Work F13. Ultrasonic Doppler effect

Purpose

- Investigation of the Doppler effect for sound.
- Determination of the variation in the ultrasound frequency as a function of the flow rate and angle of measurement.

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.
8. Do not unplug the tubes with liquid from each other.
9. Do not drink the Doppler liquid.
10. **Important!** When starting the pump programme (with the “Start” knob), assure that the flow rate control handwheel is in the leftmost position (rotate it anti-clockwise), corresponding to the minimal flow speed.

Experimental setup (figure 1)

1. Ultrasonic scanner FlowDop
2. Ultrasonic probe (2 MHz)
3. Setup for measurements (prism 3/8", set of tubes, Multiflow pump, Doppler liquid)
4. Ultrasound gel

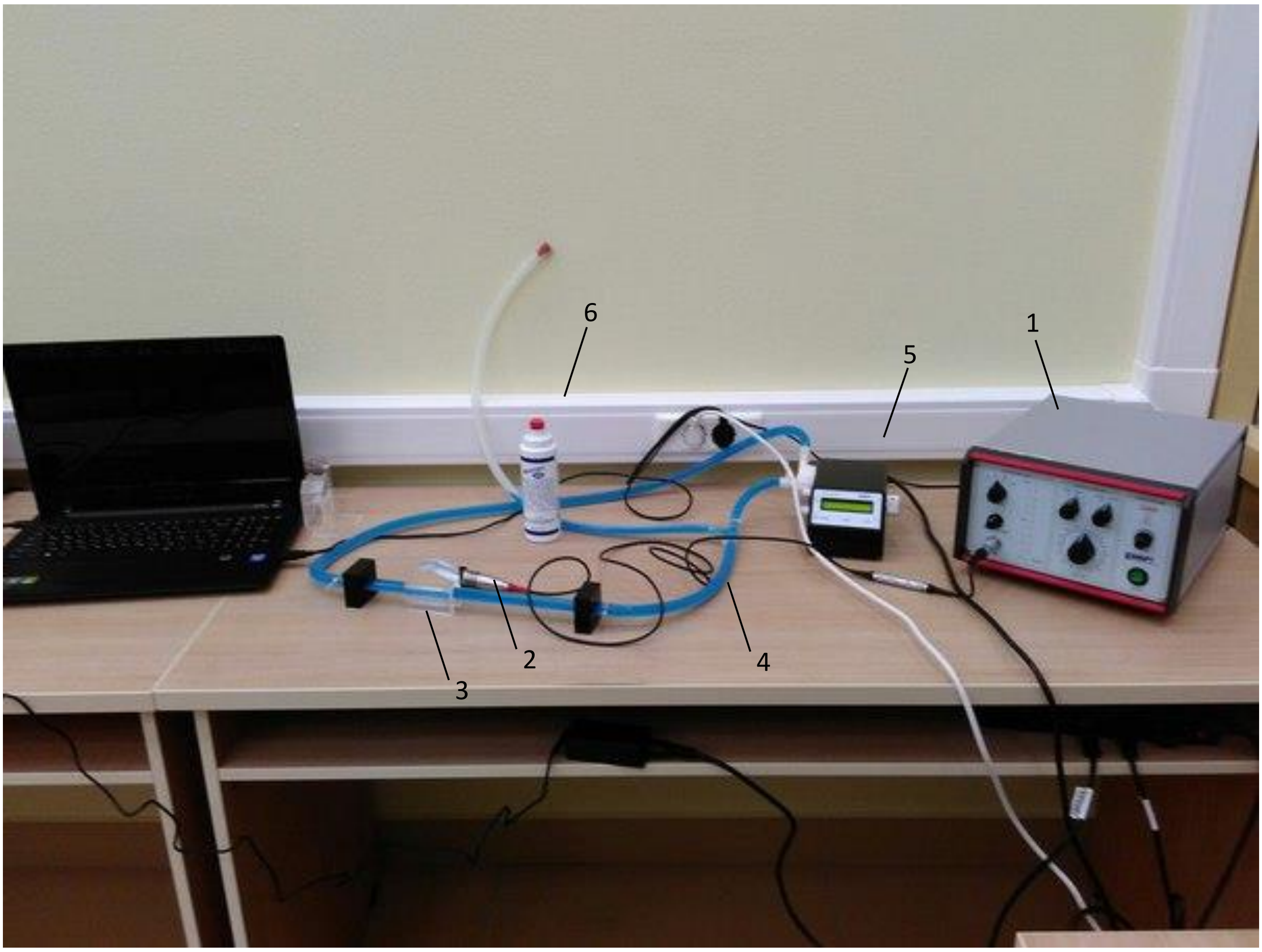

Figure 1. General view of the experimental setup for investigation of the Doppler effect in flow: (1) ultrasonic scanner FlowDop; (2) ultrasonic probe (2 MHz); (3) prism 3/8"; (4) set of tubes; (5) Multiflow pump; (6) ultrasound gel.

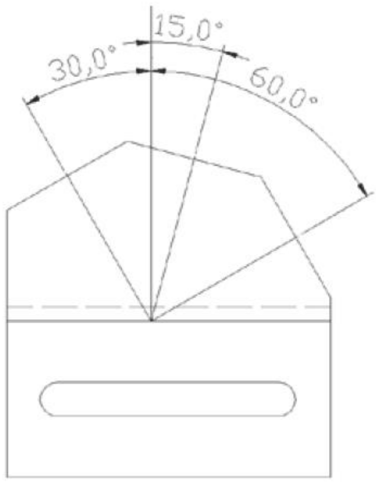

Figure 2. Prism for studying the Doppler effect.

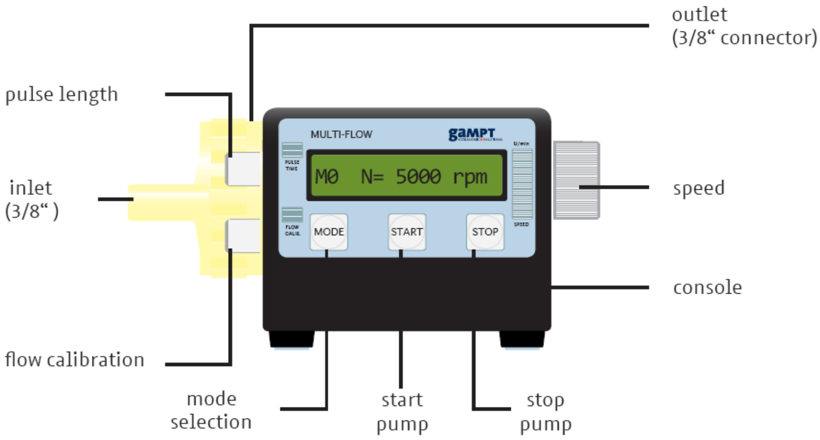

Figure 3. Scheme of the Multiflow pump.

