

Cursor 2 (69,98 : 1,000)

delta Cursors (51,98 : 1,217)

☐ cursor

Mode T1 - R1 reflection

Output 15 dB

Gain 10 dB

Probe 1 1 MHz

Probe 2 no probe

Trigger intern

Online data

FFT filter off

HF data overrun

Average off

Frame rate 7 Hz

Figure 3. Main window of the GS-EchoView program.

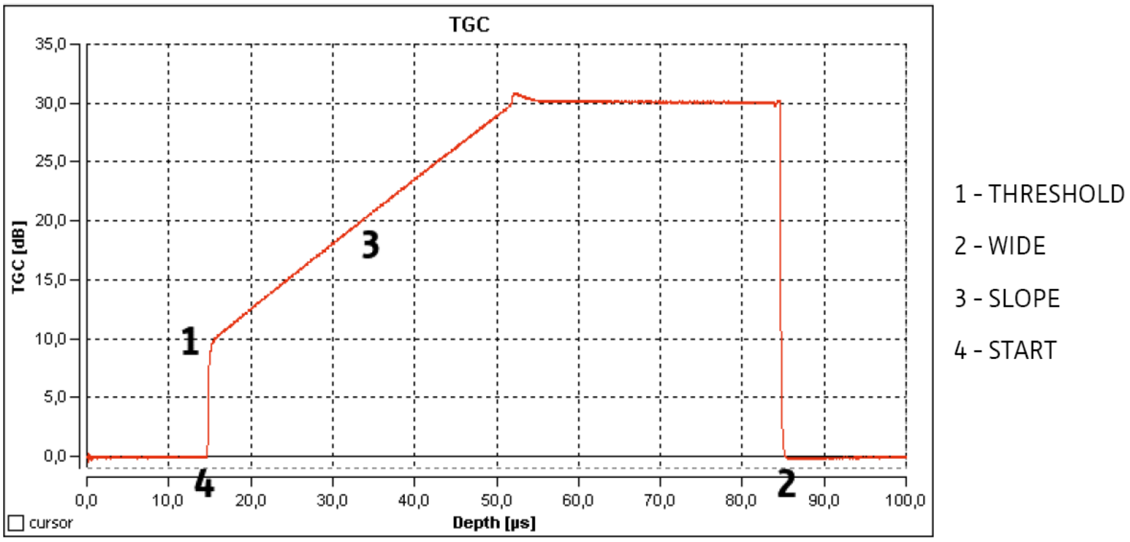


Figure 4. Scheme of controlling the time gain (TGC).

Carrying out the experiment

1. Measuring the sample length with a ruler.
    - Using a ruler, define the length s of the cylinder. Write down the results in the table (see below).
2. Finding the signal arrival time and amplitude in the transmission mode.
    - Apply a small amount of ultrasonic gel on the end sides of the cylinder and attach two probes with the same operating frequencies (as shown in figure 1).
    - Set the transmitter/receiver mode to “1 | 2” (transmission; figure 2).
    - In the A-mode, start the measurements with the “Start A-scan” button.
    - Using the mouse cursor, find the time when the signal is acquired by the second probe. Put the cursor near the maximum point of the signal and read the data from the pop-up window: amplitude A (mV, vertical axis) and time t (μs, horizontal axis).

      Note 1: In addition to the first signal there may be other signals coming to the second probe at later times. These are echoes: the wave reflects partially from the wall of the cylinder, goes back, reflects again and finally goes to the receiving probe after passing the distance of $3s$ (see figure 5). Echoes of higher order are also possible.

      Note 2: The amplitude of echoes is decreasing very quickly (according to the exponential function (1)). The acquired signal is increased as set in blocks **B** and **C** of the echoscope (figure 2). The amplification factor (gain) is increased smoothly by TGC decibels so that the latest (and hence the weakest) signals are increased most strongly. The true amplitude A of the echo acquired at time t can be calculated from the value A^{pr} shown by the program in the A-scan window as

      $$A(t) = A^{pr} \cdot 10^{-TGC(t)/20}. \qquad (4).$$
3. Finding the signal arrival time and amplitude in the transmission mode.
    - Set the transmitter/receiver mode to “1 | 1” (reflection; figure 2).
    - In the A-mode, start the measurements with the “Start A-scan” button.
    - Using the mouse cursor, find the time when the signal is acquired. Note that the first echo correspond to the ultrasonic signal which has gone the way of $x = 2s$.
4. Calculating the speed of sound
    - Using the data found on the previous stage, find the speed of sound using Eq. (5). Before that, transform the units of measurement to the SI units: meters and seconds.

$$c = \frac{x}{t}. \tag{5}$$

- Write down your result in the table.

5. Calculating the attenuation coefficient.
    - Calculate natural logarithms of the sound wave amplitudes ln$A(x)$ (A is defined as the function of distance passed by the wave in the medium).
    - Approximate the plot by a straight line and find its slope tanα.
    - Find the attenuation coefficient as

$$\mu = 8.686 \cdot \tan\alpha. \tag{6}$$

6. Repeat the measurement with the probes operating at other frequencies.
7. After you finish the experiments, wipe the probe and the model object with tissue paper.

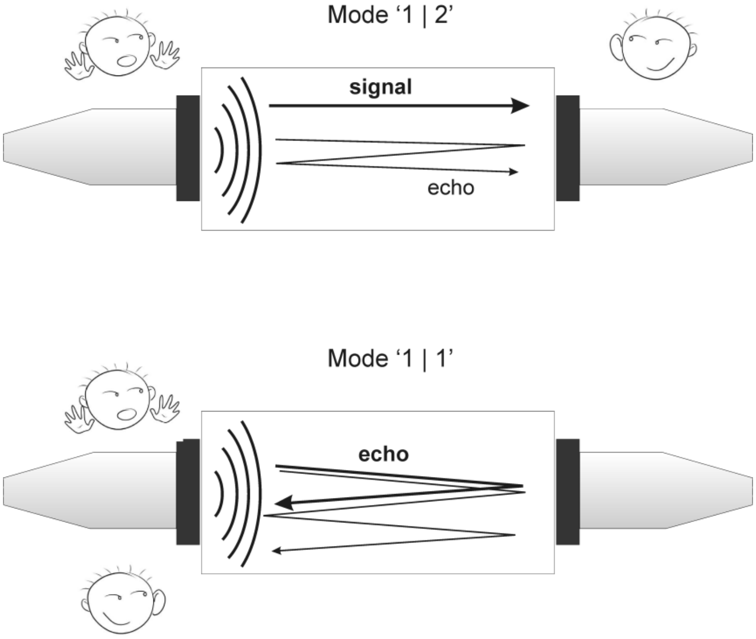


Figure 5. Two measuring modes: transmission and reflection.

Table (example)

Frequency of sound, *** MHz					
x, cm	t, µs	A^{pr}, mV	TGC, dB	A, mV	ln$A$
…					
…					
µ = … dB/cm					

Questions

1. Elastic waves. Wave equations. Speed of elastic waves. Sound.
2. Ultrasound. Interaction of ultrasound with matter. Damping of ultrasound at propagating through solid bodies.
3. Ultrasonic probe. Piezoelectric effect.