EMPIR JOINT RESEARCH PROJECT AUGUST 2021

INFRAAUV News

NEWSLETTER NUMBER 1

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WELCOME

It's a great pleasure for me to welcome you to our first Newsletter of the EMPIR project Infra-AUV *Metrology for low frequency sound & vibration*. We hope you enjoy the insights into our work that we convey with the articles in this and the coming issues and would like to encourage you to get in touch with the authors or myself if you find an aspect to be of interest.

Like the name already implies, the main project objective concern the correct measurement of sound (in air and under water) and vibration at very low frequencies. Prominent examples for such measurement applications are seismic and infrasound measurement stations in geoscience for the environmental monitoring of earthquakes, vulcanism and general atmospheric and ocean properties, or ambient noise measurement in the low frequency region in connection with wind energy plants close to urban areas.

The correctness of the measurements results and the confidence in their accuracy is of prime importance and may in fact have significant impact on administrative or jurisdictional decisions. For confidence and accuracy in measurement, traceable calibration of the respective sensors is a fundamental prerequisite, and an important cornerstone of our project.

Our collaboration of scientists from National Metrology Institutes in Europe and operators of International Monitoring System (IMS) stations aim to develop new and extended methods to allow for traceable calibration of permanently located sensors in the field (on-site) at frequencies not yet covered by standardised calibration methods. This process involves high-level primary laboratory measurements as well as on-site measurements under most demanding environmental conditions. We also intend to show-case the use and benefits of quantified measurement accuracy in the related fields of environmental monitoring.

The project is funded by the European Metrology Programme for Innovation and Research (EMPIR).

You are invited to follow our activities through our newsletters and checking out the information on the Infra-AUV project website and to share your impressions by making contact with the authors or me, the coordinator.

- Thomas Bruns

THE CONSORTIUM

This consortium brings together a wide range of expertise and leading skills found within the partner organisations and comprises national metrology institutes (NMIs) and designated institutes (DIs) who are complemented by a number of research institutes and IMS station operators representing the expertise needed from the stakeholders.

PTB, Germany
HBK, Denmark
CNAM, France
DFM, Denmark
LNE, France
NPL, United Kingdom
TUBITAK, Turkey
BGR, Germany
CEA, France
ASN, United Kingdom

NEWS IN BRIEF

LNE LASER PISTONPHONE

A laser pistonphone device has been in development at LNE for some time. The latest version has recently been commissioned and is now fully operational. Its performance has been assessed by using it to calibrate a laboratory standard microphone (B&K type 4160) and a static pressure sensor (Mensor CPT9000) which is expected to have some dynamic response; both devices having known sensitivities. Results are extremely promising showing consistency with the static pressure sensor at the lowest frequencies from 0.01 Hz to 0.1 Hz, and with the microphone at frequencies above 2 Hz. Unfortunately, neither reference device has a reliable performance at the intermediate frequencies, but the results obtained so far provide very good confidence that the laser pistonphone is performing as intended.

PROGRESS WITH SEISMIC CALIBRATION SYSTEMS

As a successful first step in realising measurement capability and traceability for ultra-low frequency vibration measurement, project partners PTB, CEA and HBK-DPLA have upgraded their measurement facilities to operate at lower frequencies and with heavier test devices (seismic sensors can be up to 20 kg).

PTB has implemented and validated a multicomponent vibration exciter capable of use as low as 0.01 Hz, CEA is evaluating their calibration setup with help from LNE, specifically focussing on load capacity, and HBK-DPLA is currently working on non-coherent power dual signal analysis, to improve results of measurements done in noisy environments and/or at ultra-low vibration levels often related to the ultra-low frequency range.

An interlaboratory comparison across these systems is planned, and an investigation to select appropriate test devices has shortlisted the seismometer models to be used.

NEW REPORT ON HYDROPHONE PERFORMANCE

Dissemination of standards for ocean-acoustic measurements requires hydrophones that have stable (or at least predictable) performance. However, the hydrophone characteristics can vary when exposed to different temperatures and depths (every 10 m of depth is equivalent to about one atmosphere of additional hydrostatic pressure). This leads to added uncertainty in dissemination chains and discrepancies in data measured at different laboratories if the environmental conditions are not controlled. NPL has assessed the stability of a wide variety of hydrophones by reviewing data collected over the past 20 years. Some hydrophones exhibit significantly better stability with temperature and depth than others. In general, devices with a simple sensor design (e.g. a spherical ceramic element) exhibit higher stability than more complex designs. A report on the review is available from the Infra-AUV web-site on request (please see 'Contact Us' below).