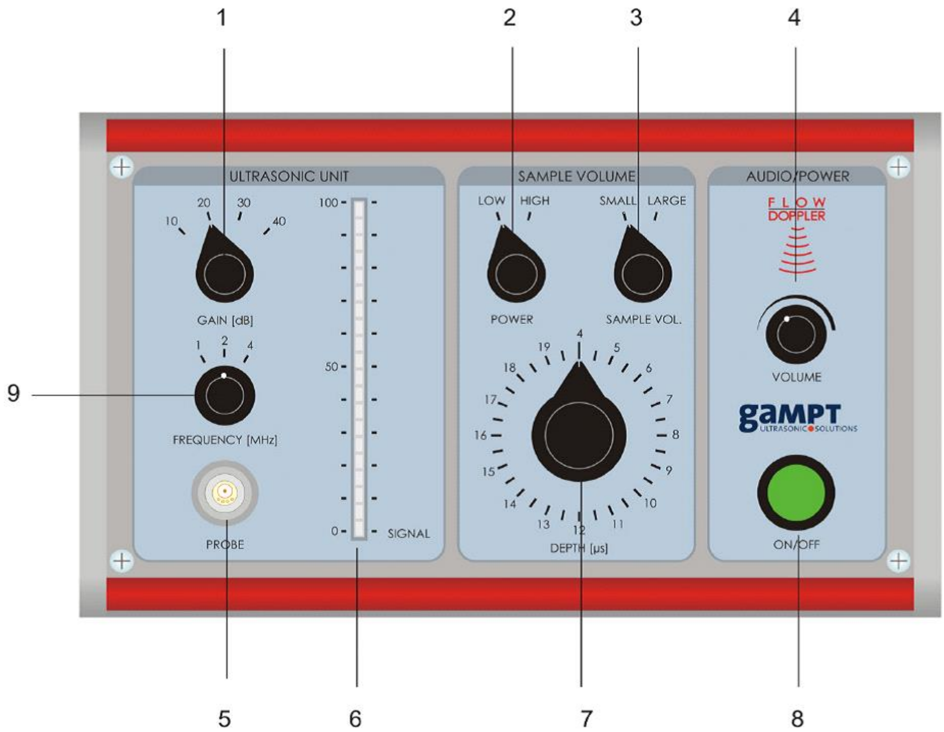

Figure 4. Front panel of the ultrasonic scanner Flow-Dop.

Description of the scanner's front panel:

1. Signal gain switcher
2. Switcher of the packet time or of the transmitter power
3. Switcher of the receiver time window or of the sample volume
4. Audio signal level (volume)
5. Socket for the probe
6. Indicator of the input signal
7. Time window of the receiver (when switcher "3" is in position "Low")
8. Power on-off

Brief theory

When ultrasound wave is reflected by a moving object, its frequency (from the point of view of the receiver/observer) is changed. When the speed of the object v is small compared to the speed of sound c, the ultrasound frequency shift can be determined as

$$\Delta f = f_0 \frac{v}{c}(\cos\alpha + \cos\beta), \qquad (1)$$

where α and β are the angles between the flow direction and the ultrasonic beam. If α = β, then

$$\Delta f = 2 f_0 \frac{v}{c}\cos\alpha\,. \qquad (2)$$

Here f_0 is the frequency of emitted ultrasound. Factor of 2 can be explained by the fact that the Doppler shift occurs twice – when the original wave is incident on the moving particles in the liquid and when the moving particle reflects it back.

Conducting the measurements

Preparations

1. Connect and tune the setup.
2. Check that there are no air bubbles in the tubes.
3. Turn the switchers “Power” and “Sample vol.” to positions “High” and “Large,” respectively.

Measurements

1. Knowing the speed of sound in the Doppler dummy liquid (c_L = 1800 m/s) and in the prism (c_P = 2670 m/s), we can write down the law of refraction and get:

   $$\alpha = 90° - \arcsin\left(\frac{c_L}{c_P}\sin\alpha_P\right). \qquad (3)$$

   Calculate the angles α (between the beam and the flow) and the values of cosα for three different angles of the prism α_P and write down your results in table 1.

   Table 1

Prism angle	Angle α, °	cosα
15°		
30°		
60°		

2. Turn on the Multiflow pump (“Start” knob). In the second regime (controlled by the “Mode” knob, regime M1), set the flow rate to 1 l/min using the handwheel on the side of the pump.
3. Turn on the ultrasound scanner Flow-Dop and launch the programme FlowView on the laptop.

4. Apply a small amount of gel onto the glass tube and put the prism above it. Check that there are no air bubbles between the tube and the prism.
5. Apply a small amount of gel onto a prism side corresponding to a chosen angle and put the ultrasonic probe (2 MHz, red) above.
6. In the FlowView programme choose the proper tube diameter and the angle in the “Parameter” tab (figure 5).

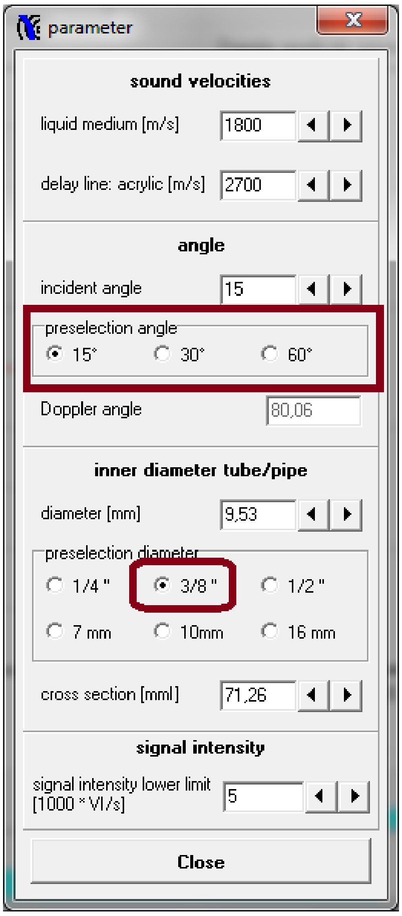

Figure 5. “Parameter” tab.

