Measuring forces in the micro range

The lifting force of a fruit fly is unimaginably small. Nevertheless, there are sensors capable of determining such small forces in the micro-Newton range. Up to now, however, it has not been possible to perform a traceable calibration of these sensors. Thanks to a new system, METAS now offers traceable calibration of microforce sensors for the benefit of micro and nanotechnology.

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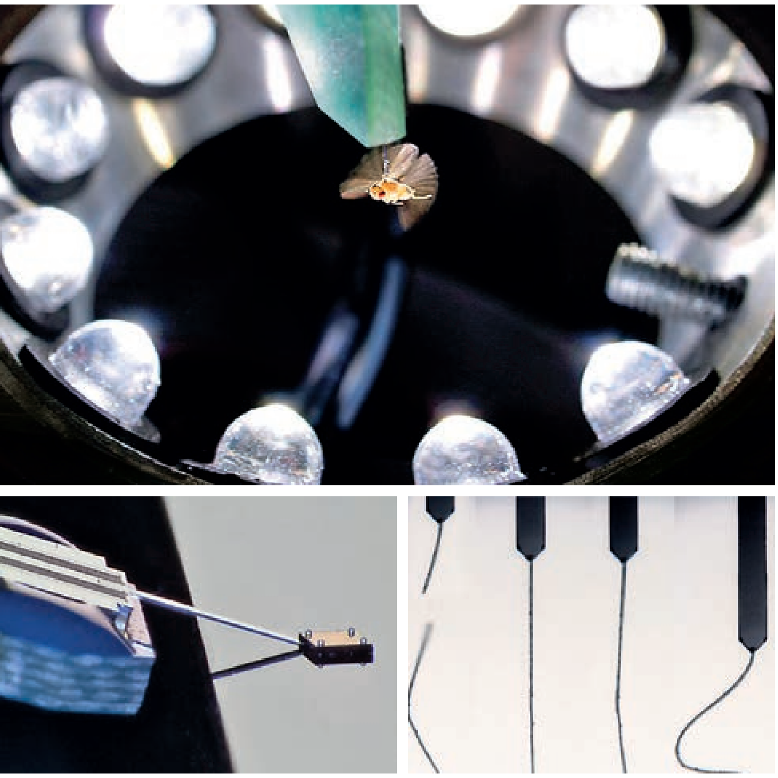
How much force can a microfibre withstand before it breaks? What is the magnitude of the static and sliding friction of objects measuring barely a cubic millimetre? Questions of this nature interest scientists and engineers in the areas of robotics, biology and the classic mechanical and electronic fields. Although it is possible to estimate the forces involved, their true magnitude cannot be determined without traceable measurement. Progress demands precision and above all comparability in order to enable new products to be developed from micro and nanotechnology.



1: Microforce sensors are employed in research and development as well as in the MEMS industry (micro-electro-mechanical-systems). These sensors are employed for quality control of minute mechanical architectures; they measure the adhesion of a microstructure (left) or the tensile strength of a silicon microfiber. Pictures: Femtotools AG.

How the sensors work

Many sensors that measure minute forces respond to both tension and compression. The principle most frequently employed is based on changes in electrical capacity. Two interlocking combs, held in place by means of flexible springs, cause a change of capacity when moved. A displacement of just a few micrometres is sufficient to transform the capacity differences into a signal.

2: The sensors to be calibrated are around the size of a fingertip. The enlarged REM image (left) shows the 50 µm-thick comb structure made of silicon.

Problem: Not traceable

Although the area of application of microfibre sensors is extremely diverse and interdisciplinary micro and nanotechnologies have grown more important over the years, up to now, there has been no means of calibrating microforce sensors of less than one milli-Newton (mN). Today, the market demands not only sensors capable of measuring the most minute forces but that they should also be able to do so with the least possible measurement uncertainty. Above all however, they must be traceable in order to ensure independence from long-term phenomena or product types.

As part of a Commission for Technology and Innovation (CTI) project, Femtotools AG, NTB (Interstaatliche Hochschule für Technik Buchs) and other partners developed together with METAS a measuring system with an ambitious goal: traceable calibrations of force sensors in the 100 nN bis 10 mN range.

Challenges on the way to the measuring station

The force unit Newton (force = mass times acceleration [$N = kg \cdot m \cdot s^{-2}$]) is traceable to the mass [kg], the length [m] and time [s].

