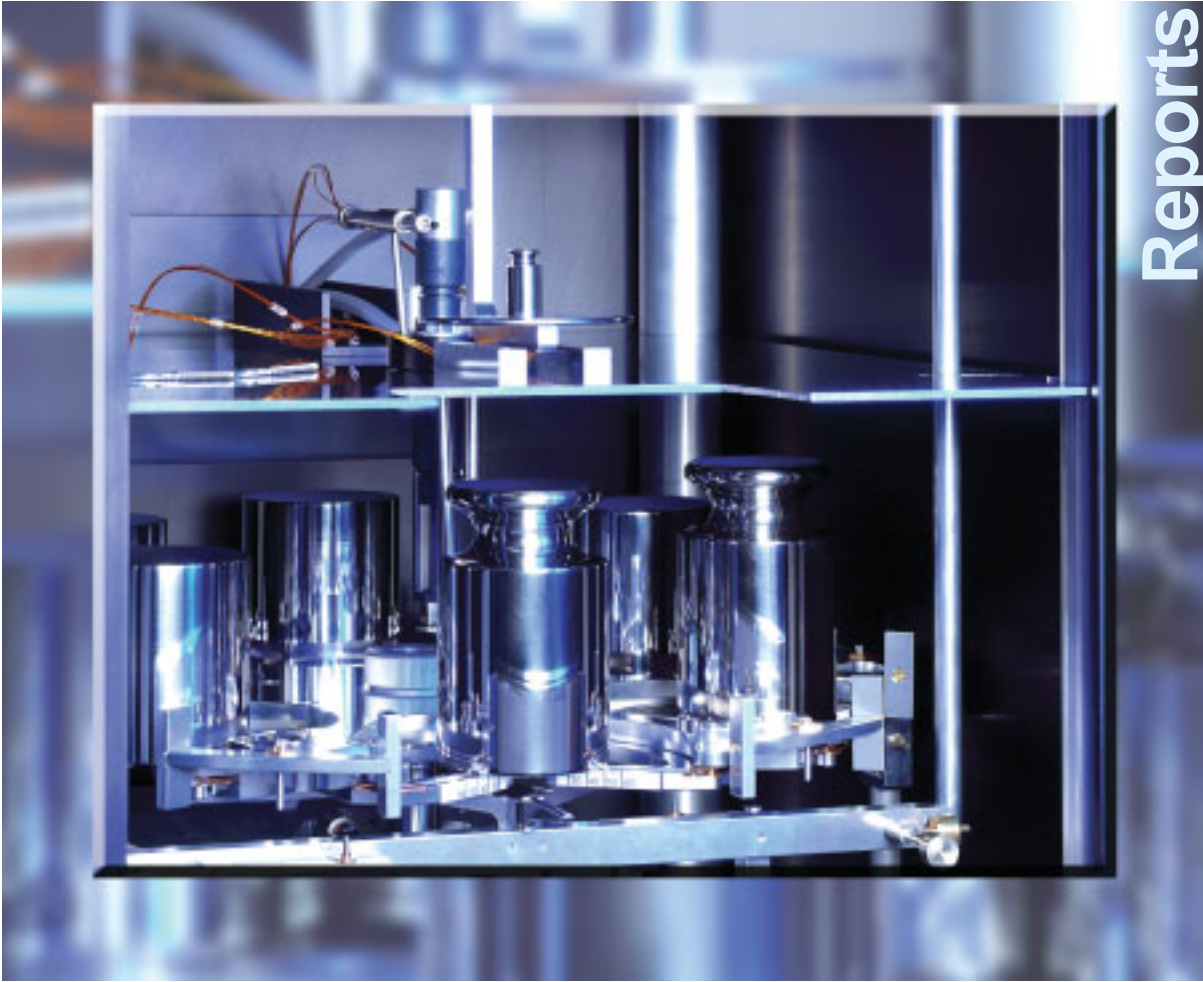


Mechanics and Acoustics



Reports from the Divisions

Mechanics a

Division 1 *Mechanics and Acoustics* is composed of the following seven Departments: 1.1 *Mass*, 1.2 *Solid Mechanics*, 1.3 *Kinematics*, 1.4 *Gas Flow*, 1.5 *Liquid Flow*, 1.6 *Sound* and 1.7 *Applied Acoustics*.

In addition to the SI base unit for the mass, derived units are realized for force, torque, acceleration, flowrate, sound pressure and sound power, and associated basic research is performed. An important task is the dissemination of these units to verification authorities, calibration laboratories (DKD), industry and users from the fields of electricity and water supply as well as from environmental protection and medicine. Other services are equipment tests within the scope of industrial and legal metrology and advice in all matters of applied metrology.

For several years, CIPM Key Comparisons or regional key comparisons have been performed in different sectors within the scope of the Mutual Recognition Arrangement (MRA) of national metrology institutes which are members or associated members of the *Meter Convention*. In the following, important activities as well as significant research work performed and developments made at the Division will be presented.

