Physikalisch-Technische Bundesanstalt

Short Report for CCAUV, October 2015

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 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). In another activity new metrological techniques for high-intensity ultrasound fields were in the focus and a novel very stable reference source was developed. It will improve all measurements which require stable measurement conditions for example the secondary calibration of power standards or dedicated hydrophones. This work was carried out in another EMRP project for the development of a dose concept for high-intensity focussed ultrasound applications.

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/SC 3/WG 6 PTB has the lead for two active standardisation projects, concerning model based parameter identification and 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.

In our daily life many sources emit infrasound and airborne ultrasound because of their function or unintended. There are numerous indicators that infrasound and airborne ultrasound events influence human beings and that sound at such frequencies can be perceived. However at present, the precise mechanisms of sound perception at these frequencies are unknown and this lack in understanding is reflected by the status of existing regulations and standards. In a project supported by the European Union "European Metrology Research Programme" (EMRP), it was therefore objectively investigated, by means of different methods of audiology and by means of the imaging procedures of neurology, how infrasound and ultrasound affect human beings. In case of airborne ultrasound new measurement and calibration methods were developed including the first realisation of measurements of the emission from ultrasound devices traceable to the first primary standard for microphone calibration in the world, made by DFM. In a second part of the project a novel universal ear simulator was developed, manufactured and tested which has the potential to significantly improve the calibration of audiological devices for better diagnosis and screening results mainly for newborns and children. Six European national metrology institutes and two external partners were involved in the project which was coordinated by PTB.

For emergency warning systems giving spoken advices to persons at risk sufficient speech intelligibility is required to hit the goal of inducing safe activities. An STI value ≥ 0.5 is required, which results in a sentence intelligibility ≥ 95 % for the normal-hearing. The sentence intelligibility at a given STI value is, however, reduced by hearing impairment. The aim of a project was the determination of objective parameters to evaluate speech intelligibility for the hearing-impaired in public transport areas. Based on the results, modified requirements were supposed to provide also the hearing-impaired with sufficient sentence intelligibility for emergency announcements.

In the time frame from 2011 to 2014 PTB lead the joint European research project IND09 “Traceable dynamic calibration of mechanical quantities” which focussed on the development of dynamic calibration methods for force, pressure and torque complemented by the necessary mathematical methods and a work package concerning conditioning amplifiers in dynamic applications. This research project generated a vast impact in terms of international awareness of the challenge that is linked to traceable dynamic measurements in principle. The scientific outcome was published in the relevant metrological journals and during conferences like IMEKO. After the closing of this project the topic of dynamic measurements is still an active research focus of PTB.

In the field of acceleration the research and development over the last years was concerned with new laser-interferometric methods, investigation of disturbing components especially in primary calibration of single ended accelerometers, improvements in dynamic charge amplifier calibration and primary high intensity shock calibration of accelerometers.

One major field of research in applied acoustics is dedicated to the measurement of airborne sound power. These activities are coordinated by PTB in the EMRP-Project “Realisation, dissemination and application of the unit watt in airborne sound”. The aim is to develop a primary standard for airborne sound power in the frequency range between 100 Hz and 20 kHz based on a vibrating solid body. This approach is applied by four European NMIs which all developed their own primary standards. The unit of airborne sound power is disseminated by aerodynamic reference sound sources. The investigations of the properties of these transfer standards and the corresponding influences on the uncertainty in the process of dissemination are another major part of the project.

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. Here, a major improvement has been achieved by collecting data from many round robins and summarising the results in the main ISO-standard which is ISO 12999-1.

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 Reference sources for therapeutic ultrasound

Ultrasound can be used in medicine for therapeutic purposes – e.g. for non-invasive local destruction of tumors (HITU) or for the treatment of muscle diseases and injuries (physiotherapy). The high acoustic output power required for these applications, however, requires high electrical input power, which can heat the ultrasound transducer during operation and thus lead to a variation of the acoustic output. This behavior can falsify secondary calibrations of the respective measuring devices or bio-effect studies. Currently, a reference setup with selected devices and feed-forward control software has been accomplished at PTB which has proven to significantly improve the temporal constancy of ultrasonic fields.

