

Physikalisch-Technische Bundesanstalt

Short report for CCAUV – September 2008

Status report PTB

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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. 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. In addition PTB is active in many basic and applied research fields and included into the European metrology research area.

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 are spent for the realisation and maintenance of units and several calibration and standard measurement set-ups are available:

- pressure reciprocity calibration of microphones between 2 Hz and 25 kHz
- free field calibration of microphones between 25 Hz and 40 kHz
- measurement of ultrasound power between 5 mW and 20 W
- calibration of hydrophones in amplitude and phase 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/s² to 100 m/s² in both, magnitude and phase of the complex sensitivity coefficient
- primary calibration of accelerometers with shock shaped excitation in the range of 50 m/s² to 100 km/s²
- primary calibration of angular accelerometers with sinusoidal excitation in the range from 0.4 Hz to 1.6 kHz and 1 rad/s² to 1400 rad/s²
- primary calibration of laser-vibrometers with sinusoidal excitation

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. The improvement and the extension of calibration possibilities attract a constant attention, for example by the improvement of the free-field calibration of microphones or the extension of ultrasound power measurement to high-intensity therapeutic devices. New measurement techniques are investigated for the characterization of therapeutic ultrasound fields within an international research collaboration. The determination of reference hearing thresholds of normal hearing persons is required by manufactures of audiometric devices for calibration purposes and is also driven by standardisation activities. Special interest is given to objective audiometry which is coming more and more into clinical practise.

Industrial applications and requirements are the scope of many activities in building acoustics. The investigation of sound sources in buildings and 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 including the development of new sensors has 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.

An effect which is relevant for calibration of accelerometers with sinusoidal and shock-shaped excitation, the so called mass loading effect of back-to-back accelerometers, is the focus of recent research by measurement and simulation.

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 ranges 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 in the appendix C of the Mutual Recognition Arrangement 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 Complex-valued hydrophone calibration

The correct measurement of the broadband nonlinearly distorted pulses as emitted by diagnostic ultrasound equipment requires hydrophones working over a broad frequency range. Commonly, the hydrophones used are not ideal, e.g. the transfer

functions show more or less variations in the frequency range of interest. The new international standard "IEC 62127-1, Ultrasonics – Hydrophones – Part 1: Measurement and characterization of medical ultrasonic fields up to 40 MHz using hydrophones" recommends the application of the impulse deconvolution method in such cases. However, besides the amplitude response that has conventionally been applied solely, the corresponding phase response of the hydrophone used is required for this procedure. Therefore, the Ultrasonics Section of PTB has worked intensively on the necessary extension of the hydrophone calibration techniques and services for the past years.

As a result, the hydrophone calibration possibilities could be extended recently and have already been used by manufacturers of diagnostic ultrasound devices for hydrophones to be used in their testing laboratories. Customers may choose between standard calibration from 1 MHz to 20 MHz, low frequency calibration from 0.3 MHz to 5 MHz and broadband calibration from 1 MHz to 50 MHz. As an option, the broadband calibration can be ordered including the phase response data in addition to the amplitude response. The measurements are performed as substitution calibrations against reference membrane hydrophones using time delay spectrometry. The reference membrane hydrophones are routinely calibrated in amplitude by a primary interferometric calibration technique (cf. appendix F of IEC 62127-2). In addition, the reference membrane hydrophones are calibrated by the aid of a pulse calibration technique against an optical multilayer hydrophone serving as a phase reference (cf. appendix I of IEC 62127-2).

For the future, it is important to realize the international validation of hydrophone amplitude calibration in the range from 20 MHz to 50 MHz and of phase response calibration in the complete frequency range missing so far.

3.2 Phase calibration for laser vibrometers

Only recently, the section Acceleration of PTB implemented a set-up for the calibration of the magnitude and the phase-response of laser-vibrometers on the basis of a homodyne quadrature set-up with high-speed PIN-photodiodes and a sophisticated optical arrangement.

The system is functioning in the range from 1 kHz to 20 kHz. Primary motivation for this was the reduction of the measurement uncertainty in primary phase calibration of accelerometers by a more precise characterisation of the laboratory's own laser vibrometers. However, the new set-up now realizes a high precision measurement system for the general laser vibrometer calibration, too. The transition from an experimental set-up to a standard facility is still in progress at the time of writing.

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 Hearing thresholds for new short-duration signals

For the objective method "brainstem electric response audiometry", the cerebral response to sound is measured by means of scalp electrodes. Usually, standardized short-duration signals ("clicks" and "bursts") are employed as stimuli. However, recent clinical research has shown, that brain responses, called auditory evoked potentials (AEP), become even more pronounced when short "chirps" having the

same amplitude spectrum as the chirps, but having the spectral phase lag relative to the chirps increasing with frequency, are used.

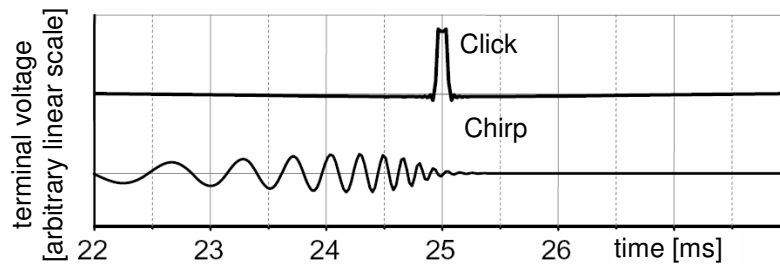


Figure 1: Earphone terminal voltages of click and chirp

The higher efficiency can only be proven when it is shown that those chirps have a higher effect not because they are generally louder than the clicks, but even when they have exactly the same loudness level. In order to demonstrate this fact, the hearing thresholds for both signals need to be measured.

