Work 198. Measuring arterial pressure using ultrasound

Purpose

Measuring pressure with the aid of ultrasound.

Studying continuous and pulsing flows.

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 Doppler scanner FlowDop (see figure 3)
2. Probe with a fixes Doppler angle
3. Centrifugal pump MultiFlow (figure 2)
4. Model of an arm
5. Arm cuff
6. Ultrasonic gel
7. Laptop

Figure 1. Experimental setup.

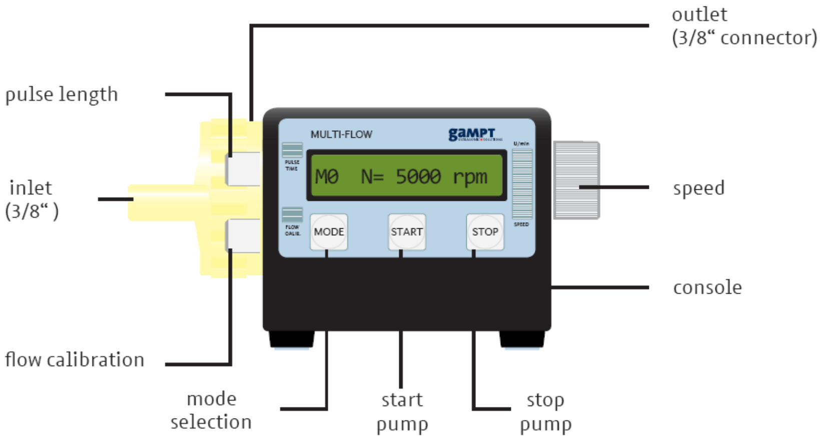

Figure 2. Scheme of the MultiFlow pump.

Using the centrifugal pump

The plump if turned on by a knob on its rear panel. To start the pumping process, press the START button. Pumping can be ceased with the STOP button. Working regimes from M0 to M4 are set using the MODE button. Other regimes are described in detail in the manual of the pump.

Note: For measuring the pressure, the pump should operate at 3000 to 5000 revolutions per minute.

Attention: The pump must not operate for a long time at the maximal rate (no longer than 30 minutes!).

Ultrasonic Doppler scanner FlowDop

Ultrasonic pulsed Doppler instrument FlowDop (figure 3) is connected to the computer via a USB port. Connected and turned on device will be automatically detected by FlowView software as soon as it is launched.
Note: Before your start the Doppler instrument and begin to use it, launch the FlowView software. If the device does not start when you launch the programme or if the programme does not reply, the software goes to the Demo regime.

Ultrasonic probe

For measurements with the model object, the probe operating at 2 MHz is connected to the Doppler instrument at socket 5 (figure 3). Corresponding transmitter frequency of 2 MHz is set by the switcher 9 above the socket. The probe is equipped with a head having the *Doppler angle* of 30° with respect to the surface. Thus it is possible to maintain relatively the same Doppler angle (the angle between the sound wave propagation direction and the flow direction) and obtain the maximal frequency shift.

