Work M1. Ultrasonic time-motion (TM) scan

Purpose
Studying of motion of the wall of a heart model using the TM regime of an ultrasonic scanner. Determination of the frequency and volume of heart contractions.

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 probe (4 MHz)
3. Object to study (heart model, see figures 1–2)
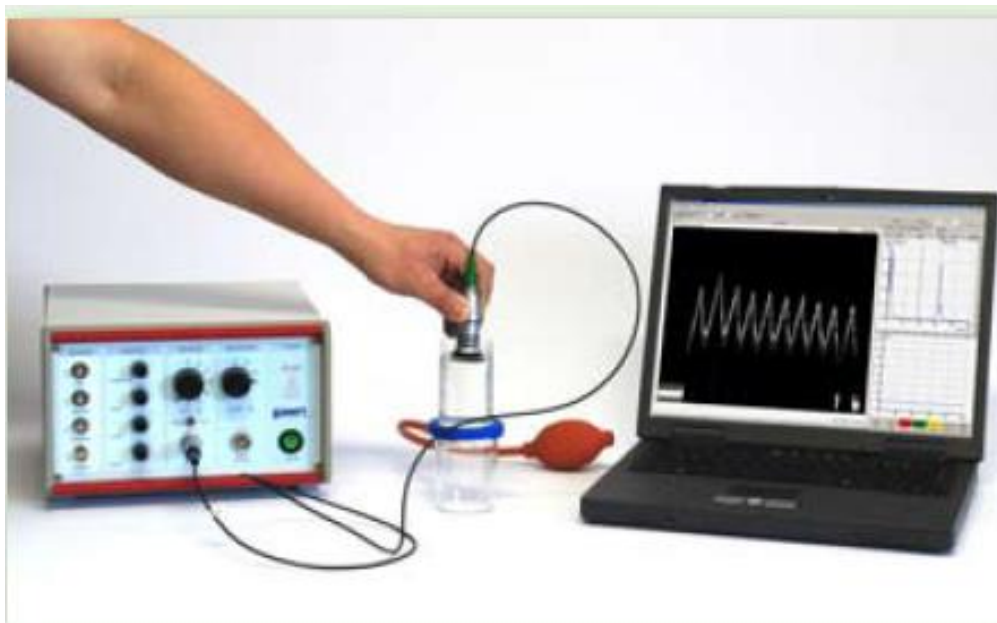4. Ultrasound transmission gel

Figure 1. Laboratory setup for studying ultrasonic echocardiography. (1) Ultrasonic echoscope GS200; (2) probe (blue, 1 MHz; red, 2 MHz; green, 4 MHz); (3) object to study (heart model); (4) laptop.

1	lower container with tubing adapter
2	upper container with lid
3	rubber pressure ball with tubing
4	membrane
5	locking ring

Figure 2. Heart model.

Tasks
1. Obtain the time diagram of movements of the heart wall
2. Determine main parameters of heart contractions

