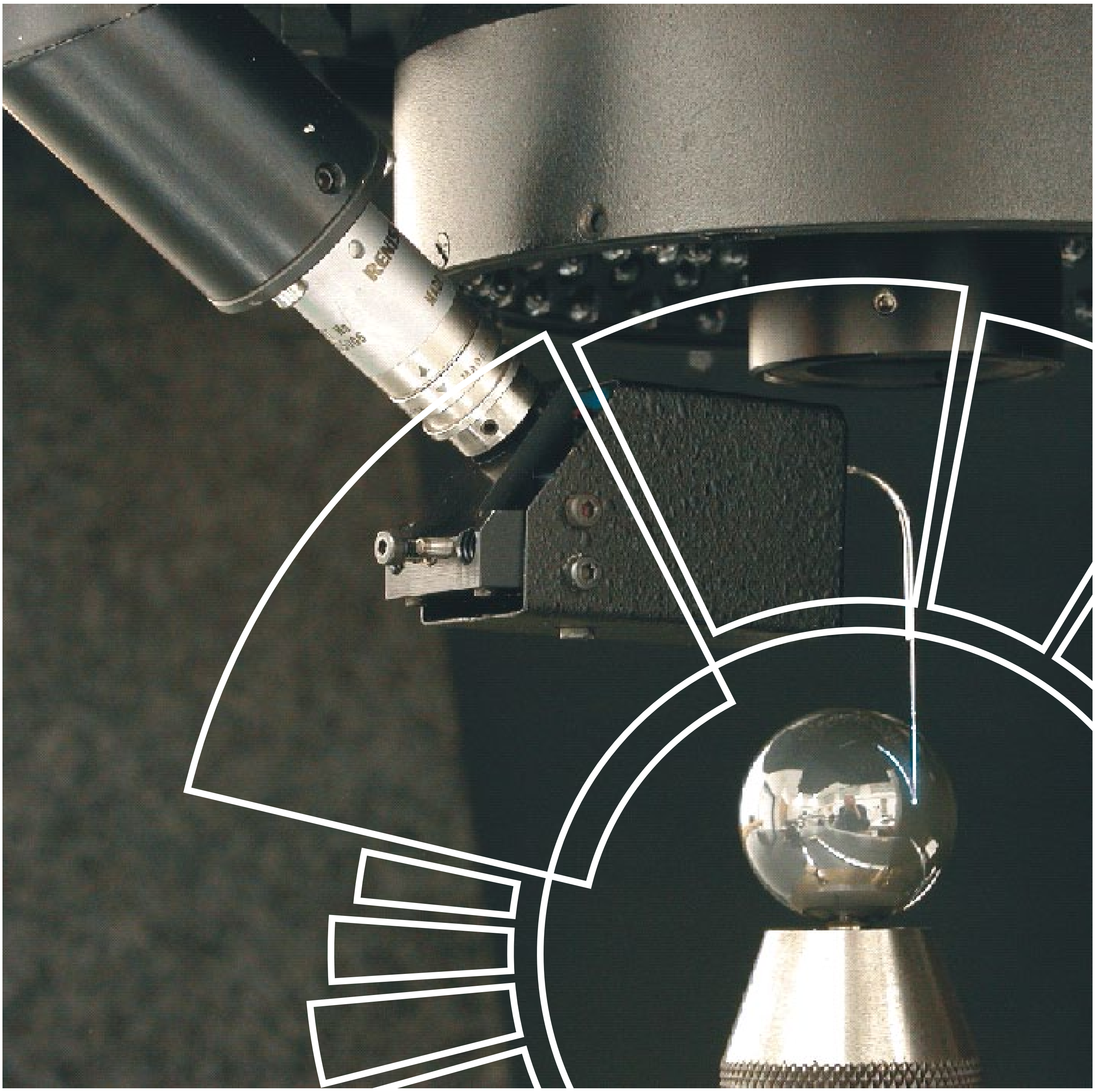
INFO SHEET

PHYSIKALISCH-TECHNISCHE BUNDESANSTALT

DIVISION 5

Precision Engineering



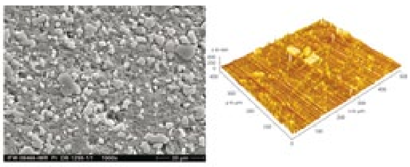
Precision Engineering

In many important technical branches of industry, length measuring techniques provide the basis for a stable and sustainable production. Here, the traceability of such measurements to the unit “metre” is a precondition for globally distributed manufacturing, because it guarantees that everywhere on earth, the same measure is valid. Quality systems are based on this proof of an uninterrupted metrological chain which reaches up to the national standards at its top of the hierarchy.

