Underwater Acoustic Measurements in Megahertz Frequency Range.

Current State and Prospects of Development in Russia

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Many medical applications of underwater acoustic measurements and effects are determined by equivalence of parameters (density, elasticity) of the water and that of human body.

<table>
<thead>
<tr>
<th>Medium</th>
<th>Sound velocity, m/s</th>
<th>Density, kg/m³</th>
<th>Acoustic impedance (ref. to water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (20 °C)</td>
<td>1482</td>
<td>1000</td>
<td>1</td>
</tr>
<tr>
<td>Lung</td>
<td>400 – 1200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Adipose tissue</td>
<td>1350 – 1470</td>
<td>950</td>
<td>0,86 – 0,94</td>
</tr>
<tr>
<td>Brain</td>
<td>1520 – 1570</td>
<td>1030</td>
<td>1,06 – 1,09</td>
</tr>
<tr>
<td>Blood</td>
<td>1540 – 1600</td>
<td>1060</td>
<td>1,04 – 1,08</td>
</tr>
<tr>
<td>Liver</td>
<td>1550 – 1610</td>
<td>1060</td>
<td>1,11 – 1,14</td>
</tr>
<tr>
<td>Muscle</td>
<td>1560 – 1620</td>
<td>1070</td>
<td>1,13 – 1,18</td>
</tr>
<tr>
<td>Kidney</td>
<td>1560</td>
<td>1070</td>
<td>1,13</td>
</tr>
<tr>
<td>Soft tissue (mean value)</td>
<td>1540</td>
<td>1060</td>
<td>1,11</td>
</tr>
<tr>
<td>Bone</td>
<td>2500 – 4300</td>
<td>1200 – 1800</td>
<td>2,2 – 5,0</td>
</tr>
<tr>
<td>Kidney stones</td>
<td>1400 - 2200</td>
<td>850 - 1080</td>
<td>0,8 – 1,6</td>
</tr>
</tbody>
</table>
These methods are most effective for diagnostics and treatment in the frequency range from a few to tens megahertz.

Therefore the two terms, - underwater acoustics on megahertz frequencies and medical ultrasound, - are equivalent.

IEC regulates in detail measurement methods for acoustic output and performance of ultrasonic medical equipment (UME): physiotherapy devices, diagnostic scanners, Doppler systems, lithotripters etc.

IEC standards are improved on a basis of deep research in metrology, underwater acoustics and materials. As a rule, they go ahead of the needs of medical industry.
### Types of Ultrasonic Medical Equipment (UME)

#### Ultrasonic Diagnostics Instruments

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Pulse-echo scanners</td>
<td>For producing black-and-white images of many soft-tissue organs</td>
</tr>
<tr>
<td>US scanners with Doppler</td>
<td>For producing images with assessment of blood flow spectrum</td>
</tr>
<tr>
<td>Color Doppler Imaging Systems</td>
<td>For producing black-and-white and colour-flow images of many soft-tissue organs</td>
</tr>
<tr>
<td>Special Purpose Diagnostic Systems</td>
<td></td>
</tr>
<tr>
<td>Hand-held Doppler foetal heart beat detectors</td>
<td></td>
</tr>
<tr>
<td>US encephaloscopes</td>
<td></td>
</tr>
<tr>
<td>US ophthalmoscopes</td>
<td></td>
</tr>
</tbody>
</table>

#### Hand-held Doppler foetal heart beat detectors

- US encephaloscopes
- US ophthalmoscopes

#### US Physiotherapy systems

- For physiotherapy treatment (warming and micro-massage)

#### Lithotripters

- For extracorporeally inducing pressure waves and disintegrating calculi and other concretions within human body

#### US Surgery Instruments

- For aspirating or disintegrating unwanted tissue in ophthalmology, neurosurgery and dental surgery

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The UME acoustic output does not relate to its performance only, but it is also a principal safety characteristic of a device.

A basis of testing UME is the measurements of acoustic pressure parameters throughout ultrasound beam.

An acoustic pressure distribution in the ultrasound field has been examined using a planar scanning method and a hydrophone with high temporal and spatial resolution.

The total ultrasonic power measurement is also an important problem for testing ultrasonic transducers.

This parameter and its measurement methods are normalized by IEC standard for all UME.
The hydrophones for measuring on frequencies up to 40 – 60 MHz are produced now in several countries, and there is IEC standard 62092 specified the hydrophone calibration in the frequency range 15 MHz to 40 MHz. The Russian national standard covers the range up to 1 MHz only.