Cover picture

View into the new prototype balance with the aid of which 1 kg mass standards of special steel can in future be linked up with a reproducibility of 0.3 µg with the national platinum-iridium kilogram prototype.

1.1 Mass

The *Mass Department* consists of the Working Groups *Realization of Mass*, *Weighing Instruments*, *Dynamic Weighing*, *IT Weighing Technology* and *Gravimetry*.

For the mass comparators of the Working Group *Realization of Mass*, another generation change took place: In July 2005, after an operation time of more than 17 years, the 1 kg comparison balance of PTB so far used as prototype weighing instrument was replaced by a high-resolution 1 kg vacuum mass comparator of the latest generation (see Fig. 1).

Essential focal points of the three Working Groups *Weighing Instruments*, *Dynamic Weighing*, *IT Weighing Technology* were:

- Putting into operation of a new temperature chamber for load cell tests in the 2-MN force standard machine of PTB. This chamber allows load cells to be tested up to maximally 200 t (pressure load) in the temperature range from -10 °C to +55 °C in accordance with the international recommendation OIML R60.
- Successful completion of the experimental and theoretical investigations into the non-linear behaviour of piezo electric sensors.
- Continuation of work on the revision of OIML Recommendation R76 for non-automatic weighing instruments. The second draft forwarded for comment to 26 OIML member states contains numerous metrologically important innovations such as, for example, extension of the modular concept, requirements for vehicle-mounted weighing instruments, requirements for metrologically relevant software, adaptation of the EMC requirements to current IEC standards and to OIML document D11 which was adopted in 2004. Completion of the revision of R76 is expected for the end of 2006.

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- Start of a new cooperation with industry in the field of “mechatronics“. It is the aim of this cooperation to systematically and scientifically investigate existing sensor technologies and to develop new technologies which in future could replace existing weighing sensors.
- Continuation of the preparations for implementation of the European Measuring Instruments Directive (MID) in the field of automatic weighing instruments by introducing concrete proposals into WELMEC Working Groups 2 and 8. The proposals relate in particular to the smooth transfer of national type approvals of automatic weighing instruments into European approvals and the preparation for the new conformity assessment module “H1“ provided for in the MID.
- Cooperation in the preparatory work for implementation of the “Mutual Acceptance Arrangement“ (MAA) adopted by OIML in 2004, in particular by training measures regarding the application of ISO/IEC 17025 to type examinations of weighing instruments and load cells in accordance with OIML Recommendations R76 and R60.

In Working Group *Gravimetry*, a procedure for obtaining heavy-field information from anomaly maps has been further developed and successfully tested for wide parts of Europe. With the aid of a statistical interpolation algorithm and a suitable reduction in the anomalies, local acceleration due to gravity can be calculated with relative uncertainties of $< 10^{-6}$. This allowed the gravitation zone concept of WELMEC to be validated and further developed with high reliability.

1.2 Solid mechanics

The *Solid Mechanics Department* comprises the Working Groups *Realization of Force, Realization of Torque, Periodic Forces* and *Ion Accumulation*.

With the increasing use of micromechanical systems in industrial production, medical engineering and research, the demand and requirements for quality assurance of force sensors in the range < 2 N are also increasing. To be able to perform traceable measurements, two measuring devices have been further developed. One is based on the use of a classical scale pan, the second – innovative – device on the use of electromagnetically compensated load cells. The latter allows any forces and force progressions with time to be continuously adjusted within the working range. The force can be kept constant except for a few micro Newton.

Within the scope of the imminent key comparison in the field of torque measurement, a climatic chamber has been developed and constructed which allows the temperature and humidity in the range of the transfer standard to be varied during a calibration and the respective influences to be determined. To improve the long-term stability under transport conditions, a transport box was for the first time assembled with vacuum insulation panels. Thermal conductivity of these panels is by a factor ten smaller than conventional insulation materials (as, for example, polystyrene). In addition, special heat storage plates which ensure constant conditions in the interior, are used in the internal space of the containers.

The 1.1 MN · m torque measuring device met with lively interest on the part of industry. Last year, several national and international firms have already asked for calibrations. A well-known system manufacturer metrologically investigated his sensors on this facility.

Within the scope of the Technical Committee “Torque” of the *Deutscher Kalibrierdienst* (DKD), an intercomparison of indicating calibration facilities has been carried out for torque tools according to DKD-R 3-8 with two devices. All ten participants obtained comparable results. This shows that the stability of the facilities used was sufficient for the comparison, that the participants have evaluated the measurement values correctly and that the measurement uncertainty interval of 1 % is complied with.

In the *Periodical Forces Working Group*, the measuring devices available are further developed and optimized (measuring range up to 10 kN and frequency range at present up to 1000 Hz). To meet the manifold requirements in practical applications, the development of novel force transducers and measuring procedures for dynamic force is increasingly gaining in importance. At present, PTB is investigating and developing new procedures and sensors to meet these requirements.

