Catalogue

Experimental manuals

Ultrasound

for education and laboratory purposes

www.gampt.de
The following examples of laboratory experiments can be classified into three section-headings:

- **PHY (Physics)** includes the basics of generation, expansion and interaction of ultrasound and the principles of ultrasonic methods
- **MED (Medicine)** includes examples of experiments with medical applications and
- **IND (Industry)** contains selected industrial applications of ultrasound and the topic of non-destructive testing.

The individual experiments are presented under the following headings:

- **PURPOSE** describes the learning objectives of the experimental set, including the knowledge, skills and understanding a student would expect to gain
- **BASICS** gives a short theoretical introduction to the topic and related applications
- **SET UP** lists all the equipment required with order-numbers and includes a photograph of the experiment
- **PROCEDURE** explains the experimental method, measurements taken and possible sources of error
- **RESULTS** are arranged as tables or graphs. Some short explanations and interrelations of the results can be found there.

The experimental instructions are updated and extended permanently and can be downloaded under www.gampt.de.
## Content

### Experiments

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Ultrasonic echography (A-Scan)

**Purpose:**
The relationship between time of flight of ultrasonic echoes, the velocity of sound and the distance between ultrasonic transducer and defect (reflector) for different size of defects is determined. Thus the velocity of the sound passing through the sample is calculated and the position and size of the defect is measured.

**Basics:**
Using the ultrasonic echoscope an ultrasonic probe coupled to the medium under investigation is excited by a short pulse. The emitted ultrasonic wave is reflected at inhomogeneities of the sound impedance and this reflection is detected by the same transducer. The time of flight \( t \) between the start of pulse at the transmitter and the appearance of the echo is related to the velocity of sound \( c \) of the medium with the distance \( s \) of the defect from the ultrasonic probe in the following way:

\[
(1) \quad s = \frac{ct}{2}.
\]

By knowing the velocity of sound of the material under investigation, the distance of a defect can be determined directly from the time of flight. The amplitude of the ultrasonic echo depends on the damping of the material between probe and defect, on the difference of the impedance of the material and defect as well as on the geometric form and orientation of the defect.

**Setup:**
- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 1 MHz order no 10131
- Ultrasonic test block transparent or black order no 10201 or 10204
- Ultrasonic gel order no 70200

**Procedure:**
The longest side of the sample (GAMPT-10201) is measured by a calliper or ruler. Then the ultrasonic transducer is coupled by a coupling gel to the sample and the echoscope is adjusted by varying the power of the transmitter, basic amplification and TGC so that the echo of the back is clearly visible. The time of flight up to the echo is measured and by using the edge length after \( (1) \) the velocity of sound of the material is determined. This is fed into the software and the display switched to „depth“. Now the distance to the defect can be measured directly. All defects of the sample are measured either relative to both long sides (so the extension of the defect can be determined) or are measured from two sides perpendicular to each other in order to find the precise position of the defect.

**Results:**
Measured: length \( s= 150 +/-0,1 \) mm, time of flight \( t = 112,1 +/-0,3 \) µs,
Calculated velocity of sound \( c = 2976 +/- 9\) m/s,
From determined distances calculated hole sizes in comparison to the actual hole sizes (all given in mm). Hole 1 and 2 cannot be separated by the 1 MHz probe. Hole 10 can be measured only from one side (acoustic shadow of hole 11).

<table>
<thead>
<tr>
<th>hole nr.</th>
<th>back</th>
<th>1/2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>echo S1</td>
<td>80,1</td>
<td>18,6</td>
<td>61,4</td>
<td>53,9</td>
<td>46,6</td>
<td>39,1</td>
<td>31,0</td>
<td>23,3</td>
<td>15,2</td>
<td>7,9</td>
<td>55,5</td>
</tr>
<tr>
<td>echo S2</td>
<td>60,0</td>
<td>14,2</td>
<td>22,3</td>
<td>30,6</td>
<td>39,5</td>
<td>47,2</td>
<td>55,2</td>
<td>63,3</td>
<td>-</td>
<td>15,9</td>
<td></td>
</tr>
<tr>
<td>hole size</td>
<td>4,5</td>
<td>3,9</td>
<td>2,9</td>
<td>1,5</td>
<td>1,9</td>
<td>1,6</td>
<td>1,6</td>
<td>-</td>
<td>-</td>
<td>8,7</td>
<td></td>
</tr>
<tr>
<td>caliper</td>
<td>80,0</td>
<td>1,5</td>
<td>6,0</td>
<td>5,0</td>
<td>4,0</td>
<td>3,0</td>
<td>3,0</td>
<td>3,0</td>
<td>3,0</td>
<td>3,0</td>
<td>10,0</td>
</tr>
</tbody>
</table>
Purpose:

The velocity of sound in acrylics shall be determined by time of flight technique with the echoscope. For this the measurement is done at three cylinders of different length in reflection as well as in transmission by ultrasound probes of different frequencies.

Basics:

From the known distance \( s \) between the ultrasonic probe and the boundary of the solid and also the measured time of flight \( t \) the longitudinal velocity of sound \( c \) can be determined for perpendicular incidence of sound in the following way:

for measurements in reflection \( (1) \)

\[
\frac{c}{s} = \frac{2s}{t}
\]

for measurements in transmission \( (2) \)

\[
\frac{c}{s} = \frac{s}{t}
\]

Since nearly all ultrasonic probes are produced with a protective layer on the active surface (ceramics) this causes an error in measurement of the velocity of sound because the time of flight is measured through this layer. That means the measured time of flight \( (t) \) is built from the time of flight in the protective layer \( (t_{AS}) \) and the time of flight in the sample \( (t_{P}) \).

This error can be eliminated if the speed of sound is determined by a difference calculation from two measurements of different sample lengths:

\[
\frac{c}{P} = \frac{(s_{P1} - s_{P2})}{(t_{P1} + t_{AS} - (t_{P2} + t_{AS}))} = \frac{(s_{P1} - s_{P2})}{(t_{P1} - t_{P2})}
\]

Procedure:

The lengths of three different cylinders made from acrylics are measured. Then both the time of flight in reflection as well as in transmission are measured with a 1 MHz probe. This measurement is then repeated with a 2 MHz probe. The measurement of the time of flight is always done from the beginning of the transmitter pulse up to the beginning of the echo (received pulse). The velocity of sound is determined for each single measurement after the formula \( (1) \) and \( (2) \), respectively as well as for the differences referring to the smallest distance after \( (3) \). The determined velocities of sound are compared with each other and statements concerning errors in measurement, systematic errors and possible frequency dependencies are made.

Results:

<table>
<thead>
<tr>
<th>( s_P ) [mm]</th>
<th>( \Delta s_P ) [mm]</th>
<th>( t_P ) [µs]</th>
<th>( \Delta t_P ) [µs]</th>
<th>( c_L(1,2) ) [m/s]</th>
<th>( \Delta c_L ) [m/s]</th>
<th>( c_L(3) ) [m/s]</th>
<th>( \Delta c_L ) [m/s]</th>
<th>( c_L(2) ) [m/s]</th>
<th>( \Delta c_L ) [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>40,2</td>
<td>0,1</td>
<td>15,7</td>
<td>0,2</td>
<td>2561</td>
<td>39</td>
<td>15,5</td>
<td>0,2</td>
<td>2594</td>
<td>40</td>
</tr>
<tr>
<td>79,8</td>
<td>0,1</td>
<td>30,6</td>
<td>0,2</td>
<td>2608</td>
<td>20</td>
<td>2658</td>
<td>85</td>
<td>30,4</td>
<td>2658</td>
</tr>
<tr>
<td>80,4</td>
<td>0,2</td>
<td>30,8</td>
<td>0,2</td>
<td>2610</td>
<td>23</td>
<td>2662</td>
<td>90</td>
<td>30,6</td>
<td>2627</td>
</tr>
<tr>
<td>119,2</td>
<td>0,1</td>
<td>45,3</td>
<td>0,2</td>
<td>2631</td>
<td>14</td>
<td>2669</td>
<td>43</td>
<td>45,1</td>
<td>2643</td>
</tr>
<tr>
<td>159,6</td>
<td>0,2</td>
<td>60,6</td>
<td>0,2</td>
<td>2634</td>
<td>12</td>
<td>2659</td>
<td>30</td>
<td>60,4</td>
<td>2642</td>
</tr>
<tr>
<td>238,4</td>
<td>0,2</td>
<td>90,2</td>
<td>0,2</td>
<td>2643</td>
<td>8</td>
<td>2660</td>
<td>13</td>
<td>90,0</td>
<td>2649</td>
</tr>
</tbody>
</table>

The velocities of sound calculated after \( (1) \) and \( (2) \) show a systematic error, whose influence becomes smaller with increasing measuring length. This error is larger for 1 MHz than for 2 MHz (the protective layer is larger for 1 MHz). The after \( (3) \) calculated values show by their homogeneity that this error has been eliminated. The mean value is 2662 m/sec for 1 MHz and 2 MHz. Moreover it appears that the error caused by the protective layer is larger than the error in measurement of the measuring set up. A comparison of the measurements for 1 MHz and 2 MHz shows that in this frequency range a frequency dependence of the velocity of sound (dispersion) does not occur for acrylics.

Literature value: longitudinal sound velocity of acrylics =2600-2800 m/s
Purpose:
The damping of ultrasound in solids shall be determined for 3 different frequencies in reflection as well as transmission and be compared with values from the literature. Moreover the frequency dependence of damping is dealt with.

Basics:
A sound wave running through a medium loses energy at different processes (scattering, absorption, reflection). This is called attenuation. The intensity $I$ of the wave obeys the attenuation law

\[ I = I_0 e^{-\mu x} \]

where $(I_0)$ is the initial intensity, $(x)$ is the path length in the medium and $(\mu)$ is the attenuation coefficient. By measuring two samples of the same material but of different lengths the material specific attenuation coefficient $(\mu)$ can be determined by (2) that comes from (1) by rearrangement. Here is taken into account that the intensity $(I)$ is proportional to the square of the amplitude $(A^2)$ and that the conversion into the commonly used unit dB/cm results in

\[ \mu = \frac{\mu [\text{dB/cm}]}{20 \log(e)} = \frac{\mu [\text{dB/cm}]}{8.686} \]

Procedure:
By means of a measuring cursor for the determination of amplitudes the amplitude $(A)$ of the (a) back wall echo and the (b) transmission pulses is determined for three acrylic samples of different length. This is done for 1 MHz as well as for 2 and 4 MHz probes. The lengths of the samples are measured by a calliper. From the measured amplitudes the damping values are calculated after (2). Because of deviations in the characteristics of the probes only measurements of the same frequency and type of measurement (reflection or transmission) are in proportion. Moreover in all cases the adjustment of amplification must be identical.

Results:

<table>
<thead>
<tr>
<th>Measurement value</th>
<th>1 MHz</th>
<th>2 MHz</th>
<th>4 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>cylinder 1: 40,2 mm</td>
<td>A [mV]</td>
<td>$\mu$ [dB/cm]</td>
<td>A [mV]</td>
</tr>
<tr>
<td>40,2</td>
<td>832</td>
<td>928</td>
<td>829</td>
</tr>
<tr>
<td>79,8</td>
<td>315</td>
<td>4,26</td>
<td>902</td>
</tr>
<tr>
<td>119,2</td>
<td>125</td>
<td>4,17</td>
<td>73</td>
</tr>
<tr>
<td>80,4</td>
<td>702</td>
<td>872</td>
<td>872</td>
</tr>
<tr>
<td>159,6</td>
<td>103</td>
<td>4,21</td>
<td>69</td>
</tr>
<tr>
<td>238,4</td>
<td>23</td>
<td>3,76</td>
<td>8</td>
</tr>
<tr>
<td>mean</td>
<td>4,10</td>
<td>5,07</td>
<td>9,08</td>
</tr>
<tr>
<td>SD</td>
<td>0,23</td>
<td>0,21</td>
<td>0,15</td>
</tr>
</tbody>
</table>

The attenuation coefficients amount to 4,1 dB/cm for 1 MHz, 5,1 dB/cm for 2 MHz and 9,1 dB/cm for 4 MHz. That means that in acrylics the attenuation increases strongly with the increasing frequency. Measurements with 4 MHz in reflection are not possible anymore because the damping is too large to allow measuring of all lengths with comparable adjustments. The attenuation coefficients do not differ much for transmission and reflection, so that the influence of sound field does not play any role.
Purpose:

The attenuation of sound in various liquids is measured depending on the layer thickness and is displayed graphically. By linear regression and by means of the law of attenuation the attenuation coefficients are calculated for particular materials.