Despite the fact that medical ultrasound is an effective way of military underwater acoustics conversion, the need to develop underwater acoustic measurements on megahertz frequencies is not fully understood in Russia.

There is neither a national standard nor a hierarchy scheme for carrying out the hydrophones calibration on frequencies above 1 MHz.

Therefore we were unable to participate in BIPM Key comparison CCAUV.U-K2 (Comparison of 1 mm hydrophone calibrations in the frequency range 1 MHz to 15 MHz).
ULTRASOUND: OTHER APPLICATIONS

The underwater acoustic measurements in the megahertz frequency range are not limited to the medical industry only, although it is a main consumer of these metrology services.

A research of cavitation, acoustic emission of different origin, industrial ultrasound technology, chemistry and biotechnology requires a reliable assessment of acoustic field parameters.

IEC started the development of some standards relating to these problems, e.g. ultrasound cleaning technology, focused high power radiator, etc.
TOP-PRIORITY TASKS OF DOMESTIC METROLOGY
IN THE MEGAHERTZ FREQUENCY RANGE

Development of a commercially available automated device for spatial and temporal measuring of acoustic pressure in ultrasound medical fields in accordance with IEC standards.

Development of probe and membrane pvdf hydrophones (diameter of 0.1 – 1 mm) with the frequency range up to 40 MHz.

Creation of national standard for the hydrophones calibration in this frequency range.

Creation of primary standard of ultrasound power unit in the dynamic range from 0.1 mW to 20 W.

Development of a set of reference transducers covering the frequency range of 0.5 to 25 MHz.

Development of an commercially available automated device for spatial and temporal measuring of acoustic pressure in ultrasound medical fields in accordance with IEC standards.

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Hierarchy Schemes and Consecution of their Achievement

Achievement of scheme correspond to consecution of its element appearance

Indicated in colour:
Primary standards

Verification
Working standards
Working measuring devices
Working measurements

Reciprocity method with 2 transducers
Hydrophone calibration standard
IEC 60866
Method of radiometer
Power measurement standard
IEC 61161

Reference transducer
Reference scanning device
IEC 61101
Measuring transducer
Reference hydrophone
Reference scanning device
Measuring hydrophone

US beam measuring device
Absorption measuring device
Reflection measuring device
US power meter

US power meter
Measurement of US field of diagnostic devices (IEC 60854 or 61157)

Measurement of US field of lithotripters (IEC 61846)
Measurement of US field of UME (IEC 61220)
Measurement of US field parameters (IEC 61102)
Measurement of US field of UME (IEC 61220)
Measurement of parameters of media (IEC 61206, 61685, 61390)
Measurement of parameters of therapy devices (IEC 61689 and 601-2-5)
Measurement of US power of therapy devices (IEC 61390, 61206, 61266)
Measurement of US field of therapy devices (IEC 61689 and 601-2-5)
Measurements of Performance of Medical Ultrasonic Diagnostic Instruments

In order to assess and check the performance of ultrasonic scanners and Doppler systems:

- image property (dead space, penetration depth, resolution, contrast range)
- measurement accuracy of internal organs, their position and motion parameters
- measurement accuracy of blood flow parameters (mean velocity and velocity spectrum in different blood vessels)

The so-called «phantoms» are used (tissue-mimicking test-objects with fixed set of exactly located heterogeneities)

As a case in point let us consider the design of «Multipurpose Phantom, Model 539» manufactured by ATS Laboratories, Inc.

This tissue-mimicking phantom is used to evaluate the accuracy and performance of ultrasound imaging systems.

Feature: Model 539 has four acoustic windows (scanning surfaces) for probe application and possibility of imaging targets in different angles.
Target structures in the phantom model 539

Convention:
- Monofilament Nylon 0.12 mm
  - for assessment of dead zone
- Anechoic cylindrical targets
  - for vertical measurement calibration
- Gray scale cylindrical targets
  - for horizontal measurement calibration
- Urethane rubber
  - for assessment of resolution
  - for assessment of maximum depth of penetration
  - for assessment of dynamic range
Ultrasound Phantoms in Russia

In Russia, there is no such domestic measuring instrument. However a need for them is very large. Some foreign imported phantoms are used in few clinics occasionally, but their not verified periodically.

This is one of the causes for poor technical condition of ultrasonic devices used in some clinics in Russia.

According to the information from metrological supervision services, approximately one third of ultrasonic scanners does not meet manufacturers specification and must be repaired.

Therefore the development and production of a full set (no less than 10 types) of phantoms is very critical for domestic health protection.

