Small is beautiful, when accurate

Micromachining technologies were the theme of an interesting symposium organised by Mikrocentrum in collaboration with K.U.Leuven on 14 October in Leuven, Belgium. It once again showed that classic machining technologies like milling still are able to move their precision limits. The symposium also demonstrated that a nearly classic technology like chemical milling becomes more attractive by adding clever inventions. Materials like ceramics that were thought to be difficult to machine gain in application width by new insights in their forming and machining. And the symposium showed that combining existing technologies leads to new opportunities for realising high-tech precision products.

• *Frans Zuurveen* •

Chairman of the day Professor Bert Lauwers of the K.U.Leuven university illustrates in his introduction the evolution in microcomponents. To that end he compares the volumes and speeds of two power generators: an antique piston steam engine with 127 kW at 100 rpm and a modern automotive petrol engine with 126 kW at 7,000 rpm. The well-known diagram of Taniguchi gives a definition of the terms precision and ultra-precision machining. However, Lauwers states that precision is a rather relative conception, as an accuracy of 1 mm for a very large product may mean high precision. This illustrates that precision engineers not always have to think in terms of micro- or even nanometers. Their challenges are reproducibility and robustness of micromachining processes, especially of advanced materials like ceramics, and the application of advanced production technologies like ECM (Electro Chemical Machining), EDM (Electrical Discharge Machining) and hybrid machining processes.

Three cases

After this introduction, Lauwers changes places with his colleague Professor Dominiek Reynaerts, who gives a

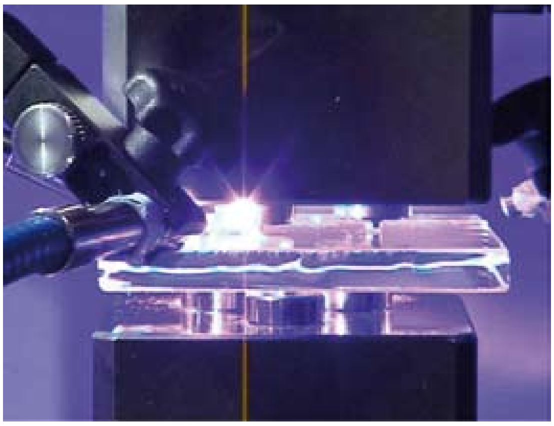

Figure 1. The application of UV hardening glues for solving aligning problems when machining optical surfaces.

Figure 2. Micro-EDM milling of a turbine impeller (Ø 20 mm) made from Si_3N_4-TiN. (Photo courtesy K.U.Leuven)

lecture entitled “Precision machining more than just a process”. To substantiate his title, Reynaerts presents three cases: grinding with ultra-high precision, measuring with ultra-high precision and repositioning a workpiece on a machine.

The ELID grinding technology (ELectrolytic In-process Dressing) is highly helpful to achieve stable grinding conditions with high accuracies as a result. Unfortunately, the arrangement of measuring devices in conventional machine slides does not correspond with the Abbe principle, which states that the distance to measure and the measuring scale should be in one line to avoid first-order deviations. Within the framework of an EU project named NanoGrind, K.U.Leuven succeeded in designing an ultra-precision grinding machine in which displacement measuring conforms with the Abbe principle by introducing separate measuring frames with high stiffness and low mass. Moreover, heat shields were used to avoid thermal deformations. Thanks to these actions the absolute accuracy during the machining process reduced to 1.6 μm reproducible error (which can be eliminated by calibration) and 0.16 μm non-reproducible error.

The case of ultra-high precision measuring is illustrated by the K.U.Leuven design of a calibration measuring machine with 1 nm accuracy. This machine can be considered as a metrological AFM (Atomic Force Microscope) and has been provided with a symmetrically formed invar measuring frame. The force and measuring loops are completely separated and interferometer measuring devices are incorporated.

When a workpiece has to be submitted to successive precision machining operations, repositioning the workpiece is an important problem, as dealt with in the third case. Reynaerts shows the design of a MacroNanoChuck for holding a workpiece with a repositioning accuracy of ± 0.5 μm. He also demonstrates that UV hardening glues can be very helpful to solve aligning problems, see Figure 1.

