Ensuring the quality of micro-parts

Both the manufacture and quality inspection of micro-parts present special challenges. With the F25, Carl Zeiss has developed a solution that unites optical and tactile measuring technology. Launched in 2006, the F25 is now used in industrial and university environments.

• *Marc Wagener, Ferdinand Bader and Karl Seitz* •

An increasing number of applications require micro-components. Micro-parts are essential to miniaturized systems such as pressure sensors, micro-motors, switches, drives, pumps, ball bearings and bioreactors, which are used in medical and metrology equipment, as well as in motor vehicles. For example, micro-parts ensure that a dentist's high-speed drill works properly. They ensure the required performance in the injection regulator of a turbo diesel engine. Thanks to their surface qualities and exact dimensions, these tiny parts ensure smooth operation despite often extreme demands.

For the production of these micro-parts, manufacturing processes had to be enhanced in step with new application possibilities. While the use of traditional manufacturing technologies such as turning, milling, grinding and forming is to a certain extent limited for micro-parts, new technologies such as laser machining, galvanic forming or chemical etching are emerging. These tooling processes can create fine and complex structures with tolerances of approx. 1 µm.

Until recently, the quality inspection of these parts was realized by comparing parts, making comparative measurements with master workpieces or conducting functional tests, etc. Needless to say, the critical applications described above require much more advanced quality inspection. Geometric product-characteristic defects or the results of defects which endanger success can only be avoided through steady quality inspection. Furthermore, the efficiency of micromechanical parts production can only be increased through efficient, fast and reliable quality inspection.

Multi-sensor CMMs

As with the production method, measuring technology had to be enhanced to meet the needs of micro-parts. The preferred solution for the quality inspection of micro-parts is multi-sensor coordinate measuring technology that combines the benefits of optical and tactile measuring in one system. Special attention is given here to contact measurements because the vertical walls of micro-parts cannot be captured optically, for example. In these cases, contact coordinate measuring technology is often the only technically suitable and economical solution.

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Figure 1. F25 coordinate measurement machine from Carl Zeiss.

However, extremely small dimensions and different forces exist here; other principles apply. Consequently, the requirements on a measuring machine for micro-system technology are completely different from those on its ‘colleagues’ in automobile production or tool making.

Positioning and fixing micro-parts requires highly precise equipment. At the same time, the holding force must be very low to ensure that a micro-part is not deformed or damaged during the measurement. This necessitates a miniaturized sensor system with very a small probe diameter that works with extremely low measuring forces, thus guaranteeing that the micro-part is not deformed or moved by the machine when it is measured with contact sensors.

CAD-based software is essential for multi-dimensional measuring tasks on micro-parts. As the features on micro-parts are practically invisible to the naked eye, the control data and measuring program should be directly programmed in the CAD module and remotely tested for interfering contours and travel paths before the measurement. This ensures that all features can be reached by the minute stylus without a collision. Feature-guided and object-oriented software enables selecting and running any number of features from the entire measurement program – a decisive advantage with detailed measurements on micro-parts.

Additional requirements on the measurement system for micro-parts include scales with very high resolution, kinematics with high stiffness, visualization of the workpiece and details, and new mathematical evaluation methods.

Figure 2. F25 SSP contact sensor.

F25

The F25 3D coordinate measuring machine from Carl Zeiss featuring CALYPSO measuring software fulfills the above-mentioned requirements; see Figure 1. The measuring volume of the F25 is one cubic decimeter – a drop in the bucket compared to its ‘big brothers’ in process control and tool manufacturing for example. Measuring uncertainty for this volume is 250 nm at a resolution of 0.25 nm. Using minimal probe forces, this resolution, along with optimum control of the linear drives, enables contact measurements even in bores less than one millimeter in diameter. The basic precision kinematics were developed in cooperation with the Dutch metrology institute NMi (now VSL) and Eindhoven University of Technology, the Netherlands.

The contact, passive scanning sensor consists essentially of a silicon chip membrane with integrated piezoresistive elements; see Figure 2. Developed in a joint effort with the Physikalisch-Technische Bundesanstalt (PTB) and the Institute of Microtechnology (IMT), both in Braunschweig, Germany, it works with a resolution of one thousandth of a micron and is designed as a flexible changer. Single-point measuring and scanning are both possible. The sensor is designed for stylus diameters of 20 to 500 microns at a free shaft length of up to 4 millimeters. Stylus tips can have a diameter between 50 and 700 microns. A 50 mm long match with a 5 mm diameter head is a giant in comparison. The probing forces were also reduced, to less than 0.5 milliNewtons per micron. The contact accuracy according to DIN EN ISO 10360-2 is $MP_{EE} = 0.25 + L/666$ µm (L in mm) and $MP_{EP} = 0.3$ µm.