7. Close the “Parameter” tab and start the experiment with the “Start” button.
8. Look at the spectrum and measure the average frequency shift Δf (parameter “f-mean” in the FlowView programme window, figure 6).

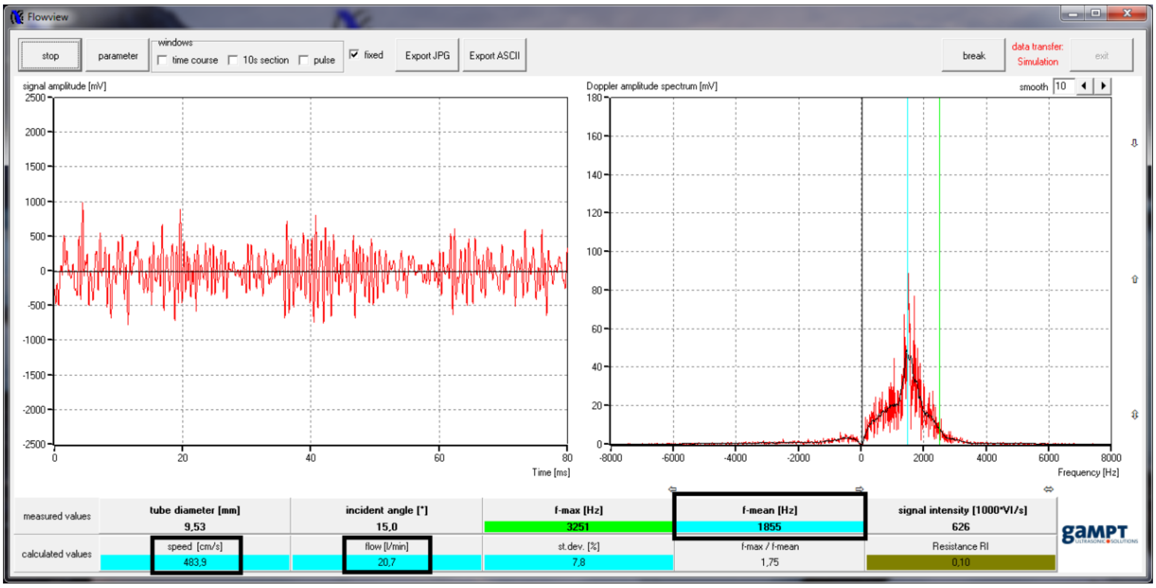

Figure 6. Main window of the FlowView programme.

9. Knowing the frequency shift Δ*f*, calculate the flow speed *v* using Eq. (2), and compare it with the values obtained in the experiment (parameter "Speed," figure 6).
10. Write down your results in table 2.

Table 2

<table>
<tr><td></td><td colspan="3">15º</td><td colspan="3">30º</td><td colspan="3">60º</td></tr>
<tr><td rowspan="2">Flow, l/min</td><td rowspan="2">Δf, Hz</td><td colspan="2">v, cm/s</td><td rowspan="2">Δf, Hz</td><td colspan="2">v, cm/s</td><td rowspan="2">Δf, Hz</td><td colspan="2">v, cm/s</td></tr>
<tr><td>Calcul.</td><td>Exper.</td><td>Calcul.</td><td>Exper.</td><td>Calcul.</td><td>Exper.</td></tr>
<tr><td>1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>1.5</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

11. Repeat steps 2–10 for other flow rates (1.5, 2 l/min).
12. Build the plots for the dependency of the frequency shift on the flow rate (Δ*f*(*v*)) and on cosα (Δ*f*(cosα)).
13. Make conclusions.

Questions

1. Elastic waves. Wave equations. Velocity of elastic waves. Sound waves.
2. Doppler effect for sound waves.
3. Viscosity of liquids. Laminar and turbulent flow. Reynolds number.
4. Hydraulic impedance. The Hagen–Poiseuille law.