Conducting the measurements
Preparations (connecting and tuning)
- Connect the echoscope GS200 to the computer.
- Connect the 4-MHz sensor (green) to the socket "Probe1" (see figure 3). Set the transmitter/receiver mode to "1 | 1" (reflection).
- 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 4).
- Set all regulators of the TGC amplification to zero (figure 3, block C) by rotating the TGC control handwheels anti-clockwise up to the stop.
- Set the switchers 3 and 5 on the Receiver/Transmitter block (block B on the picture) to positions "Gain" = 20, "Output" = 20.
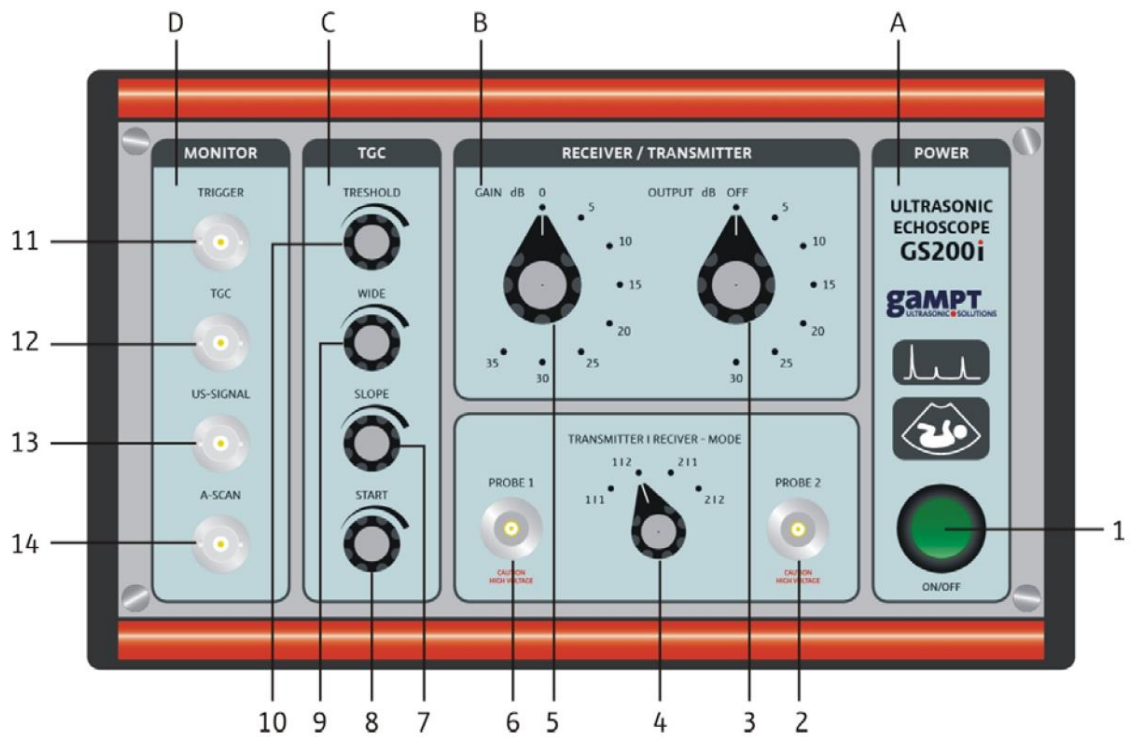
Figure 3. Front panel of the echoscope GS200. Positions of the switches shown here are not necessarily the same that you should set in the work!

