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The current status of Acoustics, Ultrasound and Vibration measurement standards at INMETRO

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Introduction:

The Division of Acoustics and Vibration Metrology (DIAVI) of the Brazilian National Institute of Metrology, Standardization and Industrial Quality (INMETRO) started activities in 1984 and at the present time comprise three laboratories: the Electroacoustics laboratory (LAETA), the Vibration laboratory (LAVIB), the Acoustics Testing Laboratory (LAENA). The implementation of an Ultrasound laboratory (LABUS) was started in 2005 and it is expected to be operational in 2007.

Fig. 1: Building of the Division of Acoustics and Vibration Metrology

These laboratories are responsible for the establishment, validation and maintenance of the Brazilian national measurement standards used for the realization of the units of the International System of Units (SI) related to acoustics and vibration. The national measurement standards comprise both absolute (primary) and comparison (secondary) calibration set-ups, which are used to cover the wide range of calibration and testing services demanded by the Brazilian society, trade and industry.

The currently implemented systems and procedures are in accordance with international technical standards and the degree of equivalence of many of the Brazilian national measurement standards have been proved through the participation of INMETRO in international comparisons. The results obtained so far by INMETRO have shown good agreement with the calculated comparison reference values, with deviations within the estimated limits of uncertainty.

Among the available facilities of DIAVI, three especial measurement environments should be highlighted:

- anechoic chamber with a volume of 70 m^3, vibration isolated with air springs, Fig. 2(a);
- reverberation chamber with a volume of 226 m^3, vibration isolated with steel springs, Fig. 2(b);
- reverberation chamber with a volume of 196 m^3, vibration isolated with steel springs, Fig. 2(c).

(a) (b) (c)

Fig. 2: Acoustic chambers

1) Dissemination of the units of the SI related to the field of acoustics and vibration

The DIAVI realizes the acoustics and vibration physical quantities that are most demanded by the Brazilian industry, users of measuring instruments and measurements of public concern, i.e., quality, health and safety, for which traceability to national standards are mandatory. The calibration and testing services are offered on a standardized basis but especial calibrations and measurements can be arranged to attend specific needs of INMETRO's customers. These services offered by DIAVI contribute to the establishment of a metrological basic infrastructure to support quality of Brazilian products and services and the competitiveness of the Country. The table of Calibration and Measurement Capabilities (CMC), which is part of the Mutual Agreement Arrangement is available at the website of the Bureau International des Poids et Mesures – BIPM (http:\\www.bipm.org). It should be noted that the complete list of services offered by the DIAVI is larger than the CMC because it does not include services like electrical calibrations, force transducer calibration and acoustical tests.

In addition, DIAVI provides technical support and technical transfer related to acoustics and vibration calibration and measurement techniques in a standardized base and as demanded by the community.

2) Participation in international comparisons with other National Metrology Institutes

In order to verify agreement between the units of acoustics and of vibration quantities, realized by the Brazilian national measurement standards, and the respective SI units, INMETRO participates in comparison measurements which are performed at international level among national metrology institutes and within regional metrology organizations (SIM in particular). Comparisons among NMIs have played an important role in establishing or improving the confidence in the results of first-level calibrations and most ultimately improved confidence in the results of acoustical and vibration measurements at every level.

In all concluded comparisons, INMETRO has shown very good results, obtaining excellent agreement with the calculated reference values. This gives high confidence on the claimed uncertainties by INMETRO, and endorses the recognition of the calibration certificates issued by the acoustics and vibration laboratories of INMETRO.

The DIAVI has been participating in all acoustics and vibration key and supplementary interlaboratory comparisons carried out under the framework of SIM Metrology Working Group for Acoustics and Vibration (MWG-9). The vibration key-comparison SIM.AUV.V-K1 carried out among NRC/Canada, NIST/U.S.A., CENAM/Mexico, INMETRO/Brazil and INTI/Argentina covered the calibration by interferometric methods of single-ended and double-ended accelerometers from 50 Hz to 5 kHz and included the electrical calibration of a charge amplifier. Two supplementary vibration comparisons carried out among NIST, INMETRO and CENAM extended the frequency range of accelerometers interferometric calibration up to 10 kHz and allowed the evaluation of the gain calibration of a charge amplifier within the period of 20 days. Currently, INMETRO and CENAM are developing a bilateral comparison on the calibration of magnitude and phase shift response of accelerometers in the frequency range from 10 Hz to 10 kHz.