In the ion experiment, a weighable mass of bismuth ions could for the first time be accumulated. Several tests were performed in which up to 40 mg were collected. In the tests, a relative measurement uncertainty of approx. $5 \cdot 10^{-4}$ could be reproduced. This was rendered possible by a complete reconstruction of the oven of the ion source which now allows a sufficiently high vapour pressure for bismuth to be generated with temperatures up to 1000 °C. In addition, beam handling was optimized for maximum transmission of bismuth (approx. 50 %). At present, currents of 2.5 mA are possible in the ion collector (see Fig. 2). Finally, a collector arrangement, composed of a collector positioning system, a cylindrical collector and a diaphragm system connected in the incoming circuit for the suppression of secondary electrons and beam position control was installed. In addition, the collector was equipped with glass monitors for the measurement of sputter losses.

1.3 Kinematics

The *Kinematics Department* is composed of the Working Groups *Realization of Acceleration*, *Speed Measuring Instruments*, *Dynamic Pressure Measurement*, *Impact Dynamics* and *Rotation Dynamics*.

In the *Acceleration Working Group*, the lower limit for the peak value of the impact acceleration was lowered for the 5 km/s² impact acceleration standard machine by optimization of the spring drive to 25 m/s² (so far 150 m/s²) – this meets a need which has for many years been existing in some DKD laboratories.

For the first time, the voltage standards used in PTB’s acceleration standard machines were calibrated also for low frequencies down to 0.1 Hz (until now 10 Hz) in cooperation with the Electricity Division. Thus the whole frequency range with calibration demand for acceleration transducers is covered without interpolations.

Within the scope of the EU project “LAVINYA”, which was successfully concluded in May 2005, an information network about the experience gained with the use and calibration of laser vibrometers was created and a draft for a respective standard (ISO 16063-41: “Calibration of Laser-Vibrometers”) drawn up.

Speed monitoring instruments are increasingly used on alternating traffic sign facilities in the case of which the indicated value of the permissible maximum speed is controlled by a central computer. During type approval, correct consideration of the changing limit value must be assured – also in the case of realistic data transmission errors. For checking, extensive tests are performed in real traffic with a specially developed simulator which allows a great number of possible setting state changes and data transfer errors to be simulated in a short time.

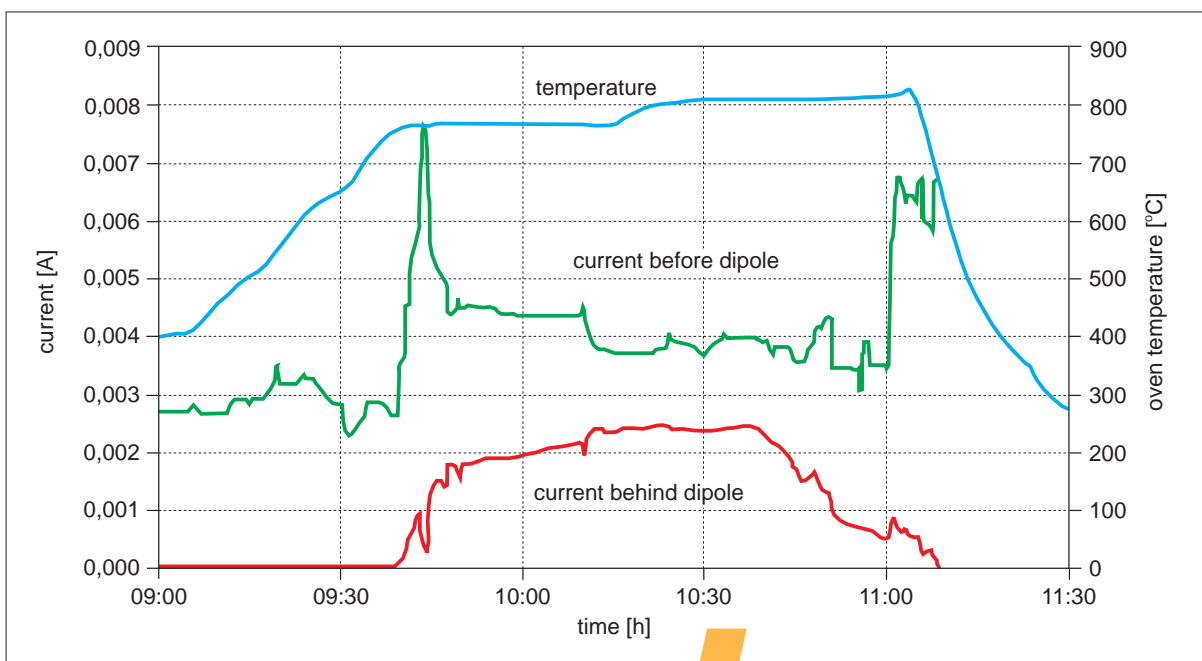
On the 20-kN force impact standard machine, investigations were performed with three different strain gauge force transducers to determine their resonance frequencies. Then the procedures applied were compared with other measurement procedures (e. g. excitation by a hammer impact) and with FEM



Figure 1: Handing-over of the new prototype balance on July 8, 2005

From left to right: Dr. Roman Schwartz, head of PTB Division 1.1 “Mass”; Roland Nater, Head of the “Metrology” business area of Mettler-Toledo AG; Martin Firlus, member of PTB Working Group 1.11 “Realization of Mass”

Figure 2: Temperature of the bismuth oven and ion currents before and behind the dipole magnet as a function of the measuring time



modal analyses. It turned out that this parameter which is frequently used for the dynamic characterization of force transducers can be reliably determined only with supplementing FEM modal analyses.