Basics:

During the extension in liquids the sound wave suffers an attenuation that is caused by a loss of energy (absorption), reflection, scattering and geometry of the sound field. For the total damping holds:

\[ DGes = DAbs \cdot DRef \cdot DStreu \cdot DGeo \]

Reflection and scattering can be neglected for many liquids. The influence of the sound field geometry can be estimated by comparison within water (absorption is negligible at low frequencies). For the attenuation of the signal amplitude the general attenuation law holds:

\[ A = A_0 \cdot e^{-\alpha x} \]

Results:

With an external program the attenuation coefficient alpha can be determined in an easier way from a linear fit if the function

\[ 2 \cdot L \cdot n \frac{A_i}{A_0} = 8,686 = \alpha (x_i - x_0) \]

is plotted corresponding to linear equation: \( y = a \cdot x + b \). 

\( A_0 \) is the amplitude of the first measurement from the sight of the ultrasound probe. All the following measurements (i) are related to this value, so that for large distances the error of measurements becomes smaller.

The measurement in comparison with water does not show a measurable damping at the applied frequency of 2 MHz, so that the influence of the geometry of the sound field can be assumed negligible for these measurements.

Setup:

- Ultrasonic echoscope GAMPT-Scan order no 10121
- 2x ultrasonic probe 2 MHz order no 10132
- Aluminium sample for shear wave order no 10213
- Shear wave set order no 10210
- Ultrasonic gel order no 70200

In liquids the amplitudes of the reflected signal for different distances are determined easily by means of a movable reflector. The attenuation coefficient alpha is then calculated for two layer thicknesses \( x_i/2 \) and \( x_i/2 \) (for measurements in reflection the path length of sound is two times the layer thickness) after the following equation:

\[ \alpha = \frac{1}{(x_i - x_0)} \ln \frac{A_i}{A_0} \]

The unit of the attenuation coefficient is in this case \([1/cm]\) or \([\text{Neper/cm}]\). Generally the unit \([\text{dB/cm}]\) is used for the attenuation coefficient for the sound intensities \( I \sim A^2 \). With the conversion of the dB-scale: \( \text{dB} = 20 \cdot \log (e) \) the attenuation coefficient alpha is calculated by:

\[ \alpha \ [\text{dB/cm}] = 2 \cdot \alpha \ [\text{Neper/cm}] \cdot 8,686 \]

Procedure:

First of all the velocity of sound in the liquid is determined in transmission. For this the sample vessel is transmitted once in longitudinal and then in cross-direction, the time of flight and distance of transducers are measured. From ratio of the differences the velocity of sound in the liquid is calculated. The values can be put into the program, so that the layer thickness can be determined directly from the measurements of times of flights. For the recording of the measuring curve it is advisable to carry out all measurements with the same adjustment of amplification. For each measurement the reflector has to be adjusted for maximum signal amplitude.
Purpose:
Using a simple model of the multiple reflection at a plate the difference between a spectrum of a pulse and the spectrum of periodic signals is demonstrated. Moreover the cepstrum shall be built from a periodic spectrum and the length of period of the signal be determined from the spectrum as well as from the cepstrum. The length of period is proportional to the plate thickness. From the received length of period the particular plate thickness shall be determined.

Basics:
By means of Fourier transformation (FFT) it is possible to decompose a time variable signal into the frequency components contained within it. From the generated spectrum one derives additional properties of the object under investigation. The influence of a periodic excitation (here multiple reflections) manifests as spectral maxima at multiples of the fundamental frequency $F_0$. Thus as multiplicative superpositions of the fundamental spectrum of the probe with an undulation in form of equidistant maxima in the spectrum, the distance of which corresponds to the fundamental frequency $F_0$. From the distance of maxima follows via $T_0 = 1/F_0$ the time of flight between the reflexes. By means of the so-called cepstrum method the spectrum can be smoothed and the length of the period $T_0$ be determined directly. The cepstrum arises by a FFT of the logarithmised spectrum. By logarithmising the multiplicative superposition of the periodicity and the fundamental spectrum becomes an addition. If $F_0$ and the fundamental frequency are wide apart from each other (e.g. 200 kHz and 2 MHz), the now additive parts can be separated by a further FFT in the generated cepstrum. If a filter is applied in the cepstrum between the frequency parts the fundamental spectrum can be restored by an inverse Fourier transformation.

Procedure:
The reflection signal generated at the combination of delay path (40 mm cylinder) and the plate is adjusted by means of TGC to nearly the same height for all reflexes. The distances of the multiple reflexes are measured, then a spectrum of the first reflex, and respectively a spectrum and cepstrum (software function FFT) of the whole time range of the multiple reflexes are built. From that the mean frequency distance and the first peak in the cepstrum is measured, resp. in order to determine the time of flight of one reflex. With the known velocity of sound of the plate (2670 m/sec) the thickness is calculated.

Results:
The echo image shows the first reflex at the transition of the delay path to the reflection plate. The multiple reflexes appear inside the plate. If one measures the distances between the particular multiple reflexes, one obtains 6,9 µs resp. and with a velocity of sound of 2670 m/s a thickness of 9,2 mm. A FFT over the first reflex at the plate yields the spectrum of the probe (Fig. 1) with a maximum at 2 MHz. A FFT over the three multiple reflexes in the plate gives a spectrum (Fig. 2) in which the parts of the probe and the periodic parts of the reflections at the plate are superimposed. If one determines the distance between the maxima one obtains a mean difference of frequency of 144 kHz. This corresponds to a time of flight of 6.95 µs, which gives a plate thickness of 9,3 mm. Creating (from this spectrum) the cepstrum (Fig. 3) from the first maximum a periodic time of flight of 6,9 µs can be read directly. In this way the spectral evaluation methods provide further possibilities for thickness measurements and the determination of scattering distances for small periodic structures.
Purpose:
By means of two neighbouring defects the different axial resolution power of a 1 MHz and a 4 MHz ultrasonic probe is examined. Thus the relationship between wavelength, frequency, pulse length and resolution power is illustrated.

Basics:
The methods of investigation with ultrasonic systems are based on the exact correlation of the information about a point in the region of examination to a recorded ultrasonic echo. The smallest distance between two points whose echoes can be just resolved is called the resolution power. The length of the sound pulse limits the axial resolution whereas the lateral resolution power is limited by the geometry of the sound field of the probe. Both effects depend strongly on the frequency. With increasing frequency the sound pulses become shorter so that the axial resolution power increases. However the depth of penetration decreases with increasing frequency.

Procedure:
First of all the frequency of the probe is determined at a slightly damped echo. For this the echo of a localised defect near the surface is examined at a test block. By adjusting the power of the transmitter and receiver and the TGC a suitable RF-signal is adjusted. With both measuring lines the pulse length and the distance are measured for a number of oscillations in the time range and from this the frequency is calculated. It is recommended to use the zoom function for the 4 MHz probe. Then consequently the double defect of the test block is investigated with the 1 MHz and 4 MHz probe respectively. In the echogram the distance of both defects is measured.

Results:
The determination of the frequency of probes from the echo in the time range shows deviations from the nominal frequency:
1 MHz: \( T = 4,7 \mu s / 5 \text{ periods} \quad f = 1,06 \text{ MHz} \)
4 MHz: \( T = 1,3 \mu s / 5 \text{ periods} \quad f = 3,85 \text{ MHz} \)
These deviations are caused by the frequency dependent damping, the large bandwidth of a pulse probe and the relative large error in measurement at the time limited resolution of the echoes.
The determination of the pulse length shows distinctly longer pulses for lower ultrasound frequency.
Pulse length:
1 MHz 10 \( \mu s \)
4 MHz 3 \( \mu s \)
During the investigation of the double defect it appeared that the holes could not be resolved by the 1 MHz probe. There is only one peak for both holes. The echogram using 4 MHz shows two distinctly separated peaks. The time distance of the peaks was determined to 1.3 \( \mu s \). With a velocity of sound of 2680 m/s the hole distance amounts to 1,7 mm.
(Control measurements by the calliper: 1.6 mm)
Purpose:
Using sound transmission through a parallel plate at different angles the origin and transmission of longitudinal and shear sound waves are shown in solids. From the relationship between amplitude and angle the longitudinal and shear velocity of sound of the plate material is determined and from that the elastic coefficients of the material are found.

Setup:
- Ultrasonic echoscope GAMPT-Scan order no 10121
- 2x ultrasonic probe 1 MHz order no 10131
- Shear wave set order no 10210
- Aluminum sample for shear waves order no 10213
- Ultrasonic gel order no 70200

Basics:
At oblique incidence of an ultrasonic wave from a liquid at a solid longitudinal as well as shear sound waves are excited in the solid. Since the transmission of the shear wave through the plate is maximal at an angle of 45° from the maximum of the shear amplitude curve this incident angle φ is determined and by that the shear velocity of sound is calculated by (1)

$$ c_s = \sqrt{1/2} \frac{c_i}{\sin(\phi)} $$

(c_s is velocity of sound in the liquid). From the angle of first total disappearance of the longitudinal wave (total reflection) the longitudinal velocity of sound is determined after (2)

$$ c_L = \frac{1}{\sin(\phi)} c_i $$

Procedure:
Using two different materials (acrylics, density = 1.2 g/cm³ aluminum, density = 2.7 g/cm³) the transmission amplitudes of the longitudinal and shear sound waves are measured for different angles of incidence in very small steps (2.5°), starting at perpendicular incidence up to angles with vanishing signals. Since the sound velocity of the shear wave is distinctly smaller than that of the longitudinal wave the echoes can be separated quite easily because of the difference in time of flights. The following ranges can be distinguished (example acrylics): 1. angle of incidence 0°, only the peak of longitudinal sound wave exists with possible multiple reflexes (no shear forces); 2. small angle (<=10°), multiple reflexes disappear, longitudinal amplitude becomes smaller; 3. angle range between 10 - 30°, peaks of longitudinal as well as shear waves exist; 4. angle range > 30°, only shear wave exists with decreasing amplitude at increasing angle. For other materials the situation is similar at other angles. The measured amplitudes are plotted versus the incidence angle from the normal. From the angle of total reflection of the longitudinal wave and the angle of maximal amplitude of the shear wave the velocities of sound are determined after (2) and (1) and the elastic coefficients are calculated after (3) and (5), the results are compared with values from the literature.

Results:
The following values of angles φ can be read from the measured numbers or be determined by means of interpolation (angle of maximum) or extrapolation (angle of total reflection) and from these the velocities of sound are calculated by (1) and (2) (velocity of sound in water = 1480 m/s):

<table>
<thead>
<tr>
<th>Material</th>
<th>Maximum shear</th>
<th>Total reflection shear</th>
<th>Total reflection longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>φ [°]</td>
<td>v_τ [m/s]</td>
<td>φ [°]</td>
</tr>
<tr>
<td>acrylic</td>
<td>41</td>
<td>1595</td>
<td>86</td>
</tr>
<tr>
<td>aluminum</td>
<td>17</td>
<td>3579</td>
<td>29</td>
</tr>
</tbody>
</table>

By comparison with values from the literature (aluminum v_τ=6320-6420 m/s, v_τ=3040-3160 m/s), we find in this case that the plate is not pure aluminum but an alloy. For acrylics (v_τ=2610-2780 m/s, v_τ=1430-1450 m/s) shows that the determination from the maximum angle gives too large values. For this, effects of damping and geometry can play a role. Therefore the calculation of the elastic coefficients by (3) to (5) the values determined from the total reflection were used.

<table>
<thead>
<tr>
<th>Material</th>
<th>calculated</th>
<th>literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>acrylic</td>
<td>1.2</td>
<td>2.7</td>
</tr>
<tr>
<td>aluminium</td>
<td>0.29</td>
<td>0.30</td>
</tr>
<tr>
<td>v_0</td>
<td>0.36</td>
<td>0.33</td>
</tr>
<tr>
<td>E [MPa]</td>
<td>6800</td>
<td>3300</td>
</tr>
<tr>
<td>G [MPa]</td>
<td>2600</td>
<td>1700</td>
</tr>
</tbody>
</table>

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<tr>
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</tr>
<tr>
<td>G [MPa]</td>
<td>2600</td>
<td>1700</td>
</tr>
</tbody>
</table>
Ultrasonic B-Scan

Purpose:
The basics of generation of ultrasonic B (Brightness) -scans are shown with a simple sample object. The the characteristics of image quality are explained, like focus zone, resolution power and artefacts.

Setup:
- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 1 MHz order no 10131
- Ultrasonic probe 2 MHz order no 10132
- Ultrasonic test block transparent order no 10201 or black order no 10204

Basics:
At the ultrasonic section image the echo amplitude is shown as a gray scale value (brightness -> B-scan) and the time of flight as penetration depth. The lining up of several adjacent A-scan lines results in the section image. For this the probe will be moved lengthwise over the area of interest, the local assignment alongside this movement is done with the position and the speed of the probe.