At PTB it was investigated whether and how the stability of therapeutic ultrasound fields can be improved. For this purpose, initially devices that are as stable as possible for signal generation, as well as two therapeutic ultrasound transducers (a transducer for high intensity therapeutic ultrasound applications (HITU) and a transducer for physiotherapeutic treatments), were selected. A feed-forward control algorithm was implemented, which continuously monitors the input voltage to the transducer, using computer-controlled stabilization. With the use of this setup, it could be shown that the stabilized input voltage leads to significantly more stable sound pressure amplitudes. Furthermore, bimonthly ultrasonic field measurements and power measurements were performed to check the long-term stability of the setup over a period of one year. The scattering of the values measured over one year was 5 % (field measurements) and 2% (power measurements), which is reasonably low.

3.2 Extension of secondary free-field microphone calibration at PTB

For the measurement of airborne ultrasound the metrological underpinning is still not in accordance with the requirements for a reliable characterisation needed for an assessment with respect to safety issues. During the EARS project, carried out within the EMRP programme, the Danish National Metrology Institute (DFM) developed the first primary standard for calibration of microphones up 150 kHz. In a next step at PTB a secondary calibration setup was established for the application to WS3 microphones up to a frequency of 100 kHz. It will be used to calibrate reference standards for manufacturers, calibration laboratories, measurement services and safety regulation bodies. Pure tones were applied as stimulation and the free-field sensitivity level is determined for a defined combination between a microphone and an adaptor. The setup is built up in a large reverberant room to reduce reflections from the walls. An estimation of uncertainties revealed values between 0,4 dB for frequencies between 5 and 20 kHz which continuously increases to 0,5 dB between 80 and 100 kHz.

3.3 Novel standard for sound power

The novel standard for airborne sound power in the frequency range between 100 Hz and 20 kHz has been constructed and tested. It consists of an electrodynamic shaker exciting an embedded piston. The vibration velocity of the piston is measured by a laser scanning vibrometer. From the discretised Rayleigh-integral, the sound power emitted by this device can be calculated for all modes of vibration. It turns out that the compromise between air tightness of the embedding and excitation of structureborne sound in the surrounding is rather difficult to achieve. The deviation to traditional sound power determination methods is at current in the order of 1.0 dB. It is expected that this can be improved considerably in the next time.

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 Can we hear signals with a frequency of 8 Hz or 20 kHz?

Numerous sources of noise at workplaces, in public, in buildings and homes emit sound not only within the so-called "acoustic frequency range" of about 16 Hz to 16 kHz, but also below (infrasound) and above (ultrasound). The indication of this "acoustic frequency range" with the above-mentioned limits has become established. This is, however, misleading as human beings can still perceive sounds and noises also in the neighbouring frequency ranges. This perception is often felt to be disturbing; little is known, however, about the basic mechanisms playing a role in this matter. This lack of knowledge is also the reason why – especially for ultrasound in air – there are hardly any provisions or standards for requirements made on measuring instruments, measurement methods and upper limits. But also in the infrasound range, there are no recognized upper limits, and the measurement regulations are again and again the subject of controversy.

In a project supported by the European Union "European Metrology Research Programme" (EMRP), it was therefore objectively investigated, by means of different methods of audiology and by means of the imaging procedures of neurology, how infrasound and ultrasound affect human beings. Initially, the subjective hearing thresholds of a group of test persons were determined in the frequency ranges 2 Hz to 125 Hz and 14 kHz to 24 kHz. In the infrared range, it was also possible to determine the curves of the same subjective loudness level individually for each test person by means of newly developed methods.

In a further step, imaging procedures were used to examine whether, and in which range, the acoustic stimuli outside the acoustic frequency range cause reactions in the brain. In this way, objective measures of modern brain research were to be compared to the subjective perception of infrasound and ultrasound. The same volunteers, for whom an audiological characterization was available, were examined by means of magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI). In the infrasound range, an excitation in the auditory cortex could be detected down to a frequency of 8 Hz. The results also suggest the conclusion that the mechanism of hearing may change at about 20 Hz, i.e. that infrasound (below 20 Hz) and 'audible' sound (above 20 Hz) are perceived and/or are processed by the brain differently. In the ultrasound range, the measurements showed no activation in the auditory cortex for frequencies above 16 kHz.

With its results, the project has provided the foundations for new and better measurement methods, by means of which better-grounded upper exposition limits can be determined in the long term.