SPECIFICATIONS FOR INFRASOUND MEASURING DEVICES

The emission of infrasound is increasing in commercial activities and everyday life, but currently available international guidelines and standard for sound level meters or sound assessment standards do not cover this range well. Reliability of low frequency or infrasound measurement are therefore inherently compromised with consequent impacts on noise mitigation and legal actions.

In response, a new document has been produced giving specifications and requirements for measuring devices used in the frequency range 1 Hz to 20 Hz. Starting with available national standards and documents with respect to regulations about the measurement of infrasound, and the IEC 61672-series of standards concerning requirements of sound level meters, the necessary specifications for using sound level meters in the infrasound frequency range have been compiled. This is accompanied with the discussion of basic features and methods for test of the specifications within a type approval, regular testing or pre-measurement checks the user should make. The document is published (see website) and will be submitted as input into international standardisation.

ENVIRONMENTAL INFLUENCE ON INFRASOUND SENSORS AND DATA

Infrasound is generated by many different sources (explosions, volcanoes, convection etc.) over a large range of frequency band (0.01 Hz to 4 Hz is of most interest for IMS stations), and to best detect and locate these infrasound sources it is necessary to have a high quality, calibrated data set.

Research is therefore being carried out on the long-term variability of the infrasound measurements based on seasonal and day-to-day variability. This includes studying both the environmental effects, such as wind noise and temperature, as well as instrumentation considerations, such as the design of the infrasound arrays and the wind noise reduction systems (WNRS). Modelling of the infrasound arrays and WNRS is being done in an on-going effort to better characterize the effects on measurement uncertainty and event detectability.

RESEARCH HIGHLIGHTS

DEVELOPMENT OF A LASER PISTONPHONE FOR HYDROPHONE CALIBRATION

The first ever laser pistonphone was developed at NPL in the 1970s for calibrating microphones used to measure sonic boom associated with supersonic aviation. NPL have now secured another 'first' by adapting the device for hydrophone calibration. Although the usual domain for a hydrophone is water, it is interesting that the sensitivity of a hydrophone is the same in air and in water.

Pistonphone devices as a means of calibrating a measurement microphone, have developed alongside the microphones themselves. They consist of a sealed piston-driven volume to systematically create a stable acoustic pressure. The innovation in a *laser* pistonphone is that interferometry is used to determine the piston displacement and hence enable the sound pressure magnitude to be determined, being a function of the chamber volume, the thermodynamic behaviour of air, static pressure and the volume displacement of the piston – which in turn is related to the optical wavelength of the laser.

The NPL laser pistonphone for hydrophone calibration

Pistonphones are inherently limited in frequency range, but are ideally suited to operation at low frequency, and therefore fitted to the project's objective for establishing a primary measurement standard for hydrophones in this frequency region.

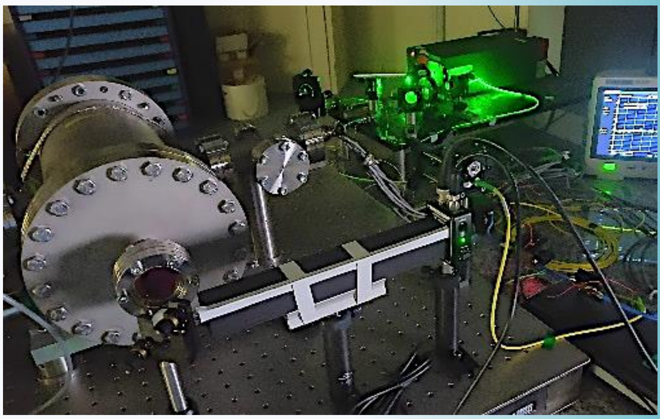
One challenge with accommodating hydrophones is that the size of some devices necessitates redirecting the optical path from the front of the piston, to the rear. The device is pictured above. The cavity is driven from the lower surface by a piston having the same diameter as the cavity and a piezoelectric stack actuator. The optical signal of the quadrature laser interferometer is also delivered via the lower surface. This type of system improves the displacement measurement. The device under test is mounted in the top surface, and different end-caps have been produced to accommodate different type of hydrophones, or combinations of sensors for comparison calibration.

