Physikalisch-Technische Bundesanstalt

Short Report for CCAUV, September2017

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 program for innovation and research (EMPIR).

The work of PTB in acoustics and vibration is carried out in two departments. The department “Acoustics and Dynamics” combines the activities in applied acoustics, vibration, dynamic force and dynamic torque. Microphone calibration, audiometry, ear simulator tasks, and sound level meter type approval as well as ultrasound issues are carried out in the department „Sound“.

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
- secondary free-field calibration of microphones between 25 Hz and 100 kHz
- measurement of ultrasound power between 5 mW and 300 W
- calibration of hydrophones in amplitude and phase between 400 kHz and 60 MHz
- free-field and diffuse field calibration of reference sound sources
- 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.

Scientific research plays an important role at PTB, and many ideas and projects are currently under consideration. The maintenance, improvement, and the extension of calibration and testing capabilities attract constant attention, for example by the extension of the frequency range of secondary free-field microphone calibration. As a follow-up of the EARS 1 project carried out under the auspice of the EMRP programme a new setup was established for secondary free-field calibration of WS3 microphones based on traceability from Danish National Metrology Institute (DFM). A fully implemented service is available now for calibration of customer microphones up to at least 100 kHz.

In the ultrasound field a completely new measurement set-up and methodology was introduced for a follow-up system for the primary calibration of hydrophones. It is based on a commercial broad-band vibrometer which is used for the determination of the elongation in a test ultrasound field later applied to the hydrophone in question. The system has overcome several drawbacks of the old system and it has allowed a more systematic investigation of the uncertainties. In addition, it significantly improves the reliability of measurement and opens up new possibilities in calibration techniques.

As an outcome of a strategic discussion within PTB the portfolio of services for customers was slightly adjusted to fully implement the subsidiary conditions which hold for PTB and to ensure an efficient working in the laboratory. All services were offered in future but in cases where accredited laboratories can offer calibrations with equivalent quality PTB will no longer carry out measurements.

In the area of mechanical Vibration and shock PTB is active in calibration, the assessment of accredited and peer laboratories, standardization and research. In the field of calibration an extension of the frequency range to low frequencies based on the results of EURAMET.AUV.V-K3 and CCAUV.V-K3 is under preparation.

In the respective standardisation committee ISO/TC 108/WG 34 PTB has the lead for one active standardisation project, concerning the calibration of conditioning amplifiers for dynamic applications. In order to support the national and global metrology system PTB supports the German accreditation body DAkkS by providing the experts for technical assessments and other NMIs by volunteering in performing peer assessments.

After finishing the work in the EARS 1 project supported by the European Union "European Metrology Research Programme" (EMRP) and subsequent project EARS 2 was successfully recruited and is granted by the European metrology program for innovation and research (EMPIR). 11 partners from 6 European countries work together to objectively investigate, how infrasound and ultrasound affect human beings. There are still numerous indicators that infrasound and airborne ultrasound events influence human beings and that sound at such frequencies can be perceived. In particular, in the infrasound frequency range an intense and hard

debate is running in the public which urgently needs rational underpinning. To solve, the partners will apply different means with methods of audiology and imaging procedures of neurology. Interest will particularly be focussed on the measurement and assessment of airborne ultrasound at workplaces. This includes also the development of new hard ware which is additionally granted by another project.
In a second part of the project the development of a novel universal ear simulator will be continued and finished. In connection with a newly developed calibration procedure for transient signal it has the potential to significantly improve the calibration of audiological devices for better diagnosis and screening results mainly for newborns and children.

In the area of metrology of dynamic measurement of mechanical quantities PTB recently started with the development of a calibration service for modal hammers which is in fact a variant of dynamic force calibration. The devices under test are widely used in structural dynamic analysis, however, SI-traceable calibration is not widely available.

In the field of acceleration, the research and development is continuously targeted at the improvement, optimization and extension of the national standard facilities for vibration and shock calibration. Important examples are:

- the shaker flatness and the influence of gravity in low frequency accelerometer calibration
- Improvement of modelling in the field of model based parameter identification
- Demodulation of heterodyne laser interferometers at low frequency vibration
- Development of a new angular velocity calibration device as a national standard

One major field of research in applied acoustics is dedicated to the measurement of airborne sound power. A corresponding EMRP-project has been accomplished by May 2016 with the major outcome that the concept of traceable sound power measurements is applicable, in general. Nevertheless, primary sound power standards developed by the different participating institutes need further improvements in order to use them in a broad frequency range. In the near future, a supplementary comparison for the airborne sound power level of an aerodynamic reference sound source will be organised within EURAMET where PTB will be the pilot laboratory.

