PTB news
Scientific Newsletter
2
2014

Three times a year, PTB News provides topical information from the varied spectrum of activities of the Physikalisch-Technische Bundesanstalt (PTB) consisting of fundamental research, legal metrology and PTB's various activities in the service of the economy.

SCIENTIFIC NEWS

TECHNOLOGY TRANSFER

MISCELLANEOUS

The ampere – on its way to a new definition

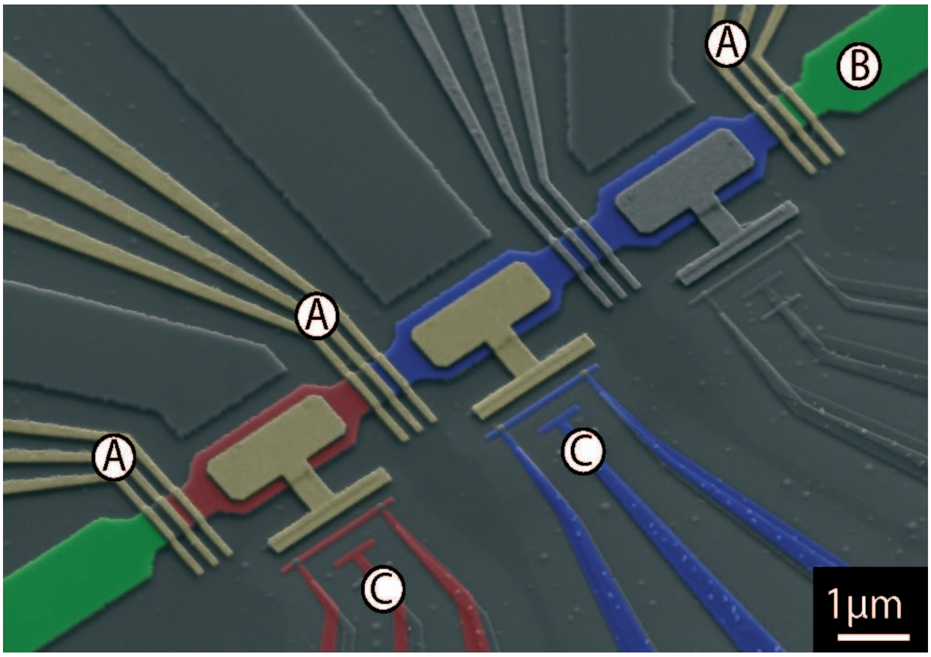
First verifiable realization by means of fundamental constants – Helmholtz Prize 2014

Especially interesting for
- fundamentals of metrology

A new basis consisting of fundamental constants is to be provided to the International System of Units (SI). In this system, the electric units are represented by the base unit ampere. Contrary to the ohm and the volt, which are already traceable to fundamental constants, such a realization has, to date, not been achieved for the unit of current. PTB has now succeeded in developing a current standard which generates a current based on the clocked transfer of single electrons and simultaneously measures the precision of the generated current independently.

The ampere is a base unit in the International System of Units (SI), and yet, to realize it with metrological accuracy in practice, a detour via Ohm's law (i.e. via the electric units the volt and the ohm) is always necessary. Those two units can be accurately realized on the basis of fundamental constants – the Josephson constant (for the volt) and the von Klitzing constant (for the ohm). The corresponding fundamental constant for the ampere is the charge of a single electron.

It is, in principle, possible to realize the ampere in a new way, by temporally clocking the flow of single electrons by means of so-called “single-electron pumps”. In the pumping mode, electrons coming from the current lead on the left are first trapped one by one and then released into the other current lead. If this procedure is repeated periodically, this generates a current which is determined only by the clock frequency, the number



This semiconductor structure can measure single electrons and their respective charge. Three single-electron pumps are operated on the chip; these are connected in series by a semiconductor wire (marked with A). The transferred electrons are detected by means of the two single-electron detectors (C). (Idle elements that do not influence the array are coloured in grey. B: Semiconductor channel) of electrons transferred per cycle and by the electric charge of the electron.