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 amplification block

(7) Slope control

(8) Starting point control

(9) Control for the amplification time range width

(10) Control for the gain level

D – Sockets for connecting an oscilloscope

(11) Trigger signal

(12) Time amplification/gain control

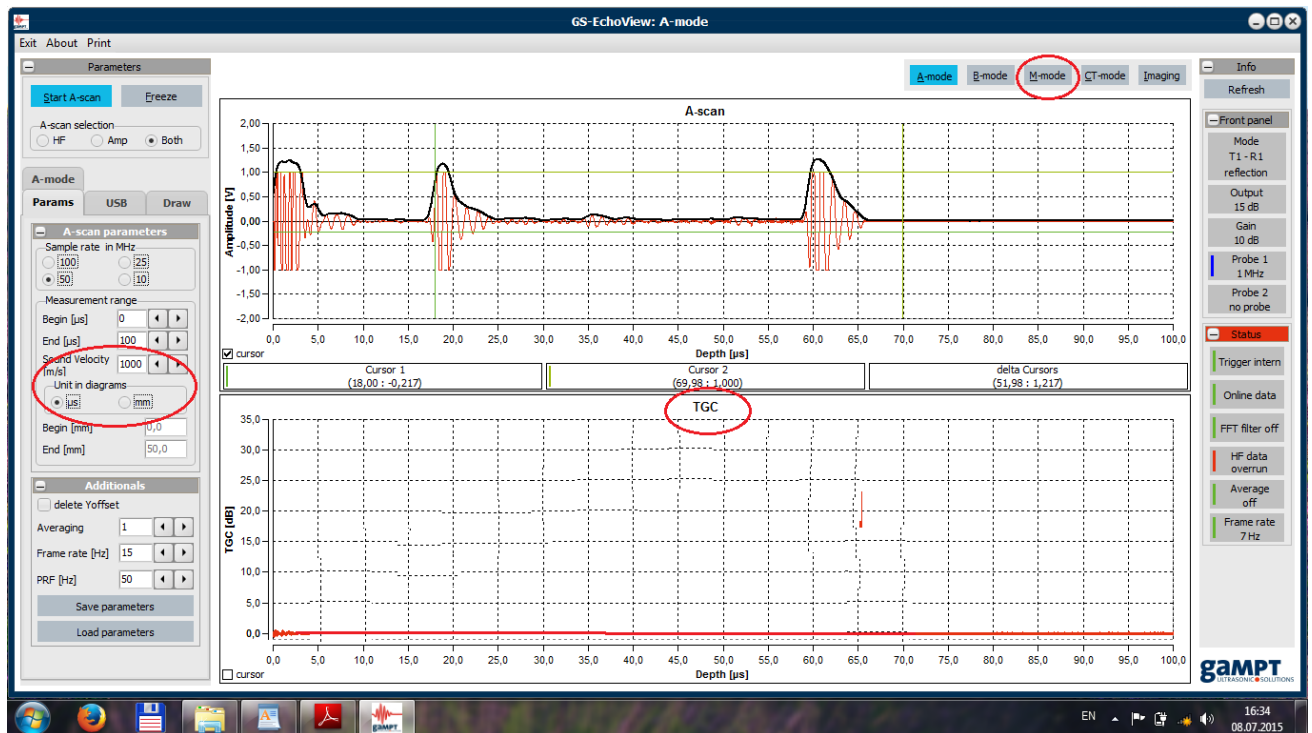(13) Ultrasonic signal

(14) Echo signal

Figure 4. Main window of the GS-EchoView program

Carrying out the experiment

1. Fill the upper container of the heart model with distilled water so that 2-3 cm from the rim remained empty.
2. On the "Params" tab set the "Sound velocity" parameter to 1480 m/s (the velocity of sound in water) and tick the radiobutton "mm" for the units of depth.
3. Switch to the M-regime by the "M-mode" button.
4. Insert the probe into water so that water does not cover the black tip of the probe. The centre of the probe should coincide with the centre of the heart model. Hold it so that it does not move up or down.
5. Start the measurements in the M-regime by pressing the "Start M-scan" button.
6. Squeeze the rubber bulb periodically and record several contractions. Try different contraction frequencies – quick and slow (see figure 5).
7. Save the obtained image by pressing the label 🖫.
8. Calculate the cardiac output and contraction frequency using the formulas described below.
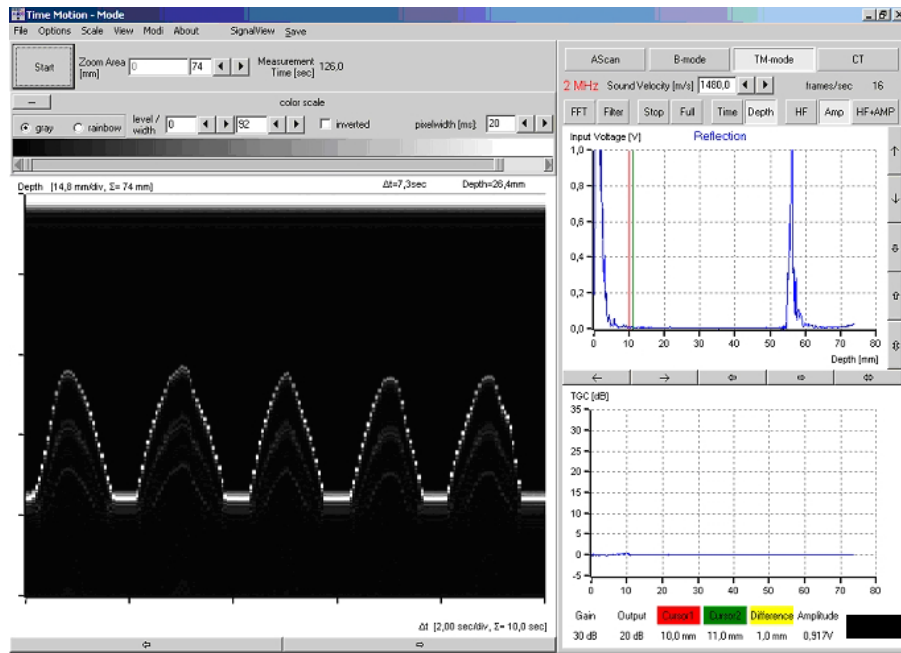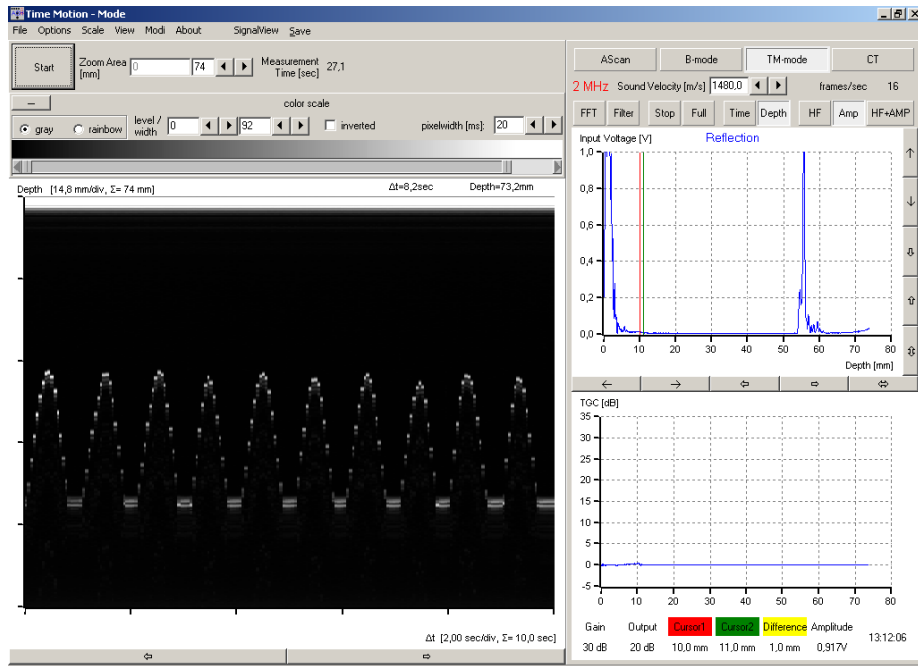
Figure 5. Working window in the M-scan regime. Typical images for quick (upper picture) and slow (bottom picture) tempos of heart contraction.