Two acoustics key-comparisons have focused on the reciprocity calibration of LS1P microphones in pressure field. Comparison SIM.AUV.A-K1.PREV was carried out among CENAM, INMETRO, INTI and DPLA and SIM.AUV.A-K1 among NRC, NIST, CENAM, INMETRO and INTI. INMETRO has also participated in the key-comparison CCAUV.A-K3 of LS2aP microphones in pressure field and in the supplementary comparison of pistonphones SIM.AUV.A-S1, which included the participation of NRC, NIST, CENAM, INMETRO and INTI.

Electroacoustics laboratory – LAETA

Main activities

Calibration of microphones, sound calibrators, pistonphones, sound level meters, dosimeters, filters, analyzers, pre-amplifiers, audiometers, mastoids and artificial ears. Testing of loudspeakers.

Fig. 3: System for calibration of pistonphones by the insert voltage technique

Fig. 4: System for calibration of sound level meter calibrators

Units

The LAETA is responsible for the establishment, validation, maintenance, reproduction and dissemination of the unit of sound pressure, pascal (N/m^2). The realization of the pascal, by means of the reciprocity calibration of laboratory standard microphones (IEC 61094-2) traces it back to mechanical and electrical quantities. The pressure sensitivity of reference standard microphones is determined by the ratio of the output voltage of the microphone to the input sound pressure.

National Measurement Standards

The pressure-field national measurement standard is based on an automated reciprocity calibration system type B&K 9699, which include a pressure chamber to allow calibration at the standardized reference pressure value. This system is used for pressure-field reciprocity calibrations of 1” and ½” laboratory standard microphones.

Dissemination

Sound calibrators or working laboratory condenser microphones are used for the dissemination of the unit pascal. These working standards are calibrated by secondary procedures (eg. IEC 61094-5). Calibration of general purpose microphones, pistonphones and mastoids are also performed by using comparison methods. Sound level meters, amplifiers, attenuators and filters are calibrated electrically. Measurements of sound power emission and of the directivity of loudspeakers are carried out in the anechoic chamber.

Calibration set-ups:

1) System for Reciprocity calibration of 1” laboratory standard microphones (IEC 61094-2)
   Uncertainty: ± 0,05 dB (63 Hz to 3,15kHz); ± 0,07 dB (4 kHz to 6,3 kHz); ± 0,11 dB (8 to 10 kHz).
2) System for calibration of pistonphones (IEC 60942)
   Single frequency pistonphone / LS1P, Uncertainty: ± 0,1 dB,
   Single frequency pistonphone / LS2P, Uncertainty: ± 0,12 dB,
   Multi-frequency calibrator /LS2P, Uncertainty: ± 0,12 dB (31,5 Hz to 4 kHz),
   Multi-frequency calibrator /LS2P, Uncertainty: ± 0,19 dB (8 Hz to 12,5 kHz)
3) System for calibration of microphones by comparison method in pressure field (sequential method)
   Uncertainty: ± 0,3 dB (63 Hz to 8 kHz)
4) System for calibration of microphones by comparison method in free field (sequential method in anechoic chamber)
   Uncertainty: ± 0,5 dB (31,5 Hz to 5 kHz); ± 0,6 dB (4 kHz to 6,3 kHz); ± 0,11 dB (8 to 10 kHz).

5) System for calibration of microphones by comparison method in pressure field (simultaneous method / IEC 61094-5,) – under development
6) System for calibration of microphones by comparison method in diffuse field (sequential method / IEC 61183 in reverberation chamber)
7) System for electrical calibration of sound level meters, dosimeters and filters, Uncertainty: ± 0,2 dB
8) System for calibration of audiometers
   Air conduction, Uncertainty: ± 0,8 dB (125 Hz to 8 kHz)
   Bone conduction, Uncertainty: ± 0,8 dB (250 Hz to 8 kHz)
9) System for calibration of mastoids.

Future R&D projects of the Electroacoustics Laboratory:

- Modernization of current calibration eletroacoustics systems;
- Simultaneous comparison calibration of for microphones in pressure field;
- Calibration of microphones by impulsive response;
- Primary calibration of microphones in free-field;
- Calibration of microphones by laser vibrometry;
- Development of laser pistonphone.