The self-referenced quantum current source developed at PTB is based on such single-electron pumps: several such pumps are arranged consecutively in a semiconductor array and are connected via islands. Highly sensitive detectors are coupled to these islands to count the number of electrons present on the island. This has allowed a clocked current to be generated and checked in situ. Since the new pump only transports a few dozen electrons per second, it is slow enough to allow the corresponding precision measurements. Additionally, it allows validated small currents down to the attoampere range (10^{-18} ampere) to be generated with a clearly lower measurement uncertainty than would be achievable using conventional current measurement methods. Hence, it enables measuring instruments to be calibrated for small currents, as are used, for example, in radiation protection.

The scientists involved in the development of this current standard were awarded the Hermann von Helmholtz Prize in 2014. ▪

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Scientific publication
L. Fricke, M. Wulf, B. Kästner, F. Hohls, P. Mirovsky, B. Mackrodt, R. Dolata, Th. Weimann, K. Pierz, U. Siegner, H. W. Schumacher: A self-referenced single-electron quantized-current source. Phys. Rev. Lett. 112, 226803 (2014)

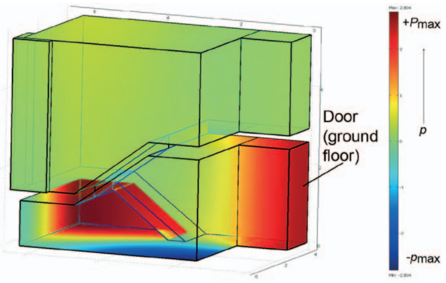
How to get rid of disturbing noise

Special resonators attenuate disturbing sound waves in small rooms

Especially interesting for
- industrial noise protection
- the automotive industry
- building acoustics

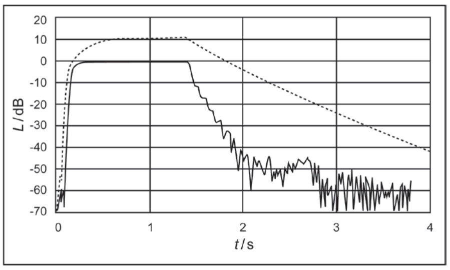
In small rooms, disturbing low-frequency sound waves cannot be attenuated by means of conventional absorbers. PTB has now developed an optimized procedure where special resonators are finely tuned, correspondingly dimensioned and positioned in the room. This considerably helps reduce not only the sound level, but also the decay process of sounds.

In small rooms, acoustic resonances (room modes) cause various problems which, to date, have not been solved in a satisfying manner. Firstly, an impulsive excitation (for example due to the loud banging of a door) can lead to resonance vibrations which, depending on the quality of the resonance, can linger on for several seconds. Secondly, the sound transmission of music and speech in the frequency range of the room modes can, due to constructive and destructive interference, generate level variations depending on the position; the quality of the sound thus varies depending on the place from where a person listens to it. Finally, disturbing sounds caused by electric devices (such as engines or transformers) with spectral components close to the room resonances can be additionally amplified in neighbouring rooms or flats if the rooms have the same geometric dimensions.



Sound pressure distribution computed at the resonance frequency of 38.5 Hz in a staircase. Due to the sound of a closing door, this resonance is particularly strong because the door is located exactly at the sound pressure maximum (red: positive/blue: negative instantaneous sound pressure value). Low acoustic attenuation at low frequencies results in a long echoing sound.

Solutions to all these problems have been found at PTB. Hereby, special resonators are used which can be finely tuned as to their resonance frequency and attenuation. A patent application has been filed for the combined tuning mechanism for both the quality and the frequency of the resonators. In a first step, the sound pressure distribution inside the room must be measured. For this purpose, modal analysis procedures known from vibration technology (for example for the investigation of musical instruments) have been transferred onto the measurement of room modes. Then, a resonator which is tuned to the corresponding resonance frequency is set up in a local sound pressure maximum of the room mode in question. It modifies the frequency response of the sound pressure transmission at the level of the resonance frequency.



Level slope without (continuous line) and with (dashed line) the optimized resonator.

