PTB news
Metrology
Technology
Services
Cooperation
02.2

# Calibration of large coordinate measuring machines

**Large coordinate measuring machines are used for quality assurance in the automobile and aircraft industry. To monitor and calibrate these machines, a procedure, based on the multilateration principle known from geodesy, has been developed. It meets the increased accuracy requirements and, in particular, does not require reference objects such as, for example, ball plates.**

Small and medium-sized coordinate measuring machines with measurement volumes below 1 $m^3$ can be well monitored and calibrated by the ball plate method which measures calibrated ball plates at different positions in the measurement volume of the coordinate measuring machine. A comparison between measured and calibrated positions of the balls allows to calculate all error parameters.

For larger coordinate measuring machines with axial lengths of two meters and more, the size of the ball plates become too large to handle. The procedure now developed by PTB makes use of the principle of the ball plate method without needing the large plates physically. The test is carried out by creating a “virtual plate” realized on the coordinate measuring machine through a large number of interferometric distance measurements.

In the course of the test, a special optical reflector unit is mounted on the coordinate measuring machine instead of the probe head. It is moved to predefined positions on a plane. An automatically tracking laser interferometer (laser tracker) successively measures the distance to the reflector unit from four different positions (therefore: multilateration procedure). Processing the four groups of length measurements, a special software calculates a two-dimensional reference grid similar to a very large ball plate. The deviations of the coordinate measuring machine can be determined by comparison with the indicated positions. Very high accuracy can be achieved as the evaluation principle only makes use of the interferometric distance signal of the laser tracker. Under good ambient conditions, deviations for coordinate measuring machines with a measurement volume of 5 m x 2 m x 2 m were determined with uncertainties below 10 µm.

The patented procedure was successfully tested in cooperation with a German car manufacturer and further developed for industrial use by a company engaged in measurement technology in Braunschweig.


*A car body on a large coordinate measuring machine (source: VW)*

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# First successful telecalibration of a high-pressure gas meter

**The German national standard for high-pressure natural gas named “pigsar” is located at the Ruhrgas AG in Dorsten/Germany. Since recently PTB scientists can carry out calibrations and approval tests from as far away as Braunschweig by means of telecalibration. The method was demonstrated at an international conference in Washington via live connection to “pigsar”.**

Calibration of industrial gas meters, i. e. ultrasonic or turbine gas meters with high-pressure natural gas, requires great technical effort. That is why there are only a few test set-ups operating in the world. The largest one (in terms of size and measurement capabilities) is called “pigsar” and is operated by Ruhrgas AG in Dorsten. This accredited test centre carries out verifications of gas meters and works as a DKD (German Calibration Services) laboratory. Since 1999 PTB has been using the test set-up on a contractual basis as the national standard for the realization and dissemination of the units of volume and flow rate of streaming gas under high-pressure conditions.

As “pigsar” is approximately 300 km away from Braunschweig, it was necessary to seek ways not

*Continued on Page 2*

*First successful telecalibration of a high-pressure gas meter*
*(Continued from Page 1)*

only to monitor and control the tests remotely but also to comply with the stringent requirements of legal metrology. Via ISDN connection, the PTB scientists are linked with the database of the test set-up. They have access to all data of the test sample as well as to all measuring conditions and parameters, and they can follow the testing procedure online. If necessary, they can also intervene in the test sequence and control it. The parameters and the test results can be presented graphically and in tabular form. A high protection level is maintained for the required exchange of data.

At the 5th International Symposium for Fluid Flow Measurements in Washington in April 2002, the telecalibration of a gas meter at "pigsar" was demonstrated online. Apart from a presentation of the software, there was a TV live connection to "pigsar" to illustrate to the conference participants how calibrations are carried out on site. It was the first time world-wide that such an experiment in the area of flow measurement was carried out with success.

*Part of the pigsar team during calibration. The calibrated gas meter can be seen in the front.*

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# Characterization of interfaces by means of X-ray scattering

**X-rays scattered at the interfaces of multilayers carry characteristic information about the layer system: The morphological structure of the interfaces between the layers can be determined from the scattered radiation. Within the framework of a project to investigate interfaces PTB has set up a measurement station to analyse multilayers of just a few nanometres in size to up to approximately 100 nm. The results of this work are of principle interest in the area of surface coating, thin film deposition and fabrication of nanostructured systems.**

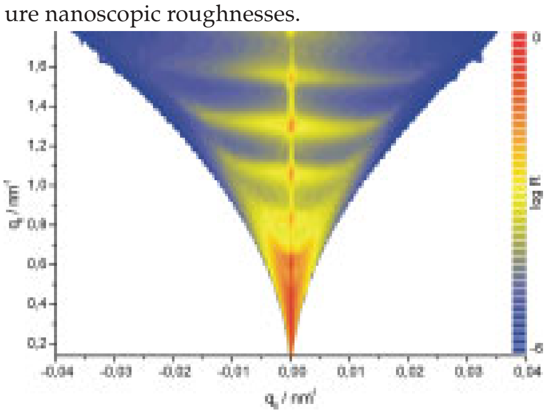
Two issues are of special interest in examining multilayers: first, the – primarily technologically oriented – measurement of layer thicknesses and second, the morphological parameters of the interfaces such as roughness and correlation lengths.