Fig. 5: System for calibration of 1” and ½” laboratory standard microphones by reciprocity in pressure-field

Fig. 6: System for calibration of 1” microfones by comparison in pressure-field

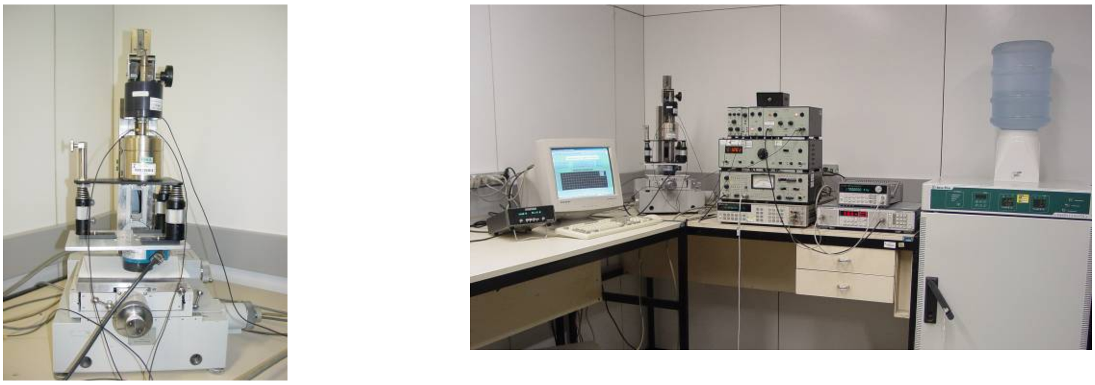

Fig. 7: Mastoid calibration system

Vibration laboratory – LAVIB

Main activities

Absolute calibration of standard accelerometers, vibration standard sets (accelerometer with associated amplifier) and force transducers. Comparison calibration of acceleration calibrators, vibration transducers, vibration measuring instruments (vibration meters and analyzers), vibration measuring chains, force transducers, impedance heads and instrumented hammers. Electrical calibration of signal conditioning amplifiers and comparison shock calibration of accelerometers.

Units

The Vibrations Laboratory (LAVIB) is responsible for the establishment, validation, maintenance, reproduction and dissemination of the units of translational acceleration and derived motion quantities of solid bodies, i.e. velocity and displacement.

At primary level, the realization of the acceleration unit m/s^2, is traced back to the mechanical and time quantities by means of the interferometric measurement of the motion quantity. The measurement of the output signal from the reference or transfer standard accelerometer provides the link back to electrical quantities (charge or voltage) and the transducer sensitivity is determined by the ratio of the electrical output to the mechanical input.

At secondary level, the sensitivity (mV/ms^{-2} or pC/ms^{-2}) of the transfer standard accelerometer links the motion measurements back to the electrical, length and time quantities.

National Measurement Standards

In accordance with the international standards that specify methods for the primary vibration calibration of transducers, laser interferometers are applied as sub-systems of national measurement standards for the realization of acceleration and derived motion quantities used for the primary calibration of reference accelerometers.

The absolute national measurement standards mainly consist of a vibration exciter to generate the motion quantities acceleration, velocity and displacement, an interferometric measurement system to accurately quantify this motion quantity and some equipment for the measurement of the signal put out by the transducer under calibration. Basically due to limitations of commercial vibration exciters, a single system can not be used to cover all calibration frequencies. In order to minimize disturbing influences on the generated motion, LAVIB uses three different systems usually referred to as:

- Low frequency system – 1 Hz to 80 Hz
- Mid frequency system – 10 Hz to 5 kHz
- High frequency system – 4 kHz to 10 kHz

The calibration of accelerometers and vibration standard sets by laser interferometry are carried out at LAVIB in accordance with the standard ISO 16063/11:1999. Currently, the Method 1 – “Fringe-counting method” is used in the frequency range from 1Hz to 1 kHz and the Method 2 – “Minimum-point method” from 1.25 kHz to 10 kHz. The laboratory is working towards the implementation of the Method 3 – “Sine-approximation method”. A calibration system was already developed and is currently being evaluated through a bilateral comparison on magnitude and phase shift response from 10 Hz to 10 kHz. This system allows automated calibration of accelerometers, reference acceleration sets and laser Doppler vibrometers.