Measurements on groups of subjects, conducted in PTB showed that in fact signals with very different time courses, but equal amplitude spectra, such as the clicks and chirps described above, produce statistically equal hearing thresholds when conventional audiometric earphones are used. The above figure (Fig. 1) shows the respective earphone terminal voltages of both click and chirp. When both signals were presented 30 dB above threshold, these chirps caused significantly greater brain responses (AEP) than the clicks.

The benefit for practical audiometry is as follows: Within a group of short-duration test signals having different phase spectra, but identical amplitude spectra, it will no longer be necessary to calibrate each signal separately. Instead, it will suffice to have just one of the signals calibrated. This means a great reduction of expensive and time-consuming hearing threshold measurements with subject groups for the determination of reference hearing thresholds.

4.2 Measurement of acoustic power in high-intensity therapeutic ultrasound fields

The ongoing use of high-intensity therapeutic ultrasound (HITU) in clinical practice and the increasing approval and manufacturing of HITU devices cause an urgent need for measurement procedures for the characterization of high-intensity ultrasound fields. The generation of much higher temperatures inside the body than in hyperthermia requires the monitoring of all relevant treatment parameters like temperature distribution, size and location of the hot spot, that corresponds with the tissue region to be treated. In addition, measurement techniques for the acoustic characterisation of the devices are required as a metrological basis for their assessment and manufacturing.

The determination of the radiation force acting on a target is the method of choice for output power measurements and is well established and described. The expansion from low diagnostic power levels and unfocused therapeutic fields towards high power levels and strongly focused fields raises, however, some major problems as the damage of the target by heat deposition, the positioning of the target outside of the focal region, the shielding effects by cavitation bubbles, and nonlinear effects (shock loss, harmonic distortion).

In first experiments at the Ultrasound section a radiation force measurement set-up was adapted to the high-power range and results could be obtained up to an electrical power of 438 W corresponding to 344 W acoustical power (Fig. 2). The absorbing target was situated in close distance to the transducer.

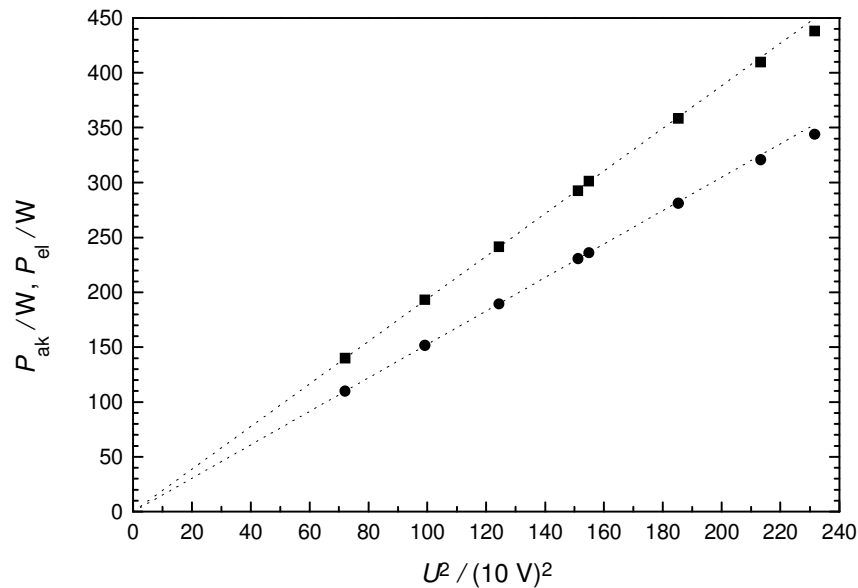


Figure 2: High-power measurement with an absorbing target using a 500 W amplifier at 1.5 MHz. Transducer efficiency = 78.5 %. Target out of focus, close to the transducer (■ P_{el} , ● P_{ak}).

The influence of the transducer-target distance in strongly focused fields was investigated in a separate experiment at low power to avoid damage of the target. The measurements confirmed the almost linear relation between the acoustical power reaching the target and the distance between transducer and target caused by attenuation in the propagation path. This is also valid in the range close to the focal region, and the correction commonly used for focused fields applies for all distances between transducer and target.

Although the measurement of fields at full output power from HITU systems still presents a technical challenge, first steps are made to establish measurement methods which are able to determine the acoustic power in strongly focused fields with reliability and sufficient accuracy.

4.3 Dynamic calibration of electro-mechanical sensors

In the field of vibration measurement as well as in the fields of force, torque, and pressure measurements, the precise acquisition of arbitrary transient signals is of increasing importance. However, in many of these fields the calibration methods used at the highest level (NMIs, accredited services) rely still on methods applying only static or stationary loads. To some extent, this is owed to the fact that the methods for the dissemination of “dynamic units” and for the necessary calculation of measurement uncertainties are also not well defined and not generally agreed upon. In order to contribute to the solution of this problem, PTB made the “dynamic measurement of mechanical quantities” to one of its focus fields of future R&D activities. This is supplemented by investments in staff and facilities in the respective sections and by co-operations with industry regarding this topic.

One of those co-operations is the recently successfully completed project “Model-based calibration of accelerometers” in the framework of the MSTQ program of the Federal Ministry of Economics and Technology. Here, the applicability of the (above mentioned) parameter identification method for the calibration of accelerometers was tested in collaboration with an industrial calibration service using different transducers. Simultaneously, the respective algorithms were transferred into

industrial application, i.e. the service of the participating accredited calibration laboratory.

In a next step, the applicability of the method and its recent refinements to other mechanical quantities will be evaluated.