PTB news
Metrology
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Cooperation
03.3

Smallest measurement uncertainties for autocollimators

High-resolution electronic autocollimators are used to determine small angular differences. Calibration of these devices requires appropriately small measurement uncertainties. With the PTB angle comparator now uncertainties as small as 3.4 · 10^{-8} rad or 0.007 arc seconds are achieved. This corresponds to a distance of roughly just 13 metres on the moon as viewed from the earth (distance approx. 384 000 km).

Autocollimators are optical precision measuring instruments which determine small angular differences with the aid of a plane mirror. They are used both, in industrial metrology and in research and development. For example, they are deployed on machine tools or coordinate measuring machines to measure the angular deviations of guideways or angle measuring tables. Scientific applications, such as measuring angular differences in high-precision determination of flatness deviations (see PTB News 02.3), call for calibrated autocollimators with measurement uncertainties smaller than 0.01 arc seconds over a measuring range of roughly 300 arc seconds. Such autocollimators are also used in rotary balance experiments to determine the gravitational constant.

To meet these accuracy requirements, electronic autocollimators are calibrated in the Clean Room Centre on the PTB angle comparator, and thus directly traced back to the SI unit of the plane angle, rad. The optical measuring principle benefits from the laminar and extremely temperature-stable air flow in the Clean Room Centre. Metrologically, the key component of the comparator is a circular graduation pitch circle disc made of glass with 131 072 (= 2^{17}) radial graduation lines on 360°. The radial grating is incorporated on an air-cushioned precision rotor. It is scanned photoelectrically by eight reading heads using a novel reflected-light phase grating technique. A resolution of 0.0012 angular seconds can be achieved. By applying two separate and independent calibration procedures the angular deviations of the comparator can be determined with a hitherto unmatched uncertainty as small as 0.005 angular seconds (k = 2).

PTB can now calibrate high-resolution electronic autocollimators with an uncertainty down to 0.007 angular seconds (3.4 · 10^{-8} rad) (k = 2) and meet the present demands, in particular, in the field of research.

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Calibration of a rotary table (index table) with autocollimator and precision polygon

Linking the kilogram to an atomic mass

In the gold ion experiment at PTB, the atomic mass of gold was determined in the SI base unit “kilogram”. In future, this experiment could lead to a new definition of the kilogram not linked to a prototype anymore, but traced back to an atomic mass and thus linked to a physical constant.

Comparisons between the international and the national kilogram prototypes as well as with the reference standards of the Bureau International des Poids et Mesures (BIPM) have shown mass changes in the range of 50 µg in 100 years. A mass change of the international kilogram prototype itself cannot be ruled out. Proof of such changes must be based on a sufficiently exact comparison of the kilogram with a physical constant. The PTB ion accumulation experiment therefore aims at linking up the atomic mass unit with the kilogram with a relative uncertainty of approximately 10^{-8}. The goal is to open up a new way to redefine the kilogram.

In the experiment, ions from an ion beam are captured in a collector. The current of the ion beam and the accumulation time are measured, and the mass of the accumulated ions is determined. From this, the unit of atomic mass can be quantified, provided the relative atomic mass and the elementary charge are known. With an ion current of approximately 10 mA a mass of 10 g of a heavy element will be accumulated. This procedure takes approximately six days.

In a first accumulation experiment, gold ions were collected on a gold-coated quartz microbalance. The atomic mass of gold was determined in

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Linking the kilogram to an atomic mass

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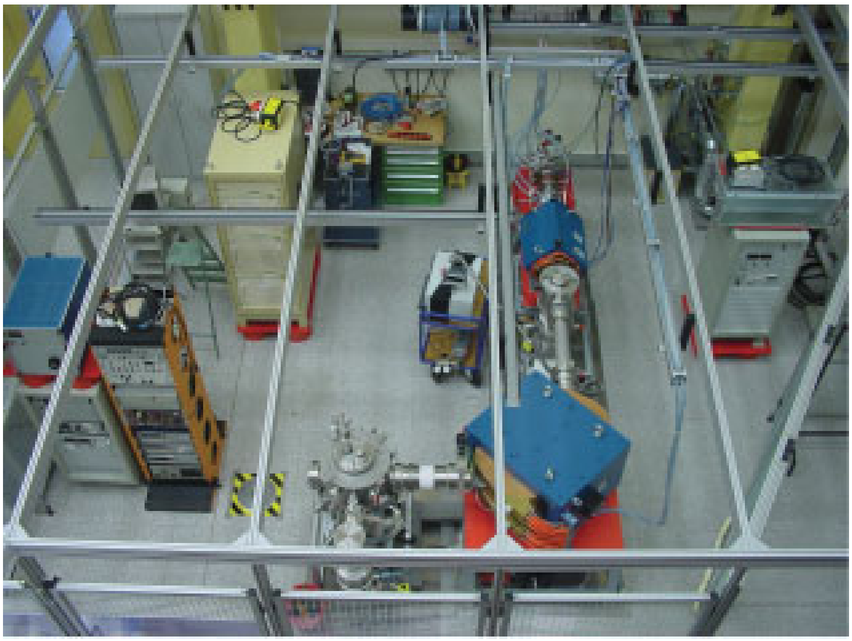
the base unit "kilogram" with a deviation of 0.6 % from the expected value and an uncertainty of 1.5 %. The accumulated mass amounted to approx. 0.5 mg at an ion current of 0.01 mA during an accumulation time of eight hours.