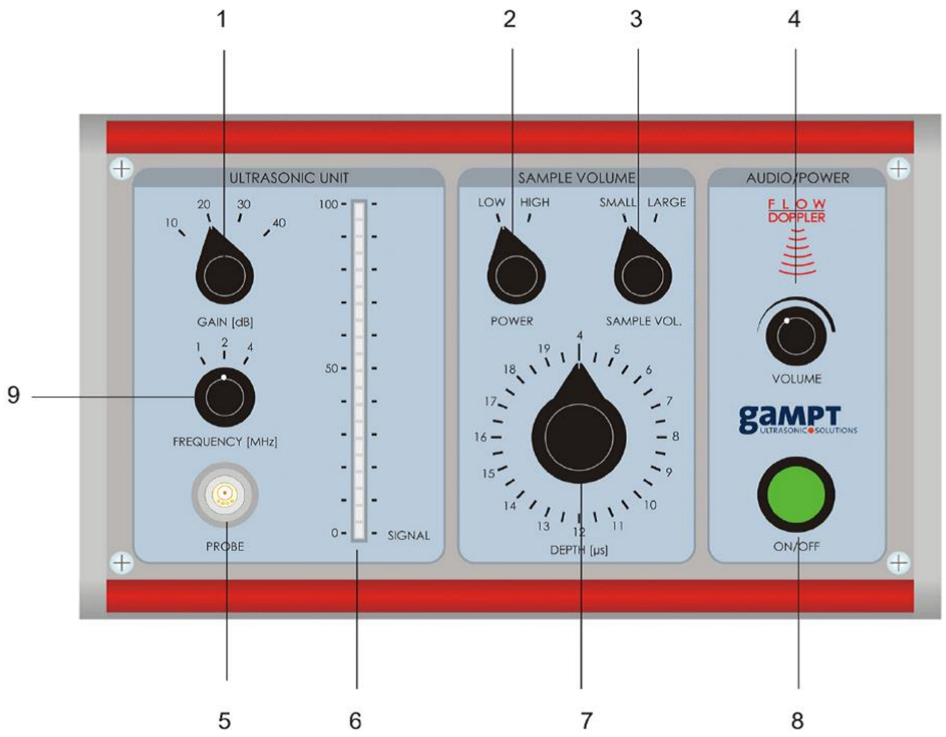

Figure 3. Front panel of FlowDop the ultrasonic scanner.

Description of the scanner’s front panel:

1. Signal gain switcher
2. Switcher of the pack time or of the transmitter power
3. Switcher of the receiver time window or of the sample volume
4. 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 “Small”)
8. Power on-off

Software

The Doppler instrument works in combination with FlowView software which allows receiving the measured data and their analysing. Functions and parameters of the programme are described in detail in the manual to the FlowDop device. Working area of the FlowView window (figure 4):

1. Amplitude of the ultrasonic Doppler signal
2. Spectrum of the Doppler signal (obtained by Fourier transform) indicating the mean Doppler shift frequency *f-mean* and the maximal frequency shift *f-max*. Scaling is adjusted by arrows on the bottom part of the window.

Switching between the processing windows (ticks in the upper part of the window, below the titlebar):

3. “Time course”: temporal behaviour of the Doppler spectrum, colour-coded
4. “10 sec section”: changes in *f-mean* and *f-max* in last 10 s of measurements
5. “Pulse”: frequency spectrum of pulses averaged over 10 s

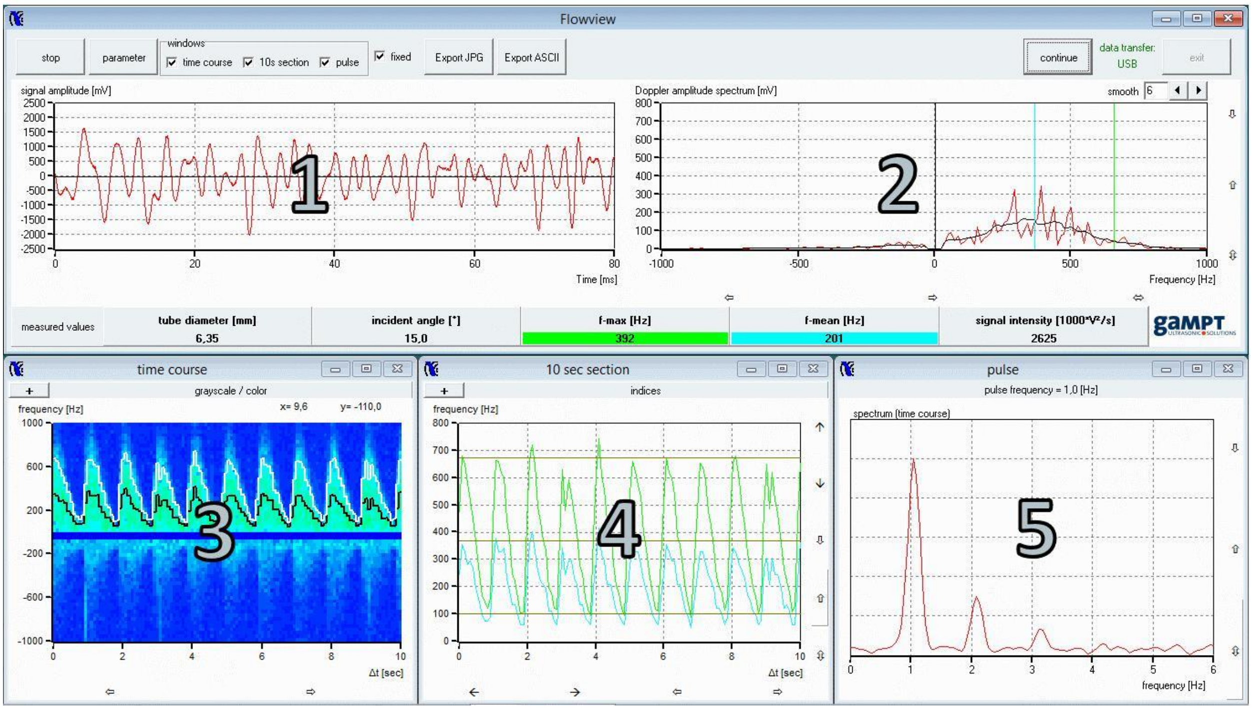

Figure 4. Interface of the FlowView programme.