A simple way to generate the B-scan is by slowly moving the probe by hand (compound scan). Thereby a precise lateral local power resolution is only possible with additional systems to get the coordinates (i.e. linear scanner). However, with the arbitrary slow scan speed it is possible to generate images with high quality in a wide area of interest. The image quality depends on the following parameters:
- precise registration of the coordinates (scanner system)
- axial power resolution (ultrasonic frequency)
- lateral power resolution (ultrasonic frequency, geometry of the sound field)
- gray scale resolution (transmission power, amplification, TGC)
- number of scan lines (speed of probe movement)
- aberrations (sound shadows, movement artefacts, multiple reflections)

Procedure:
To generate a B-scan, first estimate the sound velocity of the acrylic block. Following this the test block will be measured using the A-scan with suitable adjustments for transmitter and receiver, so that the signal amplitudes from objects near the surface are not saturated. Important beyond everything else for this is the TGC. For the acoustic coupling of the ultrasonic probe the use of a water film is recommended as the ultrasonic gel has a strong static friction. Input the size and the sound velocity of the test block into the B-scan software. After starting the measurement move the probe with constant speed over the block. The dependence of the image quality can be shown by variation of the adjustments and the scan speed. Additionally the effect of the ultrasonic frequency on the lateral resolution can be shown by using a 2 MHz probe.

Results:
The sound velocity of the acrylic block was estimated with 2680 m/s. With the compound scan the test block can be shown with high image quality. The biggest problems with lateral resolution are movement artefacts, because the probe is moved by hand. The illustration of the upper 5 holes in the oblique group (hole diameter= 3 mm) shows the third hole with the best lateral resolution. The reason for this is that the 1 MHz probe has the focus zone ca 2.5 cm (focus distance of a round sound generator: x= R² /l, radius R= 8 mm, wavelength l= 2.7 mm)
The brightly illuminated ground echo is discontinuous with dark ranges, because the holes above produce acoustic shadows. Especially in the range under the big hole on the right side no measurements are possible because there is no sound in it.
Purpose:
The several steps of the formation of a computed tomography are illustrated. The difference between damping and sound velocity as measuring parameters is analysed. The influence of filtering and image processing is investigated.

Setup:
Ultrasonic echoscope GAMPT-Scan order no 10121
Computerised Tomography Scanner order no 60100
CT control unit order no 60110
2x ultrasonic probe 2 MHz order no 10132
CT sample order no 60121
Water tank order no 60120
Ultrasonic gel order no 70200

Basics:
To form the image the attenuation of sound and the sound velocity are utilised. The attenuation coefficient of sound $\mu$ results from the measured amplitude $A$ and the amplitude without sample $A_0$ after the law of attenuation:

$\mu \propto \frac{\ln A}{A_0}$

(1)

For the generation of the sound velocity tomogram the time of flight is used as the measuring quantity and the following is valid:

$c \propto \frac{t_c}{t}$

(2)

where $t_c$ is the measured time of flight without the sample (the path length $s$ is constant).

Procedure:
The sample (damping or velocity sample) is attached to the sample holder and by means of the scanner control is positioned exactly between the two sensors. Then the sample holder is moved half of the scanning way, the accuracy of scanning and the number of angle intervals are adjusted and the CT scan is started. During the measurements the individual line scans are observed and the generation of the tomograms by superposition of the projections of line scans is studied. The resulting images are optimised by means of various filters and by brightness and contrast adjustments, then the damping tomogram is compared with the velocity tomogram.

Results:
The transmission signal (the diagram left above) has been measured with regard to maximal amplitude and time of flight of the maximal amplitude and from this a line profile (scan at one angle, 500 µm point distance) has been built (diagram left below). The superposition by means of the CT-algorithm (25 angle intervals) yields for sound attenuation to the image left above (non filtered, contrast changed) and for the sound velocity to the image right above (also non filtered, contrast changed). Filtering the attenuation image improves the contrast so the edges become visible (reflection losses). The inner part hardly distinguishes from the surrounding water, in the sound velocity image (right) the sample and the inclusion are clearly visible as homogeneous regions of a different sound velocity.
Characteristic of sound field

Purpose:
The sound pressure amplitude of an ultrasonic probe (here 2 MHz) is determined along the sound field axis by means of a hydrophone and from the distribution of amplitudes the near field length is examined and compared with the theoretical value. Then the sound pressure amplitude is measured in the region of the near field and at two additional positions perpendicular to the sound direction, in order to get information about the sound field width.

Basics:
Ultrasound spreads out from the sound source into the neighbouring medium. The energy connected with the sound fills a region called the sound field. The sound field quantities (e.g. velocity of sound, sound pressure, sound intensity) indicate quantitatively the sound phenomenon within the spreading medium. The sound field, generated by a transducer in the medium, is classified into two regions, the near field or Fresnel zone and the far field or Fraunhofer zone. The pressure distribution shows in the near field strong position dependent fluctuations due to interferences. These fluctuations decrease continuously in the far field. For a piston oscillator the near field length \( S \) can be determined from the radius \( a \) of the probe and the wavelength \( \lambda \) in the spreading medium:

\[
S = \frac{a^2}{\lambda}
\]

The near field length is defined as the last maximum on the acoustic axis. The theoretical sound pressure distribution on the transducer axis is represented for a continuous working transmitter with a diameter of 16 mm and a hydrophone with infinitesimal small surface (green curve) and for 2 mm radius (blue curve) in the following diagram. By the finite extent of the hydrophone the strong interferences in the near field range are smoothed.

In the range of the near field length the sound field of the piston oscillator has a natural focus zone, i.e. the strongest lateral decrease of the amplitude.

Procedure:
The probe with the support is coupled to the short side of the vessel and is adjusted perpendicular to the hydrophone. Then the hydrophone is moved into the far field region (ca 20 cm distance from the transducer) and their height adjusted for maximal amplitude. The hydrophone is positioned up to the vessel wall, the central positioning is checked and a scan is carried out along the axis of the transducer (ca 20 cm). From the last maximum the near field length is determined and compared with theoretical values. At the position of the near field length and at two further positions a scan perpendicular to the sound axis is carried out after having rotated the sample vessel by 90°. From the measured distributions the 6-dB-width (amplitude decrease to the half) is determined and is compared for the different positions.

Results:
Fig. 1 shows the line scan along the sound field axis. The maximum comes up to about 95 mm distance of probe. The theoretical value after (1) is 86 mm for a probe with 16 mm diameter and 2 MHz frequency in water (C=1480 m/s). One observes from the theoretical calculation that the value from the hydrophone measurement is slightly shifted to the right. Furthermore one has to keep in mind that the measurement is done with a pulse transducer. This results in further decreasing interferences clearly visible in the measurement. The lateral sound field distributions are shown in Fig. 2 to 4, where the measurements have been carried out at probe distances of 27 mm (Fig. 2), 47 mm (Fig. 3) and 95 mm (Fig. 4). From the diagrams 6-dB-widths of 13 mm, 11 mm and 7 mm are determined. A distinct focussing in the range of the near field length can be observed.
Purpose:
The light diffraction at a progressing ultrasonic wave can be demonstrated (Debye-Sears effect). For this the dependence of the diffraction maxima on the wavelength of light (red and green) and on the frequency of the ultrasound will be investigated. From the geometry of the diffraction image the sound velocity of a test liquid (here distilled water and alcohol) is determined.

Basics:
In 1932 Debye and Sears showed for the first time that light crossing a liquid that is excited by a high frequency oscillation undergoes a diffraction. The density maxima and minima of a standing or continuously progressing wave act like lattice elements of an optical diffraction lattice. The lattice constant corresponds to the wavelength of the ultrasound and therefore depends on their frequency and the sound velocity of the medium. From the diffraction images of the Debye-Sears experiment the wavelength of the sound wave can be determined and with that the sound velocity in the liquid can be calculated. Therefore the distance $s$ between the ultrasonic source and the diffraction image must be measured, the number $N$ of diffraction maxima and the distance $x$ between the $-N$th and $+N$th order of diffraction must be determined. From the known wavelength of the laser light $\lambda_L$ the wavelength of the ultrasonic wave $\lambda_S$ can then be calculated via (1).

\[
\lambda_S = \frac{2N\lambda_L s}{x}
\]

Procedure:
The distance $s$ between the ultrasonic transducer and the diffraction image is measured by a ruler. The maximum order of diffraction $N$ is determined and the distance between the $-N$th and the $+N$th order of diffraction $x$ is measured by a calliper or a ruler. The measuring is carried out for all frequencies in the range from 1 MHz on in 1 MHz steps, as long as diffraction maxima are visible and separable. The measurement is performed for red as well as green laser light. From the measured values the wavelength of sound $\lambda_S$ is determined after (1) and with the known frequency $f$ the sound velocity $c$ is obtained using $c=f\lambda_S$. The measurement should be done also for the second liquid (e.g. alcohol).

Results:
As expected from equation (1) with increasing ultrasonic frequency an increase of the distance of diffraction orders can be seen. When comparing the distances of diffraction orders for the same ultrasonic frequency but with different laser lights, red light gives larger distances. The number of diffraction orders is determined mainly by the transmission characteristics of the probe and the frequency attenuation. The main error results from measuring the distances of the diffraction orders $x$. This can be reduced applying a larger distance $s$ or a suitable optical projection. The mean sound velocity of 1479 m/s lies near the theoretical value of 1482 m/s at 20 °C.

### red laser:
- $\lambda_L=652\,\text{nm}$, $s=325\,\text{cm}$

### green laser:
- $\lambda_L=532\,\text{nm}$, $s=325\,\text{cm}$

<table>
<thead>
<tr>
<th>$f$ [MHz]</th>
<th>$N$</th>
<th>$x$ [cm]</th>
<th>$x/(2N)$ [cm]</th>
<th>$\lambda_S$ [m]</th>
<th>$c$ [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2,8</td>
<td>0,700</td>
<td>1478</td>
<td>1482</td>
</tr>
<tr>
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<td>2</td>
<td>2,4</td>
<td>0,240</td>
<td>1441</td>
<td>1482</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>3,2</td>
<td>0,640</td>
<td>1479</td>
<td>1479</td>
</tr>
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<td>4</td>
<td>4</td>
<td>3,8</td>
<td>0,875</td>
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<td>1453</td>
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<td>1482</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>4,9</td>
<td>1,530</td>
<td>1495</td>
<td>1495</td>
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<td>7</td>
<td>5,5</td>
<td>1,750</td>
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<td>8</td>
<td>6,1</td>
<td>1,875</td>
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<td>1513</td>
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<td>9</td>
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<td>10</td>
<td>7,3</td>
<td>2,250</td>
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<td>1537</td>
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<td>7,9</td>
<td>2,420</td>
<td>1549</td>
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<tr>
<td>12</td>
<td>12</td>
<td>8,5</td>
<td>2,550</td>
<td>1561</td>
<td>1561</td>
</tr>
</tbody>
</table>

mean 1479
SD 26
Projection of standing waves

Purpose:
Using divergent laser light the image of a standing ultrasonic wave can be demonstrated. By means of the originating projection image the dependence on the wavelength of light (red and green) and on the frequency of the ultrasonic wave is investigated. From the geometry of the projection image the velocity of sound of the test liquid (here distilled water) is determined.

Basics:
At exact alignment of the ultrasonic probe to the bottom of the vessel a standing wave arises. This can be displayed in transmission with divergent light because the sound pressure generates periodic changes of the refraction index. On the screen the density distribution of the standing wave will be shown as modulation of brightness. The distance of brightness maxima follows from

\[ x = \frac{2s}{N - (f - a_1 - g_1 - g_2)} \]

For the exact determination of the wavelength from the image and the geometry the refraction corrections through the glass walls and the measuring liquid have to be considered beside the focal distance \( f \) of the lens in air (concerning the geometry see the following scheme). Furthermore one has to consider, that by using monochromatic light the focal distance of the lens \( f \) as well as the refraction index are functions of the wavelength of light. For the exact determination of the wavelength the method of light diffraction is recommended as described in the experiment of Debye-Sears effect.

Results:
\[
\begin{array}{cccccc}
\hline
f & N & x & \lambda_s & c \\
[MHz] & & [cm] & & [m/s] \\
\hline
2 & 2 & 4,1 & 793 & 1626 \\
3 & 3 & 4,0 & 529 & 1586 \\
4 & 4 & 4,0 & 407 & 1586 \\
green & & & & 1573 \\
\hline
\end{array}
\]
\[
\begin{array}{cccccc}
\hline
f & N & x & \lambda_s & c \\
[MHz] & & [cm] & & [m/s] \\
\hline
2 & 4 & 7,7 & 763 & 1527 \\
3 & 7 & 9,0 & 510 & 1530 \\
4 & 7 & 6,9 & 391 & 1564 \\
red & & & & mean 1540 \\
\hline
\end{array}
\]

Red laser: \( \lambda = 652 \) nm, Green laser: \( \lambda = 532 \) nm

As expected from equation (1) the distance of brightness maxima decreases with increasing ultrasonic frequency. The determined sound velocity value is always too large and is larger for green light too. This error results from the change of the focal length of the lens due to transmission through the glass plates and the measuring liquid. The difference between green and red light is explained by the wavelength dependence of the refraction indices.
Purpose:
The dependencies of the ultrasonic Doppler effect on the velocity of flow and the Doppler angle are investigated.

