

Physikalisch-Technische Bundesanstalt

Short Report for CCAUV, June 2006

1. Organisation

PTB is the National Metrology Institute of Germany and the highest technical authority for the field of metrology and certain sectors of safety. The PTB comes under the auspices of the Federal Ministry of Economics and Technology. PTB has several fundamental tasks for example to realise and maintain the legal units in compliance with the International System of Units (SI) and to disseminate them. Another task is type approval and calibration of devices that are covered by national or international regulations.

The work, which is done in acoustics and vibration at PTB, is spread over several departments. Most of microphone calibrations, audiometry and ear simulator task as well as ultrasound are carried out in the department „Sound“. The department „Applied Acoustics“ comprises activities in building acoustics, sound level meters and heat conduction. „Vibration“ belongs to the department of „Kinematics“ dealing with calibration and measurement of accelerometers.

2. Activities in acoustics, ultrasound and vibration at PTB

PTB is active in a variety of fields in acoustics, ultrasound and vibration. Lots of effort is spent for the realisation and maintenance of units and several calibration and standard measurement set-ups are available:

- calibration of microphones in the pressure chamber between 2 Hz and 25 kHz
- calibration of microphones in the free field between 25 Hz and 20 kHz, currently increasing the upper frequency limit to 160 kHz
- measurement of ultrasound power between 5 mW and 20 W
- calibration of hydrophones between 400 kHz and 60 MHz
- primary calibration of accelerometers with sinusoidal excitation in the range of 0.4 Hz to 20 kHz and 0.01 m/s^2 to 100 m/s^2 in magnitude and phase of the complex sensitivity coefficient
- primary calibration of accelerometers with shock shaped excitation in the range of 50 m/s^2 to 100 km/s^2
- primary calibration of angular accelerometers with sinusoidal excitation in the range from 0.4 Hz to 1.6 kHz and 1 rad/s^2 to 1400 rad/s^2

Another important task concerns legal metrology issues. PTB is responsible for a number of type approvals and safety investigations:

- type approval and calibration of sound level meters
- type approval and calibration of sound calibrators and pistonphones
- calibration and testing of mechanical couplers
- testing of reference couplers and artificial ears.

Scientific research plays an important role at PTB and many ideas and projects are currently under consideration at PTB. The improvement and extension of calibration possibilities attract a constant attention for example by the increase of the upper limit of the free-field calibration of microphones to 160 kHz or the high-frequency calibration of hydrophones. New measurement techniques are investigated for the determination of the output parameters of diagnostic machines. This is accompanied by the development of novel sensors and sensor concepts. The determination of hearing thresholds of normal hearing persons is required by manufactures of audiometry devices for calibration of output level and is also driven by standardisation activities. They ensure a high level of patient safety required for higher quality of life. Other projects, for example the investigation of safety aspects for ultrasound surgical devices or the determination of the heating potential of contrast agents are also closely connected to safety issues.

Industrial applications and requirements are the scope of many activities in building acoustics. The investigation of sound sources in buildings or the measurement of acoustic parameters has a direct impact on the quality of everyone's life. Another task is the assessment of noise in buildings including prediction methods with respect to individual psychological reception of sound. A project about the investigation of high-power ultrasound fields used in cleaning baths had also high relevance to industrial application.

In the field of primary accelerometer calibration by shock excitation PTB research follows a new approach of parameter identification, which proves capable to eliminate the inherent spectral dependence of the shock sensitivity currently used.

The emerging field of laser-vibrometer calibration by different methods is an area where PTB is strongly engaged in metrological research and standardization. The goal is to provide best knowledge about feasible procedures in primary and secondary calibration and the involved uncertainty contributions.

Closely related to the service of primary calibration of accelerometers by shock excitation is the research field of impact calibration of force transducers to which a working group of PTB is dedicated. Within the working scope of this group is the development of two (future) standard facilities for force transducer calibration by shock excitation with a range of 20 kN and 250 kN respectively. In addition the research covers calibration procedures and uncertainty evaluation. This work is closely coupled to a new work package in the scope ISO TC108/SC3.

3. Current status of standards

PTB operates a couple of acoustic and vibration standards in agreement with international regulations. Many of them are included into the appendix C of the Mutual Recognition Agreement as CMC entries and can be found in the on-line database. Other special services that are also covered by a quality management system following ISO/IEC 17025 were offered to meet requirements of our customers. A summary list of all services can be found on the web-site of PTB (www.ptb.de). Here only several quite new aspects will be highlighted.