Brief theory

The notion of blood pressure usually implies the pressure experienced by the wall of blood vessels. In different parts of the blood circulatory system there are different conditions and pressure gradients. The blood pressure depends on the cardiac output, total blood volume, and resistance of the vessels to the blood flow. Blood pressure (in particular, arterial pressure) is an important parameter in medical diagnostics. Blood tension changes between the maximal and minimal values during a cardiac cycle. On the ventricular systole, the blood is pushed into aorta at the pressure of about 120 Torr. On the diastole, the tension decreases to about 80 Torr.

Measuring the blood tension

The blood tension can be measured directly (invasively) or indirectly (noninvasively). Usually the pressure is measured with the aid of an arm cuff.

1) *Riva-Rocci method*

In this method, the inflatable arm cuff is fastened around the arm at the level of the heart and is inflated until the pulse on the radial artery disappears. Strong compression of vessels under the cuff makes the blood flow stop. After that the pressure in the cuff is smoothly decreased until the pulse tones appear. The pressure in the cuff observed immediately after the reappearance of the pulse corresponds to the systolic blood pressure.

2) *Korotkoff tones*

Detonation noise synchronized with the pulse, which was discovered by Nikolai Korotkoff in 1905, enhanced indirect measurement methods by allowing measuring diastolic pressure. Korotkoff tones arise due to turbulent blood flow appearing in a pinched vessel. The tones can be heard using a stethoscope under a sphygmomanometer's cuff (on the bend of elbow). The first tone appears when the pressure in the cuff decreases to the systolic pressure. Blood runs through the arm only near the peak value of the tension. As the pressure in the cuff decreases further, periods when the blood flow is not occluded become longer and longer. Finally, normal pulse in the artery will recover. At this moment, when the artery in not pinched any more, the blood flow loses turbulence and becomes laminar, smooth; as a result, no audible sound is produced. The pressure in the arm cuff after disappearing of the Korotkoff tones is regarded as the diastolic pressure.

3) *Using ultrasound: Doppler blood pressure measurement*

One of possible noninvasive methods of measuring the blood pressure is a combination of ultrasonic investigation (based on the Doppler effect) and a sphygmomanometer's arm cuff. Doppler measurement is used instead of a stethoscope; it allows not only hearing, but also watching the blood flow in a vessel.

The method is based on changing of the ultrasound propagating in blood and reflecting from blood cells which move in the flow. The frequency change Δf is directly proportional to the speed of the blood cell, and thus it represents approximately the speed of the blood flow. This dependence can be described by the following equation:

$$\Delta f = 2 f_0 \frac{v}{c} \cos\alpha , \qquad (1)$$

where f_0 is the frequency of transmitted ultrasound, α is the angle of incidence with respect to the blood flow direction (the Doppler angle), v is the mean speed of the flow over the vessel cross-section, and c is the speed of ultrasound in blood. Similarly to direct measurement of the blood pressure by the Riva-Rocci of Korotkoff methods, the studied blood vessel is squeezed by the arm cuff, and the blood flow stops ($\Delta f = 0$). The measurements are performed distally by an elongated ultrasonic probe distally. The pressure inside the cuff at which the blood flow starts again ($\Delta f > 0$) is the systolic pressure. Since the pressure in the cuff gives the maximal value of the oscillations of the pulse pressure, the diastolic pressure cannot be measured.

Frequency variations Δf which are typical of the blood flow fall within the audible region. Thus they can be observed additionally as acoustical signals (via loudspeakers); the pitch level of the signals would depend on the blood flow speed.

Tasks

1. Studying continuous blood flow using colour coding of the Doppler spectrum as a function of the pressure in the arm cuff.
2. Determination of the dependence of the mean and maximal frequency shift and of the pressure parameters for two different blood flow speeds (cardiac output dependence).
3. Studying the pulsed flow using colour coding of the Doppler spectrum as a function of the pressure in the cuff and pump rate.
4. Determination of the pressure of the pulsed flow at various pump rates and pressures in the cuff.