The secondary national measurement standards consist of systems based on vibration or shock exciters to generate the motion quantities, a transfer standard previously calibrated by interferometry and the instrumentation to compare the signal put out by the transfer standard and by the transducer under calibration. The comparison calibrations with sinusoidal excitation are carried out in accordance with the standard ISO 16063-21:2003. Comparison calibrations include calibration of vibration measuring chains, acceleration, velocity and displacement transducers, acceleration calibrators, vibration meters, vibration analyzers, force transducers, impedance heads and instrumented hammers.

The laboratory is equipped with the necessary instrumentation and standards to perform internal electrical calibrations. These standards include an AC calibrator, one two channel signal generator, precision 8½ digits voltmeters, standard capacitors, one standard resistor, resistive decades and voltage dividers, a step attenuator and programmable switches. Electrical calibrations are focused on signal conditioning amplifiers, attenuators and filters used in vibration measuring chains.

The absolute calibration services offered by LAVIB are periodically checked by reference transducers calibrated at other NMIs and by the results obtained in interlaboratory comparisons. The deviations obtained have shown good agreement with the estimated uncertainty claimed giving high confidence of the results reported on the calibration certificates issued by LAVIB. In addition, some overlapping of the frequency ranges of use allows cross-checks to be made among the different calibration systems at LAVIB.

Dissemination

The units realized by the vibration national measurement standards are disseminated to accredited and non-accredited calibration laboratories by standardized calibrations of reference and transfer standards. These reference standards are mainly standard accelerometers, or standard reference sets. For the first type, charge sensitivity is reported and for the second, voltage sensitivity.

Accelerometer calibrators are also used for the dissemination of the units of motion in field measurements. These working standards are calibrated by comparison against a transfer standard.

Calibration set-ups:

1) Low-frequency absolute calibration system – freq.: from 1Hz to 80 Hz (ISO 16063/11:1999 Method 1)
   Uncertainty: ± 1,5 % (1 Hz to 5 Hz); ± 1 % (6,3 Hz to 20 Hz), ± 0,5 % (25 Hz to 80 Hz)
2) Mid-frequency absolute calibration system – freq.: from 10 Hz to 5 kHz (ISO 16063/11:1999 Methods 1 & 2)
   Uncertainty: ± 1 % (10 Hz to 40 Hz); ± 0,5 % (50 Hz to 1 kHz); ± 1 % (1,25 kHz to 5 kHz)
3) High-frequency calibration system – freq.: from 4 kHz to 10 kHz (ISO 16063/11:1999 Method 2)
   Uncertainty: ± 1 % (4 kHz to 5 kHz); ± 1,5 % (6,3 kHz to 10 kHz)
4) Vibration transducer comparison calibration system (ISO 16063/21:2003)
   Uncertainty: ± 1,5 % (10 Hz to 50 Hz); ± 1 % (63 Hz to 1 kHz); ± 1,5 % (1,25 kHz to 5 kHz), ± 2 % (6,3 kHz to 10 kHz)
5) Vibration measuring systems comparison calibration system – freq.: from 10 Hz to 5 kHz
   Uncertainty: dependent of type of equipment and readout, ± 1,5 to 5 %
6) Comparison shock calibration (ISO 16063-22) - peak amplitude from 200 to 100000 m/s^2, 0,1 to 3 ms
   Uncertainty: ± 3 %
7) Electrical calibrations system
   Charge amplifier sensitivity - Uncertainty: ± 0,20 %
   Voltage amplifier sensitivity, voltage gain / attenuation - Uncertainty: ± 0,1 %
8) Quadrature absolute calibration system – freq.: from 10 Hz to 10 kHz (ISO 16063/11:1999 Method 3)
   Uncertainty: system under evaluation

Future R&D projects of the Vibration Laboratory:

- Development of a primary accelerometer calibration system by shock excitation;
- Implementation of a heterodyne interferometer for calibration of accelerometers at high-frequencies;
- Implementation of a low-frequency secondary calibration system based on a shaker APS129;
- Development of a calibration system for vibrometers with digital output;
- Improvement of the homodyne quadrature calibration system;
- Development of calibration exciters.