By varying the resonance quality, an optimization adapted to each of these three problems can be attained. This procedure has been tested in several rooms with different acoustic problems. Further applications can be envisaged for acoustics in the passenger compartment of vehicles, for recording studios and small music rooms or in the field of industrial noise protection. ▪

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Scientific publication
J. Klaus, I. Bork, M. Graf, G.-P. Ostermeyer: On the adjustment of Helmholtz resonators. Appl. Acoust. 77, 37–41 (2014)

Detector standard for terahertz radiation

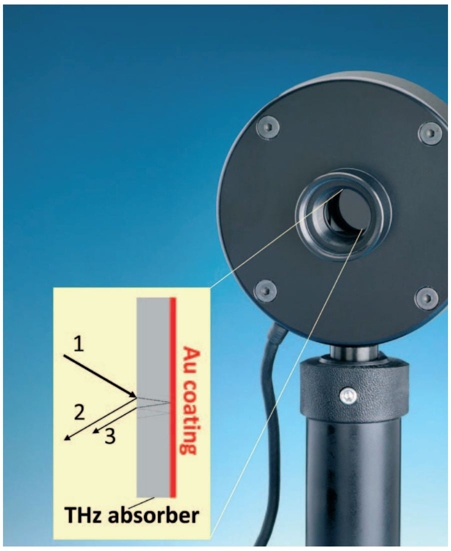
Novel absorber with gold coating

Especially interesting for
- metrology institutes
- manufacturers and users of THz radiation sources

The first capacity worldwide for the precise calibration of the power responsivity of detectors for terahertz (THz) radiation has been developed at PTB in the form of a novel detector standard. Its spectral responsivity was traced back to the International System of Units (SI) by means of visible laser light. This was achieved with a standard measurement uncertainty of less than 2 % for all emission lines of a molecular gas laser in the spectral range from 1 THz to 5 THz.

Terahertz radiation has wavelengths that are nearly 1000 times longer than those of visible light. The radiation's diffraction is stronger, so that it is more difficult to focus it compared to visible light. The aperture of a THz detector must therefore be large enough to detect all the radiation without losses due to diffraction. Also, the wavelength-dependent absorption of the detector absorber has to be taken into account.

The absorber and detection medium for the new THz standard is a special neutral-density glass plate of optical quality. It is mounted into a conventional measuring instrument for laser radiant power. The optical losses could be determined accurately because, in addition, the rear side of the glass plates was coated with a thin layer of gold. The specular reflection of the front surface is thus the sole significant detection loss. This could be measured accurately – namely both in the THz and in the visible spectral ranges where the absorptivity of the neutral-density glass is similar. It was thus possible to trace back the spectral responsivity of the THz detector to the International System of Units (SI) at the wavelength of a red helium-neon laser with the lowest possible uncertainty and to extend this precision into the THz range. A consistent THz scale is essential for risk assessment in potential new applications of THz radiation, which is invisible and penetrates numerous substances. Examples are security applications, medical diagnostics and the non-destructive testing of materials.



PTB's new THz detector standard. The cutaway view depicts a cross section of the THz absorber with gold coating (Au) on its rear side. The radiation loss due to specular reflection (2) of the incident (1) radiation has been precisely measured. If the absorption is strong enough in the absorber, the beam (3) is negligible.

PTB is the first metrology institute to be able to calibrate THz detectors. This service immediately sparked interest worldwide: the first calibration orders were placed by customers from Israel, the USA, France and Canada. Further customers in Japan, Russia and China were served with THz detectors developed in collaboration with a German manufacturer and calibrated by PTB. ■

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Scientific publication
R. Müller, W. Bohmeyer, M. Kehrt, K. Lange, C. Monte, A. Steiger: Novel detectors for traceable THz power measurements. J. Infrared Millim. Terahertz Waves 35, 8, 659–670 (2014)

PTB nano-SQUIDs in service

Newly developed nanostructured magnetic field sensors used in a scanning SQUID microscope

Especially interesting for
- fundamental research
- manufacturers of magnetic storage units and magnetic sensors

Nano-SQUIDs with Josephson junctions smaller than 100 nm have been developed within the scope of a cooperation project with the University of Tübingen. They were integrated into a multi-function scanning sensor of the University of Basel with which successful measurements were carried out on magnetic nanostructures. This opens up new fundamental investigation methods in the field of magnetism, for example for magnetic storage technologies.

For investigations on small spin systems such as molecules or cold atom clouds, nano-particles, atoms or even on single electrons, it is becoming increasingly important to measure the properties of magnetic structures with nanometric dimensions. SQUIDs (Superconducting Quantum Interference Devices), as the most sensitive magnetic field sensors, are predestinated for this task. Their mode of operation is based on effects of superconductivity in Josephson tunnel junctions.