Determine the period of heart contractions from the beginning (T_{start}) and final (T_{end}) points of the pulses; take five (in the slow contractions case) or ten pulses (in the large frequency case):

$$T_{start} = t_{s2} - t_{s1} \, , \qquad\qquad (1)$$

$$T_{end} = t_{e2} - t_{e1} \, . \qquad\qquad (2)$$

Write down the results in table 1 (slow contractions) and table 2 (fast contractions); calculate mean periods $<T_{start}>$ and $<T_{end}>$.
Find the average heart contractions period T using the formula

$$T = \frac{\langle T_{start} \rangle + \langle T_{end} \rangle}{2}.$$ (3).

Calculate the heart contraction frequency (HCF) f:

HCF $= f = 1/T$. (4)

For each pulse, determine the end systolic diameter (ESD), which is the distance between the highest (X_{max}, mm) and the lowest (X_{min}, mm) positions of the membrane (see figure 5; X_{min} is the zero level):

ESD $= h = X_{max} - X_{min}$. (5)

Calculate the mean value $<h>$.

Assuming that the deformed membrane has a conical shape, the displaced volume is

$$V = \frac{1}{12} \pi D^2 h,$$ (6)

where the diameter of the membrane is $D = 45$ mm.

Since the membrane is flat, the end diastolic volume (EDV) can be assumed to be zero; then the cardiac output is found using the expression

$Q = Vf$, (7)

where V is the end systolic volume and f is the heart contractions frequency.

9. Write down the results in tables 1–3.

Table 1. Parameters of the TM image for slow contractions

Pulse no.	1	2	3	4	5	Mean
Measurements						
t_s, s						
t_e, s						
X_{max}, mm						
X_{min}, mm						
Calculations						
T_{start}, s						
T_{end}, s						
h (ESD), mm						

Table 1. Parameters of the TM image for fast contractions

Pulse no.	1	2	3	4	5	6	7	8	9	10	Mean
Measurements											
t_s, s											
t_e, s											
X_{max}, mm											
X_{min}, mm											
Calculations											
T_{start}, s											
T_{end}, s											
h (ESD), mm											

Table 3. Summary parameters of the TM images

	Slow contractions	Fast contractions
Heart contraction period T, s		
Hear contraction frequency (HCF) f, Hz		
End systolic diameter $<h>$ (ESD), mm		
End systolic volume (ESV), ml[*]		
Cardiac output Q, ml/s		

* In your calculations, pay attention to measurement units for h and D! <u>1 L = 10^{-3} m^3 = 1000 mL</u>

Questions
1. Elastic waves. Wave equations. Velocity of elastic waves. Sound waves.
2. Acoustic impedance. Ultrasound.
3. Scheme of an ultrasonic probe. Piezoelectric effect.
4. Methods of ultrasonic investigation. A-regime, B-regime, M-regime.