Layer thicknesses can be determined by analysing the interferences of the specular-reflected partial beams from the interfaces. For this purpose, computer-aided simulation models for the samples are indispensable. The achievable uncertainties are in the subnanometre range depending on layer thickness and sample material.

The morphological structure of the interfaces between the layers is investigated by measuring and analysing the amount of diffusely scattered radiation. The characteristic parameters (roughness, vertical and lateral correlation length, Hurst exponent) are extracted by means of a complex computer model of the scattering process. In analysing the diffusely scattered components, the main focus is on fundamental questions concerning growth models and interface formation in solids.

The most crucial part in the experimental set-up is the high-power rotating anode. The anode, in particular, provides the great dynamic range of the scattered radiation with which the high accuracy for the thickness measurements is achieved. To measure the diffusely scattered components with sufficient resolution a high quality beam of x-rays is required, i. e. highly parallel and monochromatic radiation. This is achieved by means of an optical system connected to the rotating anode which transforms the originally divergent beam. A goniometer is used to monitor the angles of incidence and of reflection independently, with an accuracy of a hundredth degrees, in a range of up to 5 degrees in relation to the sample surface.

Within the framework of the project, a new method for certified layer thickness measurements by X-ray reflectometry is in development. In addition new impetus is created for new methods to measure nanoscopic roughnesses.




*Scattered intensity of a GaAs/A1As multilayer in reciprocal space. The intensity is colour coded and plotted over the x- and z-components of the scattering vector q. The banana-shaped intensity maxima indicate a strong correlation of the interface roughness.*

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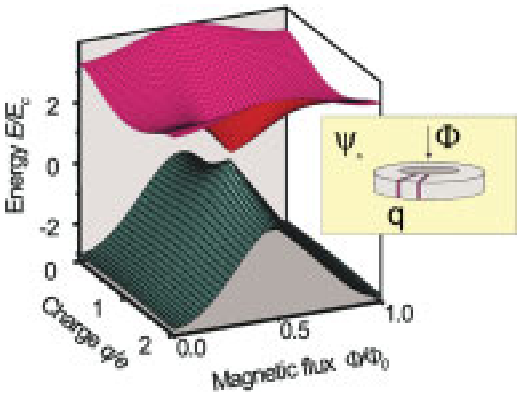
# Novel electronics for a Quantum computer

**Computing with quantum states is a fascinating idea which is, however, still far from being put into practice. One step forward is now being made with a concept under development at PTB. The new concept exploits special properties of a novel electrical component. Its basic unit of storage – the quantum bit (qubit) – is located on a superconducting ring. Its outstanding features: The qubit is infallible and its state can be easily read out.**

Quantum computers are intended to exploit the fact that conventional logic is not applicable in the world of quanta: While a classical bit either has the value zero or the value one, a qubit is in a coherent superposition of the two states. Arithmetic operations which must be carried out sequentially in the classical case could be performed in a single operation by a quantum computer – thanks to the qubits. Furthermore, it is thought that – in principle – quantum computing will be the only way to solve specific tasks, such as large prime number factorizations. For some years superconducting circuits have been discussed to make qubits. In these circuits, quantum-mechanical effects (due to Bose-Einstein condensation of the charge carriers, i. e. of the Cooper pairs) can arise on a macroscopic scale. The behaviour of the macroscopic system is determined by a Schrödinger wave function depending only on a few collective variables.

The novel electrical unit is based on experience and results gained at PTB during the development of quantum standards for the electrical units. It consists of a superconducting ring with two closely adjacent Josephson tunnel barriers with an area of less than 0,01 μm². The ring carries the qubit. Even at a ring diameter of about 1 mm, its states are quantized and depend on the charge q induced on the island and the magnetic flux $\Phi$ through the ring. On the basis of the two states of lowest energy, the "zero" and the "one" state and coherent mixed states – the qubits proper – can be formed. The qubit is controlled via the two electrical parameters of charge $q$ and flux $\Phi$.

Particular properties of this qubit are its low liability to electrical interferences as well as the possibility to read out the state with almost no loss of coherence. For the readout, the change in the resonant frequency of an inductively coupled resonant circuit can be determined. Conceptionally, the qubit has thus been trapped. Experimental realization will be the next step.




*Calculated characteristic energy values of a superconducting qubit (schematically shown in the small picture) as a function of island charge q and magnetic fluxF through the ring. $E_c$ is the charge energy of the island. Fast transfer of the system from the edge state (charge and flux equal to 0) into the middle of the energy areas leads to pronounced oscillations in the development of the states – in this dynamic situation, the qubit becomes active.*

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# Requirements for cooling meters

**In addition to the more established provision of "heat" for heating various public utility companies also offer "cold" for air conditioning. In response to the increasing economic importance of "cooling services", the European standard for heat meters is complemented by requirements for cooling meters. Basis for these requirements were metrological investigations at PTB.**

The main purpose of an air conditioner is to cool down the ambient air. To this effect it removes thermal energy and "supplies cool air." Cooling meters which determine this thermal energy do not differ in principle from heat meters. Therefore, the European standard EN 1434 of April 1997 which so far only contained requirements for heat meters, is now valid for both types of meters. However, compared to heat meters, cooling meters operate in a clearly restricted temperature range from 3 °C to 20 °C and with lesser temperature differences reaching 20 K at most. The requirements for cooling meters which have now been drawn up (for water as a heat-conveying fluid) will complement the standard which itself will not distinguish between meters for household air conditioning and meters for industrial applications.