4.2 Directivity pattern of airborne ultrasonic sources

Airborne ultrasound can be emitted with a very strong directivity by sound sources such as ultrasonic cleaning baths or welding equipment. Due to this focusing, very high and hearing-damaging sound pressure levels may occur locally. A new measuring arrangement now allows the emissivity of various sound sources to be determined with high resolution and with level accuracy.

For this purpose, a measuring arrangement was set up which allows the sound pressure level occurring around a certain source of interest to be recorded, quantized and assessed with high resolution and with level accuracy. The sound sources should be characterized independently of the influence of the surrounding space. For this purpose, they are placed in an anechoic chamber where reflections distorting the sound level are suppressed. Two controllable axes are used to record and assess the sound pressure signal along a fixed, adjustable radius and at several points that are distributed around the sources. The principle of this arrangement is, thus, similar to that used to determine the sound power of machines. Here, however, not a semi-infinite space with a reflecting floor, but a full-anechoic room is used to be able to determine the real directivity pattern. The recordings are carried out with a ¼"-measuring technique, which allows the actual levels to be determined with a specified measurement uncertainty. For the assessment, different quantities can be used such as, e.g., the non-weighted peak sound pressure level L_{Zpeak} suggested in VDI 3766. Thanks to the offline analysis, any assessment quantity can be used. Directivity patterns detected in such a way can, for example, be used to predict how certain sources will behave in a reflecting environment. But in particular, it makes it possible now to characterize and to modify fields of nearly any ultrasonic sources.

4.3 Better accessibility for the hearing-impaired in public transport areas by optimizing public address announcements

The transmission quality of public address systems is evaluated by means of the Speech Transmission Index (STI) that essentially describes the goodness of modulation transfer (DIN EN 60628-16). An STI value of 0 corresponds to a total loss of signal modulation, whereas an STI value of 1 represents ideal signal transmission. For emergency warning systems an STI value ≥ 0.5 is required, which results in a sentence intelligibility ≥ 95 % for the normal-hearing. The sentence intelligibility at a given STI value is, however, reduced by hearing impairment. The aim of a project was the determination of objective parameters to evaluate speech intelligibility for the hearing-impaired in public transport areas. Based on these parameters, modified requirements were supposed to be derived, to provide also the hearing-impaired with sufficient sentence intelligibility for emergency announcements.

Speech intelligibility was measured in a synthetic sound field with a 9-channel setup using the Oldenburg Sentence Test (OLSA). To simulate the acoustic characteristics of public transport areas, the speech material was modified by adding reverberation or noise, each resulting in the realization of ten different measurement conditions with STI values reaching from 0.48 to 0.75. In the third test setting, the STI was set to a fixed value of 0.5 with ten different combinations of reverberation time and noise level. The frequency spectrum of the noise corresponded to the average spectrum of passing passenger trains in railway stations.

The results of the study showed that the speech intelligibility of the hearing-impaired is more strongly affected by reverberation than by noise. Despite the fact that a mean sentence intelligibility of 95 % could not be completely achieved by the hearing-impaired in reverberation, summarizing the statistical analysis of the results showed no significant differences of the sentence intelligibility of the hearing-impaired, compared to the 27 normal-hearing test-persons, at STI values ≥ 0.69 (mean value: 93 %). Therefore, the safety limit "STI ≥ 0.69" was derived as a modified requirement to provide the hearing-impaired with sufficient sentence intelligibility in public transport areas.

4.4 New measurement method for walking noise verified by an inter-laboratory test

In 2011, the FprEN 16205 “Laboratory measurement of walking noise on floors” has been introduced. It describes a laboratory method to determine walking noise on all kinds of floor coverings. The noise radiated from a floor covering is measured in the room where the floor covering and the excitation are located. The measurements take place on a standard concrete floor when excited by a standard tapping machine. Also the impact sound improvement can be measured within this method; it is very similar to the known impact sound measurements. An additional measurement with so called “pads” is necessary to determine the self noise of the tapping machine. With these two measurements, the walking noise can be calculated.

An international Round Robin Test was organised by the Physikalisch-Technische Bundesanstalt to evaluate this method. About sixteen laboratories took part and four different floorings (carpet, PVC and laminate with two different underlayers) were tested. It turned out that the standard deviation of reproducibility – the best available estimate for the standard uncertainty – is about 2.0 dB for laminates and PVC floorings whereas the procedure fails to describe walking noise for carpets. In view of the complexity of the procedure this is an excellent result.