Their creation demands a development of special polymeric materials with required acoustic parameters and measuring methods and instruments for measurements and verification of phantoms.
VERIFICATION OF PHANTOMS

- **UVT 90-A-96**
  - National standard for sound velocity
  - Working standard: 1407 - 1620 m/s ±0.25

- **attenuation standard**
  - In range 0.4-1.5 dB/cm MHz

- **reference phantoms**
  - Reference scanner

- **sound velocity**
  - Temperature alteration

- **attenuation**
  - Temperature alteration

- **back scatter coefficient**

- **target linearity**

- **coordinates**

- **direct measurement**

- **comparison**

- **Multi-directional examination**

- **tissue-mimicking material**
  - Filament target structure
  - Dead zone
  - Axial resolution

- **slice thickness**

- **depth of penetration**

- **parameters to be measured**

- **test objects**
  - For pulse-echo scanners

- **gray scale targets**
  - Anechoic targets

- **method of unit reproduction**

- **reference instruments**

- **verification of phantoms**

- **parameters**
  - Sound velocity
  - Temperature alteration
  - Target linearity
  - Coordinates

- **parameters for measurement**
  - Direct measurement
  - Comparison
  - Multi-directional examination

- **reference scanner**

- **reference materials**

- **comparison**

- **parameters**
  - Attenuation standard in range 0.4-1.5 dB/cm MHz

- **Hydrophone**

- **reflectance**

- **instruments**

- **parameters**
  - Direct measurement
  - Comparison
  - Multi-directional examination

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  - Direct measurement
  - Comparison
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The phantoms for testing Doppler ultrasound systems simulate:

- Blood flow in very small blood-vessels using a string generating a single Doppler frequency.
- Blood flow in wide blood-vessels using a band or a disk generating a single Doppler frequency.
- The pulsating surfaces of blood-vessels and heart, cardiac valve using the back-and-forth motions of a piston on 1 - 2 Hz.
- Velocity spectrum of blood flow within a blood-vessel using flow Doppler test object with a parabolic profile of the flow.

Diagram:
- TIM absorber
- Transducer
- String
- Band
- Disk
- Water
Physical properties (sound velocity, attenuation coefficient, backscatter coefficient, viscosity, etc.) of phantom principal parts – target (string, band, piston, tube, blood-mimicking liquid) and medium, they are located in, must correspond to the examined tissue of human body.

- **Attenuation:** 0.5 to 1 dB cm\(^{-1}\) MHz\(^{-1}\) for human soft tissue (average values)
- **Sound velocity:** 1540 m s\(^{-1}\)
- **Density:** 1060 kg m\(^{-3}\)
- **Attenuation:** 0.15 to 0.22 dB cm\(^{-1}\) MHz\(^{-1}\)

- **For blood at 37 °C**
- **Sound velocity:** 1570 to 1595 m s\(^{-1}\)
- **Density:** 1050 to 1055 kg m\(^{-3}\)
- **Attenuation:** 0.15 to 0.22 dB cm MHz\(^{-1}\)
- **Viscosity:** 1.7 to 4.4 mPa s
Doppler phantoms are not manufactured in Russia.

Without them, it is impossible to produce modern Doppler diagnostic instrument.

As in a case with pulse-echo scanners, the development and use of these instruments demand deep metrological maintenance illustrated by following hierarchy scheme.
**Reference measuring devices**

- **Sound velocity standard**: UVT-90-A-96, Working standard
- **Reference materials**: direct measurement
- **Flow meter**: direct measurement
- **Spectrum analyzer**: tachometer

**Parameters to be measured**

- **Sound velocity**: temperature alteration
- **Attenuation**: temperature alteration
- **Back scattering**: temperature alteration

**Flow**

**Band**

**Doppler test objects**

**Doppler shift**

**Flow velocity meter**

**References measuring devices**

**Flow velocity meter**

**Doppler**

**String**

**Disk**

**Piston**
CONCLUSION

Russian level of development of metrology in the field of megahertz underwater acoustics is characterized by significant lagging in comparison with some foreign countries.

The necessity of development of domestic metrology and normative base for testing and quality control of medical ultrasound equipment still does not find enough understanding among medical authorities and in medical industry.

Nevertheless, our institute developed perfection tracks of metrology maintenance in the field of megahertz underwater acoustics and medical ultrasound and intends to realize it.

We determined some top-priority problems and the most necessary measuring instruments.

We developed some normative documents (about 10) harmonized with IEC standards.

We have national standard for ultrasound power in the water and developed four types of commercially available devices for measuring ultrasonic power in the water in order to testing diagnostic and therapy medical equipment.