Practical No 31

MEASUREMENT OF LIQUID FLOW VELOCITY WITH THE USE OF DOPPLER EFFECT

Aim:

The aim of the practical is the measurement of flow velocity of blood-imitating liquid through elastic tube modelling blood vessel. The influence of the angle between ultrasonic probe and the axis of the vessel on velocity measurements will also be studied.

Equipment:

1. Doppler ultrasound unit
2. centrifugal pump
3. ultrasonic probe, 2 MHz
4. vessel model filled with liquid
5. Doppler prism
6. software „measure ultraflow"

Set up of the measurements:

1. Check the parameters of Doppler ultrasound unit:
   Burst Length: 2 [μs]
   Sample wide: 30 [μs]
   Penetration Depth 14 [μs] (left knob set to 1, right knob set to 4)
   Gain: 85 [dB]
   Transceiver mode: PW
   Frequency: 2 [MHz]
   Low Pass Filter: 2,5 [kHz]
   Volume: minimum
2. Using the knob placed at the right side of the pump set the minimal speed of the pump (the knob should be set to "3" o'clock).
3. Using the buttons placed on the back side of the instruments turn on the pump and Doppler ultrasound unit.
4. Turn on the computer and start the software „measure ultraflow". The windows Frequency Signal & Result Values should be visible as well as the tab Main Values.

Procedure:

1. Start the pump with the button START placed on the front panel of the device. Make sure the pump works in M0 mode (if it does not, use the button MODE).
2. Set the speed of the pump to 2700 revolutions/min [rpm]. Ask the teacher to place some ultrasound gel on the surface of the Doppler prism. Place the ultrasonic probe the prism's surface marked A (angle 30°). Start the measurement by pressing the button START on the computer screen. After ca. 1 minute read the mean value of Doppler shift (f_{mean}) [Mean frequency] and write in down to the Table 1. Stop the measurement with the STOP button on the screen.
3. Next place the ultrasonic probe the prism's surface marked B (angle 15°). Start the measurement by pressing the button START on the computer screen. After ca. 1 minute read the mean value of Doppler shift (f_{mean}) [Mean frequency] and write in down to the Table 1. Stop the measurement with the STOP button on the screen.
4. Place the ultrasonic probe the prism's surface marked C (angle 60°). Start the measurement by pressing the button START on the computer screen. After ca. 1 minute read the mean value of Doppler shift (f_{mean}) [Mean frequency] and write in down to the Table 1. Stop the measurement with the STOP button on the screen.
5. Change the speed of the pump to 4500 rpm. Perform the measurements for angles 15, 30 and 60°.
6. Change the speed of the pump to 6300 rpm. Perform the measurements for angles 15, 30 and 60°.
7. Set the minimal speed of the pump. Turn off the pump with the button STOP placed on the front panel of the device.
8. Using MODE button change the pump to M2 mode (pulse work).
9. Start the pump with the button START placed on the front panel of the device.
10. Set the appropriate speed of the pump (the line on the knob should point to "9" o'clock). time of pulse duration should be 0.5 s(use upper knob on the left side of the pump to regulate it). Place the ultrasonic probe the prism's surface marked B (angle 15°). Start the measurement by pressing the button START on the computer screen. After ca. 1 minute press the button FREEZE.
11. Set the minimal speed of the pump. Turn off the pump with the button STOP placed on the front panel of the device.
12. For five freely chosen pulses read off instantaneous values of maximal (diastolic) and minimal (systolic) frequencies from the window Frequency Signal. Write them down to the Table 2. To find the values place the cursor on the appropriate points of the graph. Pay attention to the units of vertical axis!
13. After finishing the measurements turn off the software, turn off the computer, turn off and clean the experimental setup.

Evaluation of the results:

If the Doppler method is applied, the frequency shift that occurs when the sound wave is scattered at small particles or impurities is measured. If an ultrasound wave with the frequency f_0 hits a moving object, this causes a frequency shift due to the Doppler effect.

1. **Table 1.** Find the velocity of the liquid flowing through the tube using the measurement of Doppler shift, i.e. the change of frequency occurring between the emission of the wave by the probe and the wave reflected from the moving particles that returns to the probe. To achieve this one has to know the angle between ultrasonic beam (Doppler angle, α) nd the axis of the vessel. Doppler angle is not the same as the angle of incidence of the ultrasonic beam on the surface of the prism (α_p). To find Doppler angle use the following formula:

$$\alpha = 90° - \arcsin\left(\sin\alpha_p \frac{c_L}{c_P}\right)$$

   where:
   α_p – angle of incidence of the ultrasonic beam on the surface of the prism
   c_L – velocity of sound in the liquid; $c_L = 1800$ [m/s]
   c_P – velocity of sound in the prism; $c_p = 2670$ [m/s]

2. Next, on the basis of Doppler shift f_{mean} find the flow velocity of the liquid (v) through the tube (v). When v is small as compared to the velocity of sound in the surrounding medium c the following formula can be employed:

$$|f_{mean}| = 2f_0\frac{v}{c}\cos\alpha$$

   where:
   f_0 – frequency of ultrasound wave emitted by the probe; $f_0 = 2$ [MHz]
   c – velocity of sound in the prism; c = 2670 [m/s]

3. On the plotting paper plot f_{mean} as a function of the speed of the pump (U) for all studied angles.
4. On the plotting paper plot v as a function of the speed of the pump (U) for all studied angles.
5. **Table 2.** The pump working in a pulse mode imitates the phenomena occurring in blood vessels during the cycle of heart work. Calculate average Doppler shifts during “diastole” and “systole” phase.
6. Calculate “systolic” and “diastolic” velocity of liquid flow through the vessel.

Required theoretical knowledge:

1. Waves. Physical parameters describing waves. Wave equation.
2. Acoustic waves. Audible sounds, infra- and ultrasounds.
3. Ultrasound and its basic properties. Ultrasound sources (piezoelectric effect), the near and the far field.
4. Doppler effect and its application for velocity measurements.

Recommended sources:

1. Glaser, “Biophysics”, Springer, 2001.
2. http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

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Grade:	Tutor's signature

1. Fill in the table.

Table 1.

Speed of the pump **U** [rpm]	Angle of incidence α_p [°]	Mean value of Doppler shift f_{mean} [Hz]	Doppler angle α [°]	Velocity of the liquid flow **v** [cm/s]
2700	**15 (B)**			
2700	**30 (A)**			
2700	**60 (C)**			
4500	**15 (B)**			
4500	**30 (A)**			
4500	**60 (C)**			
6300	**15 (B)**			
6300	**30 (A)**			
6300	**60 (C)**			

2. On the plotting paper plot $|f_{mean}|$ as a function of the speed of the pump (U) for all studied angles.

   How does the value of Doppler shift change when the speed of the pump increases??

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How does the value of Doppler shift change when the angle of incidence of increases?

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3. On the plotting paper plot v as a function of the speed of the pump (U) for all studied angles.

Do the obtained values of v depend on the angle of incidence?

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4. Fill in the table.

Table 2.

Systolic phase			
Instantaneous value of Doppler shift **[kHz]**	Mean value of Doppler shift **f_{mean} [Hz]**	Doppler angle α [°]	Velocity of the liquid flow **v [cm/s]**
Diastolic phase			
Instantaneous value of Doppler shift **[kHz]**	Mean value of Doppler shift **f_{mean} [Hz]**	Doppler angle α [°]	Velocity of the liquid flow **v [cm/s]**