In the meanwhile, total ion beams (xenon and gold) with a current of more than 60 mA have been produced with a new set-up designed to increase the ion current. However, the gold ions only accounted for a current of 0.8 mA. As this current is still insufficient, a new ion source will be used in future. The new source will generate a bismuth ion beam with the aid of an oven. This will probably provide the required current of at least 10 mA. The mass of the accumulated ions will be determined in vacuum with a symmetrical equal-armed balance. This balance has been developed at PTB and is currently undergoing tests. The present standard deviation of the balance is $3 \cdot 10^{-9}$ kg. It will be improved to less than $1 \cdot 10^{-10}$ kg to allow an accumulated mass of approx. 10 g of bismuth to be determined with the sufficient accuracy.



Top view on the experimental set-up. In the foreground: ion source and mass separator (blue).

European cooperation in thermal energy measurement

Together with other national metrology institutes in Europe, PTB has founded the "European Metrology Association for Thermal Energy Measurement e.V." (EMATEM). The aim of this association is to establish networks with a central information office, a forum for the harmonization of test procedures in accordance with the new European Measuring Instruments Directive, and to create a liaison office for research and development in the field of thermal energy measurement.

Recently, PTB founded the registered association EMATEM together with the national metrology institutes (NMIs) of Austria (BEV), Sweden (SP), Norway (Justervesenet), Denmark (Delta) and Switzerland (METAS). The reason for this founding is the European Measuring Instruments Directive (MID) which finalizes the single European market for thermal measuring instruments and hereby modifies the roles of manufacturers, public utilities, consumers and NMIs. In Germany the value of thermal energy invoiced through thermal measuring devices per year is approximately 1 billion Euros.

EMATEM serves the establishment of three networks: the first network bundles the competencies and capacities to enhance the joint utilization of measuring and testing capabilities and to make the joint know-how available to manufacturers, public utilities and consumers in the whole of Europe without the notion of making commercial profits. A European information system will enable high standard/quality knowledge transfer via the internet (www.ematem.org) and through international workshops, seminars and conferences.

A second network offers a forum to all parties concerned (NMIs, manufacturers, public utilities, consumers and their associations) to technically harmonize the assessment procedures for conformity of heat and cold meters.

The volume flow measuring facility at the historical Hermann von Helmholtz Building in Berlin with 25 m long measuring sections (nominal diameter: 80 mm and 400 mm) and weighing container (volume: 20 m³)

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European cooperation in thermal energy measurement

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A third network is to coordinate and promote research and development work. The last EMATEM workshop already led to two joint projects for the development of transfer standards for water flow rates with low measurement uncertainties. Leading manufacturers of flow meters for liquids are participating in these projects.

Two new PTB measuring facilities constitute a substantial contribution to these European activities in the field of thermal energy measurement. These facilities serve as national standards for the flow rate of water from 5 l/h to 7000 l/h and from 3 m^3/h to 1000 m^3/h respectively. The smaller facility operates in a temperature range from 20 °C to 80 °C while the larger facility covers a range from 3 °C to 90 °C. Both measuring facilities allow measurements to be performed with an expanded uncertainty of 0.04 % over the whole temperature range.

New Optics Building at PTB Braunschweig

On October 2, 2003, PTB's new Albert Einstein Building for Optics was inaugurated. At its Braunschweig site, PTB now has a laboratory building at its disposal which – with a floor area of approximately 3100 m^2 replacing a pre-war building – offers excellent conditions for the metrological tasks and new optical developments.

The building was constructed in three years at a cost of approximately 19 million euro. With it PTB wishes to strengthen its fields of work in photonics and optics – considered to be key technologies for industrial growth sectors. This development became possible through the increased national support to raise the international competitiveness of German industry and to create new jobs as required by the agenda "Optical technologies for the 21st century".