Fig. 8: Low-frequency absolute calibration system of accelerometers

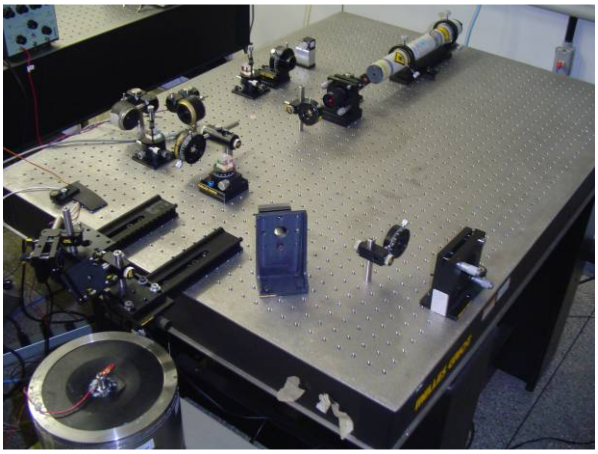

Fig. 9: Homodyne quadrature interferometer for calibration of accelerometers by the sine-approximation method

Acoustics Testing Laboratory – LAENA

Main activities

Calibration of reference sound source in reverberation chamber. Measurement of environmental and workplace noise. Measurement of sound absorption coefficient in impedance tube with two microphones, in reverberation chambers and *in situ*. Measurement of sound power emission in reverberation chambers, in semi-anechoic room and *in situ*. Measurement of reverberation time of rooms. Measurement of room sound quality parameters. Measurement of audiometric testing environments, cabin sound isolation and background noise.

Units

The Acoustics Testing Laboratory (LAENA) is responsible for the establishment, validation, maintenance, reproduction and dissemination of the unit of sound power (dB ref. 10^{-12} Watt).

National Measurement Standards

Reference sound sources are calibrated in accordance with the standard ISO 6926. According to this standard, calibrations in both reverberation and semi-anechoic rooms are possible. LAENA preferably uses the reverberation room method because this is the same method used by secondary testing laboratories and the second one requires mounting a rigid floor inside the anechoic chamber. To enhance the diffusivity of the sound field, the non-rectangular reverberation room is equipped with additional hanging reflection panels. The frequency range for calibration is 100 Hz to 10 kHz and the sound power level is determined in the third-octave band as an unweighted or A-weighted total level.

The national measurement standard for sound power in diffuse-field includes the reverberation chamber, the measuring instrumentation for measuring the diffuse-field sound pressure and equipment and software for processing the data. The use of sound calibrators previously calibrated by LAETA provides knowledge of the sensitivity of each measuring channel and traces the pressure measurements back to mechanical and electrical quantities. Electrical verifications and the use of standardized reference data can be used to verify software used for the data processing.

Dissemination

The measurement of the sound power can be carried out either directly or by comparison with a reference sound source whose radiated sound power has been determined by calibration. LAENA calibrates reference sound sources of testing laboratories and can additionally perform qualification tests of their reverberation rooms using one of INMETRO’s reference sound sources.

The absorption coefficient of small samples of materials is measured by LAENA in impedance tubes by the well-known standing waves method (ISO 10534 part 1) or by the transfer function or 2-microphone method (ISO 10534 part 2). The absorption coefficients of large samples of materials and panels are measured by LAENA in the 226 m^3 reverberation room by comparing the reverberation time of the room with and without the absorbing material. For in-situ measurements a special homemade measuring device is used and the reflection subtraction technique is applied. The frequency range covered by this system goes from 100 Hz to 5 kHz.

Characteristics of LAENA Impedance Tubes:

Nr.	Material	Shape	Edge length/ Diameter	Total length	Lower limiting frequency	Upper limiting frequency
1	steel	round	0,100 m	1,00 m	200 Hz	1250 Hz
2	steel	round	0,033 m	0,28 m	800 Hz	6300 Hz
3	plastic	round	0,075 m	1,00 m	20 Hz	1000 Hz

Tubes Nr. 1 and Nr. 2 are the original parts that were received with the standing wave apparatus B&K 4002. The tube Nr. 3 was home-built to permit the use of the 2-microphone method.

LAENA is usually requested to carry out in-situ measurements for legal purposes. Among these requests, measurements of noise exposure at the working place and environmental noise measurements are typical. In these cases, traceability is mandatory and LAENA is called to assure the reliability and impartiality of the measurements.