For pressure pulses with an amplitude of up to 20 MPa and a pulse duration of 2 ms, a new pneumatic pressure pulse calibration device was developed for pressure transducers with larger dead volumes (a few cm³), see Fig. 3. Compared with the facility manufactured in the preceding year, it is characterized by a larger compression volume and thus meets the requirements of research and development of diesel engine technology and explosion protection.

For the hydraulic pressure-impact calibration facility with pressure pulses with an amplitude of up to 800 MPa, the stamp position and the speed of the falling sphere were for the first time interferometrically determined – an important step towards the further development of the facility into a standard measuring machine for dynamic pressure.

For the Proof Testing Ordinance, which has recently been submitted to the EU for notification, in particular the annexes for the technical requirements could be specified and the respective test devices (for electro pulse equipment in cooperation with Division 2 *Electricity*) or procedures (in particular for type controls of shooting tools with intermediate piston) developed and applied.

In a cooperation project dealing with the measurement of the kinetic energy of fast microparticles in space promoted by ESA/ESTEC, a calorimetric detector was developed and successfully tested with impacting high-velocity particles, see Fig. 4. The measuring arrangement designed by PTB uses a new thermopile array of IPHT in Jena and metal foils as particle absorber.

1.4 Gases

The *Gas Flow Department* is composed of the Working Groups *Fluid Flow Measuring Techniques*, *Gas Meters* and *Pigsar*.

Since the 4th of May 2004, the German, Dutch and French national metrology institutes (PTB, LNE and NMi-VSL) have made a uniform gas cubic metre for natural gas under high pressures available which is referred to as “harmonized European gas cubic metre”. For harmonization, a weighted mean value is formed from three independent realizations of the participating partners which is more stable and has a smaller uncertainty than the individual single realizations in the participating institutions.

The weighted averaging procedure was started in 1999 between PTB and NMi-VSL and completed on May 04, 2004 by the inclusion of the LNE in France. The harmonized natural gas cubic metre is realized in the high-pressure test rigs pigsar, Bergum and LADG of the three NMIs.

Within the scope of international activities of CIPM/BIPM for the mutual recognition of calibration certificates, a key comparison, which was completed in April 2005, was organized in the high-pressure range of natural gas. The reference value obtained is regarded as the best realization of the respective quantity in the world. After the key comparison, the harmonized European gas cubic metre is identical with this reference value.

After the optical primary standard for natural gas had successfully passed test operation on the high-pressure test rig pigsar, extension of LDA measuring technique is now investigated in detail with respect to the flow and nozzle limit layer profiles on the LDA nozzle outlet to assure the measurement uncertainty of 0.1 % aimed at for the volume flow rate. For this purpose, both LDA line sensors and traversable LDA systems have been provided.