To measure magnetic fields, the nano-SQUIDs developed within the scope of a cooperation project between the University of Tübingen and PTB can be used with a lateral spatial resolution below 100 nm. To manufacture them, a technological process has been developed and optimized at PTB which allows extremely small Josephson junctions to be manufactured from a complex series of layers of niobium (superconductor) and HfTi (normal conductor). This involves the most modern thin-film procedures, electron-beam lithography and chemical-mechanical polishing. The contact surfaces of the first generation of nano-SQUIDs which were produced this way were 200 nm × 200 nm and the lateral dimension of the detector loop 500 nm only. First test measurements in the DC gradiometer mode have already shown excellent electrical properties. The magnetic flux noise of the nano-SQUIDs was around 250 $n\Phi_0/\sqrt{Hz}$. In addition, the detectors could be used at relatively high magnetic fields of up to 500 mT.

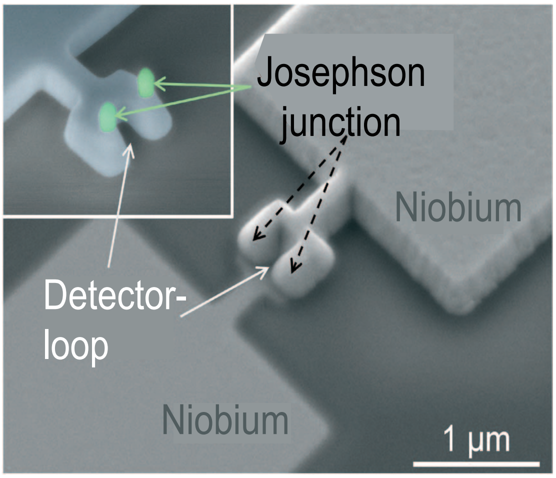

Image of a nano-SQUID taken with the aid of a scanning electron microscope. This utilization shows the detector loop and the two nano-scale Josephson junctions (coloured) on the niobium basis electrode which, in the finished SQUID (see large photo, same scale), are covered by the niobium wiring layer.

Further optimization of the process has permitted further miniaturization of the Josephson contact surfaces down to 90 nm × 90 nm and of the SQUID detector loop down to 250 nm. The flux noise has hereby been reduced to 200 $n\Phi_0/\sqrt{Hz}$, and the magnetic coupling to structures to be investigated has been clearly improved, so that an extremely low spin sensitivity of only 23 $\mu_B/\sqrt{Hz}$ could be achieved. In addition, with this latest generation of SQUIDs, detector loops can be manufactured which are vertical to the chip surface of the sensors, so that further miniaturization – and thus an increase in the spatial resolution – is possible. The nano-SQUIDs were integrated into a prototype of a low-temperature scanning SQUID microscope at the University of Basel. This microscope has already allowed nickel nanotubes to be measured magnetometrically. ▪

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Scientific publication
Buchter et al.: Reversal mechanism of an individual Ni nanotube simultaneously studied by torque and SQUID magnetometry. Phys. Rev. Lett. 111, 067202 (2013)

New insight into matter

At the QUEST Institute, scientists have succeeded in extending spectroscopy using quantum logic to the investigation of very short-lived energy states

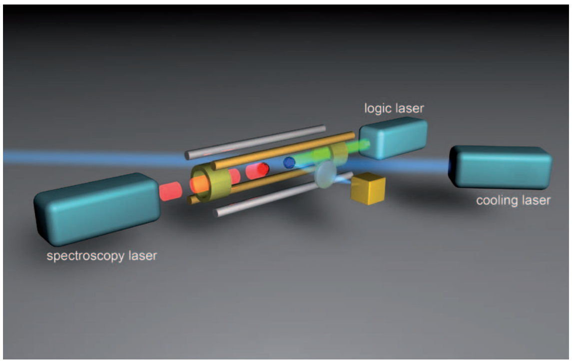
Especially interesting for
- high-precision frequency measurements
- fundamental research in physics
- astronomy, chemistry

A new method developed by the QUEST Institute at PTB in collaboration with Leibniz Universität Hannover has considerably enhanced the possibilities provided by spectroscopic investigations on atom systems: photon-recoil spectroscopy not only allows extremely accurate frequency measurements, but could also contribute to discovering possible temporal changes in the fine-structure constant. Furthermore, numerous other applications will arise in astronomy or chemistry.