Automotive and Mechanical Engineering

Automotive and mechanical engineering are important pillars of the national economy. A successful international division of labour and production processes which become increasingly complex in these fields of industry are possible only if work is performed with utmost accuracy. Vehicle construction, for example, requires exact and reliable manufacturing processes to comply with the narrow component tolerances of just a few micrometres as are, among other things, demanded for the components of drive chains or engines. Manufacturing of the most important geometries is frequently supervised by means of 3D coordinate measuring machines which, due to their universality, are particularly suited to this. For traceability to the unit “metre”, industry uses gauge blocks in wide range – and, PTB offers high-precision interferometric calibrations. With the increasing miniaturization and the aim of achieving a higher measuring velocity and measurement point density, optical sensors have become – in addition to scanning metrology – more and more important. Industrial computer tomographs have also found their way into precision engineering. Their technique allows components to be determined for the first time in a non-destructive, volumetric way and thus, the internal and external structures to be determined dimensionally. In close cooperation with industry, PTB develops application-specific standards, high-precision measurement procedures and universal methods for the determination of task-specific measurement uncertainties.

Coordinate measuring machines (CMMs) are important auxiliaries in industrial metrology.The figure shows a CMM during the calibration of a motor block which is used as a workpiece-like calibration standard in accredited calibration laboratories (DAkkS).



(source: Hannover University, authorized by Daimler AG)

Surface of an Si/Al cylinder tread; On the left: image of a scanning electron microscope; On the right: topography of an area of 500 µm x 400 µm, measured with a scanning force microscope.

The surface of components must fulfil specific requirements such as, for example, varnishability of sheet surfaces, oil retaining ability of cylinder paths in combustion engines or friction behaviour in gears. To ensure fulfilment of these requirements, the surface characteristics specified for this purpose must be measured during the production process. ■

Aviation and Aerospace

Whereas in the aerospace industry, highly complex single specimens or small series at the limit of what is technically feasible are mainly developed, the aviation industry is focussed on the production of relatively large quantities of high quality. In this case, the large structures with dimensions of up to several ten meters represent a special challenge to production processes and the measuring technique associated with them. For this purpose, mobile measuring devices are frequently used. These are systems based on spatial angle measurement (triangulation), on a combination of angle and distance measurement and on pure distance measurement (trilateration). For the precise interferometric calibration of such length measuring devices, PTB has a high-precision geodetic basis – 50 meters in length – at its disposal. ■

Photo: Leica company

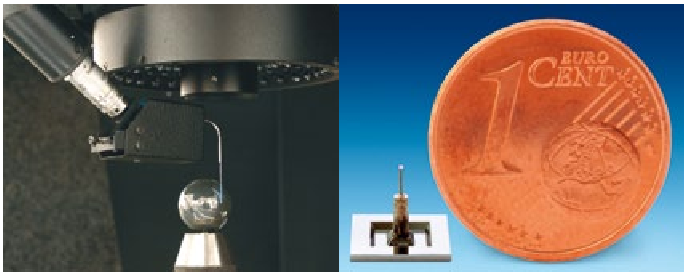
Flexible determination of large measurement ranges: Theodolite system – in the fore-ground, on the left – during use in dimensional measurements on an aircraft component.

Microsystems Technology

In microsystems, sensors, actors and data processing interact on the smallest possible space. Some examples are acceleration and rotation rate sensors for the release of airbags, sensors in stabilization and navigation systems, instruments in minimal-invasive surgery as well as endoscope systems or chemical sensors for food control.