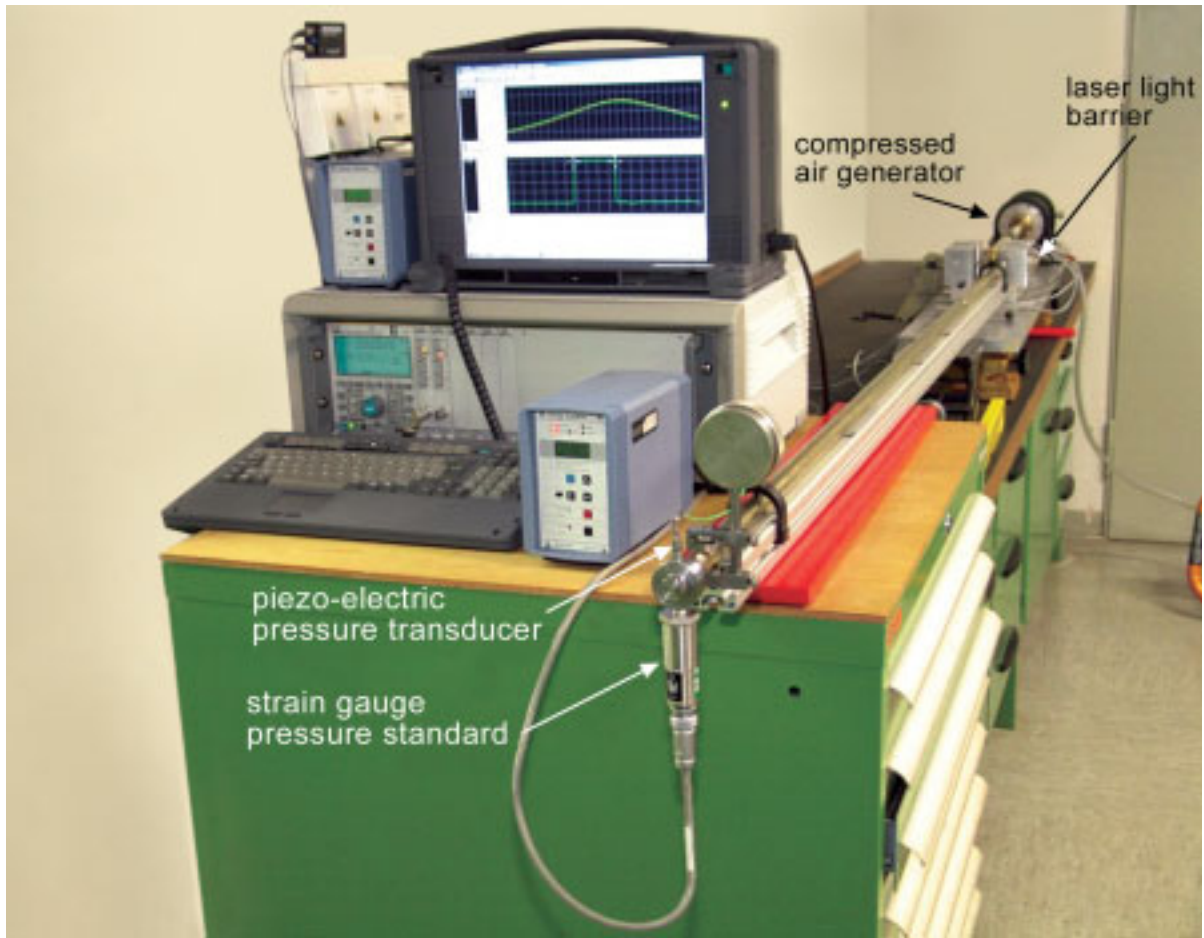


Figure 3: Novel two-stage, pneumatic pressure-pulse calibration device with pressure pulses of

20 MPa amplitude and 1 ms duration for pressure transducers with large dead volume

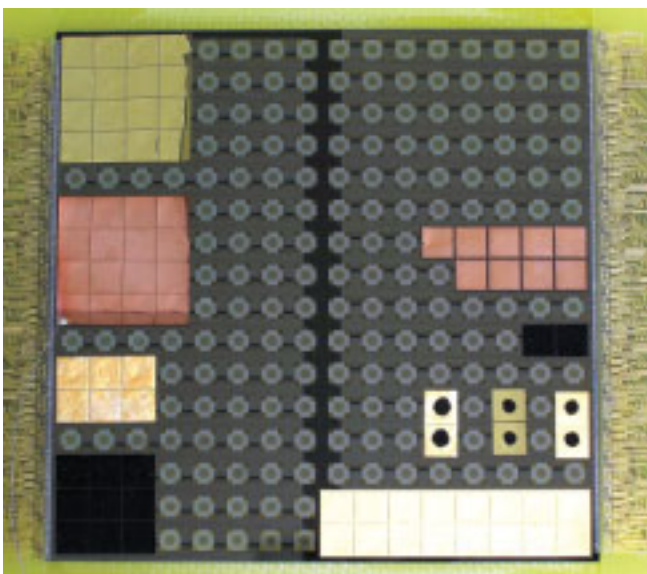


Figure 4a: 16×16 thermopile array (each sensor with 100 thermocouples) with different metallic particle absorbing foils

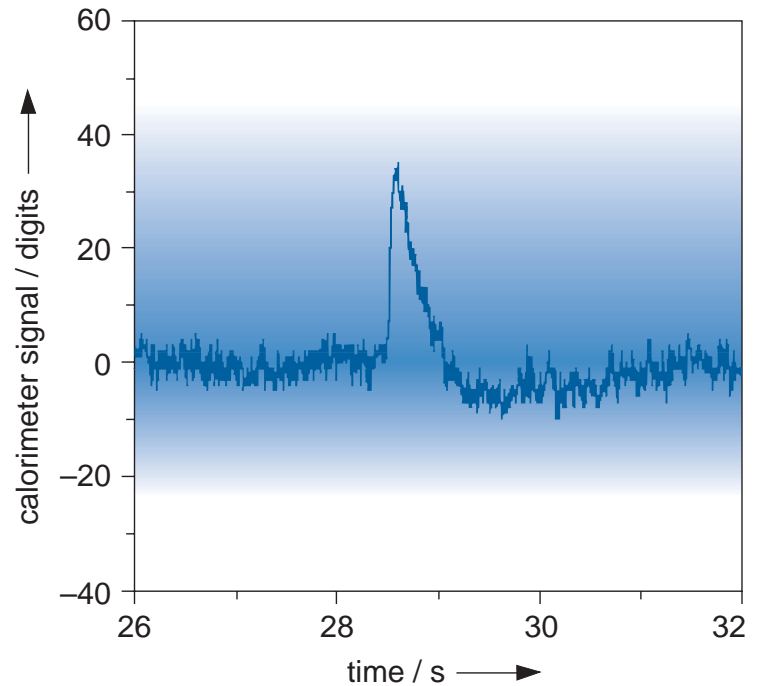


Figure 4b: Signal curve of an impacting iron particle of 140 nJ kinetic energy (mass: $1.2 \cdot 10^{-14}$ kg, velocity: 4.9 km/s)