Similar to quantum logic spectroscopy, photon-recoil spectroscopy uses an auxiliary ion trapped together with the ion under investigation to provide cooling and efficient signal detection as required for precision spectroscopy. The trap keeps the two ions together whereas they would normally repel each other due to their respective electric charge. Similar to Siamese twins, these two ions are forced to do everything together. In this way, it is possible to obtain information on the ion to be investigated (in this experiment: calcium) by observing the behaviour of the easily controllable so-called “auxiliary” or “logic ion” (magnesium). Close to an atomic resonance, photons from the spectroscopy laser pulses are absorbed and cause the spectroscopy ion to oscillate due to their recoil kick. Due to the strong coupling, the auxiliary ion also oscillates. Its oscillation can be detected with high efficiency using quantum logic techniques, which amplify the signal of a few absorbed photons into thousands of photons. Recoil kicks from less than 10 photons suffice to generate a measurable oscillation.

In this way, the absolute frequency of a certain transition in calcium was measured to with an accuracy of 88 kHz; this corresponds to a relative inaccuracy of 10^{-10} at a transition width of approx. 30 MHz. Previous measurements were less precise by more than an order of magnitude. One of the main features of the experiment is its versatility. The reason why this experiment is so special is that it is flexible. The only thing it takes to iInvestigatinge other spectroscopy ions requires just a change in the spectroscopy laseris to re-adjust the laser used; the auxiliary ion and the elaborate laser set-ups required for cooling and detection remain unchanged.

The objective of this new method is to carry out absolute frequency measurements on many different ions with the greatest possible precision. This new technique extends quantum logic spectroscopy to the investigation of ions which remain in their excited state for a few micro- or even nano-seconds only. Together with the greater sensitivity, this opens up new possibilities in the precision spectroscopy of molecular and metal ions which are found in space and are often used as a reference by astronomers – for example to compare atomic resonance lines from some billion years ago with the respective resonances today in order to detect possible changes in the fine-structure constant. ■



Photon-recoil spectroscopy: An auxiliary ion (the logic ion, blue) is trapped in an ion trap together with the ion to be investigated (the spectroscopy ion, red). Due to the strong coupling to the logic ion, the spectroscopy ion is cooled down to the ground state of motion by means of laser cooling (cooling laser and logic laser). Laser pulses (spectroscopy/repump laser) excite the spectroscopy ion and put both ions into motion. This motion represents the spectroscopy signal and can be read out via the logic ion (cooling laser and logic laser).

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Scientific publication
Y. Wan, F. Gebert, J. B. Wübbena, N. Scharnhorst, S. Amairi, I. D. Leroux, B. Hemmerling, N. Lörch, K. Hammerer, P. O. Schmidt: Precision spectroscopy by photon-recoil signal amplification. Nat. Commun. 5, 3096 (2014)

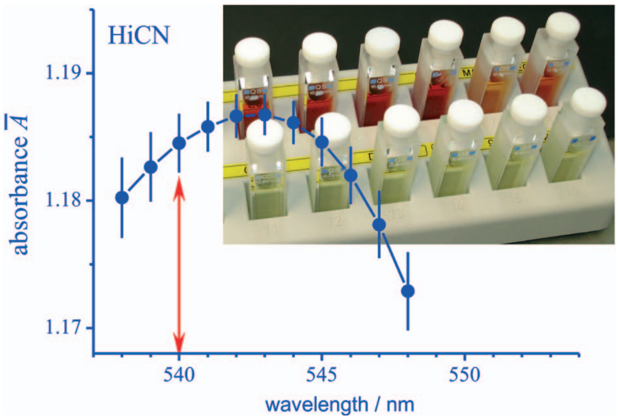
How much haemoglobin is there in the blood?

Traceable photometric absorption measurements

Especially interesting for
- laboratory medicine
- haematologists

The haemoglobin concentration in the blood (Hb) is one of the most important laboratory parameters for the diagnosis and classification of diverse anomalies of the haemoglobin metabolism, e.g. anaemia. To improve accuracy and reliability, PTB has investigated two methods with regard to their suitability as reference measurement procedures. Both methods are based on the determination of the haemoglobin content in the blood by means of photometry. In order to establish a representative comparison of these two procedures, the absorbance values measured with the photometer must be traceable. A corresponding procedure which is specifically suited for haemoglobin measurements has been successfully applied.