Accordingly, a high-precision balance measures the mass, while an absolute gravimeter determines the local gravitational field. These two main components encapsulate the basic principle: press the force sensor on the balance and multiply the indicated value by the gravity. Although the principle is simple, the practical application with components in the sub-millimetre range and the degree of accuracy demanded is challenging: A three-axis robot aligns the sensor to the balance. The process is invisible to the human eye and is therefore computer controlled and monitored by two microscope cameras. The nano stage employed has a movement range of 30 µm and a resolution of 0.06 nm. Various mechanical components for this purpose were manufactured with great precision by the METAS workshop. At the heart of the measuring station is a Mettler Toledo precision balance (modified version of the XP6U) with a weighing range of 6 g and a resolution of 0.1 µg which corresponds to a resolution of approximately 1 nN.

How the calibration works

Once the microforce sensor is mounted in a holder, the alignment begins. The sensor alignment angle is determined by means of a microscope camera and LabView algorithms, and adjusted until the direction of the sensor is parallel to the weighing axis. Since the contact point can no longer be optically determined, this approach process proceeds automatically.

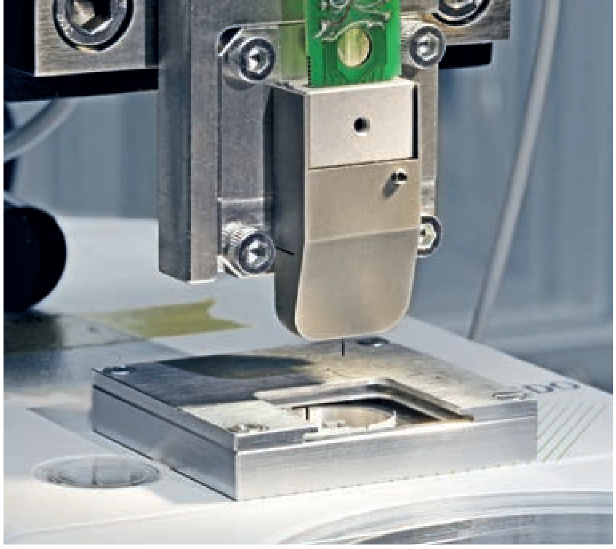
This is when the measurement process actually begins. The force measurement points pre-defined by the user are approached by means of a PID control. On reaching this point, a measurement is carried out over a predefined period of time. At the end of the measurement, a record is produced containing the results and the corresponding measurement uncertainties: the basis for the certificate of the retraceably calibrated sensor.

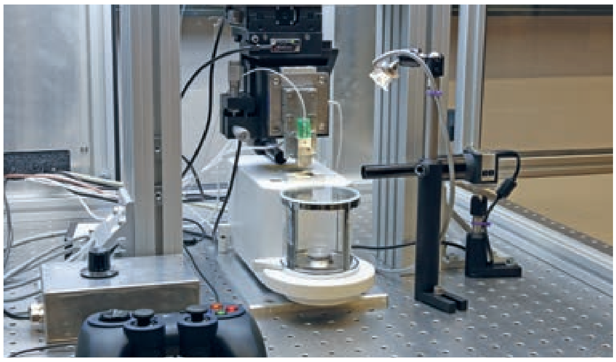
A measurement station and its limitations

When weighing, the normal procedure is to place a sample in the weighing pan and take the measurement. When using the highly sensitive balance to determine the force, this is not quite so easy. Because the stiffness for this specific application at this point is not ideal, the balance was modified by the manufacturer. The force application is thus as close as possible to the weighing cell. In order for the balance to be used as a primary standard, it had to be characterised and the measurement uncertainties determined.

Sensor	200 µN	2000 µN	20 mN
Reproducibility (%)	0.15	0.21	0.11
Measurement uncertainty (%)	0.3	0.26	0.25

It was possible to achieve and exceed the required uncertainty of less than one per cent (1 %) with the system in the intended range of 100 µN to 10 mN. Various sensors were measured for this purpose.

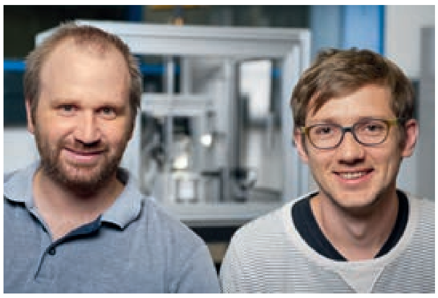




3: The measurement station stands on an optical table. The bridge for the 3-axis robot and the housing which serves as a draught shield are made of aluminium sections. The centrepiece of the measurement station is a precision balance which operates in accordance with the electromagnetic force compensation principle.

Traceable to the limit of feasibility

With the construction of the traceable calibration system for microforces, METAS has demonstrated that it can keep pace with the technological advances emerging from micro and nanotechnology. A metrological service for future applications from the robotics, medicine and mechanical-electronic areas in which traceable measurements will play an important role.



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