Physikalisch-Technische Bundesanstalt

Short Report for CCAUV, October 2010

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 program (EMRP).

The PTB work in acoustics and vibration is done in two departments, now. A change in organizational structure moved the vibration working group to the department "Acoustics and Dynamics" which now combines the activities in building acoustics, vibration, dynamic force, and heat conduction. Microphone calibration, audiometry, ear simulator tasks, and sound level meter type approval as well as ultrasound are carried out in the department „Sound". This change of organisation strengthens the AUV-activities at PTB and allows more efficient work in this area.

2. Activities in acoustics, ultrasound and vibration at PTB

PTB is active in a variety of fields in acoustics, ultrasound and vibration. One of the main duties and responsibilities is the realization and maintenance of units, and several calibration and standard measurement set-ups are available:

- pressure reciprocity calibration of laboratory standard microphones between 2 Hz and 25 kHz
- free-field calibration of microphones between 25 Hz and 20 kHz
- measurement of ultrasound power between 5 mW and 300 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 acoustic couplers and ear simulators
- testing of free-field and diffuse field environments
- supervision of building acoustic test facilities
- testing of ISO tapping machines and loudspeakers for building acoustics
- free-field and diffuse field calibration of reference sound sources.

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 constant attention, for example by the development and improvement of the free-field calibration of microphones or the extension of ultrasound power measurement to high-intensity therapeutic devices, which is an available service, now. New measurement techniques for high-intensity ultrasound fields were investigated and developed within national and international research collaborations. 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 standardization activities. Special interest is given to objective audiometry which is coming more and more into clinical practise. Here a nationally funded research project was successfully finished which investigated hearing thresholds and calibration techniques of brain-stem response devices. Current projects deal with devices for otoacoustic emission audiometry.
Projects with industrial applications are also in the scope of PTB research. The development of cavitation indicator measurement methods is aimed at improving the quantitative description of every-day technical ultrasound applications. The development of new sensors for technical ultrasound and the measurement of high-intensity sound fields also have high relevance to industrial application.
A major task in applied acoustics is the uncertainty determination of different quantities like sound power levels, airborne sound insulation or impact noise levels. These activities are based on the compilation of many round robin data. The results will be used in international and national standardisation. Further current research topics in applied acoustics are the characterisation of structure-borne sound sources, the qualification of highly absorbing measurement chambers, the development of a test method for walking noise and the measurement and prediction of installation noise in buildings.

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 Pattern approval tests of sound level meters: the influence of mechanical vibrations on the performance

Mechanical vibrations of the base, which affect the sound level meter (SLM) via a tripod, can have an influence on the measuring value displayed. Especially vibrations along the main measuring direction of the microphone (reference direction) cause a mechanical stimulation of the microphone and a considerable reduction of the linear measuring range. To check the sensitivity of a SLM to vibrations, an automatic measuring set-up has been developed in which two sound level meters are exposed simultaneously to a sound field of constant frequency. The displayed A–rated values of both meters are checked against each other while one of the two meters is stimulated by an electro-dynamic shaker to vibrate at a band-limited acceleration of 1 m/s². The stimulation is applied in two directions: (1) in the reference direction of the microphone and (2) turned 90° in the direction parallel to the diaphragm plane of the microphone. The frequency of the stimulation varies between 31.5 Hz and 1 kHz. The results of the measurement show that the lower working range limit under the specified conditions of mechanical vibration may be shifted up to more than 75 dB(A). This significantly reduces the linear application range for measurements in practise.