Another novel feature of the newly engineered device is that the chamber can be pressurised. Hydrophones are used at varying water depths and are therefore designed to withstand a large range of static pressure. By calibrating at different static pressures, a more complete characterisation of the hydrophone is anticipated as well as potential improvement in the measurement uncertainty.

CNAM REFRACTOMETRY CALIBRATOR

Le CNAM has established a novel calibration device based on a Fabry-Pérot cavity and the first measurements in the range 0.1 Hz to 5 Hz have been carried out using a measurement microphone (B&K type 4192) and a conventional barometer (Druck PACE1000) to establishing its feasibility.

Fabry-Pérot cavities are subject to environmental influences, so measurements are normally corrected for the influence of the thermal expansion coefficient of the materials. However, in this application, precise environmental control (e.g. temperature is controlled to around 1 mK and ambient pressure to 10 Pa) renders such corrections negligeable.



The refractometer coupled to an infrasound generator (left)

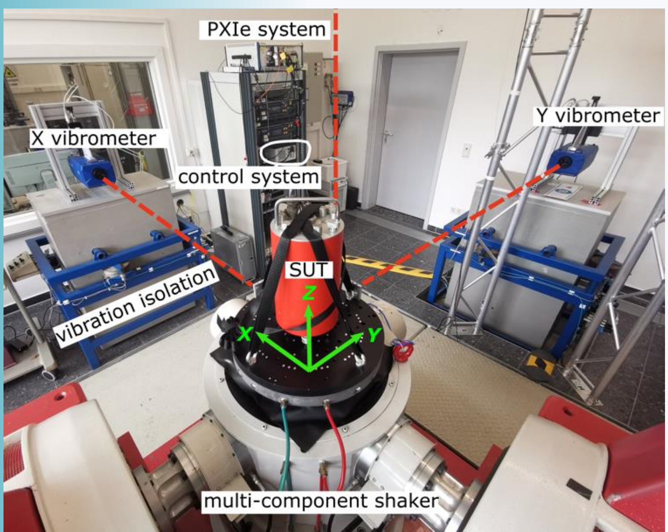
What is a Fabry-Pérot refractometer?
A Fabry-Pérot refractometer can be described as a resonant optical cavity with regularly spaced resonance frequencies, that depend on the refractive index of the medium. Since the relationship between the refractive index and the sound pressure is well-established, a Fabry-Pérot refractometer provides the basis for a novel acoustical calibration device.

PRIMARY SEISMOMETER CALIBRATION WITH IR-INTERFEROMETRY

In order to extend the capabilities for seismic calibration in the frequency range down to 0.01 Hz, the existing multi-component calibration facility in PTB was modified with several improvements over the past months.

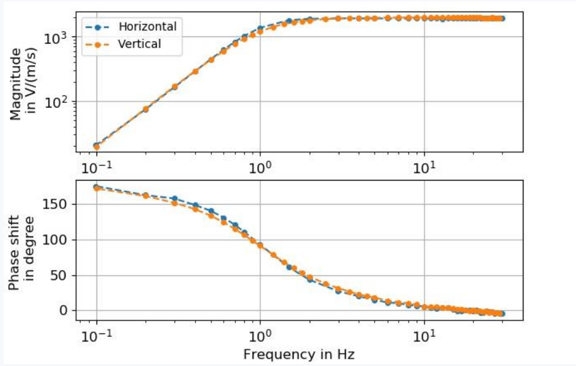
The multi-component calibration facility set up for primary seismometer calibration is shown below. The sensor under test is located on the table of the multi-component shaker, each axis featuring an infrared laser vibrometer as the reference. Compared to the usual use of He-Ne lasers, the infrared vibrometer has a higher output power, which guarantees the vibration measurement tasks even on rough surfaces and/or with long measurement distance.

Two kinds of output signal of the vibrometer are available: (1) a velocity-proportional voltage for secondary calibration and (2) a frequency-modulated signal suitable for primary calibration. During the calibration, the data acquisition and signal generation are handled by a PXIe system. After demodulation of the frequency-modulated signal in the data evaluation, the measured displacement of the excited vibration is directly linked (traceable) to the wavelength of the laser in the vibrometer.



Calibration facility for primary seismic calibration in all 3 spatial directions.