Conducting the measurements

Preparations

1. Connect and tune the experimental setup.
2. Check that there are no air bubbles in the tubes.
3. Put the cuff on the arm in the region of the brachial artery (see figure 5).

To carry out ultrasonic pressure measurement (indirect method), put the cuff firmly on the part of the silicon tube imitating the brachial artery which is about 8–10 cm from the model arm's end. The measurement itself is performed in an area between the cuff and the bend of elbow. The measurement procedure depends strongly on the position of the cuff and on the power of the pump (number of revolutions per minute, rpm).

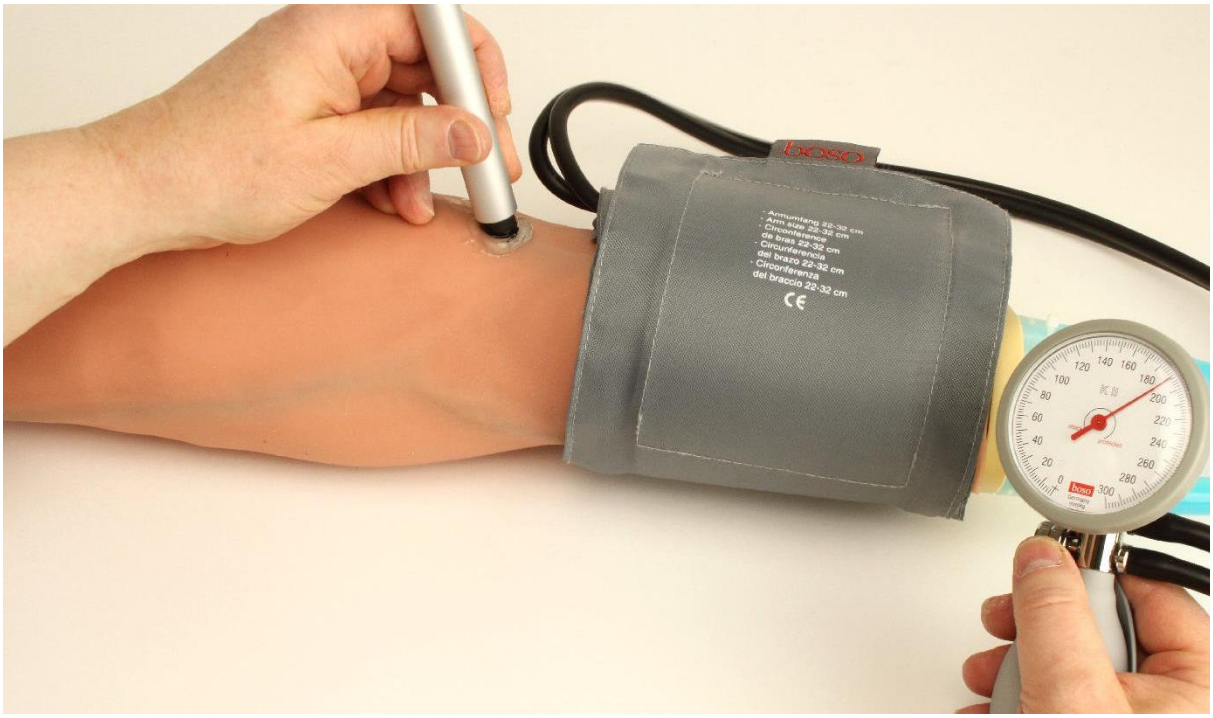

Figure 5. The place for putting on the cuff on the arm model.

Carrying out the experiment

Exercise 1. Measurement of the blood pressure with continuous flow

1. Set the “Gain” switcher on the front panel of the scanner to 40 dB.
2. Set the switchers “Power” and “Sample volume” to “high” and “large,” respectively (figure 3).
3. Set the pump regime to “M0” using the “Mode” button; the pump rate should be within 3000–5000 revolutions per minute (rpm).
4. In the “Parameter” tab of the FlowView programme window choose the appropriate tube diameter (1/4") and angle (30°) (figure 6).
5. Apply ultrasonic gel and put the probe onto the vessel, showing through the skin of the model arm, like in figure 5. Find the position of the probe at which the signal intensity is maximal (by observing the spectrum and the sound).
6. Demonstrate the influence of the pressure in the cuff by changing it with a rubber bulb. The frequency shift and the sound should disappear as the cuff occludes the liquid flow. When air is released smoothly from the cuff, the image in the “time course” window should change (figure 7) according to reappearance of liquid flow and sound signals. The frequency shift also appears as the pressure in the cuff decreases (white line corresponds to f_{max} and black line reflects f_{mean}).