In projects and cooperations funded by third parties, miniaturized LDA systems are developed for multicomponent flow velocity measurements as well as whole field measuring procedures for the time-resolved investigation of flow velocity fields in pipelines and wind channels. A newly developed procedure allows above all the reference camera required for Doppler Global Velocimeter (DGV) systems used so far to be dispensed with, and the measurement uncertainty for the velocity field measurement to be drastically reduced compared with conventional systems. With the Frequency Shift Keying (FSK) DGV technique, whole field measurements of unsteady velocity fields could for the first time be carried out with reduced technical effort and a temporal resolution of 0.5 s and a velocity resolution of 0.1 m/s (so far approx. 4 m/s).

A new geometrical primary standard based on the flow comparator developed at and patented for PTB was installed for the flowrate range from 0.02 m³/h to 4 m³/h (see Fig. 5).

On the basis of the mechanical concept it will be possible to perform calibrations with different non-aggressive gases up to a pressure of 10 bar with an uncertainty of approx. 0.05 % ($k = 2$).

Essential advantages compared with conventional piston devices are:

- stationary pressure and temperature conditions before and during calibration
- very small uncertainty of the geometric reference volume
- possibility of checking the internal tightness during a calibration and
- calibration of test pieces which specify a flowrate themselves (critical nozzles, flow controllers or mass flow controllers).

The main field of application will be the calibration of flow meters such as diaphragms, laminar flow meters, thermal mass flow meters, flow controllers (mass flow controllers) and critical nozzles.

1.5 Liquids

The *Liquid Flow Department* is composed of the Working Groups *Liquid Meters*, *Hydrodynamic Test Field* and *Transfer Standards*.

The activities of the Department concentrate on three large areas of work – legal metrology in the form of type approvals in accordance with the Verification Act and the associated work in bodies and work related with the elaboration of regulations, the hydrodynamic test field as high-precision liquid standard measuring device as well as research and development work for the establishment of efficient transfer standards.

Now as before, approximately 50 % of the activities of the Department are performed in the area of business “Metrology for Society”. The type approvals of measuring instruments and measuring facilities to be handled in the *Liquid Meter Working Group* show a pronounced trend towards increasing complexity, increased use of electronic components and comprehensive software. In this context, questions regarding safety against manipulation and its checkability are constantly gaining in importance as well as the development of a completely new measuring technique which is based on modern sensors with automatic control and monitoring of the measuring processes and which more safely meets the requirements of legal metrology. This comprises, for example, the use of automatic level indicating sensors for fuel oil measurement on tankers. Achieving the admissibility for verification of such measuring facilities was decisively supported by PTB. At present, the respective international recommendation OIML R 80 “Road and rail tankers” is thoroughly revised by PTB and SLM (Slovakia) to bring the requirements of legal metrology rapidly into line with these new developments.

One of the focal points of the scientific activities of the *Hydrodynamic Test Field Working Group* investigates the influence which the process parameters pressure, temperature and flowrate exert on the measuring behaviour and the accuracy of the liquid meters to be tested. For this purpose, the hydrodynamic test field offers conditions which are unique in the world as these parameters cannot only be varied in wide ranges, but also defined and

kept constant to a high degree. At present, these investigations are also necessary for a safe and comprehensible evaluation of international comparison measurements – a field with an extreme need for action.

With respect to the development of media-independent transfer standards, a new dynamic measuring procedure has been developed for which a patent is pending. This procedure largely works independent of the viscosity. At the same time, first investigations were performed in the field of flow diagnostics and flow conditioning at the place where the transfer standards are installed. This included both the recording of velocity profiles in relevant pipelines with laser Doppler anemometers (see Fig. 6) and tests with rectifiers in special arrangements with low pressure loss. In addition, first positive results were obtained within the scope of a joint research project performed by PTB and verification authorities for the development of transfer standards designed for “in situ” testing of domestic water meters. Proof of the technical viability of such transfer standards was furnished on the basis of numerous concrete tests, and corresponding test instructions and inspection schedules were elaborated.

1.6 Sound

The *Sound Department* is composed of the Working Groups *Realization of Sound Units, Ultrasonics and Medicine* and the Working Group *Sound Fields*.

The activities of the *Sound Department* cover the whole frequency range of mechanical sound waves. Work is focussed on the realization and dissemination of the units of sound pressure and sound power, tests, calibrations and approvals and also includes a wide range of research tasks with medical and safety-relevant objectives.