The total Hb concentration in the blood is measured by transforming each of the different variants of haemoglobin (e.g. oxyhaemoglobin or carboxyhaemoglobin) into a uniform, stable end product using specific conversion reagents and by determining the spectral absorbance of the solution by means of a spectral photometer. The first procedure is the frequently applied HiCN method, where a conversion into the end product cyano methaemoglobin takes place. This method has certain disadvantages: it is too expensive for non-industrialized countries; there is no pure calibration material; and its application is not allowed in all countries due to its toxicity. The second investigated method (the AHD method) – based on a conversion into a complex composed of alkaline haematin and non-ionic dispersant – is, thus, of particular interest. After conversion into the respective end product, for both methods a dilution series is prepared and the spectral absorbances are determined at the wavelengths 540 nm (HiCN) (see figure) and 574 nm (AHD). In order to derive the "true" (or the so-called "conventional quantity") values from the spectral absorbance values, which are measured relative to the conversion solution, they have to be traceable by measuring the characteristic line of the spectral photometer used for the Hb determination. This characteristic curve is obtained by comparing the absorbance values of neu-



Absorption spectrum of a diluted blood sample after conversion of the haemoglobin variants into HiCN. The expanded measurement uncertainties (95 % level of confidence) include the contributions of the traceability, the preparation and the repeatability. The photo shows six different dilutions for Hb measurement in the back row and the photometric cuvettes with the conversion solution required for the differential measurement.

tral-density glass filters with the reference measurement values of the spectral absorbance of these filters determined with the national reference instrument at PTB. These experiments for the traceability of the photometer have shown that the measured absorbance of the filters is in very good agreement with the reference measurement values.

The uncertainty of measurement of the "true" absorbance values is higher by approx. one order of magnitude compared to that of the measured absorbance values, which corresponds to the repeatability in the case of filter measurements and of Hb measurements. This indicates that the measurement uncertainties of the filter absorbance values used for the traceability contribute considerably to the combined measurement uncertainty of the haemoglobin determination. Hence, a reduction of this measurement uncertainty would improve Hb measurement all in all. The good agreement of the haemoglobin concentrations determined with these two conversion procedures proves that both methods are suitable as higher-order methods for the determination of reference values.

The work was partly supported by the funding programme "Messen, Normen, Prüfen und Qualitätssicherung" (MNPQ) of the Federal Ministry of Economic Affairs and Energy and by the European Union within the European Metrology Research Programme (EMRP) HLT-05 2012 "Metrology for metalloproteins". ■

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Scientific publication
K. Witt, H.U. Wolf, C. Heuck, M. Kammel, A. Kummrow, J. Neukammer: Establishing traceability of photometric absorbance values for accurate measurement of the haemoglobin concentration in blood. Metrologia 50, 539–548 (2013)

How much liquid is there really in the tank?

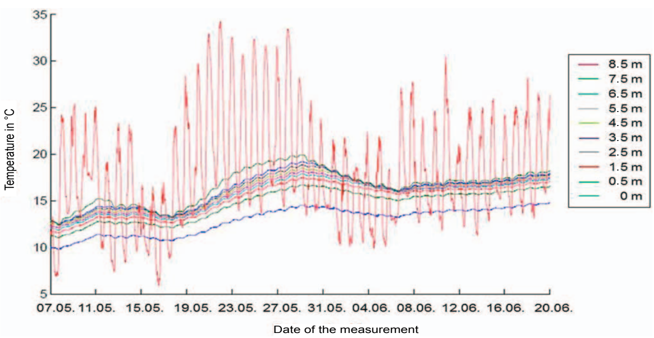
Experiments and simulations on temperature distribution in large storage tanks

Especially interesting for
• the energy industry

Storage tanks such as those used for petroleum products and their derivates may have a capacity of more than 50 million litres. In such cases, temperature variations of a few tenths of a degree Celsius in the liquid can suffice to modify the volume by thousands of litres. When trading with large quantities, it is therefore very important to determine the mean temperature of the liquid inside the tank with great accuracy. Based on exhaustive experiments carried out on a real storage tank in combination with mathematical simulations, sound recommendations on how to determine the mean temperature can now be put forward for the first time.