Setup:

- Ultrasonic pulse Doppler „FlowDop“ order no 50100
- Ultrasonic probe 2 MHz order no 10132
- Doppler prism 3/8“ order no 50112
- Flexible tubes set order no 50120
- Centrifugal pump „MultiFlow“ order no 50130
- Doppler dummy fluid order no 50140
- Ultrasonic gel order no 70200

The applications of the Doppler effect in the medical diagnostics are at the investigation of running movements and moving structures as in cardiology diagnostics, arterial and venous blood vessels, brain blood circulation and postoperative blood vessel control.

Procedure:
The Doppler prism is attached to a 3/8“-tube as measuring distance. On the control of the centrifugal pump three different flow velocities (voltages) are adjusted and at each angle of the prism (\(\alpha = 15°, 30° \text{ and } 60°\)) the shift of Doppler frequency is determined for each velocity. From the known sound velocities in the liquid (\(c_l=1490\,\text{m/s}\)) and in the prism (\(c_p=2670\,\text{m/s}\)) the respective Doppler angle can be calculated (law of refraction)

\[
\alpha = 90° - \arcsin (\sin \alpha, \frac{c_l}{c_p})
\]

By means of the Doppler angle and the measured Doppler frequency shift \(\Delta f\) the mean flow velocity is calculated via (2) \((f_o=2\,\text{MHz})\).

Results:

Values calculated with formula (3):

<table>
<thead>
<tr>
<th>angle of prism</th>
<th>Doppler angle</th>
<th>(\cos (\alpha))</th>
</tr>
</thead>
<tbody>
<tr>
<td>15°</td>
<td>81,7°</td>
<td>0,144</td>
</tr>
<tr>
<td>30°</td>
<td>73,8°</td>
<td>0,279</td>
</tr>
<tr>
<td>60°</td>
<td>61,1°</td>
<td>0,483</td>
</tr>
</tbody>
</table>

results and velocity of the movement:

<table>
<thead>
<tr>
<th>pump voltage [V]</th>
<th>15°</th>
<th>30°</th>
<th>60°</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta f) [Hz]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(v) [cm/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3,00</td>
<td>185</td>
<td>48</td>
<td>342</td>
</tr>
<tr>
<td>(\Delta f) [Hz]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(v) [cm/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5,00</td>
<td>285</td>
<td>74</td>
<td>515</td>
</tr>
<tr>
<td>(\Delta f) [Hz]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(v) [cm/s]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7,00</td>
<td>405</td>
<td>105</td>
<td>700</td>
</tr>
</tbody>
</table>

The upper diagram shows that the Doppler frequency shift increases with increasing voltage (velocity) and decreasing Doppler angle. The lower diagram shows that for one velocity the ratio of \(\Delta f/\cos(\alpha)\) is constant therefore no angle dependent error measurement occurs.
Basics:
A stationary flowing liquid is characterised by a constant flow of liquid at each point of the system. Therefore the continuity equation for two different tube areas $A_1$ and $A_2$ results as:

$$A_1 v_1 = A_2 v_2 = V = \text{const.}$$

$v_1$ and $v_2$ being the mean velocities in the respective section and $V$ the flow rate (volume per time unit). The static pressure in a flowing liquid is always smaller than in a motionless liquid, and reduces the greater the flow velocity is (Bernoulli equation). For the flow through a horizontal tube (without gravity pressure) the total pressure $p_0$ is:

$$\rho \frac{V^2}{2} + \frac{1}{2} \rho v^2 = p_0$$

Only in a friction-less liquid $p_0$ is constant. In a flow pertaining to friction the total pressure decreases in dependence on the viscosity $\eta$, the length $l$, the cross-section $A$ of the passing through region and the flow rate $V$. For liquids with not too high flow velocities (laminar flow) in narrow tubes the Hagen-Poiseuille law is valid for the pressure drop $\Delta p$:

$$\Delta p = R \frac{V}{l}$$

where $R$ is the radius of the tube and $l$ is the length. That means that a reduction of the diameter of the vessel to half results in an enhancement of the flow resistance to 16 times. By this principle blood vessels regulate the blood distribution between extremities and inner organs.

Procedure:
A circulation is built consisting of 3 tube lines of equal lengths but different diameters $(1/2", 3/8", 1/4")$. At the beginning and end of each line is a measuring point of equal diameter $(3/8")$. At the tube lines the mean velocity is measured for 3 different flow rates (3 different voltages at the centrifugal pump) by means of the Doppler prism and the FlowDop. Knowing the measured flow velocities the flow rate can be determined after (1) and compared. At the measuring points the pressure drop due to the flow resistance can be measured. Calculating the flow rate from (1) the flow resistance can be determined after (4) and from this using the known geometry the dynamical viscosity of the liquid is obtained.

Results:
A $(1/2")=1.1 \text{ cm}^2$; A $(3/8")=0.66 \text{ cm}^2$; A $(1/4")=0.32 \text{ cm}^2$

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>16.0</td>
<td>1.06</td>
<td>27.1</td>
<td>1.08</td>
<td>55.6</td>
<td>1.07</td>
</tr>
<tr>
<td>3</td>
<td>26.4</td>
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<td>45.3</td>
<td>1.79</td>
<td>92.2</td>
<td>1.77</td>
</tr>
<tr>
<td>4</td>
<td>35.7</td>
<td>2.36</td>
<td>57.4</td>
<td>2.27</td>
<td>118.5</td>
<td>2.28</td>
</tr>
</tbody>
</table>

The diagram shows that the flow rate calculated from the measured velocity and the area is nearly the same at all tube diameters for equal voltages and therefore the continuity equation is fulfilled.

<table>
<thead>
<tr>
<th>U [V]</th>
<th>$\Delta p$ [mm H2O]</th>
<th>$\Delta p$ [g/(s cm4)]</th>
<th>$\Delta p$ [mm H2O]</th>
<th>$\Delta p$ [g/(s cm4)]</th>
<th>$\Delta p$ [mm H2O]</th>
<th>$\Delta p$ [g/(s cm4)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.3</td>
<td>16.8</td>
<td>0.8</td>
<td>44.9</td>
<td>3.4</td>
<td>218.3</td>
</tr>
<tr>
<td>3</td>
<td>0.5</td>
<td>16.9</td>
<td>1.5</td>
<td>50.8</td>
<td>8.5</td>
<td>902.7</td>
</tr>
<tr>
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<td>23.5</td>
<td>3.1</td>
<td>80.9</td>
<td>18.0</td>
<td>2484.0</td>
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</table>

Length of the tube sections: 30 cm

<table>
<thead>
<tr>
<th>$d$ [cm]</th>
<th>$R$ [g/(s cm4)]</th>
<th>$\eta$ [g/(s cm)]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.18</td>
<td>16.8</td>
<td>0.027</td>
</tr>
<tr>
<td>0.92</td>
<td>44.9</td>
<td>0.026</td>
</tr>
<tr>
<td>0.64</td>
<td>218.3</td>
<td>0.030</td>
</tr>
</tbody>
</table>

The mean dynamical viscosity amounts to 0.027 g/(s cm) and this is in the range of the viscosity of water (0.01 g/(s cm)).
Mechanical scan methods

Purpose:
By means of a computer controlled scanner the B-image of a sample is recorded for 2 different frequencies (1 MHz and 2 MHz) and different local resolutions and the consequences on the resolution power are compared.

Basics:
To generate a B (Brightness) -image (scan image in sound direction) it is necessary to move the sound head or sound beam, respectively. For this a number of mechanical and electronic sampling methods have been developed. The advantage of automatic mechanical systems is the high image quality due to a good resolution power and a free selectable line density. The disadvantage is a low frequency of image succession and the necessary coupling. For real-time images and moving structures electronic multi-element scanners are therefore used. For the sampling geometries, line scan and divergent resp. convergent sector-scan can be distinguished.

Results:
Fig. 1 shows a B-image of the acrylic block (holes are filled with water) recorded with a 1 MHz probe at a sampling rate of 250 µm. Acoustic shadows are distinctly visible in the bottom echo, as well as the reflexes at the beginning and end of the respective holes. The near-field lies in the region up to 2.5 cm and is not very pronounced. Fig. 2 shows a B-image recorded by a 2 MHz probe with the same sampling rate of 250 µm. Since the sound pulse for 2 MHz is distinctly shorter, the axial resolution is improved and the images of the edges of the holes are much sharper. The clearly larger near-field range results in the effect that the surface-near holes are displayed too large. The group of test holes for resolution in the upper left is resolved approx only by the 2 MHz probe. Fig. 3 is a B-image taken by a 1 MHz probe at a sampling rate of 1 mm. There is no significant difference to the measurement with 250 µm, that can not be expected either for a probe of a diameter of 16 mm and a sound field width in the focus of about 5 mm.

Setup:
Ultrasound echoscope GAMPT-Scan order no 10121
Ultrasound probe 1 MHz order no 10131
Ultrasound probe 2 MHz order no 10132
Ultrasound test block transparent or black order no 10201 order no 10204
Computerised Tomography scanner CT control unit order no 60100 order no 60110
Water tank order no 60120
Ultrasound gel order no 70200

Procedure:
The sample is put into the water-bath and the respective probe is adjusted in a way that it is moved only a very short distance over the sample surface. With that one avoids the multiple reflections of the surface superimposed with reflections of the sample holes. The scan parameters (sampling rate and total length) are given into the software and the scan for 1 MHz and 2 MHz is carried out at different line densities (250 µm, 1 mm). The images are compared mutually for the same contrast adjustments and judgments about resolution power and focus zone are made.
Purpose:

Characterisation of the interference maxima developing at the diffraction on a standing acoustic wave regarding amplitude and phase shift. Determination of the sound velocity in a test liquid by frequency variation.

Basics:

The interference maxima developed at the diffraction on a standing ultrasonic wave are amplitude modulated. Thus is caused by the periodic change of the standing ultrasonic wave. The 0-th order has its maximum at the minimum of the standing wave (no diffraction), the n-th orders at the maximum of the standing wave. Minima and maxima appear two times per period at a standing wave. This effect of the light intensity modulation by an acoustic wave is used for acousto-optical modulators (AOM).

The modulation amplitude is the largest for the best approximation of the geometry on a standing wave.

In this case is: \( h = \frac{m \cdot \lambda}{2} \)

(h...distance between sender and bottom of the reservoir; m...number of half wave lengths n h).

Because of the change in frequency the number of half wavelengths will be reduced by \( \Delta m \).

It follows: \( h = (m + \Delta m) \cdot \frac{\lambda}{2 + \Delta m} \)

(for the particular modulation maximum)

Results:

1. Modulation amplitude at \( f = 4.73 \text{ MHz} \)
   - 0-th order: 600-800 mV
   - 1-st order: 200-300 mV
   - 2-nd order: 50-100 mV
   - Phase shift 0-th to 1-st order: 180°
   - Phase shift 0-th to 2-nd order: 180°
   - Phase shift 1-st to 2-nd order: 0°
   - Modulation frequency: 9.46 MHz

2. \( h = 72 \text{ mm} \)
   - \( f_m = 4.7300 \text{ MHz} \)
   - test liquid: water (20°C), theoretical value: 1482 m/s

Setup:

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Order No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultrasonic wave generator SC500</td>
<td>20100</td>
</tr>
<tr>
<td>Complete set Debye-Sears</td>
<td>20200</td>
</tr>
<tr>
<td>Semipermeable reflector</td>
<td>20301</td>
</tr>
<tr>
<td>2x adjustable reflector</td>
<td>20302</td>
</tr>
<tr>
<td>2x photodiode</td>
<td>20303</td>
</tr>
<tr>
<td>Oscilloscope</td>
<td></td>
</tr>
</tbody>
</table>

For waves is: \( \lambda = \frac{c}{f} \)

therefore \( m \) can be calculated from: \( m = \frac{\Delta m \cdot f_m}{\Delta f} \)

and for the sound velocity follows now: \( c = \frac{2 \cdot h \cdot \Delta f}{\Delta m} \).

The sound velocity can be determined by variation of the ultrasonic frequency and the determination of the modulation maxima (standing wave).