The outstanding environmental conditions at the Albert Einstein Building (stable temperature, almost free of vibrations, defined air humidity, high air cleanliness with only small numbers of disturbing particles) make it possible to venture metrologically into new areas. On the one hand, into a larger scale: in future, highly precise photometric measurements will be carried out on novel light sources with a novel robot goniophotometer in a volume six meters in diameter. On the other hand, into smaller space: quantitative microscopy will be performed in the submicrometer range on smallest structures in micro-, nano- and semiconductor technology. In addition to photometry, work at the Albert Einstein Building will focus on metrology for optical communications technology, photovoltaics, integrated and micro-optics and different areas of applied radiometry.

The Albert Einstein Building, the new Optics Building of PTB.

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Four Decades of Technical Cooperation

In 1963 PTB launched a program to support the national metrology institute of Argentina. Since that time, PTB supports developing and threshold countries to establish their own infrastructure for Metrology, Standardization, Testing and Quality, Accreditation and Certification (MSTQ). The projects which are funded by the Federal Ministry for Economic Cooperation and Development (BMZ) are part of a program which focuses on the global fight against poverty. The PTB projects help the project partners to increase their competitiveness, to gain access to export markets, and so, to improve their economic situation.

What initially started as a promotion program to set up national metrology institutes has meanwhile developed into a comprehensive concept aiming to create viable MSTQ infrastructures. This is the only way to effectively support economic and social development. Sustained development aid also implies the creation of the prerequisites for participation in international trade. The development of trade is considered to be a key to reducing poverty. The problems hindering access to the markets of industrialized countries for developing countries are, however, still numerous. In addition to customs duties and fixed quotas for their products, technical trade barriers in particular must be overcome. Proof of compliance with regulations and standards regarding health, sanitary, environmental or safety requirements must be furnished. In the producer countries, such proofs of conformity often fail, because the required metrology, standardization, testing and quality services are not offered

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Four Decades of Technical Cooperation

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or confidence in the certificates is lacking. This is where the PTB projects start: In addition to establishing the required technical infrastructure, the project measures also cover fostering the awareness of political decision-makers and the qualification of technical personnel.

Experience shows that success can scarcely be achieved on a short term. On the long path towards international recognition of certificates, accreditations by German accreditation bodies are helpful and necessary as long as the partner institutions are not in a position to fulfil the international requirements.

In view of the fact that food commodities are important export products for developing countries, development of metrology in chemistry is of particular importance – a task which also represents a new key area of activity at PTB. Projects which promote regional cooperation to support the realization of regional markets are also gaining importance. At present, such projects are being implemented in Central and South America, in West and South Africa and in Asia.

Since the EXPO 2000, governmental and non-governmental institutions of the German Development Cooperation have presented joint initiatives and initiatives of their own under the One World logo.

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Digital X-ray processing: How good is the technology?

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It is now possible for the first time to determine the quality of digital medical X-ray image detectors in a reliable manner with a mobile measuring facility developed at PTB.

In medical X-ray diagnostics, great effort is being made to replace conventional analog X-ray films by digital image detectors and the German medical technology industry has gained an outstanding position in the international competition. Main arguments to introduce digital systems are the reduced radiation exposure (and related risks) for the patients and the improved availability of the images via electronic data networks. It is frequently regarded as a disadvantage of these systems that their resolution does not yet come up to that of conventional analog X-ray devices. At PTB, a measuring facility has now been developed to investigate the performance of digital X-ray image detectors.

The project was supported by the European Commission and by the Federal Ministry of Economics and Labour (BMWA). Project aim was to develop a measuring facility and suitable measuring procedures for the physical characterization of digital X-ray detectors – in cooperation with industry. Since digital X-ray image detectors are usually stationary devices and form a unit with the X-ray source, the measuring facility was designed as a mobile device. To evaluate the recorded digital X-ray images, suitable image-analyzing programs were developed. Among other things the apparatus can measure resolution and quantum efficiency as well as the image noise of detectors as a function of the X-ray dose.

The results obtained with this measuring facility and the methods derived from them – for example, to measure the spatial resolution – had a direct influence on an IEC standardization project to determine the quantum efficiency of X-ray image detectors. That project has been completed in the meantime (IEC 62220-1). In addition, the measuring set-up was successfully used within the funded projects, and some digital X-ray image detectors were exemplarily measured. In result, the new digital image-recording techniques are found to be equivalent to conventional analog technology and even clearly superior concerning the quantum efficiency. Regarding the spatial resolving power, however, they do not yet really come up to the analog systems.

The new measuring device in operation.

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