3.1. *Free-field reciprocity calibration of quarter-inch microphones up to 150 kHz*

Ultrasound is used in many technical, industrial and medical applications where high-intensity sound waves were applied. There is a significant risk of exposure to high-level airborne ultrasound emitted from ultrasound machines, which may be harmful for the hearing or may have negative bio-effects on man. To ensure safety of persons in the vicinity, ultrasound levels in air must be measured with calibrated devices

traceable to the national standard. Current measurement standards for airborne sound are realised by means of the sensitivity of half-inch laboratory standard microphones, calibrated with the reciprocity method in the frequency range from 20 kHz to 40 kHz.

At present the Physikalisch-Technische Bundesanstalt is developing a free-field reciprocity calibration technique permitting the realisation of the sound pressure unit in the frequency range from 20 kHz to 160 kHz. After a first feasibility study a measurement system was built up that allows the calibration of quarter-inch working standard microphones. Based on a set-up used for calibration of one-inch and half-inch microphones in a 15 m³ anechoic room new transmitting and receiving techniques and data acquisition methods were established. First calibrations were obtained and good agreement with electrical actuator measurements was found. First uncertainty estimation needs more detailed investigation in future.

3.2 Membrane hydrophones for application in high-frequency ultrasonic measurement and calibration

Hydrophone measurements are indispensable for the determination of the acoustic output of all ultrasound devices in medicine and technology. Because of the relevance to patient safety and the prevention of misdiagnosis the characterisation of ultrasound diagnostic machines is of special importance. To increase the spatial resolution the operating frequencies of transducers have been increased significantly during the last two decades. In addition, high-pressure pulses produce more harmonics due to non-linear interaction and high-frequency measurement techniques exceeding 50 MHz are necessary to meet the requirements of declaration regulations. Besides an appropriate calibration technique hydrophones of sufficient bandwidth and small active diameter are required but hardly available on the international market.

In a project PTB developed a wideband membrane hydrophone for the use as transfer standard for metrology purposes. The coplanar design using a 9 µm PVDF-membrane and an extreme wideband amplifier technique provides a bandwidth of more than 130 MHz with an active diameter of 200 µm. A first calibration proved an application range up to 140 MHz where the sensitivity is 2 dB below the low frequency value. Between 1 and 40 MHz the frequency response is extremely flat and the variations are below 1 dB in this range. The hydrophone can be used as standard for the verification and traceability of calibration techniques but also for exposimetry measurements at medical ultrasound devices.

3.3 Low frequency voltage measurement

In close co-operation with the department for "Direct Current and Low Frequency" of PTB the traceable calibration of the voltage standards used for accelerometer calibration could be extended down to 0.1 Hz. This became possible with the application of the direct sampling method, provided by the facilitated digital voltmeters of type HP3458A in combination with the synchronous synthesis and sampling technique developed at named department. Therefore the complete frequency range of sinusoidal calibration is now directly covered with the same voltage measurement techniques without extrapolation.

4. Research areas

PTB is active in a wide range of research activities summarised in the annual reports that can be found at the PTB web-site (www.ptb.de). In the field of acoustics three projects should be highlighted:

4.1 *Reference zero for the calibration of air-conduction audiometric equipment using 'tone bursts' as test signals*

The aim of the investigation was to determine reference peak-to-peak threshold sound pressure levels for air conduction sound transducers using groups of tone bursts as test signals.

Tone bursts are sinusoidal acoustical test signals having a duration of less than 200 ms. They have a limited bandwidth and are used in objective audiometry, e.g. in Electro-Cochleography or for Auditory Brainstem Responses and for Transient Evoked Otoacoustic Emissions, to discriminate the frequency dependence of the human hearing ability. Often they are applied to a newborn child when a preceding measurement with broad band clicks has shown evidence of a frequency-dependent hearing loss.

Threshold measurements with five different earphones and a loudspeaker were carried out on groups of 25 young, otologically normal test subjects in the frequency range between 250 Hz and 8000 Hz, following as closely as possible the ISO Preferred Test Conditions. The dependence of the results on repetition rate, type of sound transducer, gender and age of the test subjects and on reference pure tone thresholds was investigated.