Procedure:

1. The laser, the adjustable and the semipermeable reflectors and the probe shall be adjusted in a way, that an optimal diffraction image will develop. The intensity of the higher orders and the distances between the diffraction maxima should be as large as possible. (wenn Platz Skizze einfügen). Ultrasonic frequencies around 5 MHz are very suitable for this. With a photodiode the 0-th order will be detected on the oscilloscope and with the second photodiode a higher order (1-st, 2-nd ...). The modulation shall be measured compared to the total amplitude. The phase shift between the orders shall be measured. The frequency of the modulation shall be measured.

2. Only one photodiode without a semipermeable reflector will be used. It shall be adjusted in a way that the 0-th order hits the photodiode. It requires a long light way since the best results will be achieved with sound frequencies between 3 and 5 MHz, but the diffraction maxima are very close together at these frequencies.

The complete setup (also the ultrasonic probe) shall be re-adjusted until the amplitude modulation is maximal. The generator’s frequency shall be attuned in 100 Hz steps until the amplitude modulation reaches a maximum again. The frequency change shall be registered and the procedure repeated ca. 5 times. With the measured distances between the bottom side of the ultrasonic probe and the bottom of the reservoir and the frequency changes the sound velocity of the test liquid can be calculated.

<table>
<thead>
<tr>
<th>( \Delta m )</th>
<th>( f ) [MHz]</th>
<th>( \Delta f ) [kHz]</th>
<th>( c ) [m/s]</th>
</tr>
</thead>
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<tr>
<td>1</td>
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<td>10.3</td>
<td>1483</td>
</tr>
<tr>
<td>2</td>
<td>4.7507</td>
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</tr>
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<td>4</td>
<td>4.7714</td>
<td>41.4</td>
<td>1490</td>
</tr>
<tr>
<td>5</td>
<td>4.7818</td>
<td>51.8</td>
<td>1492</td>
</tr>
<tr>
<td></td>
<td>mean</td>
<td></td>
<td>1489</td>
</tr>
</tbody>
</table>
Phase shift on the acoustic lattice

**Purpose:**
Characterisation of the interference maxima which develop at the diffraction on a travelling acoustic wave regarding their frequency shift.

**Basics:**
Unlike a standing acoustic wave the light diffraction on a travelling acoustic wave is time-constant. The amplitude of the density modulation does not change, the wave just propagates. It is a time-constant, local variable lattice. A standing wave shows a time variable, local-constant lattice. The intensity of the light beam is time-constant in all orders. The beam will only be deflected but not amplitude modulated. This effect finds its application as acousto-optical deflector (AOD). However, the movement of the acoustic lattice causes/generates a frequency shift of the laser light. At a travelling sound wave with the velocity \( c \) a frequency shift in the diffracted beams is generated for the frequency of light \( n \) due to the

\[
\nu_n = \nu \left( 1 + \frac{c \sin(\theta_n)}{c_L} \right)
\]

with \( c \) being the sound of light. With \( c = \lambda f, \ c_L = \lambda v \) and the conditions of the \( n \)-th interference order

\[
A \cdot \sin(\theta_n) = n \lambda
\]

follows: (1) \( \nu_n = \nu + n f \)

**Procedure:**
An ultrasonic absorber in the reservoir impedes the development of a standing wave. The frequency shift of the laser light is very small since the ultrasonic frequencies are in the area of \( 5-10 \text{ MHz} \). To measure this frequency shift two beams of different orders and different frequencies have to be mixed on the photodiode. On the signal an interference with the frequency difference of both orders will be developed. Therefore both beams have to hit the photodiode parallel which can be realised with a good adjustment of the reflectors. To receive a larger interference amplitude signal it is recommended to reflect the weaker beam (e.g. \(-1\)-st order) directly with the semipermeable reflector and the stronger beam (e.g. \(0\)-th order) with a circuitous over the adjustable reflectors to the photodiode. If possible the interference between the \(-1\)-st and \(1\)-st and \(2\)-nd orders shall be measured. After equation (1) the interference frequency in these cases is \(2f\) and \(3f\).

**Results:**
The following images demonstrate the superposition of the diffracted beams of different orders. The sound frequency is ca. 9 MHz. It can be seen that the interference frequency increases linear with the distance of the order number from \(f @ 9 \text{ MHz} \) (a) to \(3f @ 27 \text{ MHz} \) (c).

**Setup:**
- Ultrasonic wave generator SC500
- Complete set Debye-Sears
- Semipermeable reflector
- 2x adjustable reflector
- Photodiode
- Ultrasonic absorber
- Oscilloscope

Doppler effect:

\[
\nu_n = \nu \left( 1 + \frac{c \sin(\theta_n)}{c_L} \right)
\]

### Images:

- **a.** Superposition of the \(-1\)-st and 0-th orders
- **b.** Superposition of the \(-1\)-st and \(1\)-st orders
- **c.** Superposition of the \(-1\)-st and 2-nd orders
Since the frequencies are known, the phase velocity can be calculated without any other measurements:
\[ c_P = \frac{f}{l} \]

The group velocity can be calculated from the time of flight \( t \) and the distance probe - hydrophone \( s \):
\[ c_G = \frac{s}{t} \]

Procedure:

The multifrequency probe will be connected to the water filled reservoir using ultrasonic gel and the hydrophone with holder will be placed in the reservoir. The hydrophone signal will be connected to an oscilloscope (channel 1). The sinus signal output of the ultrasonic generator will be connected to channel 2 of the osci. For measurements in the frequency area of 5-10 MHz the time base on the osci is 100 ns/div or 50 ns/div. The amplitude of hydrophone and sinus output shall be calibrated to one another.

The distance between probe and hydrophone will be measured. Afterwards, slow and steady the hydrophone will be moved away from the probe and the number of detected zero crossings of the curves can be measured. The distance between shall be again measured after a certain amount of phases to determine the difference to the starting point. This should be repeated for 5 distances. Wave length and phase velocity then can be determined. The whole process should be performed for various frequencies in the area between 5 and 10 MHz to receive information if the phase velocity depends on the frequency.

The time of flight of an ultrasonic impulse can be measured (TTL exit as trigger) by switching to pulse mode on the ultrasonic generator and choosing 1kHz repetition rate. The group velocity will be calculated out of the measured distance between probe and hydrophone and the time of flight.

Results:

The phase velocities for 6 frequencies and 5 distances were determined, mean values and standard deviations calculated. The distances were measured with a calliper.

<table>
<thead>
<tr>
<th>( f ) in MHz</th>
<th>( x )</th>
<th>( l ) in cm</th>
<th>( n )</th>
<th>( \lambda ) in m</th>
<th>( c ) in m/s</th>
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</thead>
<tbody>
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<td>46,3</td>
<td>20</td>
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<td>1481,3</td>
</tr>
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<td>70</td>
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<td>1500</td>
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<tr>
<td>10</td>
<td>42,8</td>
<td>45,8</td>
<td>100</td>
<td>48,8</td>
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</tr>
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<td>1500</td>
<td></td>
<td>1483,3</td>
<td>1475</td>
</tr>
</tbody>
</table>

Pulse measurement: \( l = 10 \text{ cm} \)

Group velocity \( v = 1485 \text{ m/s} \).

The diagram shows that there is no change in the phase velocity depending on the frequency \( \frac{dc_P}{dl} \). This demonstrates that the phase velocity does not depend on the wave length. No dispersion in water appears in this frequency range. An additional comparison with the group velocity confirms this conclusion.
Determination of the focus zone

Purpose:
The sound field intensities of three ultrasonic probes of different frequencies shall be measured along the acoustic axis. The near field lengths (focus zone) of the probes shall be calculated from the measuring curves and compared with the calculated values.

Basics:
Ultrasonic probes show a different axial and lateral resolution depending on their frequency. Additionally, the area with the highest resolution can be found in different distances in front of the probe area. The reason for this is because of the different sound field geometries of the probes. Because of interferences a sound field builds up on a round ultrasonic probe which can be classified in two areas. The near field is characterised by strong amplitude modulations. The far field shows a sound beam with decreasing amplitude. The distance of the last amplitude maximum before the monotonically decrease is called near field length (S). It can be calculated for a simple ceramic disk with the radius (r) and the wave length l after the following equation:

\[ S = \frac{r^2}{l} \]

The sound beam shows here a contraction called focus zone. In this area the biggest lateral resolution of an ultrasonic probe can be expected.

Results:
The measured amplitudes for each probe shall be presented in standardised form in a diagram. For each frequency the near field length in water shall be calculated at a probe radius of 8 mm (the active probe area is smaller then the geometrical radius) and charted as vertical lines in the diagram.

- 1 MHz, \[ S = 42,6 \text{ mm} \] (sound velocity of water: 1500 m/s)
- 2 MHz, \[ S = 85,3 \text{ mm} \]
- 4 MHz, \[ S = 170,6 \text{ mm} \]

The measured maxima for the 1 MHz and die 2 MHz probe are located in the calculated near field length. The signal amplitude varies strongly in the whole measurement range for the 4 MHz probe since the measuring area is inside the near field. The probes are a pulsating probes with a very wide spectrum, this explains the strong variations.

Setup:

- Ultrasonic echoscope GAMPT-Scan \( \text{order no} \ 10121 \)
- Hydrophone set \( \text{order no} \ 10251 \)
- Ultrasonic probe 1 MHz \( \text{order no} \ 10131 \)
- Ultrasonic probe 2 MHz \( \text{order no} \ 10132 \)
- Ultrasonic probe 4 MHz \( \text{order no} \ 10134 \)
- Ultrasonic gel \( \text{order no} \ 70200 \)

Procedure:
The exact adjustment of the hydrophone to the sound axis is very important for the measurement along the acoustic axis of a probe. The particular ultrasonic probe shall be connected to the reservoir with a good amount of gel. In reflection mode the signal amplitude shall first be adjusted to a maximum (side adjustment of the probe, height and turning of the hydrophone) while the distance between hydrophone and probe shall be maximised. Now switch to transmission mode and choose the appropriate amplification properties. The amplitude response will be measured along the sound axis by moving the hydrophone holder. It is recommended to measure the position of the hydrophone using the depth scale in the software.

Sound field of a 2 MHz probe with a diameter of 16 mm

Results:  

The measured amplitudes for each probe shall be presented in standardised form in a diagram. For each frequency the near field length in water shall be calculated at a probe radius of 8 mm (the active probe area is smaller then the geometrical radius) and charted as vertical lines in the diagram.

- 1 MHz, \[ S = 42,6 \text{ mm} \] (sound velocity of water: 1500 m/s)
- 2 MHz, \[ S = 85,3 \text{ mm} \]
- 4 MHz, \[ S = 170,6 \text{ mm} \]

The measured maxima for the 1 MHz and die 2 MHz probe are located in the calculated near field length. The signal amplitude varies strongly in the whole measurement range for the 4 MHz probe since the measuring area is inside the near field. The probes are a pulsating probes with a very wide spectrum, this explains the strong variations.
Purpose:

For a normal probe an adjustment of the ultrasonic device shall be carried out for the location of a discontinuity. The determination of the size of the discontinuity is done by shifting the test head and by using the DGS diagram (distance-gain-size). The DGS diagram shall be examined. By means of time-dependent amplification a horizontal evaluation line shall be adjusted in the DGS diagram.

Basics:

In the NDT different test heads are employed for different test tasks. For the pulse-echo-method normal probes are used for longitudinal waves of perpendicular incidence. The discontinuity is located by reflection of the sound wave. The time of flight is a measure for the depth of the discontinuity and is dependent on the respective velocity of the material. Since the echo amplitude depends not only on form and size of the discontinuity, but also on the damping of the material and the characteristic of the sound field, an exact determination of the size is often problematic. The size of the located discontinuity is determined by sampling for large spatial extensions. For that the test head is moved over the whole discontinuity and each time the distance from the full echo to the drop of half of the signal is determined. For smaller discontinuities the measured echo amplitudes are compared with signals of an idealised substituted discontinuity. The amplitude values of the substituted discontinuity are plotted as DGS diagrams.

Setup:

- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 2 MHz order no 10132
- Ultrasonic test block order no 10201 or black order no 10204
- Ultrasonic gel order no 70200

The DGS diagram shows the functional relationship between the depth (D), the relative echo amplitudes (Gain), and the discontinuity size (S). The distance D is represented relative to the near-field length $x_N$:

$$A = \frac{x}{x_N}, \quad x_N = 0.25 \times \frac{d^2}{l}.$$

The discontinuity size is given relative to the diameter of the probe ceramic d:

$$G = \frac{D}{d}.$$

The amplitude $H_U$ is related to the amplitude of an infinite extended reflector $H_0$ with a distance zero:

$$V = 20 \log \frac{H_U}{H_0}.$$

Procedure:

For the sample the sound velocity of the material is determined using a suitable back wall echo and the display of the GAMPT-scan is adjusted in a way that the depth is directly readable.