A total of eight partners – apart from PTB and verification authorities, also manufacturers of measuring instruments, tank storage operators as well as Hamburg University of Technology (Technische Universität Hamburg-Harburg – TUHH) – dealt with the issues of reliable temperature measurement in storage tanks for petroleum products within the scope of a two-year scientific cooperation project. The investigations were aimed at elaborating recommendations to improve the relevant national and international regulations in this field, paying special attention to the aspects of legal metrology.

For the experimental investigations – which, for practical reasons, were carried out with water – a storage tank with a total capacity of 2440 m^3 (14.9 m in diameter, 14 m in height) was available on the premises of the mineral oil port of Hamburg. Thirteen temperature measurement chains consisting of nine and ten, respectively, vertically arranged temperature sensors were installed with regular spacing inside the tank so that the current temperature could be measured at 123 points inside the tank. The experiments took place over a period of 16 months, and the measured data were retrieved every 10 minutes.



Temperature distribution in a storage tank filled up to 8 m in height with water, over a period of 6 weeks, at outer temperatures such as those typically prevailing in the summer. The lowest of the 10 temperature sensors arranged vertically is located on the tank bottom, the highest one in the air-filled space above the liquid level.

The exhaustive measurement data, together with sophisticated numerical simulations, make it possible to determine, for the first time, a realistic measurement uncertainty for the mean liquid temperature prevailing inside a large storage tank and to derive appropriate installation conditions for the required temperature sensors. This therefore allows a metrologically secured conversion of the liquid volumes determined under operating conditions to the reference temperature which is legally laid down and is 15 °C for the petroleum industry. The results of the measurements and of the numerical simulations also allow a transfer to other liquids, to other weather conditions and to special filling cycles with liquids of different temperatures, as encountered in practice with large storage tanks. ■

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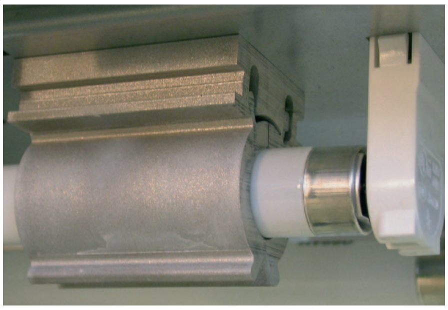
Increased safety with luminaires

Especially interesting for
- manufacturers of luminaires
- applications in explosion protection



A new development made at PTB allows commercial T5 fluorescent lamps with higher power to be used in luminaires located in potentially explosive atmospheres. In the relevant zone, the hot spots at the surface of the spiral are safely enclosed, so that the surface temperature that is relevant from the point of view of explosion protection is reduced. This development takes not only the tolerance ranges of the T5 lamp diameters of different manufacturers into account, but also the spatial variation of the lamp's axis when the lamp is turned into place inside the socket as well as further degrees of freedom for safe use. ■

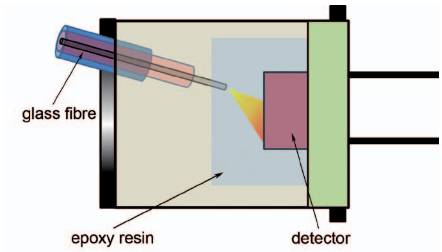
Advantages
- *applicable to T5 fluorescent lamps in explosion-protected luminaires*
- *tripping threshold of the electronic ballast increased to 7.5 W*
- *no additional effort when changing the lamp*

Improved optical gas analysis

Especially interesting for
- the chemical and pharmaceutical industry
- process control engineering

A coupling between an optical fibre and a detector, which was developed at PTB, enhances the measurement accuracy of gas analyzers by minimizing the influences of parasitic gas volumes along the measurement section. Hereby, the surface-treated glass fibre end which is normally open is embedded into gas-tight epoxy resin having the same refractive index. In this region, the signal can, thus, no longer be influenced by ambient air. In addition, the light is defocused in the epoxy resin, so that the anti-reflex-coated detector is not saturated locally. ■

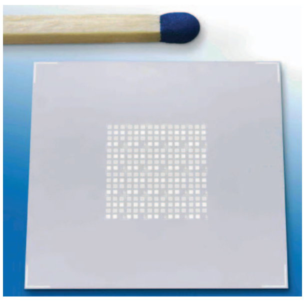
Advantages
- *fibre/detector coupling "without air gap"*
- *reduces the influences of the ambient gas*
- *minimizes interference effects*
- *insensitive to vibrations*