3.2 Measuring the photodetector frequency response by a heterodyne system with difference-frequency servo control

One of the important quantities describing the properties of photodetectors is the frequency response. Photodetectors in ultrasonic applications, for example interferometry for sound field calibration, are applied in very different optical configurations, and during photodetector calibration these conditions should be reconstructed to ensure that the frequency response obtained matches the application conditions. So it was advisable to have an in-house calibration set-up which is adapted to the ultrasound application requirements. Since sophisticated and costly optical equipment was not present in a laboratory dealing with ultrasonic applications, a set-up had to be constructed which used only simple components available in a standard optical laboratory.
A heterodyne system was realized using two commercially available DFB lasers and the required frequency stability and resolution was ensured by a difference-frequency servo control scheme. The frequency-sensitive element generating the error signal for the servo loop comprised a delay-line discriminator constructed from electronic elements, which converts a frequency deviation into an amplitude deviation. The output signal is used as an error signal for a servo loop controlling the emission frequency of one laser via the driving current.
Measurements were carried out up to 450 MHz for detectors used in the interferometric sound pressure standard. The uncertainties of about 4% (k=2) can be further reduced without losing the feature of using only simple elements by improved RF power measurement.

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 some projects should be highlighted:

4.1 Otoacoustic emissions by means of bone-conduction stimulation

An objective hearing test with otoacoustic emissions (OAE) provides information on the inner ear sensory cell performance (cochlear function), even if no cooperation of the subject (e.g. babies) can be expected. OAEs are evoked as a response to an acoustic stimulus and indicate a healthy inner ear. Usually, the stimuli are presented in the ear canal with miniature loudspeakers. When two pure tones are presented

during an OAE hearing test, the sensory cells in the inner ear generate an additional deeper tone. This tone is known as the distortion-product otoacoustic emission (DPOAE) and can be recorded by means of a miniature microphone placed in the ear canal.
If the stimuli are presented with miniature loudspeakers in the ear canal, an intact middle ear chain is necessary for the detection of DPOAE. For certain types of hearing loss (conductive hearing loss), however, the acoustic stimuli are attenuated before they reach the sensory cells and might fail to evoke a DPOAE in spite of intact hair cells. An alternative and rather less investigated constellation is the bone-conduction stimulation of DPOAE. For this kind of stimulation, so-called bone vibrators are placed on the cranial bone of the patient. The presented stimuli reach the inner ear directly via the bone-conduction path and the influence of the middle-ear chain on the stimuli is largely avoided.
In a feasibility study, the applicability of the bone-conduction stimulation of DPOAE was assessed using commercially available bone vibrators. DPOAE, stimulated through bone conduction, could be recorded in the ears of all test subjects at least for one frequency. With respect to the calibration of the stimuli, this kind of stimulation provides the advantage that simple microphone probes are sufficient to record the DPOAE. Furthermore, known interference due to evanescent waves of the probe loudspeakers affecting the probe microphone simply does not exist, since the bone vibrators and the probe microphone are spatially separated.

4.2 Characterization and Quantification of HITU Fields with a Fiber-optic Displacement Sensor

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 which corresponds with the tissue region to be treated. In addition, measurement techniques for the acoustic characterisation of the devices, mainly the spatial distribution of sound pressure, are required as a metrological basis for their assessment and manufacturing.
Appropriate sensors for the characterization and quantification of HITU fields should not only be very robust, so that they withstand the high pressures in the sound field, but also small, to enable a high-spatial-resolution measurement in the focus region. It is well known that due to their small outer diameter in the sub-mm range and their high mechanical robustness, fiber-optic probes can fulfill these requirements.
A fiber-optic hydrophone was developed which comprises a metal-coated fiber tip and an interferometric set-up. The particle displacement of the ultrasound wave in the liquid causes a change in the optical path length in the fiber tip and, thus, a phase modulation of the light. This modulation is detected by the interferometer and electrically transformed into an amplitude-modulated voltage which is proportional to the particle velocity in the sound field.
Measurements at different HITU sound field configurations were successfully carried out. Comparison with other techniques showed that the fiber-optic sensor correctly and reliably determines sound velocity and, using the complex valued frequency response of the sensor which has been determined in a calibration procedure, also the sound field pressure. In test experiments the fiber-optic concept proved to be robust enough to withstand against the particular conditions of sensing high-intensity fields and it showed a clear advantage over other detection techniques.