To excite the shaker to the desired vibration, a closed-loop multi-input-multi-output control system is used. However, this system was not designed for frequencies below 1.0 Hz, and therefore not for the ultra-low frequencies targeted in this project. Therefore, instead of the closed-loop control system, a simple signal generator is applied to generate the drive voltage below 1.0 Hz. With the open loop using the signal generator, a well evaluable sinusoidal vibration at 10 mHz can still be excited.



First primary calibration results of the sensitivity of two GS13 seismometers in the range 0.1 Hz - 30 Hz. (in a former version the phase was inverted due to an error in the analysis software)

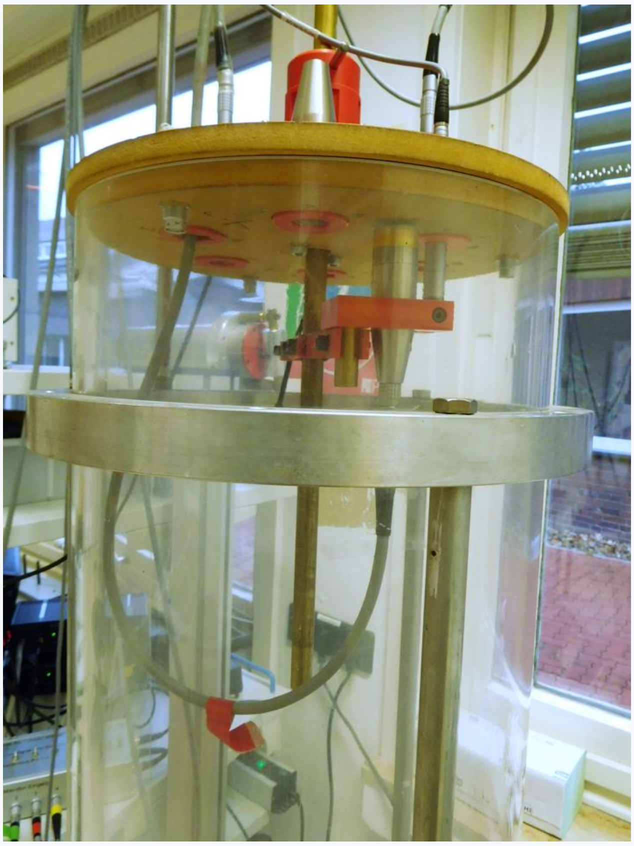
Very recently, the first tests for the primary seismometer calibration were carried out. The test devices were two single-axis seismometers of type Geotech GS-13, one was configured for measuring horizontal seismic vibration while the other one was for vertical direction. The sensitivity given by the manufacture is (2180 ± 545) V/(m/s). According to the bandwidth and the high sensitivity of the seismometer, the shaker was set to excite the sinusoidal vibration with 1 mm/s amplitude in the frequency range of 30 Hz down to 0.1 Hz. The plots above show the calibrated transfer functions of the two seismometers. The relative standard deviation for the magnitude of sensitivity in this first run was approximately 1%.

More information about these activities are available on the Infra-AUV project website.

SECONDARY CALIBRATION FOR AIRBORNE INFRASOUND

A key component in the task of establishing traceability is a secondary calibration method, which provides a way to transfer the calibration results obtained in a well-equipped standard laboratory to practical devices in the field. At PTB a sound tube apparatus has been developed, which enables this transfer for measurement devices for airborne infrasound. A wide variety of currently available measurement microphones and sound level meters can be calibrated.

The sound tube consists of an acrylic tube which is sealed off by a lid at the top. A loudspeaker at the bottom provides a sinusoidal excitation signal, a device under test and a reference transducer can be mounted via the lid. Both are subjected to the sound field created by the loudspeaker. The particularly designed excitation configuration ensures a homogeneous sound field at the locations of the microphones and sound level meters. Mounting brackets in the lid allow positioning the venting holes



The sound tube apparatus at PTB

of the reference microphones either inside or outside of the sound field, depending on the primary calibration method used and the addressed application.

The sound tube covers a frequency range 0.5 Hz o 100 Hz. For higher frequencies the sound field becomes more and more inhomogeneous and at frequencies below 0.5 Hz leakage occurs, which results in a limited excitation sound level. The uncertainty from the primary calibration is currently the largest contribution to the uncertainty of the measurements in the sound tube. A repeatability of 3/100 dB is achievable for suitable measurement microphones, while the primary calibration method currently contributes a systematic uncertainty of 0.23 dB at 2 Hz. Methods which will be developed in the infraAUV project will provide a significant improvement of this contribution.