Standard for Raman microscopy

Especially interesting for
- manufacturers and users of Raman microscopes

Raman microscopy is a measurement procedure for the spatially resolved determination of the chemical composition of samples. A new PTB Raman standard allows Raman microscopes to be calibrated laterally and their optical resolution to be performed with particularly high quality. It consists of a silicon surface (a material with excellent Raman activity) which is almost free of topography, to which very thin gold-palladium patterns have been applied in a coating procedure. These covers effect an attenuation of the Raman signal. ■



Advantages
- *high Raman contrast*
- *2D calibration*
- *determination of the optical resolution*
- *suitable for nearly all instrument configurations*

Contact person for questions about technology transfer
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Awards

Ernst O. Göbel

PTB's previous president has received the "DIN Ehrenring" (Ring of Honour) – the highest award granted by the Deutsches Institut für Normung (DIN, German Institute of Standardization). In addition, the Euro-Asian Cooperation of National Metrological Institutions (COOMET) awarded him the honorary title "Merited Metrologist of COOMET", thus recognizing his continuous support of the regional metrology organization during his term of office.

Lukas Fricke, Bernd Kästner, Ralf Dolata, Frank Hohls, Hans Werner Schumacher

These PTB members of staff were awarded the Hermann von Helmholtz Prize for developing a self-referenced quantum current source which is deemed a decisive step towards the realization of the base unit the ampere based on a fundamental constant. The prize was presented to them on 24 June 2014, following the Hermann von Helmholtz Symposium held in Braunschweig.

from left to right:
Nathalie von Siemens (treasurer of the Helmholtz Fund), Hans Werner Schumacher, Frank Hohls, Bernd Kästner, Lukas Fricke, Ralf Dolata, Joachim Ullrich (President of PTB and Chairman of the Helmholtz Fund)

In short

PTB is taking part in two large-scale DFG-funded research projects: In the special research area "Relativistic geodesy and gravimetry with quantum sensors" (geo-Q) (a project with an estimated term of up to 12 years), PTB will, together with several other research partners, investigate the fundamentals of trendsetting procedures for the measurement of the Earth and of its constant changes, including climate change. In the Research Training Group "Metrology for Complex Nanosystems" (Nanomet), PTB, together with scientists from the Technische Universität Braunschweig (TUBS) will, for an initial period of 4 years, investigate topics revolving around the accurate measurement of ultrasmall and ultraprecise objects.

PTB and TUBS have intensified their collaboration in the field of metrology. On 25 June 2014, the respective presidents signed a cooperation agreement which includes, among other things, the first master's course "Metrology and Analysis" at the national level; the beginning of this course is planned for the winter semester of 2014. The lectures will be given by lecturers from TUBS and PTB. In addition, there will be joint research projects as well as joint research training groups and research institutes. Their largest joint project to date is the Laboratory of Emerging Nanometrology. It is being set up on TUBS's campus; the necessary funds amounting to 30 million euros are provided by the Federal Government and the federal state of Lower Saxony.

The newly founded association "Traceability for Computationally Intensive Metrology" (TraCIM e.V.) develops and monitors quality characteristics. Based on these, analysis algorithms of metrological applications can be validated via the Internet. The founding members are PTB as well as 6 members of its staff. In the future, further members in the form of European metrology institutes, and designated institutes or actively involved employees of these institutes will be able to join this association.

EMRP News

Newly launched
projects of the European Metrology Research Programme (EMRP) coordinated by PTB:

Towards an energy-based parameter for photovoltaic classification (PhotoClass)
Contact: Stefan Winter
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Project website: http://www.photoclass.ptb.de/emrp/eng55.html

Metrology for radiological early warning networks in Europe (MetroERM)
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For further information on the project, please visit:
http://www.euramet.org/fileadmin/docs/EMRP/JRP/JRP_Summaries_2013/Environment_JRPs/ENV57_Publishable_JRP_Summary.pdf
(shortlink: http://goo.gl/X1VRTX)

Traceable measurement of drivetrain components for renewable energy systems (DriveTrain)
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http://www.ptb.de/emrp/drivetrain.html

For further information on EMRP, please visit:
www.euramet.org > Research EMRP > Calls and Projects

Publications

PTB-Mitteilungen Vol. 2/2013
Der neue Deutsche Kalibrierdienst (DKD) (available in German only) (The new Deutscher Kalibrierdienst (German Calibration Service – DKD))

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