At specific frequencies, sound calibrators generate acoustic signals with known, high-precision sound pressure levels and are used as transfer standards for the sound pressure unit. As the devices are subject to legal control, a type approval must be performed which meets the requirements of standard IEC 60942 which has shortly been distinctly extended. To be able to implement the re-

quirements, a new, transportable measuring set-up (Fig. 7) was designed. For this purpose, a software was developed which allows the measured data to be automatically determined in accordance with the test procedures described in the standard and checked with respect to their compliance with the maximum permissible errors. After a transition period, in which measurements were performed at the same time on the “old” and on the “new” measuring set-up, good agreement of the results was obtained. For the sound pressure level, measurement uncertainties of up to 0.05 dB are achieved. This ensures reliable and effective testing and calibrations of sound calibrators in accordance with IEC 60942 in future.

Ultrasound physiotherapy is a widely spread medical application. In standards it has been specified that the ultrasound power determined in water must be indicated for characterization of the emitted ultrasound field. To facilitate and improve traceability of this measurement, a transportable ultrasound power standard was developed and tested within the scope of an international cooperation promoted by the EU. This standard can be used for the on-site calibration of technical devices. Moreover, a special software also allows the whole measuring process to be checked. For this purpose, the responsible institute determines by “secret” programming which performance data will be examined. The user must determine these performance data with his measuring instrument and report on them without knowing the values in advance. For a fee, the device is now available to those interested.

Ultrasound in the frequency range from 20 kHz to 200 kHz is intensively used for cleaning of all kinds of parts. Due to the complicated cavitation processes which the cleaning effect may cause, the real cleaning effect can so far only be estimated. Metrological access by characterization of the sound field opens up the possibility of understanding the complicated processes and their description and control more exactly. Within the scope of a project promoted by AiF, direct spatial correlations between spectral sound field parameters and the cleaning effect achieved could for the first time be determined with the aid of suitable sensors for

spatial determination of the performance sound fields and by the development of procedures for effect determination.

1.7 Applied acoustics

The *Applied Acoustics Department* is composed of the Working Groups *Building Acoustics*, *Noise Measuring Technology* and *Thermal Conductivity*.

The scientific activities are, among other things, focussed on the determination of uncertainties of measurements in building acoustics. In addition to the summary analyses of all uncertainty influences, for which a great number of intercomparisons and comparison measurements was evaluated, single uncertainty components were also determined separately. Moreover, investigations performed on miniaturized test rig models of building acoustics furnished essential knowledge about the measurement of flanking sound reduction and about provision for the attenuation, as well as about the influence of the body sound modes of the test piece and provision for the attenuation. In connection with the attenuation, tests were also carried out for the frequency-dependent determination of the complex material parameters of the materials used in the models (see Fig. 8). In addition, a proposal for the light-weight catalogue of the new DIN 4109 was elaborated within the scope of an extensive multisectoral project financed by the Deutsches Institut für Bautechnik, on which prognoses in building acoustics will be based after it has been implemented by the building inspection authority.

To determine the admissibility for verification of sound level meters, a new automated measuring set-up has been developed with the aid of which these measuring instruments can be electrically tested in accordance with standard DIN EN 61672-2, and which will be used for acceptance tests from January 2006

on. In addition, first preliminary investigations have been performed which are to clarify for which frequency range a free-field reciprocity calibration can be carried out in the large anechoic measurement room of PTB. Moreover, the question was treated how the alarm signal of an ambulance vehicle approaching a crossover is perceived by the driver in the interior of a private car. The values measured show that in the interior of the vehicle, the warning is often perceived only with restriction or is not perceived at all. With the aid of auralization, the sound events have been made audible so that they can, for example, be used for driver training.

The activity in room acoustics was also focussed on investigations into the influence which low-frequency room resonances in small rooms exert on the sound field and on the quality in room acoustics. For these investigations, modal analysis and auralization methods as well as subjective evaluation tests were performed. In addition, noise protection shields against too high a noise exposure in orchestras were developed.

In the field of thermal conduction, the activities related with the development of new transient measuring procedures for thermal transport quantities, which have been successfully performed for many years, were continued. A third measuring instrument licence was granted to a Swedish manufacturer; a German manufacturer is negotiating the licence of another patent. Moreover, a reference material for thermal conductivity was qualified on behalf of the *Deutsches Institut für Bautechnik* together with 18 national and international partners from research and industry. It mainly supports the European test institutes in the sector of building physics. In addition, precision measurements on different nanoliquids showed that it has not yet been possible to achieve the expected improvement of thermal conductivity.



Figure 7: Sound calibrator (black box, foreground, right) attached to a reference microphone (silver, vertical cylinder, foreground, right)



Figure 8: Test arrangement for determination of the complex elasticity module of silicon in the frequency range from 10 Hz to 600 Hz composed of an electro-dynamic shaker (at the top), the silicon sample (white rod in the centre) and two piezoelectric acceleration transducers with connecting cables (at the ends of the white rod).