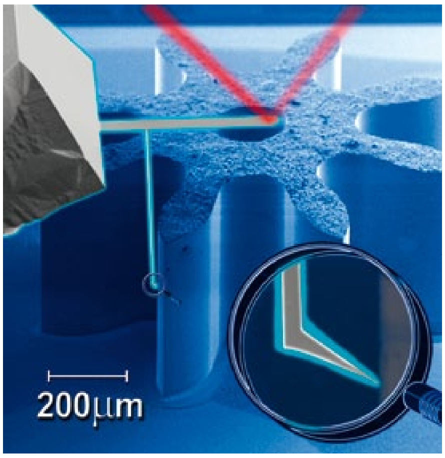
Here – as in conventional technologies – dimensional metrology is the most important means of quality assurance. An essential characteristic of technical components of microsystems are their – compared to semiconductor components – greater vertical dimensions and high aspect ratios. Dimensional measuring systems from semiconductor manufacturing, as well as conventional surface measuring devices can therefore be employed only to a limited extent. Micro-measuring systems for genuine three-dimensional measurements are required – with reduced dimensions – in particular of the stylus tips. A tactile-optical 3D fibre probe for microstructures developed at PTB was the first practical solution to this problem. At present, the smallest obtainable probe sphere diameter amounts to 15 µm.

For special fields of activity, micro-mechanical probing systems are developed in cooperation with institutes of Braunschweig Technical University. A successful example is the 3D micro-probe (figure) which allows microstructures to be scanned with resolutions in the nanometre range.



Photos: Werth company, PTB

The smallest parts must be measured – on the left: fibre probe (industrial version), on the right: microprobe, a development of the Institute for Microtechnology of Braunschweig Technical University (membrane chip) in cooperation with PTB.



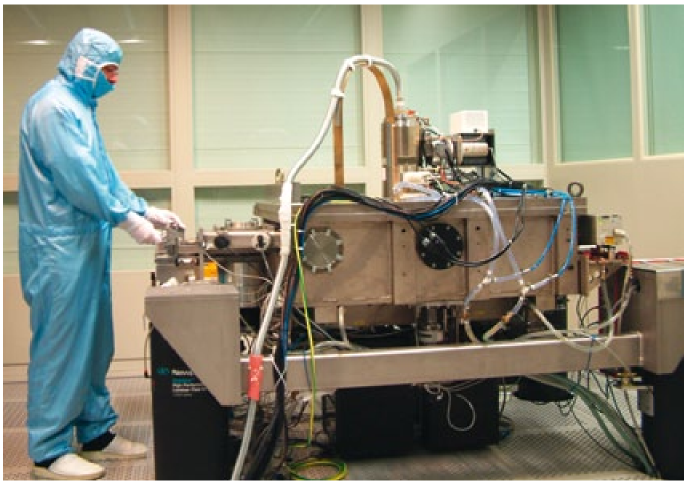
“Assembled cantilever probe” for the scanning of front and lateral surfaces of a microgear. The light beam deflection system of the SFM serves to detect the deflections of the cantilever of a scanning force microscope. The inlet image shows the stylus tip.

Nanotechnology

Structures or particles with dimensions below 100 nanometres often exhibit properties which strongly differ from those of the solid matter. These dimensional properties are very often relevant to the function and an adequate, traced-back measuring technique is indispensable for industrial production. Examples of the use of such small structures are quantum dots in optics, magnetic nanoparticles in medical therapy, carbon-nanotubes for information technology and the improvement of mechanical properties of composite materials or nanoparticles for the improvement of surface characteristics.

PTB recognized the potential of high-resolution scanning probe microscopes for metrology at an early stage and developed the scanning force microscope (SFM) from a purely imaging device into a quantitative measuring device. Today, the SFM allows the smallest structures from the fields of microsystems technology, semiconductor technique, biology and chemistry to be imaged and measured.
The metrological SFMs developed at PTB are used to calibrate standards for industry and research institutes, to ensure the “correct measure” also in the nanometre range.

The development of new probing systems allows the field of application for these scanning force microscopes to be extended and possible solutions to so far unsolved measurement tasks to be offered. At PTB, a probe has been developed which measures virtually “around the corner”. Only small changes in the software of the measuring instrument are necessary to convert a normal SFM into a genuine 3D-capable measuring system.



Measuring of nanostructures on large substrates – the combination of low-energy electron microscope, large sample chamber and laserinterferometrically controlled x-y positioning table in the electron-optical metrology system allows precise dimensional measurements to be performed on mask and wafer structures.

Semiconductor Industry

The semiconductor industry is the best known example of how the performance of products can be constantly improved by ever smaller structures. Here, linewidths and the x-y coordinates are essential dimensional measurands at the structures on lithography masks and silicon disks (wafers). In Division 5, the activities in linewidth metrology are concentrated on high-resolution microscopic measuring procedures, such as scanning electron and scanning probe microscopy. For length and coordinate measurements, special comparators are used. If, for example, length graduations of 300 mm are measured with a vacuum length comparator, uncertainties of a few nanometres can be achieved. Further developments shall, in future, allow uncertainties below one nanometre.