In the future, this setup can be used for low frequency calibrations and test measurements as, for example, part of type approvals for sound level meters. Another application is the low frequency calibration of microphones of any kind for infrasound measurements outside the laboratory.

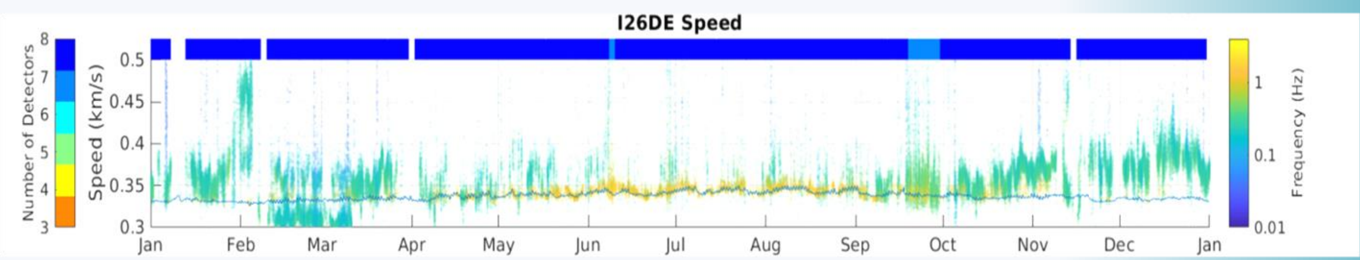
APPLICATION FOCUS

POTENTIAL FIELD-CALIBRATION STIMULI

The creation of a global infrasound monitoring network is a vital element in the verification regime of the provisional Comprehensive Test-Ban Treaty. The process to establish 60 infrasound monitoring stations is well under way with over 50 operational sites. However, there are many other infrasound sources such as volcanoes and earthquakes, so data from infrasound measurements are of wider interest to the scientific community. The purpose of the network is to locate the origin of the infrasound by triangulation, the same principle used in GPS systems. Sensor calibration and knowledge of uncertainties are therefore essential considerations which directly affect the precision of the location determination.

The project is examining potential calibration stimuli for calibrating sensors in-situ. These include a variety of naturally occurring sources such as microbaroms, infrasound (at around 0.2 Hz) created through the interaction of sea surface waves and the atmosphere. Whatever stimulus proves to be most effective, the ability to calibrate sensors in-place is essential. Mostly these sensors are in remote locations and for obvious reasons, need to be operational *all* of the time. Autonomous calibration therefore has enormous advantages.

In parallel the natural variability of infrasound measurements is being evaluated using the existing data. The study includes the effects of environmental parameters such as ambient temperature, pressure, precipitation, and instrumentation factors such as upgrades and filtering systems on the measurement capabilities.



Example of external factors impacting the estimation of infrasound wave speed. The period is from 2015 and between late January to March, shows events with a rapid increase in the measured velocities, followed by a period with many sub-sonic detections. Such unexpected variations are likely associated with instrumental issues.

STAKEHOLDER ENGAGEMENT

EUROPEAN METROLOGY NETWORKS

The European Metrology Network (EMN) for Climate and Ocean Observation is a network of European national metrology institutes, designated institutes and affiliated partners to support the application of metrology to climate and ocean observations. The EMN aims to build partnerships between measurement specialists and the climate & ocean observation communities to enhance metrological best practice across Europe and beyond.

The need for and impact of the Infra-AUV project is directly referenced in the EMN Stakeholder Needs Review Report, with specific relevance to ocean acoustic metrology where a project partner plays a key EMN role. The project will be engaging further with the EMN during the preparation of their Strategic Research Agenda, on the acoustic and vibration metrology needs related to climate and environment.

For more information on the EMN, see: www.euramet.org/climate-and-ocean-observation/

CONFERENCE PARTICIPATION

The project team have been active in raising awareness of the project and presenting an overview of its objectives and activities. Lars Ceranna gave such a presentation "Metrology for low frequency sound and vibration" at the General Assembly of the European Geophysical Union (vEGU2021) that took place from 19-30 April 2021, and Thomas Bruns gave a similar overview presentation at the CTBTO Science and Technology Conference (SnT2021) from 29 June to 2 July 2021. Dr Bruns also took part in a panel discussion on future innovations impacting geophysical monitoring, highlighting the impact of metrology in this field.