Further research areas of applied acoustics focus on the determination of uncertainties for quantities determined by complex measurement procedures, e.g. airborne sound insulation, impact noise levels or sound absorption. A current activity in this field is the development of ISO 12999-2 "Acoustics — Determination and application of measurement uncertainties in building acoustics — Part 2: Sound absorption" where PTB is the project leader.

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 PTB calibration service for airborne ultrasound

For measurements of sound with frequencies above 20 kHz, metrological traceability has not been possible so far for the unit of sound pressure, the pascal. Now a procedure for the calibration of microphones in the ultrasound range up to 100 kHz has been developed at PTB. With this procedure, reference standards and working standards can be produced for laboratories from industry and research to ensure the traceability for airborne ultrasound.

With the increasing use of ultrasound technology in all fields of daily life, the number of quantitative measurements of airborne ultrasound has also increased. Up to now, metrological traceability has not been possible yet for measurements of sound with frequencies above 20 kHz for the unit of sound pressure, the pascal. At the Danish Metrology Institute (DFM), a primary standard has recently been developed which allows measurement microphones to be calibrated as a primary transfer standard up to 150 kHz. The procedure is, however, limited to special microphones (combination of a WS3 ¼-inch microphone mounted on a ½-inch adapter without a protection grid) which are not used in this way in common measurement practice. Another calibration step is required to transfer the unit of sound pressure from the primary transfer standard – the special reference microphone – to any microphone kind.

Such a procedure has now been developed and implemented at PTB. The new procedure is based on the classical substitution procedure according to DIN EN 61094-8 which has been adapted to the specific properties of airborne ultrasound. For that purpose, a controlled sound field is generated and successively measured by the reference and by the test piece. The specific properties of airborne ultrasound place special demands on the procedure. The short wavelengths of the sound cause reflections and diffraction which severely disturb the sound field and, thus, the precision of the calibration. The damping in air is no longer negligible which depends, in addition, strongly on the ambient conditions. This places high demands on the sound source and requires the precise control of the conditions of measurement.

The new calibration procedure now allows calibration of working microphones of the sizes ½ inch and ¼ inch (with adapter) up to 100 kHz to be traced to the Danish primary standard. In the next step, the procedure will be further developed in such a way that any microphones whatsoever, such as, for example, microphone-amplifier combinations, MEMS microphones, optical microphones or sound level meters, can be calibrated.

3.2 New testing procedures for software in sound level meters in legal metrology

Sound level meters serve the purpose of measuring sound levels and are used to measure and check the observance of legally prescribed maximum or reference values. Sound level meters can be found in private life, in environmental protection, and at work. In order to ensure a correct and verifiable measuring process, all equipment used in official transactions must undergo a type approval that is carried out according to the Measures and Verification Act of Germany. Now, also a software test must be included in this type examination.

To harmonize acoustic metrology and the procedures that are required for a type examination, technical standards have been developed which lay down the requirements for measuring instruments (e.g. DIN EN 61672:2014, DIN 45657:2014). To fulfill these requirements, a metrological evaluation of microphone signals is necessary which, however, can be realized today only by means of sophisticated software. Since the new Measures and Verification Act of Germany and the Measures and Verification Ordinance took effect, in type examinations that are to be carried out by PTB on sound level meters, also WELMEC's requirements for software security (Software Guide 7.2, Version 5) have to be complied with. The aim of these requirements is to prevent users from manipulating sound level meters. Such manipulations can lead to intentional or unintentional changes of the measurement results during measurement or after the storing of the measurement data. Such changes might be, for example, changes in microphone calibration, changes to the internal clock, or changes to the saved measurement data. Also, the use of unapproved equipment software or the changing of metrology-relevant software by means of updates must be prevented.

At PTB, a range of requirements has been developed for approving sound level meters. They define several procedures, as for example that updates of the operating software should only be carried out by authorized persons, and calibrations should only be made possible by the user in the maximum level range of ±1.5 dB and should be automatically documented in the internal data memory. A complete list of requirements can be found on the website at: http://www.ptb.de/cms/fileadmin/internet/fachabteilungen/abteilung_1/1.6_schall/1.63/Softwarepruefung.pdf. The implementation of the required measures and compliance with the requirements will be checked during every type examination carried out at PTB.