The angle measuring technique provides the basis for new methods for precise topography measurements – also of large substrates – in the semiconductor industry, for synchrotrons and as a flatness standard at PTB. The angle measuring devices and standards required for this purpose can be calibrated in the Division by means of high-precision primary standards.

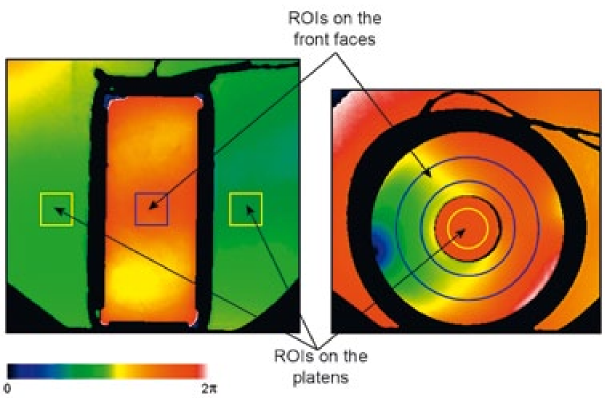
Material Properties – Hardness and Thermal Expansion

Hardness determination ranks among the most important material tests in industry intended to determine the mechanical properties of the materials used. Hardness measurements are applied to determine the mechanical properties of materials and components. The conventional hardness measuring procedures according to Rockwell, Vickers and Brinell are widely spread. In the case of these procedures, a hardness indentation is produced in the sample, whose dimensions are determined and from which the hardness is calculated. For the measurement of additional elastic and plastic properties of materials, the depth of penetration and the test force are measured for increasing and decreasing test force. This so-called instrumented indentation test allows the mechanical properties of ultra-thin layers (depth of penetration ≤ 0.2 µm), which are used, e. g., in microelectronics, microsystems technology and technical optics, to be measured in the nanorange in particular.

To ensure the traceability of hardness measurements, reference hardness blocks which are calibrated at PTB are used in accredited laboratories (DAkkS) and in industry. In addition, PTB provides hardness reference standards and measurement techniques for the force, the depth of penetration and the form of the indentors.

As an ever increasing precision is required – especially in manufacturing processes in the semiconductor industry – the properties of the high-tech materials used – as, for example, the dimensional stability and the thermal expansion properties – must be exactly known. In its precision interferometer, PTB applies the method of the absolute length determination by means of optical interferometry to determine these properties directly.

For this purpose, the length – but also the topography – of macroscopic samples is measured as a function of the temperature and/or time. The results allow the expansion coefficient to be calculated as a function of the temperature. Quantitative statements regarding the homogeneity of the thermal expansion, the compressibility, length relaxations and long-term stability of samples are, however, obtained as well.



Interferential phase topography of two different samples. On the left: block-shaped sample (centre, yellow/reddish), whose upper end face is measured relative to an end plate which was “wrung” onto the lower end. On the right: the same measuring procedure for a cylindrical sample. The areas which are evaluated for the length measurement are marked.

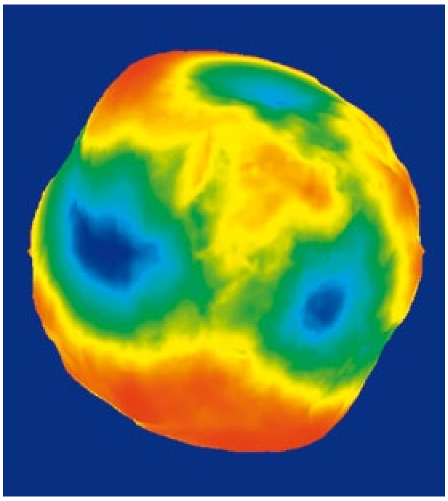
Fundamental Constants

The General Conference for Weights and Measures (CGPM), the highest international committee in the field of units and metrology, has decided to redefine the units kilogram, ampere, kelvin and mol on the basis of suitable fundamental constants within the next years. This calls for the highest requirements for determination of the constants. The Precision Engineering Division is involved in two projects whose work is aimed at new determinations of the Avogadro constant N_A and the Boltzmann constant k_B, respectively.