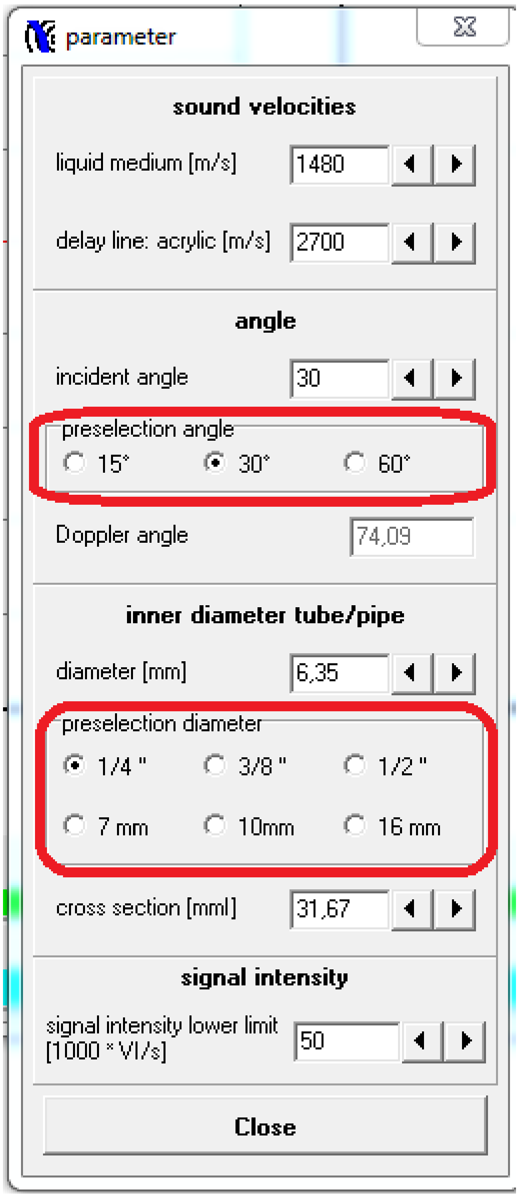

Figure 6. "Parameter" tab.

7. Set the pump rate to 3000 rpm.
8. Pump the cuff until the frequency shift and the sound signal disappear.
9. Release gradually air from the cuff and write down the values of f_{max} and f_{mean} in steps of 10 Torr (down to 0 Torr).
10. Repeat the measurements at the MultiFlow pump rate of 4000 rpm.
11. Decrease the pump rate to 0 rpm.
12. Build the plot of the dependency of f_{max} and f_{mean} on the pressure in the arm cuff at the two pump rates (draw four curves on a single diagram).
13. Make conclusions about the influence of the pump rate (which is analogous to the cardiac output) on the pressure in the system (in the blood-vascular system).