The amplitudes of the bottom echoes of the test block are determined for two different layer thicknesses and from that the amplitude for the layer thickness zero is calculated via the attenuation law. For the diagonal group of drillings the depth and the amplitude are determined, respectively. For that, the time-dependent amplification (TGC) is adjusted to zero. All holes are measured from all four sides as far as possible. From the measured results the data for the DGS diagram are calculated. By means of the TGC the signals for the row of holes of equal size are adjusted to a constant amplitude. For all holes of the group again the amplitudes are determined from one surface of incidence and the calculated data are entered into the DGS diagram.

Results:

Determination of sound velocity:

- Measured value: $t = 60 \mu s; s = 80.7 \text{ mm}$;
  - $c = 2s/t = 2690 \text{ m/s}$

Calculation of near-field length:

- $f = 2 \text{ MHz}; d = 16 \text{ mm}$;
  - $\lambda = c/f = 1.345 \text{ mm}$;
  - $x_N = 0.25 \times \frac{d^2}{\lambda} = 47.5 \text{ mm}$

Calculation of the comparative amplitude $H_0$:

- Attenuation law: $H_U = H_0 \times e^{-\mu}$
  - From this follows for the amplitudes of two different layer thicknesses: $\mu = 1/(x_1-x_2) \ln (H_2/H_1)$;
  - Measured values:
    - $x_1 = 2 \times 40.6 \text{ mm} = 81.2 \text{ mm}$ (twice length for the echo);
    - $H_1 = 1.029 \text{ V}$
    - $x_2 = 2 \times 80.4 \text{ mm} = 160.8 \text{ mm}$;
    - $H_2 = 0.106 \text{ V}$
    - $\mu = 0.0286 \text{ [1/mm]}$

With that the amplitude for an infinite extended reflector at the distance zero can be calculated:

$$H_0 = H_1 \times e^{-\mu} = 10.496 \text{ V}$$
Rayleigh waves

Purpose:
The generation and expansion of Rayleigh waves are investigated in an aluminum specimen. At first the sound velocity of the Rayleigh wave is determined. At cracks of different depth in the specimen the dependence of the transmission amplitude on the crack depth is examined.

Basics:
Rayleigh waves are a member of the group of interface waves, the expansion of which occur along the interfaces of differences of acoustic impedance. The Rayleigh wave (also surface wave) exists at the free interface of a solid and represents a combination of longitudinal and transverse displacements of particles. Rayleigh waves are used in the nondestructive material testing for the verification of surface defects. The generation takes place by means of a 90° test head by mode conversion of longitudinal waves into Rayleigh waves by putting on a perpendicular thickness oscillator with comb (GAMPT-10321; Raleigh wave attachment). The edges of this comb are in resonance with the Rayleigh wavelength. Another possibility to produce Raleigh waves is using the interdigital transducer (IDT). The reflected or transmitted amplitude of the Rayleigh waves can be put into relation to the crack depth in the range of small crack depths (crack depth in the range of the wavelength).

Results:
From the measured values, after taking the average, follows a sound velocity of the Rayleigh wave of about 2920 m/s in aluminum. With that a wavelength $\lambda$ of 2.92 mm follows for a frequency of 1 MHz.
The transmission measurement with probe distances of each 5 cm from the respective crack yields the following amplitudes (see next table). A nearly linear relation results between the crack depth and the transmission amplitude in dB corresponding to the exponential drop of amplitude of the Rayleigh wave with the penetration depth.

Setup:
Ultrasonic echoscope GAMPT-Scan order no 10121
2x ultrasonic probe 1 MHz order no 10131
2x Rayleigh waves attachments order no 10231
Material sample for Rayleigh Waves investigations order no 10232
Ultrasonic gel order no 70200

Procedure:
For the determination of the velocity of Rayleigh waves an ultrasonic probe with a Rayleigh wave attachment as transmitter is adjusted at one end of the specimen and the receiver with attachment is installed at distances from 5 cm to 50 cm in steps of 5 cm. The distance is measured between edges of probes facing each other. Now the time of flight between the transmitter pulse (ca. 0.1 µs) and beginning (or maximum) of the echo is determined. The sound velocity follows from the ratio of the differences of distance and the time of flight per pair of measurements. Thereby the influence of the point of length measurement and of the attachment is eliminated. At cracks of different depths the transmitter and receiver are positioned on both sides at always the same distance from the crack and the transmission amplitude is measured. This is put into proportion to the amplitude without a crack and the coefficient in dB in relation to crack depth is plotted (or the relative crack depth versus Rayleigh wavelength is plotted).

Results:
From the measured values, after taking the average, follows a sound velocity of the Rayleigh wave of about 2920 m/s in aluminum.

\[
\text{literature value } 2900-2950
\]
Purpose:

For an arbitrary formed vessel a calibration curve shall be taken for an ultrasonic fill level measurement. Then the calibration is checked by means of a defined filling.

Setup:

Ultrasonic echoscope GAMPT-Scan order no 10121
Ultrasonic probe 2 MHz order no 10132
Ultrasonic gel order no 70200
Water tank, stand, measuring cylinder

Basics:

Measurements of fill level play an important role at many industrial processes, e.g., at filling-stations, reactors, reservoirs or tanks. Ultrasonic devices for fill level measurements are suitable particularly for the control of the state of liquids. They are applicable for almost every media, for overlaying of several media, in the case of foaming and also for very aggressive liquids, since the measurement takes place through the vessel wall. According to the damping of the liquid and the demanded accuracy ultrasonic frequencies from 40 kHz to 5 MHz are applied. Basically two types of measuring devices are in use: Threshold switch and fill level measurement. In the graphic some measuring devices with the corresponding measuring signals are shown.

To measure the liquid volume in a tank a sensor is attached at the bottom side and the time of flight of the reflection of the liquid surface is determined.

Procedure:

By means of a suitable tripod the 2 MHz probe is fixed to an appropriate vessel in such a way, that a perpendicular direction of incidence from below is achieved. The probe is coupled by ultrasonic gel to the vessel wall. After filling the vessel with a defined liquid volume a good detectable echo of the liquid surface is adjusted by means of the transmitter power, the receiver power and the TGC. Thus the time of flight is determined. Then the vessel is filled in several steps and to each filling volume the time of flight is measured. After evaluating the calibration curve any fill levels of the vessel can be determined.

Results:

For the very simple formed vessel used here (conical vessel, truncated cone) the calibration curve of the filling measuring device can be fitted by a second-order polynomial. The filling volume of the vessel follows from the time of flight after the equation:

\[ V[\text{ml}] = 1.94 + 2.23 \times \text{T}[\mu\text{s}] + 0.0033 \times \text{T}^2 \]

\[ \text{T} \ldots \text{Time of flight} \]

For the measured filling height with a time of flight of 122.5 µs a filling volume of 324.6 ml results. By means of a graduated cylinder a volume of 325 ml has been determined. For very irregularly formed vessels that contain additional installations, the filling volume can be read directly from the calibration curve.
Concentration measurement

Purpose:
The dependence of sound velocity of a salt solution on the concentration is determined by means of the Debye-Sears effect and is compared with an empirical equation for the sound velocity in sea water after Mackenzie.

Basics:
With increasing concentration in electrolytes a decrease of compressibility follows. This leads to a concentration-dependent increase of the sound velocity. From the diffraction patterns of the Debye-Sears experiment (PHY11) the wavelength of the sound wave can be determined and with that the sound velocity of the liquid can be calculated. The distance between the ultrasonic source and the diffraction patterns has to be measured, the number of diffraction maxima \( N \) and the distance between the \(-N\)th and the \(+N\)th diffraction order \( x \) must be determined. From the known wavelength of the laser light \( \lambda_L \) the wavelength of the ultrasonic wave \( \lambda_S \) can be calculated:

\[
\lambda_S = \frac{2N \lambda_L s}{x}
\]

The empirical formula for the sound velocity in sea water after Mackenzie (JASA, 70, 807-12) is:

\[
c = 1448.96+4.591* T - 0.05304* T^2 + 0.0002374* T^3 \\
+1.34*(S-35)-0.01025* T*(S-35)
\]

With \( T \) = temperature [°C], \( S \) = concentration of salt [g salt/kg sea water].

Procedure:
The distance between the ultrasonic transducer and the diffraction pattern \( s \) is measured by a tape. The maximal diffraction order \( N \) is determined and the distance between the \(-N\)th and the \(+N\)th diffraction order \( x \) is measured by a caliper. The measuring is carried out for a frequency with a large distance of diffraction maxima and still sufficient number of maxima e.g. 9 MHz and with the red laser (larger diffraction distance). From the results of measurements after (1) the wavelength of sound \( \lambda_S \) is determined and with the known frequency \( f \) the sound velocity \( c \) is calculated by \( c=f \lambda_S \). A respective amount of rock salt is added in order to enhance the concentration stepwise from 0 to 10 mass per cent. After complete solution the measurement is repeated. The temperature of the solution is measured in order to take into account the dependence of the sound velocity on temperature. The measured and after (1) calculated sound velocities are plotted versus the concentration.

Results:

<table>
<thead>
<tr>
<th>( S ) [g/kg]</th>
<th>( x ) [mm]</th>
<th>( \lambda_S ) [µm]</th>
<th>( c ) mess [m/s]</th>
<th>( c ) (2) [m/s]</th>
<th>( T ) [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>51</td>
<td>164,7</td>
<td>1482</td>
<td>1485</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>50,6</td>
<td>166,0</td>
<td>1494</td>
<td>1496</td>
<td>21</td>
</tr>
<tr>
<td>20</td>
<td>50,1</td>
<td>167,6</td>
<td>1509</td>
<td>1507</td>
<td>21</td>
</tr>
<tr>
<td>30</td>
<td>49,5</td>
<td>169,7</td>
<td>1527</td>
<td>1519</td>
<td>21</td>
</tr>
<tr>
<td>40</td>
<td>48,9</td>
<td>171,7</td>
<td>1546</td>
<td>1531</td>
<td>21,5</td>
</tr>
<tr>
<td>50</td>
<td>48,3</td>
<td>173,9</td>
<td>1565</td>
<td>1542</td>
<td>21,5</td>
</tr>
<tr>
<td>60</td>
<td>48,2</td>
<td>174,2</td>
<td>1568</td>
<td>1555</td>
<td>22</td>
</tr>
<tr>
<td>70</td>
<td>47,9</td>
<td>175,3</td>
<td>1578</td>
<td>1566</td>
<td>22</td>
</tr>
<tr>
<td>80</td>
<td>47,3</td>
<td>177,5</td>
<td>1598</td>
<td>1577</td>
<td>22</td>
</tr>
<tr>
<td>90</td>
<td>46,9</td>
<td>179,1</td>
<td>1612</td>
<td>1588</td>
<td>22</td>
</tr>
<tr>
<td>100</td>
<td>46,7</td>
<td>179,8</td>
<td>1618</td>
<td>1599</td>
<td>22</td>
</tr>
</tbody>
</table>

The sound velocity increases clearly with the increasing concentration of the salt solution and shows in the measuring range (0 - 10% (g/g)) an almost linear dependence. The measured values (red curve) agree in the range of small concentrations (< 3%) with the theoretical values.
Purpose:
The dependence of the measured Doppler frequency on the flow rate shall be determined for a fixed measuring arrangement (tube diameter and Doppler angle). By means of the investigated dependence a flow meter can be calibrated, by which the flow rate can be measured using a pump.

Setup:
- Ultrasonic pulse Doppler „FlowDop“ order no 50100
- Ultrasonic probe 2 MHz order no 10132
- Doppler prism 3/8“ order no 50112
- Flexible tubes set order no 50120
- Centrifugal pump „MultiFlow“ order no 50130
- Doppler dummy fluid order no 50140
- Ultrasonic gel order no 70200
- Mariotte-bottle, measurement cylinder, timer

Basics:
The employment of ultrasonic methods to measure flow rates in liquids arises from the necessity of touch-free and recoiling-free measuring principles at low effort. Because of the dependence of Doppler frequency shift on the velocity and due to the proportionality between flow rate and the mean velocity in a constant cross section, the Doppler effect can be used for flow measurements. This is however only possible for liquids having a sufficient number of scattering particles (e.g. blood, liquids with gas bubbles) and for which the scattering angle is unlike 90°. The advantage lies in the very high sensitivity, the possibility of local resolution and the employment at arbitrary flow velocities below the sound velocity.

The Mariotte-bottle is closed at the upper end by a plug and is supplied at the lower end with an outlet. Through the upper plug leads a glass tube which is open at both ends. If liquid runs out of the bottle then the air pressure decreases above the water level. This pressure is equalised via the glass tube which projects into the liquid (air bubbles rise up). Therefore only the water column between the outlet and the lower end of the glass tube is responsible for the volume flow. Thereby an equal flow is obtained even for the lowering of the total water level.