The Avogadro project is aimed at characterizing – with the utmost accuracy – both the microscopic and macroscopic density of a precise, polished sphere (mass: approx. 1 kg) made of highly enriched, almost isotopically pure (99.99 %), single-crystal ^{28}silicon material, and to determine the Avogadro constant from it with a relative uncertainty of $2 \cdot 10^{-8}$.

In the Precision Engineering Department, the volume of the silicon sphere (diameter: approx. 93 mm) is determined with an aspired relative measurement uncertainty of $1 \cdot 10^{-8}$. This is done with the aid of an interferometer for spheres especially developed for that purpose.

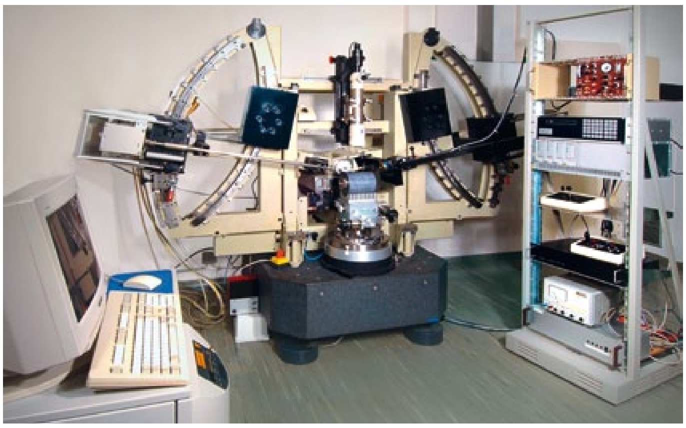
It is the aim of the Boltzmann project to redefine the thermodynamic temperature scale via an improved knowledge of the Boltzmann constant k_B. For this purpose, the Precision Engineering Division performs dimensional precision measurements on piston-cylinder pairs for pressure balances. When the effective piston area is determined, the measurement uncertainties must not be larger than 10^{-7} – another great challenge to metrology which requires the use of specially developed devices.



Diameter variants measured with the interferometer for spheres within the scope of the Avogadro project on a silicon sphere. The colour variation from blue to red visualizes deviations from the perfect spherical form of approx. 20 nm. The volume is calculated from a great number of diameter measurements.

Development and Manufacturing of Precision Devices

In the field of metrology, PTB holds a top position worldwide. This will remain possible only if the Scientific Instrumentation Department continues to develop, construct and manufacture new ultra-precise measuring devices and test facilities in co-operation with the corresponding departments. Depending on the experimental task to be solved, materials rarely used must also be processed – beyond standardized procedures. To accomplish these tasks, the latest manufacturing technologies are applied and computer-supported system components are used for construction (CAD and FEM), order planning and manufacturing (CAM). To be able to meet the high – and continuously increasing – requirements for production accuracy and material variety, new technologies are developed, optimized and tested. The production-oriented developments made at PTB lead to precision components which – as regards the accuracy achieved – occupy an international top position. This is why the Scientific Instrumentation Department also participates in international projects and thus allows extraordinary components to be realized for scientific experiments such as, for example, the international “MicroSCOPE “ experiment for the verification of the principle of equivalence.



Orientation apparatus for single-crystal materials. The device is approx. two meters in height and has a weight of about two tonnes.

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- Dimensional Computed Tomography
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- Interferometric Calibration of Gauge Blocks
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- Ultra-precision Production
- Manufacturing Technology
- Surface Technology

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With a great number of measuring instruments and procedures adapted to the respective length range and the measurement task, PTB's Precision Engineering Division provides a link-up to the unit "metre". For this purpose, basic principles are investigated, measurement and calibration procedures and standards developed, and measuring instruments installed. This is frequently done in cooperation with universities, users in industry and manufacturers of measuring instruments. Here, PTB's Scientific Instrumentation Department provides assistance with the construction and manufacturing of special sub-assemblies and precision measuring instruments.

Over a length range which extends from a few nanometres to several hundred metres, the Division offers a great number of services. These comprise calibrations which are mainly performed for laboratories of the Deutsche Akkreditierungsstelle (DAkkS), which then disseminate these measurands to industry. The offer extends from validated measurement procedures and standards and the rendering of advice in metrological matters to conformity assessment. In addition, the Division develops and tests measurement procedures for the safeguarding of the reliable maximum permissible errors of length measuring machines for log wood, cargo, cables, textiles etc. It also deals with hardness measurements and angle metrology. ■

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