Measuring set-ups:

1) System for sound power measurement of reference sound sources in reverberation chamber (0,1 to 10 kHz);
2) System for sound power measurement in reverberation chamber (Noise Label program);
3) System for sound absorption in reverberation chamber (f = 100 Hz to 5 kHz);
4) System for measurement of sound absorption in Impedance Tube (ISO 10534 part 1 & 2);
5) System for in-situ measurements of sound power;
6) System for in-situ measurements of sound absorption;

7) System for in-situ measurement of reverberation time of rooms;
8) System for environmental / workplace noise measurements.

R&D projects of the Acoustics Testing Laboratory:

- Acoustical certification of buildings by in-situ evaluations;
- Acoustical measurements of music halls;
- Development of multi-channel room acoustic measurement systems;
- Sound power measurement comparisons for refrigerators (Noise label program).

Fig. 10:Concert hall sound quality measurement

Fig. 11: Acoustical testing using artifitial speaker and head in a classroom.

Ultrasound laboratory – LABUS

Activities under implementation

Primary and secondary calibration of hydrophones, calibration of sound power emission by radiation force balance, field mapping of ultrasonic beam.

Units

The LABUS will be responsible for the establishment, validation, maintenance, reproduction and dissemination of the unit of ultrasound power and ultrasonic transducer's (both for emission and/or imission) sensitivity. The realization of the watt, by means of a radiation force balance, traces it back to mechanical quantities. Transducer's sensitivity, in units of V/Pa (volts per pascal) for imission transducers (hydrophones) or in Pa/A (pascal per ampere) for emission transducers, is realized by means of auto-reciprocity methods, accordingly to IEC 60866, and traces those quantities to mechanical and electrical quantities.

National Measurement Standards

The ultrasound national measurement standards include a reference power source and membrane reference hydrophones. A radiation force balance and an ultrasonic beam mapping system are currently under development.

Dissemination

Reference hydrophones and the reference power source will be used for the dissemination of the units watt and pascal (sensitivity). Initially, calibrations of radiation balances for physiotherapy, power sources and needle hydrophones will be offered.

Calibration set-ups under development:

1) Radiation force balance for calibration of hydrophones - 1mW to 20 W up to 25 MHz
2) System for calibration of ultrasonic transducers by auto-reciprocity - 0,5 to 15 MHz (IEC 60866:1987)
3) System for beam mapping of ultrasonic sources - 0,5 to 15 MHz (IEC 61101, 61102)
4) System for comparison calibrations of radiation balances

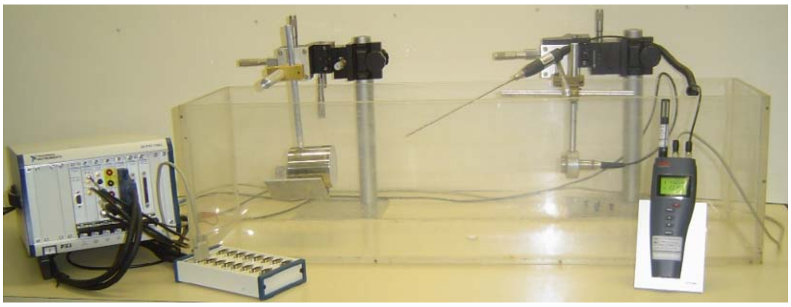

Fig. 12: Set-up for autoreciprocity calibration of hydrophones

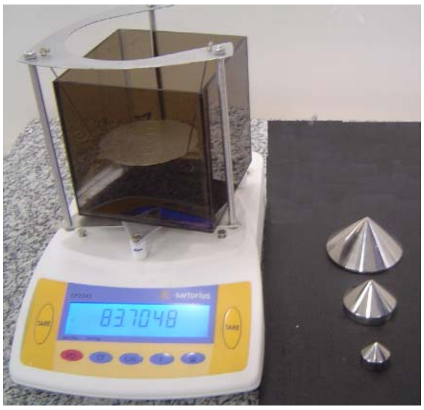

Fig.13: Radiation force balance

Future R&D projects of the Ultrasound Laboratory:

- Participation in bilateral interlaboratory comparisons focusing:
  - calibrations of radiation force balances;
  - calibrations of hydrophones.
- Coordination of a national ultrasonic power measurement intercomparison;
- Certification of reference materials:
  - Ultrasonic absorbing material;
  - Reference block for Non-Destructive Testing.
- Development of a reference ultrasonic power source.