The results for tone bursts mainly depend on the type of sound transducer and on the repetition rate. However, the difference of the results for tone bursts and for pure tones turned out to be essentially independent of the type of earphone for one and the same repetition rate. This may enable the prediction of peak-to-peak equivalent reference equivalent threshold sound pressure levels (peRET SPLs) for an unknown earphone if the corresponding pure-tone reference threshold levels are known. The peRET SPL values of earphones decrease with increasing repetition rate. The measured pure-tone reference equivalent threshold levels for pure tones agree well with those given in the ISO Standard, with the exception of the two old types of earphones, TDH 39 and DT 48, for which systematically lower values were measured.

Together with the results of another study carried out in Denmark, the data of the present study shall form the basis for the International Standard ISO 389 Part 6 on reference hearing thresholds for acoustic test signals of short duration.

4.2 *Measurement of sound field and cavitation effect in ultrasound cleaning baths*

High-power ultrasound is used in many technical processes of industrial manufacturing, service procedures or medical applications. Although a variety of methods in solid state processing exist most of these applications are working in fluids spanning an extremely wide range from engineering to medicine, including for example cleaning, extraction, emulsification, chemistry or cutting of soft materials. In most of all cases the mechanism behind these applications of ultrasound is cavitation. Because of its stochastic and highly non-linear behaviour the characterisation of all technical processes based on cavitation is extremely difficult and in many cases only empirical methods promise practically useful strategies.

In a project it was investigated whether sound field measurements and the determination of spectral parameters can be exploited for a prediction of cavitation

effects. The sound fields in two ultrasonic cleaners were measured using different techniques, for example various piezoelectric hydrophones and fibre-optic sensors. Three-dimensional measurements were carried out and from the results spectral parameters like fundamental, harmonics, subharmonic, noise parameters were deduced. In a next step the effect of cavitation was determined by several methods providing a spatially resolved quantitative effect parameter. Using a two-dimensional correlation calculation the effect parameters were compared to the sound field measurements to investigate their potential for description and prediction of the cavitation effect.

Many measurements were carried and a good correlation between the fundamental and the cavitation field was found. The fundamental was also the most reliable parameter. All results depended strongly on the environmental conditions and it was difficult to compare the measurements. It became; however, clear that the measurement always described the current situation and a sound field measurement turned out to be a serious way to obtain a basis for a quantitative description of cavitating processes.

4.3 Measurement of output intensities of multiple-mode diagnostic ultrasound systems using thermoacoustic sensors

Ultrasound exposure measurements for medical ultrasound systems are essential as regards aspects of safety and quality assurance. Spatial peak temporal averaged output intensities of ultrasound machines which have to be declared by the manufacturer according to IEC 61157 or for FDA approval are commonly derived from hydrophone measurements. In the case of modern multiple-mode diagnostic equipment the required hydrophone measurements are quite cumbersome and expensive. Much effort is necessary to find out the parameter settings and operation modes that produce the highest intensities, and synchronisation of the measurement system to all ultrasound pulses incident at the position of interest is a difficult task.

Thermoacoustic sensors are a very simple and low cost alternative for the determination of local temporal averaged intensities. The measurement technique investigated is based on the transformation of the incident ultrasonic energy into heat inside a small sized cylindrical absorber, and the detection of the temperature rise on the rear side of the absorber. Here, inclusion of all contributing pulses and temporal averaging is done by the sensor inherently without the need for synchronisation to individual pulses and pulse sequences.

To enable quantitative measurements, sensors with 3 mm and 1 mm absorber diameter are calibrated in the frequency range from 1 MHz to 9 MHz. The calibrated sensors are then applied to acoustic output measurements on a commercial diagnostic ultrasound machine at different parameter settings. The results for M-mode and for pulse-Doppler mode, i. e. for non-scanning beams, are compared with the intensities derived from additional hydrophone measurements, and agreement is found within the typical uncertainty ranges for ultrasound intensity determination. The investigation of more complex scanning modes and combined modes shows that the sensor technique can efficiently be used to identify the parameter settings of the diagnostic machine, which lead to maximum acoustic output. Therefore, use of the measurement technique described can reduce the expenses of the manufacturer for regulatory testing and may improve the results and reliability of output parameters.