Procedure:
Using a 3/8“ tube as measuring distance a Doppler prism is attached. The maximal Doppler angle (60° prism angle) is used. The tube is connected to a Mariotte-bottle. By changing the height of the glass tube or by changing of the total resistance (by means of a clamp at the outlet) five different flow rates are adjusted. These are measured by a measuring cylinder and a stopwatch. The averaged Doppler frequency shifts, determined for the respective flow rate, are plotted in a diagram. From the slope of the curve follows the calibration factor for our flow meter (tube with prism). Now the tube is connected to the centrifugal pump and the flow rate (Doppler frequency shift with calibration factor) is determined in dependence on the control voltage.

Results:

<table>
<thead>
<tr>
<th>Measuring result with Mariotte-bottle:</th>
</tr>
</thead>
<tbody>
<tr>
<td>V [l/min]</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>0,4</td>
</tr>
<tr>
<td>0,7</td>
</tr>
<tr>
<td>0,95</td>
</tr>
<tr>
<td>1,25</td>
</tr>
<tr>
<td>1,5</td>
</tr>
<tr>
<td>1,8</td>
</tr>
</tbody>
</table>

From the diagram follows a slope of \(a=265 \text{ Hz/(l/min)}\) and for the determination of the flow rate from the Doppler frequency shift a calibration factor of : \(K= 0.00331 \text{ l/(min Hz)}\). Therewith the flow rate can be determined for measurements with the pump (flow meter).

Results with pump:

<table>
<thead>
<tr>
<th>U [V]</th>
<th>∆f [Hz]</th>
<th>V [l/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,00</td>
<td>293</td>
<td>0,97</td>
</tr>
<tr>
<td>3,00</td>
<td>500</td>
<td>1,66</td>
</tr>
<tr>
<td>4,00</td>
<td>680</td>
<td>2,25</td>
</tr>
<tr>
<td>5,00</td>
<td>890</td>
<td>2,95</td>
</tr>
<tr>
<td>6,00</td>
<td>1070</td>
<td>3,54</td>
</tr>
<tr>
<td>7,00</td>
<td>1233</td>
<td>4,08</td>
</tr>
</tbody>
</table>
Purpose:
An angle beam probe shall be adjusted for the discontinuity location in aluminum. For this the length of the delay line, the sound velocity of the transverse wave and the incidence angle of the test head as well as the beam exit point of the delay line are determined. The adjustment of the test head is controlled at a cylindrical discontinuity with half and full skip distance.

Basics:
While for normal probes the adjustment of the distance follows simply from the time of flight and the sound velocity, in the case of the angle test head the respective incidence angle, the length and the exit point of the delay line have to be determined. For the adjustment different control samples or the distance adjustment by projection intervals can be used. The control sample has an arc-like reflector whose echoes come independently of the incidence angle always from the same depth. By clever positioning of an incision multiple echoes are generated, so that the influence of the delay line length $t_v$ is eliminated. The exit point is for maximal amplitude exactly at the circle center. This position is given usually as distance $x_v$ from the test head edge. At a cylindrical reflector (drilling) the incidence angle can be read from a scale.

In case of adjustment by projection distances the maximal angle echoes are measured at the edge of two plane-parallel surfaces with known distance and from this all required values are calculated. Exit point of sound: $x_v = p_1 - 2p_0$

Setup:
- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 2 MHz order no 10132
- Delay line for angle beam 38° order no 10234
- Sample for angle beam test order no 10240
- Ultrasonic gel order no 70200

With this follows the simple path length between the surface and the bottom side, also called skip distance after:
$$x_a^2 = a^2 + (p_1 - p_0)^2$$
and the angle of incidence: $\tan \beta = (p_1 - p_0)/a$.
The sound velocity can be calculated from the difference of both measurements.

With the double path length for the echo and the measured time of flights $t_1$ and $t$, the sound velocity follows from:
$$c = (4x_a - 2x_v)/(t_2 - t_1) = 2x_v/(t_1 - t)$$

Using the known sound velocity finally the time of flight of the delay line can be determined:
$$t_v = t_1 - 2(x_v/c)$$
For the location of discontinuities this value must be subtracted from the determined times of flight of the echoes. The depth $T$ of a discontinuity and the projection distance $P$ resp. the shortened projection distance $P'$ of a discontinuity are calculated as follows:
$$T = c(t-t_v)/2 \cos \beta$$
$$P = c(t-t_v)/2 \sin \beta$$
$$P' = (c(t-t_v)/2 \sin \beta) - x_v$$

Procedure:
The angle delay line is coupled to the ultrasonic probe by coupling gel. The angle test head is moved on the test sample as long as the first echo near the test sample edge has a maximum. By rotating the test head the incidence plane is aligned onto the axis of the test sample. At the maximal echo the time of flight and the distance of the test head to the sample axis are measured. From the measuring data the required data of the test head are calculated. Consequently the echo of the half and full skip distance is measured on the cylindrical discontinuity.

Results:
- Height of sample: $a = 25$ mm
- Mean projection distance: $P = 24$ mm
- Exit point of sound: $x_v = 20$ mm
- Sound path: $x_s = 34.6$ mm
- Sound velocity: $c = 3108$ m/s.
- Angle of incidence: $\beta = 43.8°$
- Time of flight of delay line: $t_v = 17.2$ µs
- Measurement of discontinuity: $t = 31.7$ µs
- Sound path $x_s = c(t-t_v)/2$
- $x_s = 22.5$ mm

For the verification of the depth we recommend you determine the centre of the drilling, since the point of incidence of the sound wave onto the drilling is difficult to measure. With that the sound path $x_s$ becomes longer by the radius (4 mm) of the drilling. For the depth and the projection distance one gets:
$$T = (x_s + 4) \cos \beta$$
$$T = 19.12$ mm
$$P = (x_s + 4) \cos \beta$$
$$P = 18.34$ mm
Purpose:

At a sample two methods of determination of crack-depth are carried out. Cracks of materials with different depths are investigated by means of the ultrasonic angle test head and the results of measurements compared in view of capability and detection limit.

Setup:

- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 2 MHz order no 10132
- Delay line for angle beam 38° order no 10234
- Test block with cracks order no 10241
- Ultrasonic gel order no 70200

Basics:

For the judgment of mechanical crack behavior of components material defects such as plane cracks are dealt with. For the judgment test specifications are defined which are not allowed to be exceeded. For this accurate indications are needed concerning the geometry of defects such as crack depth, crack length and position of deep cracks. Surface cracks can be detected very sensitively by ultrasonic angle beam transducer. For that the corner effect is used, i.e. an echo generated between the crack and the surface. This echo is greater the deeper the crack extends in the material. However this applies only for cracks smaller than half the probe diameter. The deeper cracks cannot be distinguished. A precise analysis of deeper cracks can be achieved by the TOFD method (time of flight diffraction). For that the diffraction of sound waves at the crack tip is utilized. The sound wave originating at the crack tip produces (besides the corner effect echo) a time-shifted diffraction echo. From the position of both echoes the depth of the crack can be determined. Starting from an angle beam transducer with known material thickness, a known sound velocity of the material and of the delay line $V_0$ [µs] the crack depth follows from the equations:

$$ x = x_1 - x_2 = s_2 - s_1 $$

and for the thickness:

$$ D = T_1 + T_2 $$

By simple geometric considerations follows:

$$ T = D - \sqrt{a_2^2 - x_1^2} = D - \sqrt{a_2^2 - (x_2 - x)^2} \quad \text{with} \quad x_1 = \sqrt{a_2^2 - D^2} $$

The sound paths $a_1$ and $a_2$ come up from the half time of flight and the sound velocity: $a_1 = t_1 \cdot c/2$ und $a_2 = t_2 \cdot c/2$.

Procedure:

By means of the angle beam transducer (delay line length 16.7 µs; angle of incidence 43°, transverse sound velocity of aluminum 3040 m/s) the corner echo of each crack is measured. For that the test head is moved and rotated so that the echo reaches a maximum. The time of flight and the amplitude are measured and the distance from the front edge of the probe to the edge of the work piece is determined. Then the diffraction echo at the crack tip is looked for and is likewise adjusted to maximal amplitude. The time of flight and the probe distance are measured in the maximum. The corner echoes are plotted versus the crack depth. For the diffraction echoes the crack depths are calculated corresponding to the given formula and are represented in a diagram too.

Results:

The determination of the crack depth by the corner echo amplitude is, for small depths, the best method to obtain the highest sensitivity. By determining the echo amplitude at comparative samples (nut characteristic line) the crack depth can be estimated. For crack depth in the range of half of probe diameter (probe diameter 16 mm) the corner echo goes into saturation, then an estimation of the crack depth is impossible. However the cracks can be located and the crack length can be examined.

By means of the TOFD method the smallest crack (crack depth 2 mm) could not be detected because the diffraction signal was covered by the corner echo. With increasing crack depth the diffraction signal can be measured separately from the corner echo. From the distance between the corner echo and the diffraction echo the crack depth results. The TOFD method can be utilized also for very large crack depths. A complete examination of the material arises however best by the combination of both test methods.
Detection of discontinuities

Purpose:
At a sample with various types of discontinuities different location techniques shall be carried out, first by scanning of the sample, then for each discontinuity the signal-noise-distance is examined for an angle beam probe and a normal probe, respectively. The results are discussed concerning the choice of the right location technique for a special test task.

Basics:
The non-destructive testing by ultrasound requires information about the geometry of the sample and the position and alignment of the discontinuities, in order to radiate the sound into various directions and to receive the sound from different directions, respectively. The direction of incidence is measured always relative to the normal of the surface. From the direction of the incident wave three classes of location methods are distinguished: normal (perpendicular), oblique and orthogonal direction of incidence. The received signal amplitude is dependent on the type, the size and the alignment of the defect. Two principal interactions of the defect and the ultrasound are distinguished: the reflection (strong interaction) and the scattering (weak interaction). The reliable detection of the discontinuity in the test sample requires a sufficient signal to noise distance level of the chosen location technique:

\[ A = 20 \log \frac{U_s}{U_r} \, [\text{dB}] \]

where \( U_r \) is the noise amplitude and \( U_s \) is the signal amplitude. For the detection limits of the individual defects and the location methods registration thresholds are defined. Since the ultrasonic echoes of real defects are built mostly of a mixing of reflection and scattering the interpretations can become easily wrong for low thresholds of registration. For the detection of defects with strong interactions the sensitivity of the ultrasonic device must be adjusted by using appropriate idealised test reflectors. As test reflectors mainly circular discs (bag holes), cylinders (through drillings), back walls and angle mirrors are used in different geometrical alignment.

Results:
In the scanning image taken with the normal probe all discontinuities are very clearly visible by the vanishing back wall echoes. But only the echoes of the back wall, of the circular disc and of the horizontal cylinder have sufficiently strong signal amplitude. The remaining echoes are generated at edges by scattering effects. In the case of the angle beam probe the strongest echoes appear for the crack, the oblique crack and also for the horizontal circular disc. As noise threshold the maximal amplitude of the scattering echoes is assumed. In the diagram of the signal to noise distances for the individual test reflectors one observes, that for the location of the back wall and the horizontal cylinder only the normal test head is applicable, on the other hand for the perpendicular and the oblique crack only the angle beam probe is usable. The horizontal circular disc could be localised by both techniques.

Setup:

- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 2 MHz order no 10132
- Delay line for angle beam 38° order no 10234
- Test block with discontinuities order no 10242
- Ultrasonic gel order no 70200

Procedure:
For the investigation of the signal to noise level of the test reflectors in the test sample, using at first the 2 MHz normal probe and then the 45° angle beam probe, the power of transmitter and receiver is adjusted in such a way, that none of the reflector signals is over-driven. Afterwards the sample is scanned manually. For that appropriate parameter can be chosen in the program. The scan images give an overview of the position and the signal amplitude of the defects. The signals produced by scattering (weak interaction) at the edges of the reflectors are judged as noise.
motion of the cardiac wall and the valves are recorded. From the changes of the cardiac wall distances and of the cavity area in the B-image the cardiac output can be calculated. From the measurement of the end-diastolic and the end-systolic ventricular diameter (distance of the cardiac walls) the corresponding heart volumes EDV (end-diastolic volume) and ESV (end-systolic volume) are determined. From this the heart time volume comes out via:

\[ HZV = (EDS-EDV) \times HF \]

HF = heart frequency.

Procedure:
After filling the heart model with water the probe shall be fixed to a tripod in such a way that the echo of the membrane appears at a sufficient distance to the impingement surface. Since in water the attenuation of the ultrasonic wave is negligible the measurements can be performed without use of the TGC. The software parameter „sound velocity” is adjusted to water (1480 m/s). After that one switches the software to the M-mode. By periodically compressing the rubber ball the rubber membrane simulates the heart wall motion. The periodical motion of the membrane is recorded in the M-mode and can be printed.