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 New reference hearing thresholds for use with an ear simulator for newborns

Since newborns and infants only react to relatively loud sounds, hereby demonstrating auditory perception, objective audiometric procedures are used when testing their hearing (e.g. measuring the brain waves evoked by acoustic stimuli). The acoustic stimuli are hereby transmitted via insert earphones. The reference hearing threshold levels necessary for this can, however, only be determined as equivalent reference threshold sound pressure levels of young adults with healthy hearing.

A conventional simulator for the occluded ear canal (standardized in IEC 60318-4) is used for this; it simulates an adult's ear. Calibrating the stimuli for newborn/infant audiometry with this conventional simulator therefore represents a contradiction, since the hearing threshold levels refer to the ear canal of an adult whose geometry, however, considerably differs from that of a newborn or of an infant. The consequence is that, depending on frequency and on the signal shape, sound pressure levels occur in the infant's ear canal which are approx. 2 dB to 10 dB higher

than in the conventional ear simulator according to IEC 60318-4 and in the average adult's ear.

Within the scope of the EMRP project "EARS", a prototype of a simulator of the occluded ear canal was developed which is based on the ear canal geometry of newborns. In a first step, reference hearing thresholds were determined for a Bio-logic SINSER earphone on 25 young adults with healthy hearing for the standardized short-term signals (reference impulse and reference short-term signals to trigger auditory evoked potentials) as well as for pure tones, and defined on the adult ear simulator. The EARS newborn and infant ear simulator prototype is then used to calibrate the stimuli for newborns and infants, and after this, the reference levels measured in the adult ear simulator are set. It was shown, as a function of the frequency and of the type of stimulus, how much lower the level in the child's ear can be set with this procedure.

When using the newborn ear simulator to calibrate the stimulus level to perform audiometry of newborns and infants, the stimulus is thus no longer adjusted much too loud, but is adequate. Firstly, this prevents wrong conclusions when estimating the hearing ability of infants; secondly, this avoids unnecessary sound exposure of infants' ears during hearing tests.

4.2 Robust membrane hydrophone for the measurement of high-intensity therapeutic ultrasonic fields

The characterization of medical high-intensity therapeutic ultrasonic devices poses particular challenges for the hydrophones used to measure acoustic pressure in water. In order to allow measurements at clinical levels in the focal region of the emitting transducers which are used in applications such as tumor ablation within the scope of cancer treatment, extreme robustness, large detection bandwidth, large dynamic range, and small detection element size all are needed simultaneously. So far, the available measurement equipment, like fiber-optic hydrophones, has only been able to meet these requirements with certain limitations. Conventional piezoelectric membrane hydrophones are frequently preferred as measurement tools when it comes to determining broadband ultrasonic waveforms in the most objective manner possible. However, these sensors can be destroyed easily in the event that cavitation occurs at very large pressure amplitudes.

In a project in cooperation with a company, the development of especially robust membrane hydrophones was successfully completed now to the point where they were ready for marketing. In this construction, the sensitive element, which is susceptible to damage, is protected on the front side by a thin stainless steel foil, which gives the measurement device the appearance of a pocket mirror. This foil impedes the erosion of the electrode underneath it if cavitation occurs in the water; secondly, due to its smoothness, it increases the acoustic pressure threshold at which cavitation starts at the boundary surface. The rear electrode is protected by a special cavitation-withstanding oil to prevent damage to this part as well. The oil chosen features a similar characteristic acoustic impedance as water to minimize acoustic reflections from the rear side.

After having performed a broadband calibration of the “pocket mirror hydrophones” at PTB, they can be applied to ultrasonic field measurements. It is possible to observe all important sound field features as for example the increasing distortion with an increasing driving level due to nonlinear sound propagation. Measurements with

peak compressional and peak rarefactional pressures of 90 MPa and 15 MPa, respectively, were successfully performed without any damage to the instrument. The active element size is only 0.2 mm in diameter, and frequency components of up to 100 MHz are included. Therefore, the hydrophone, as developed, significantly expands the variety of measurement instruments and tools available for ultrasonic exposimetry; the first purchase orders for the product have already been received by the cooperation partner.