In type approval tests, each individual flow rate sensor in a cooling meter must be tested at at least

*Household cooling meter with an integrated temperature sensor on the outlet of the flow rate sensor.*

*Continued on Page 4*

PTB

*Requirements for cooling meters*

*(Continued from Page 3)*

one water temperature in the range of (15 ± 5) °C. For mechanical meters, additional tests at (5 ± 1) °C are prescribed.

If cooling meters are to handle similarly large quantities of exchanged thermal energy as heat meters they need flow rate sensors designed for large volume flows due to the smaller temperature differences. For the tests, PTB has measuring devices for water flow rates up to 1000 $m^3$/h and for temperatures as low as 3 °C.

Air conditioning units often run only in partial load operation at small temperature differences down to 2 K. To assess temperature sensor pairs of cooling meters in metrological terms, testing devices with very small measurement uncertainties are needed. These devices are also available at PTB.

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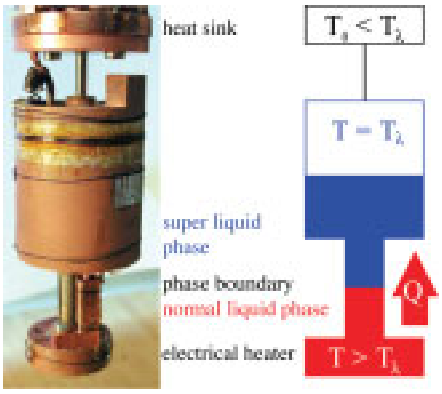
# New low-temperature fixed point

**In the range of liquid helium temperatures between 1,5 K and 4 K, which is also important from the technical point of view, the necessary stability control of thermometers has so far been a complex undertaking. Now PTB has developed a temperature fixed point which can be easily managed using a lambda-point cell. The new device will enable a large number of users to carry out (cross) check measurements.**

The liquid helium range of low temperatures is no longer of interest only for investigations related to solid-state physics and materials investigations but also for technical applications such as cooling the superconducting magnets of nuclear magnetic resonance tomographs or particle accelerators. This further increases the demand for reliable low-temperature measurements. However, the long-term stability of thermometers presently available is generally not sufficient for medium and high accuracy requirements. Therefore, the stability must be checked in regular intervals. For this purpose, temperature fixed points based on well-defined phase-transition temperatures of suitable substances are used. For liquid helium temperatures between 1,5 K and 4 K, however, the fixed points available until now relied on sophisticated measurements of other physical quantities such as, for example, vapour pressure.




Within the scope of an EU project PTB has developed and investigated a compact and easy-to-handle lambda-point cell for a wide variety of applications. At the lambda point, i. e. at $T_\lambda$ = 2,1768 K, the quantum liquid $^4$He passes from the superliquid into the normal liquid state. This is, however, a second-order phase transition at which no latent heat appears which could be used for temperature stabilization as in the case of melting points. The new cell nevertheless allows the lambda point to be used as a fixed point. For this purpose, the cell is first cooled down to just below $T_\lambda$ by cooling an upper heat sink. Next, a lower copper disk is electrically heated to just above $T_\lambda$. Inside the cell a phase boundary between $^4$He in the normal liquid state (bottom) and $^4$He in the superliquid state (top) is formed. The heat flow Q can be set to provided steady-state conditions over a long period of time, provided the upper heat sink has a sufficiently long working time. Due to the extremely high thermal conductivity of the superliquid phase, the copper volume of the actual cell practically has the temperature $T_\lambda$ of the phase boundary. In tests using a commercial measuring set-up, the temperature could already be stabilized within a few µK for up to 18 hours.

The new lambda-point cell thus can provide ideal conditions to control the stability of thermometers by simple means readily accessible to a large number of users. In view of the uncertainty level achieved, the cell can probably also be used for the realization of the International Temperature Scale.

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# Helmholtz-Prize 2003

**In the summer of 2003, the Helmholtz Prize will be awarded in the field of precision measurement in physics, chemistry and medicine. The Prize consists of a certificate and is endowed with 15 000 Euro. The deadline for application is December 15, 2002.**

For the first time, scientists from all over Europe are called to apply. The work, which has to be submitted until December 15, 2002, must be a recent research achievement of a theoretical or experimental nature, either contributing to fundamentals or aiming at concrete applications. It must have been developed in Europe or in cooperation with scientists working in Germany. To participate in the competition, the application must be sent to: The Chairman of the Helmholtz-Fonds e.V., Prof. Dr. E. O. Göbel, President of the Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany.

*For further information: http://www.helmholtz-fonds.de*