Results:
From the recorded M-mode image first the mean heart frequency is determined over some heart cycles. For this the time distances of the neighbouring heart cycles are measured and the average is calculated:

- Pulse duration: \( DT = 0,8 \) s
- Heart frequency: \( HF = 1/DT = 1,25 \) Hz

For all heart cycles the end-systolic diameter ESD (distance of the maximum of the curve from state of inactivity) of the heart model is determined.

- Mean = 14,6 µs

By using the sound velocity we get for

- \( ESD = c \times t = 1480 \) m/s \( \times 14,6\)µs
- \( ESD = 21,6 \) mm

The heart volume is obtained under the assumption of a cone as model volume \( V = \frac{1}{12} \pi \times D^2 \times h \) with a diameter of 45 mm. From that follows:

- \( ESV = \frac{1}{12} \pi \times D^2 \times ESD \)
- \( ESV = 11,45 \) cm³ = 11,45 ml

The end-diastolic volume is taken as zero in this model case. Therefore the heart time volume can be calculated:

- \( HZV = ESV \times HF = 14,3 \) ml/s

Basics:
In echo-cardiography a special ultrasonic method is applied for the investigation of the heart movements. The time-motion-mode, called also TM- or short M-mode, is indicated particularly as one dimensional technique but shows still two dimensions: one spatial dimension (superimposed interfaces or structures) and one temporal dimension (changes of the structures in the systole and diastole). By means of the TM-mode the motion of heart structures (cardiac wall, septum or cardiac valve and vessel valve) are displayed as picture points of different brightness. This form of recording yields an anatomically unusual image. For the determination of cardiac extensions, e.g. of cardiac walls and cardiac cavity diameter, the TM-mode is the investigation technique of choice. Also the judgment of the opening of heart and vessel valves is a domain of the TM-mode. For image recording first an appropriate region of the heart is chosen in the B-image (e.g. the long heart axis), then the M-mode is activated and the

Purpose:
Using a simple heart model the wall motion is recorded by means of the ultrasonic time-motion method (M-mode). From the M-mode recording the heart frequency and the heart volume (HZV) are determined.

Setup:
Ultrasonic echoscope GAMPT-Scan order no 10121
Ultrasonic probe 4 MHz order no 10134
Heart model order no 10220

Results:
From the recorded M-mode image first the mean heart frequency is determined over some heart cycles. For this the time distances of the neighbouring heart cycles are measured and the average is calculated:

- Pulse duration: \( DT = 0,8 \) s
- Heart frequency: \( HF = 1/DT = 1,25 \) Hz

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- \( HZV = ESV \times HF = 14,3 \) ml/s

Results:
From the recorded M-mode image first the mean heart frequency is determined over some heart cycles. For this the time distances of the neighbouring heart cycles are measured and the average is calculated:

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By using the sound velocity we get for

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- \( ESV = \frac{1}{12} \pi \times D^2 \times ESD \)
- \( ESV = 11,45 \) cm³ = 11,45 ml

The end-diastolic volume is taken as zero in this model case. Therefore the heart time volume can be calculated:

- \( HZV = ESV \times HF = 14,3 \) ml/s
Purpose:
In this experiment a typical application of ultrasound in medical diagnostics is given. At a realistic breast model a non-malignant tumor is diagnosed and by means of the brightness scan imaging method it can be localised and measured.

Setup:
- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 1 MHz order no 10131
- Breast dummy with tumor order no 10221
- Ultrasonic gel order no 70200

Basics:
The mamma tumor is the most common malignant alteration of the female breast. Besides the mammography (X-ray investigation) the mamma sonography is the most important examination for diagnosis. The sonography is applied in the early diagnosis of breast cancer. Its strong point lies especially in the distinction between liquid filled cavities (cysts) or alteration of tissue. By means of this method better targeting of the biopsy can be achieved. Immediately before the operation the ultrasonic investigation can show the precise position of the alteration and allows the surgeon to make a targeted operation. Especially after a cancer operation the remaining tissue can be controlled better by means of mamma sonography. Scar tissue (or the changed tissue density) distort the image of the mammogram. The mamma sonography so complements the mammography. For young patients the mamma sonography can be sufficient without mammography. An experienced physician using an advanced device detects knots in the breast up about 0.1 cm in size. Recent investigations show that the detection rate in comparison to mammography is nearly the same. In big and dense breasts ultrasound is the better method for the detection of knots. If mamma sonography is applied additionally to mammography the detection rate improves by circa 30 per cent.

Procedure:
First of all the breast model is examined by touching with the fingers. In this way both tumors can be found and the position can be determined roughly. By the 1 MHz probe an echogram of the breast is taken in the fixed region of examination. For this it is necessary to choose the device parameter so that besides the echo from the bottom mainly the echo of the tumor is measured. The adjustments and the alignment of the probe demand some experience from the student. After choosing suitable adjustments a B-image of the breast model is taken along a chosen line. If the adjustment of amplification especially of the TGC and the movement of the probe are well done, an ultrasonic brightness image of the tumor is clearly visible.

Results:
For the evaluation of the ultrasonic image one has to keep in mind that the lateral local assignment may be inaccurate because the cross section image was taken hand-guided. Of course the precise position of the tumor can be palpated. On the other hand the depth and size of the tumor are determined only by the ultrasonic image. The image of the breast model can be somewhat irritating because the outer form of breast is displayed downwards. This echo is produced by the plain back of the model and therefore the distance to the surface is displayed, respectively. In the upper left area the tumor is recognisable as a weak reflection. However, the imaging of the sound shadow behind the tumor is more clear. The sound impedance of the tumor tissue is only slightly different from the surrounding tissue, however the attenuation is clearly higher. For the sound velocity of the B-image intentionally the double velocity of water (3000 m/s) has been chosen in order to enhance the depth resolution in the presentation. All depth numbers must be dived by two. So the tumor exists in a depth of about 10 mm and has an extension of circa 20 mm.
Doppler sonography

Purpose:
The goal of the experiment is to learn how blood flow measurements are made with Doppler ultrasound. A realistic arm model is used to show the differences between continuously (venous) and pulsatile (arterial) flow and between normal blood flow and a stenosis.

Basics:
Doppler sonography uses the Doppler effect to assess whether structures (usually blood) are moving towards or away from the ultrasonic probe, and its relative velocity. By calculating the frequency shift of a particular sample volume, for example a jet of blood flow over a heart valve, speed and direction of this sample volume can be determined and visualised. Doppler frequency shift is the difference in ultrasonic frequency between transmitted and received echoes, i.e. the echo frequency minus the transmitted frequency. The Doppler frequency is proportional to the blood flow velocity. Doppler sonography is particularly useful in cardiovascular studies (sonography of the vasculature system and heart) and essential in many areas such as determining reverse blood flow in the liver vasculature in portal hypertension. The Doppler information is displayed graphically using spectral Doppler or as an image using colour Doppler.

Procedure:
The pump is switched on and the speed is adjusted in a middle range (ca. 4000 min⁻¹). The mode is GK (continuously, venous). With the Doppler probe and coupling gel the arm model is scanned for a vessel with a significant audio signal. The flow in the spectral image is analysed for negative and positive components. The probe direction is then switched by 180°. Then the vessel is scanned for changes in the spectral image (stenosis) and the differences between the images of the „healthy“ vessel and the stenosis will be characterised. Lastly the pump is switched to P1 and P2 mode (pulsatile) the images are analysed and the pulse rate is determined.

Results:
Figure 1 shows a continuously (venous) flow with a mean Doppler shift of ca. -700 Hz. The minus in the Doppler shift means flow away from the probe. Figure 2 is the spectral distribution with rotated probe. Flow towards the probe (the same Doppler shift, but positive). Figure 3 is the Doppler spectral figure of a stenosis. The differences to a normal (healthy) figure like figure 1 are: 1. A local increase of the maximum Doppler shift (maximum flow velocity). 2. A decrease of mean frequency and a broadening of the spectra. 3. An increase of reflux phenomenon (negative and positive parts of the spectra). Figure 4 shows the pulsatile flow of P1 with an pulse rate of ca. 90 min⁻¹.

Setup:
- Ultrasonic pulse Doppler „FlowDop“ order no 50100
- Ultrasonic Doppler probe order no 50135
- Centrifugal pump “MultiFlow” order no 50130
- Arm dummy incl. dummy fluid order no 50160
- Ultrasonic gel order no 70200
Ultrasonic investigation with the eye dummy

**Purpose:**
In this experiment a typical application of A-scan ultrasound biometry in medical diagnostics used in ophthalmology is given. At an eye dummy all parts of the healthy eye are measured and correction calculations shall be done.

**Setup:**
- Ultrasonic echoscope GAMPT-Scan order no 10121
- Ultrasonic probe 2 MHz order no 10132
- Eye dummy order no 10222
- Ultrasonic gel order no 70200

**Basics:**
Ultrasound is used also in ophthalmology. Its largest importance lies in the area of biometry, in the measurement of distances in the eye. The distance between cornea and retina is very significant for the calculation of the characteristics of the artificial lens implanted to patients with cataract. Sonography is necessary in this case since the cornea or the lens are too cloudy for the use of optical methods. Investigations of the aqueous, vitreous humour and the thickness of the lens are nowadays often done with new methods of laser light or ultrasonic B-mode imaging.

The given measured time of flight of the echoes of the A-scan can not be calculated as distance in a simple way, because of different velocities in the different media (cornea, lens, vitreous humour). Therefore a corrective calculation is necessary. Two velocities are given for the dummy:
- lens: 2500 m/s,
- humours: 1410 m/s.

These values and the time of flight from the measured A-scan image shall be used to determine the distances with the help of the following equation:

\[ s = \frac{v \Delta t}{2} \]  

**Results:**
The time of flight of each peak was measured and the averaged velocity was calculated with the equation (2). The result was adjusted to the A-scan device, it was switched to the depth scale and the depth of each peak was measured.

<table>
<thead>
<tr>
<th>velocities in m/s:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(aqueous/vitreous humour)</td>
<td>1410 m/s</td>
</tr>
<tr>
<td>(lens)</td>
<td>2500 m/s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>values:</th>
<th>front of lens</th>
<th>back of lens</th>
<th>retina</th>
</tr>
</thead>
<tbody>
<tr>
<td>time in 10^-6 s</td>
<td>13,7</td>
<td>21,1</td>
<td>74,8</td>
</tr>
<tr>
<td>averaged velocity</td>
<td>1518 m/s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>measured depth in mm</td>
<td>11,9</td>
<td>15,9</td>
<td>42,5</td>
</tr>
<tr>
<td>real depth in mm</td>
<td>9,66</td>
<td>18,91</td>
<td>56,77</td>
</tr>
<tr>
<td>thickness/ distance in mm</td>
<td>9,66</td>
<td>9,25</td>
<td>37,86</td>
</tr>
</tbody>
</table>

In medical diagnostics „averages“ are often used known from experience. This average velocity shall be calculated for the dummy with the following equation:

\[ v = \frac{v_1(t_1 + (t_3 - t_2)) + v_2(t_2 - t_1)}{t_3} \]

**Procedure:**
Ultrasonic coupling gel is used to connect the probe to the cornea of the dummy. Slowly move the probe over the cornea to look for the optimal signals (2 large lens peaks and one smaller from the retina). After measuring the time of flight of the peaks the real distances can be calculated.
All products and experiments can be found and downloaded on our website www.gampt.de.
Company profile

GAMPT mbH was founded in 1998 by 5 physicists of the Medical Faculty of the Martin-Luther-University Halle-Wittenberg, Germany. Ever since the company has evolved continuously into a competent partner in the field of ultrasound-based measurement technique.

With their unique know-how our highly qualified employees develop and produce special measuring equipment for industry and medicine. Another important field of activity is the development and production of ultrasonic equipment for education.

The performance profile of our company varies from circuit design over sensor construction and software development to the finished device.

Maximum customer satisfaction is one of our particular objectives. To ensure this, our multilingual team keeps an intense and open contact to the customer and guarantees the highest quality of our products. We handle special customer needs very flexibly and offer unconventional solutions for complex problems.

Our customers include international businesses, research organisations, universities and large clinics in Europe, North America, North Africa, Asia and Middle East.

References:

Charité Berlin, Germany
Martin-Luther-University Halle-Wittenberg, Germany
GOSH London, UK
Freeman Rd. Hospital, UK
King Faisal Hospital Riyadh, Saudi Arabia
Fresenius Medical Care
Inselspital Bern, Switzerland
PTB, Germany
Fraunhofer Institutes, Germany

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