To measure soft materials, analyze extremely fine structures or to conduct 2D evaluations, the system uses an optical sensor, whose optics have been optimized and adjusted based on proven Carl Zeiss microscope lenses; see Figure 3. The optical sensor can be selected with 10x or 20x magnification; its measuring accuracy is $MPE_{PF} =$ 0.6 µm. An additional camera aids visualization when probing the miniaturized features, thus simplifying learn programming.

Figure 3. Contact sensor, visualization camera, optical sensor.

Accuracy test

The F25 demonstrated its measuring capabilities in an accuracy test involving a Zerodur ball plate that exhibits practically no thermal expansion; see Figure 4. Nine half balls (hemispheres) are positioned on the ball plate, the distances between the hemispheres, which have to be measured, are between 13 and 100 mm. For the test, normals were used that were calibrated by the Carl Zeiss IMT Measuring and Calibration Center and are traceable to the gauge blocks calibrated by the PTB.

To verify accuracy, a 2D test was conducted on a flat plate. This was followed by a 3D test in which the plate was tilted 30 degrees; see Figure 4. The results of the accuracy check demonstrate that the system delivers measuring accuracy clearly better than the specified MP_{EE} = 0.25 + L/666 µm (L in mm). In the specific 2D measurement, the measuring accuracy, even for lengths up to 100 mm, was E_{max} = 0.05 µm; for the 3D measurement E_{max} = 0.18 µm.

Outlook

Launched in 2006, the F25 is now used in industrial and university environments. In 2009, Carl Zeiss introduced an additional system, the F40. This system features a VAST XXT sensor, and optics with 10x magnification. The contact accuracy according to DIN EN ISO 10360-2 of the F40 is MP_{EE} = 0.4 + L/666 µm (L in mm) and MP_{EP} = 0.5 µm.

Furthermore, a joint project with the PTB is examining the use of a T-stylus on the F25. Initial results indicate that the T-stylus easily meets the specifications during calibration, single-point measuring and scanning. The use of this T-stylus will further simplify measurements for the user and open up new fields of application.

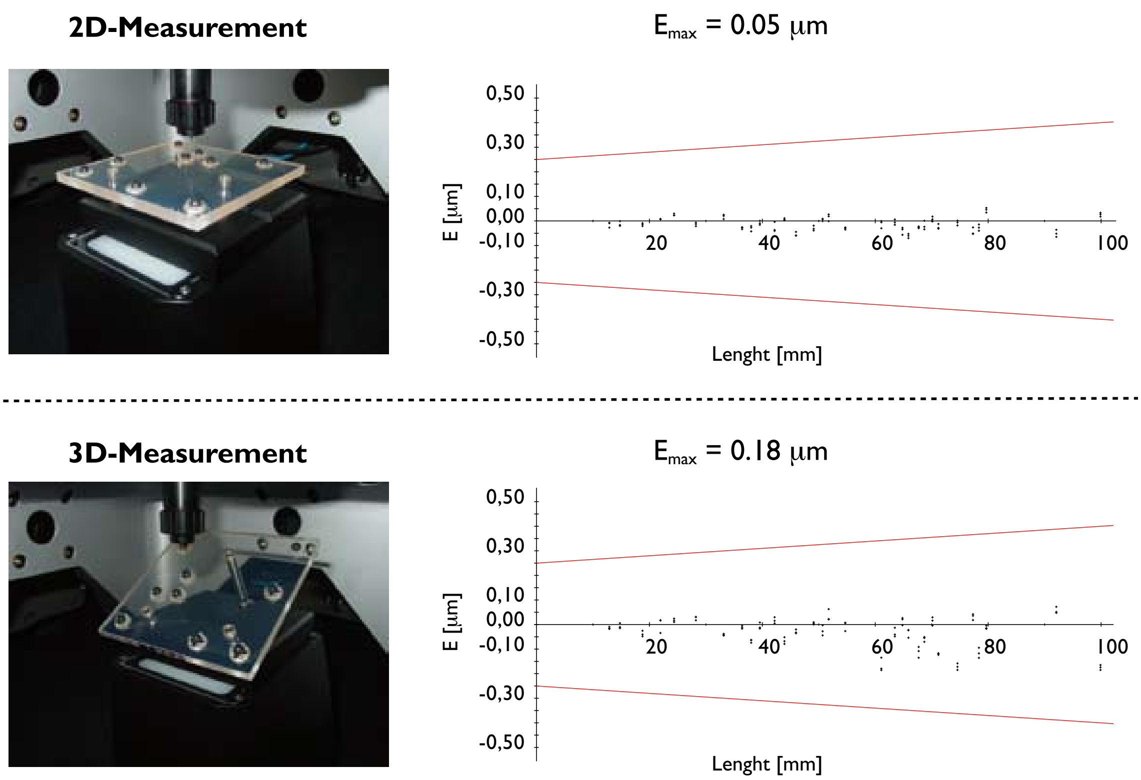

Figure 4. Accuracy test with ball plate.