Two presentations focussing on underwater acoustics aspects of the project were made at Underwater Acoustic Conference and Exhibition 2021 (UACE2021), 21-25 Jun 2021. Jake Ward presented "Laser pistonphone for hydrophone calibration: coplanarity and frequency response" and Benjamin Ford presented "A Study of the stability exhibited by hydrophones when exposed to variations in temperature and hydrostatic pressure".

Planned contributions to forthcoming events include:

The XXIII IMEKO World Congress 2021, 30 August to 3 September 2021 – Thomas Bruns will present *"Efficient very low frequency primary calibration method for accelerometers"*

TEAM MEMBER 'BUSINESS CARD'

In each issue of the Newsletter we will introduce a selection of the participating institutes to highlight their contributions to the project and their wider activities. This time we introduce the partners CEA and PTB.

cea

French Alternative Energies and Atomic Energy Commission
Commissariat à l'énergie atomique et aux énergies alternatives

The CEA, is an institute leader in research, development and innovation, following two main objectives: to become the leading technological research organization in Europe and to ensure that the nuclear deterrent remains effective in the future.

The CEA is active in four main areas: low-carbon energies, defence and security, information technologies and health technologies.

CEA is the French representative to the International Atomic Energy Agency (IAEA) and Comprehensive Nuclear-Test Ban Treaty Organization (CTBTO), and plays an active part in the fight against nuclear proliferation. Under the CTBT, it is responsible for operating and servicing monitoring stations at various points around the world. The DASE (Département Analyse Surveillance Environnement), part of CEA/DAM, is specialized in the scientific study and operational monitoring of certain phenomena liable to affect the three physical media which make up our planet: the solid earth, the atmosphere and the hydrosphere. Its main missions are the monitoring and verification of Treaties (CTBT, NPT) and the environmental monitoring (seismic hazard, seismic warning, tsunami hazard). In the framework of monitoring CEA Centres, the DASE carries out impact studies and is responsible for the assessment of seismic hazards. Alerting of major earthquakes for the civil authorities thanks to the French Seismic Network is supported by the DASE.

CEA data centre supporting digital services

To best respond to these missions, several activities contribute to the design and the development of instruments for geophysics, their metrology, testing with regard to the environmental parameters of temperature, static ambient pressure, and their deployment in the field in order to acquire robust and quality assured data. In the field of metrology for environmental quantities, CEA/DAM works specifically on acoustic pressure in air and vibration quantities at low and ultra-low frequencies. Its research activities are concerning calibration benches design and calibration methods in laboratory and on site specifically for infrasound sensors like microbarometers and seismic sensors.

www.cea.fr

Physikalisch-Technische Bundesanstalt

The PTB is the national metrology institute of Germany providing scientific and technical services and the highest technical authority for the field of measurement science and certain sectors of safety engineering. It operates under the auspices of the Federal Ministry of Economics and Technology. PTB performs fundamental research and development work in the field of metrology as a basis for all the tasks entrusted to it in the areas concerning the determination of fundamental and natural constants, the realization and dissemination of the legal units and the SI, safety engineering, primary calibration services and legal metrology. Only fundamental research work performed by PTB itself using latest technologies will enable it to ensure its metrological competence recognized on the international level, and to extend it further.

PTB in Braunschweig, Germany

Major areas of technical expertise and experimental activity of PTB comprise service and research in acoustics, mainly on calibration, measurement and sound field characterization. A wide range of primary and secondary calibration services are offered including continuous research activities in improving the methods and extending the frequency range. Within Germany, PTB is responsible for type approval of sound level meters and sound calibrators and a full-range testing of the complete procedure following IEC 61672 standard is offered. In addition, PTB has developed a comprehensive competence in the assessment of infrasound and ultrasound noise and its impact on humans within the last decade.

In the field of mechanical vibration and shock, PTB provides leading edge primary calibration services for accredited industrial calibration labs or other national metrology institutes with internationally approved capabilities at vibration frequencies from 0.1 Hz to 20 kHz and shock intensities up to 100 km/s². The respective group at PTB is a global driver for the development of new methods and technology in that field, providing input to the international community by publications and active contribution to documentary standards.

www.ptb.de

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EMPIR EURAMET
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