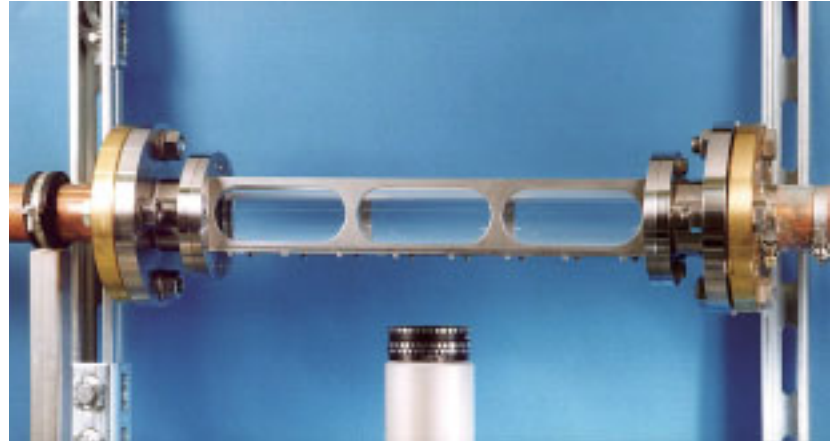


Figure 6: Measuring arrangement for the investigation of velocity profiles, composed of a pipe adjusting piece (50 mm nominal width) with refractive index and contour-adapted windows and LDA headwork

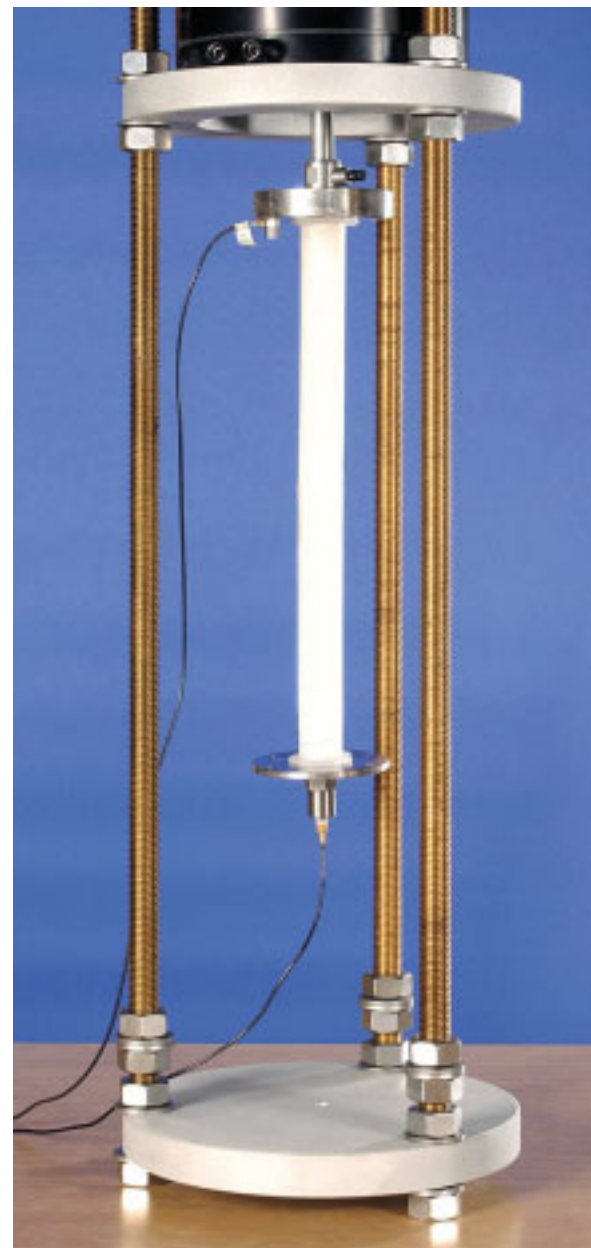


Figure 5: The newly installed flowrate comparator for up to 4 m³/h

Headlines; News from the Division

Fundamentals of Metrology

PTB obtains new prototype balance

Accumulation of 40 mg bismuth

Laserinterferometric measurement of the motion disturbances of acceleration exciters and calibration procedures adapted to them

Doppler global velocity field measurements with only one camera

The hydrodynamic test field – utilization for improved device characterizations

The influence of structure-borne modes on sound attenuation

Metrology for economy

Reduction of the measurement uncertainty of force standard machines

Great demand for calibrations on the 1.1 MN · m torque standard machine

Installation of patented flowrate comparator for flowrates between 0.02 m³/h and 4 m³/h

New measuring set-up for type testing and calibration of sound calibrators

Quantitative determination of the cleaning effect of ultrasound baths

Measurements of flanking sound reduction in normal test facilities

Metrology for society

New thermalizing chamber for the testing of load cells up to 200 t

List of PTB tests and approvals according to sections 7, 8 and 9 of the Proof Testing Act in the Internet

PTB Requirements for speed monitoring devices

In-situ tests of domestic water meters soon possible

Impulse force flowmeter

Portable power standard for traceability of measuring devices for instruments used in ultrasound physiotherapy

Acoustic perception of the alarm signals of approaching ambulance vehicles

Great differences found in the comparison of auralization results

International affairs

Revision of the worldwide applied weighing instruments standard R76 considerably proceeded

Key comparison “torque”

Key comparisons for high-pressure natural gas successfully concluded

Key comparison EUROMET.AUV.V.K1 (vibration calibration)