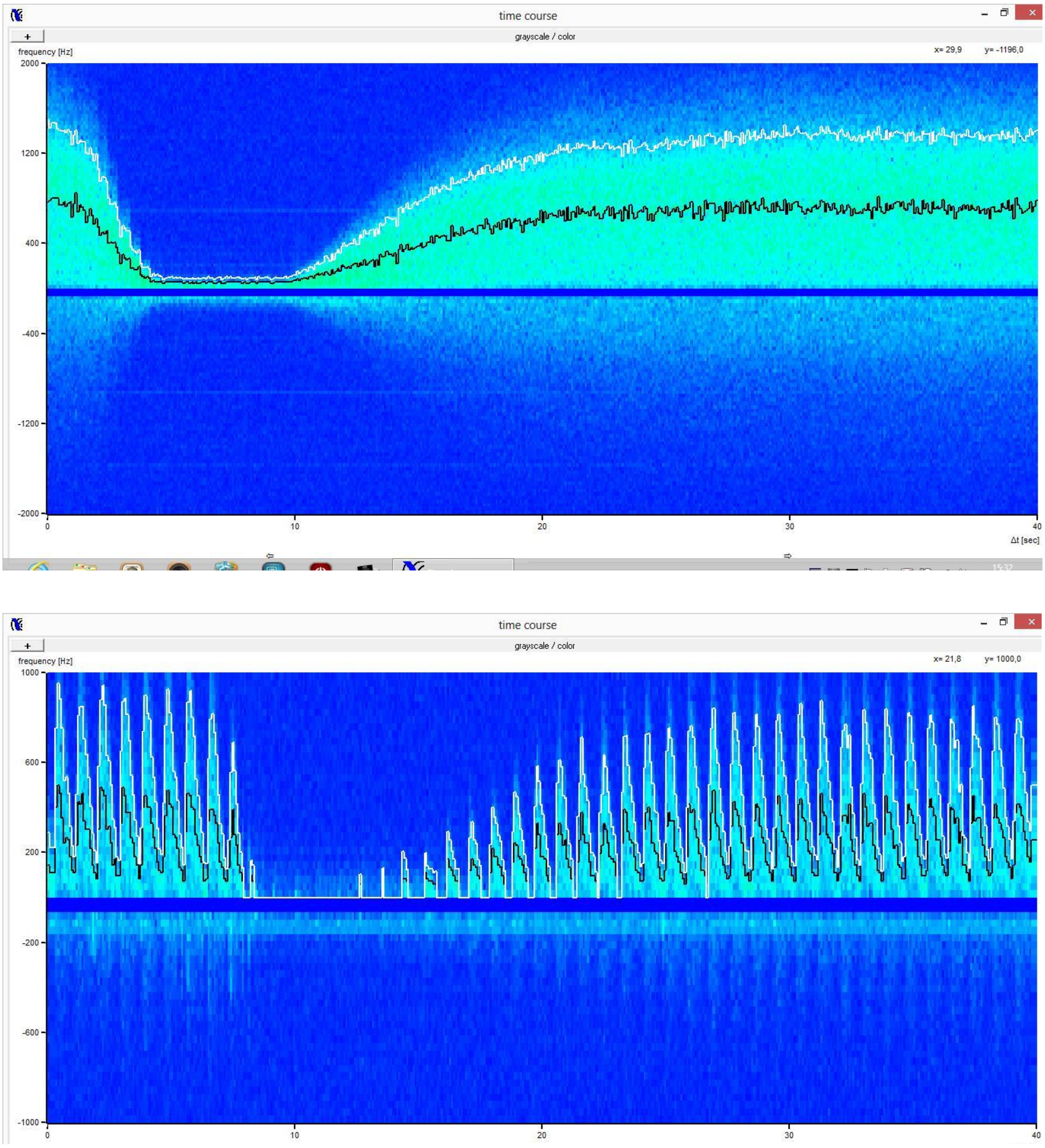

Figure 7. Behaviour of the signal in the colour-coded spectrum with changing pressure: pumping of the cuff – smooth releasing of air – onset of the flow – total release of air.

Exercise 2. Measurement of the blood pressure with pulsed flow

1. Change the pump regime to "M2" (pulsed flow regime).
2. Set the pulse length to a value in the range from 0.7 to 1 s using a small handwheel on the side.
3. Set the pump rate to 3000 rpm.
4. Pump the arm cuff until the sound, the signal in the spectrum and in the pulse window (figure 4, window 5) disappear.
5. Release air gradually from the cuff and find the pressure values at which the changes will occur in the spectrum, in the sound indication, and in the pulse

window. In other words, use three criteria of reappearing of the pulse: spectrum (figure 4, window 3), sound from the apparatus, and pulse recording (figure 4, window 5).

6. Repeat steps 4, 5 at higher pump rates (increase it in steps of 500 rpm up to 5000 rpm, so that finally you have five different pump rates).
7. Build a plot showing the dependency of the pressure in the cuff, at which the changes appear according to the chosen criteria (spectrum, sound, pulse), on the pump rate. Draw three curves on a diagram.
8. Make a conclusion about the effect that the choice of criterion for measuring the pressure has on the measurement accuracy.

Questions

1. Arterial pressure. Methods of measuring.
2. Ultrasound. Types of ultrasonic investigations.
3. Doppler effect.

Recommended sources

1. Vowden P, Vowden K, „Doppler assessment and ABPI: Interpretation in the management of leg ulceration,“ March 2001
2. Holger Lawell, Curt Diehm, „Leitlinien zur Diagnostik und Therapie der peripheren arteriellen Verschlusskrankheit (PAVK),“ April 2009