4.3 New economic calibration concept for objective audiometry

To date, the "Normal hearing thresholds" for the calibration of audiometric devices are expressed by so-called "Peak-to-peak equivalent Reference Equivalent Threshold Sound Pressure Levels", depending on the span between minimum and maximum instantaneous sound pressure values. For both the PTB-conducted threshold measurements with test subject groups and the clinical audiometer calibration only minor instrumentation is required: a signal generator, an acoustic coupler or ear simulator including a calibrated microphone, a graphical display for the temporal waveform, and a standard sound level meter.

One of the procedure's drawbacks is the lack - in terms of hearing physiology - of coherence with the hearing threshold. Even signals with very similar amplitude spectra yield widely spaced reference threshold sound pressure levels. Therefore, for a long time, researchers and development engineers were calling for a calibration scheme producing reference values with a physiologically adequate relation to the hearing threshold. A first step in that direction is to simplify the procedure by assessing equal reference values to signals having identical amplitude magnitude spectra, by integrating them into signal classes. This is legitimate, since such signals yield identical hearing thresholds when presented by usual audiometric headphones, which was shown in a previous PTB study.

4.4 Sound insulation screens for musicians in a symphony orchestra

Is music a noise? Although this is a defamation of the musician, during performance or practising of a symphony orchestra 8-houre exposure levels of more than 95 dB(A) can occur. These values are much higher than the 87 dB(A) which is the exposure limit value of the “Noise” directive 2003/10/EG of the European Union. It holds at working places and since 2008 it has been holding also in the music and entertainment sector. Because the “noise” cannot be reduced at the place of generation passive methods need to be applied.

In PTB sound insulation screens were developed which can be mounted between the rows of the musicians, in particular in front of the brass. They reduce the loudness especially at the heads of the players in front of the most emitting instruments without changing the sound of the music. The upper part of the screen is optically clear and the musicians have visual contact to the conductor. Sound level measurements at about 10 different positions on the stage were made with and without screens and at the positions in front of the brass players a reduction of 8 – 12 dB(A) was obtained. At the position of the conductor at least a reduction of 3 dB(A) could be found. So, the screens are a significant element of a safety concept for protecting the hearing of orchestra musicians.

4.5 A compact method for the determination of impact sound reduction

Impact sound reduction is the main quantity for the description of the acoustic behaviour of floor coverings. Its determination is standardised in ISO 140-8 and requires the use of a special test facility. This facility consists of two rooms of about 50 m^3 each, separated by a concrete slab with a thickness of about 14 cm and a size of about 20 m^2. The sound pressure level in the lower room is measured when the slab is excited by a tapping machine. Two measurements are necessary, one with and one without the covering. The impact sound reduction is calculated from the sound pressure level difference according to ISO 717-2.

Manufacturers of floor coverings are interested in having their own test facilities for reasons of quality management and product development. But the effort is often inappropriate for the mostly small and medium-sized enterprises. Therefore, a joint

research project was started by PTB and FILK (the Research Institute of Leather and Plastic Sheeting) which was funded by AiF, the German Federation of Industrial Research Associations. The main outcome of this project is a compact measurement setup (COMET) for the determination of impact sound reduction.
The chosen construction consists of a concrete slab with the dimension 1.2 m x 0.8 m x 0.2 m which lies on soft pads in a steel rack in the Euro format. This desk-sized setup replaces the complete two-room configuration. In analogy to the ISO procedure, an ISO tapping machine is used, and two tests are performed, once with and once without the floor covering on the slab. Instead of the sound pressure in the receiving room, the appearing oscillations are measured at the bottom surface of the concrete slab. The difference between the oscillation levels can be evaluated according to ISO 717-2. The deviations between both methods are very small for locally reacting coverings, such as PVC, carpet and linoleum. Laminate reveals larger discrepancies since this is not a locally reacting covering. The observed deviations are generally small in view of the uncertainties in building acoustics which often reach values of several dB. With these excellent results, the project was completed successfully. The compact setup was introduced as a new work item proposal in ISO. The first manufacturers of floor coverings have shown their interest in this method. A follow-up project is in preparation to develop a compact method for timber floorings.