Micromachining ceramics

In the next lecture, Bert Lauwers first explains some characteristic advantages of ceramics: hardness, wear and heat resistance, chemical and electrical resistivity. Applications include precision nozzles, moulds and dies. Another interesting example is a gas turbine impeller from Si_3H_4-TiN for a power unit, with a rotational speed of 500,000 rpm and 1,200 K inlet temperature, see Figure 2.

Conventionally, ceramic products are produced by an elaborate process of “green body” forming, firing and sometimes final machining to achieve high accuracy (for reasons of volume shrinkage and deformation). This labour-intensive procedure together with a better knowledge of grinding machining processes – like ELID and vibration-assisted processes – has led to a tendency to machine directly from a ceramic block.

Moreover, it has been discovered that some ceramics are sufficiently electrically conductive to apply electro-discharge machining processes: wire EDM, die sinking EDM and micromilling EDM. A better knowledge of ceramics made it possible to add elements to enhance mechanical properties, machinability and conductivity. Also EDM processes could be improved thanks to new generators and strategies.

Other machining processes for ceramics are water-jet machining, laser milling and drilling, and hybrid processes that combine some of the processes mentioned before. Classical technologies like turning and milling are being investigated for their ability to machine ceramics.

Optimised process combinations

Tim Hösel from IMTEK (Institut für Mikrosystemtechnik) of the University of Freiburg, Germany, discusses the combination of processes like lithography, micromilling, EDM and ECM for large-scale micro- and nano-integration. He first states that silicon-based processes are very well suited to micro- and nanostructuring and therefore can provide ideal combinations with non-silicon processes to realise innovative products that combine advantages of both.

Lithography is the general designation for silicon-based technologies. They can either be subtractive using masks or interference lithography for dry or wet etching of photo-resists, or additive with SU8 or dry resists for multiple layer structuring.

The applied non-silicon based shaping methods are UPM (Ultra-Precision Milling), EDM and ECM. Next to these shaping methods different replication techniques are used, like µIM (micro Injection Moulding), HE (Hot Embossing) or NIL (Nano-Imprint Lithography), see Figure 3.

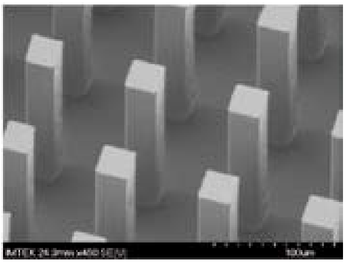

Figure 3. High aspect-ratio structures made by UV-assisted NIL (Nano-Imprint Lithography).

Interesting process combinations including micro- and nanostructures are a moth-eye-like anti-reflection structure on a structured Fresnel lens surface. Here UPM, HE and interference lithography were combined. Another example uses interference lithography and UV-assisted NIL for large-scale replication of nanostructures on foils. The combination of standard lithography and ECM leads to microstructures in mould inserts for replication in tool steels, see Figure 4.

Figure 4. A tool steel with the IMTEK logo structured by ECM, surface roughness R_a = 90 nm.

Electro Chemical machining

Hans-Henk Wolters of ECM Technologies defines ECM as “a metal machining technology based on electrolysis with processing without contact and thermal influence”. Currently, the process has been improved by introducing pulsating power supplies and mechanical vibrations. The latter alternated by rinse cycles for better disposal of reaction products. Thus the minimum gap widths could be reduced to less than 5 ± 1 µm with extra accurate products and lower power consumption as results.

Some advantages of ECM are freedom of burrs, absence of thermal or physical strains, surface quality R_a < 0.05 µm attainable, high machining speeds at low costs, nearly or no electrode wear, relatively environment-friendly by re-using of the electrolyte. High tooling development costs might be considered as a disadvantage.

Wolters shows a turbine wheel with a process time of 12 minutes as an illustrative ECM-product, see Figure 5. ECM is also able to generate microstructures, like pillars of some tens of micrometers wide and centre-to-centre distances of 0.2 mm, see Figure 6. Thin-wall profiles with a minimum of 15 µm thickness are challenging but realisable. And heads of modern rotating shavers are currently being fabricated by ECM, instead of by conventional mechanical machining and polishing.

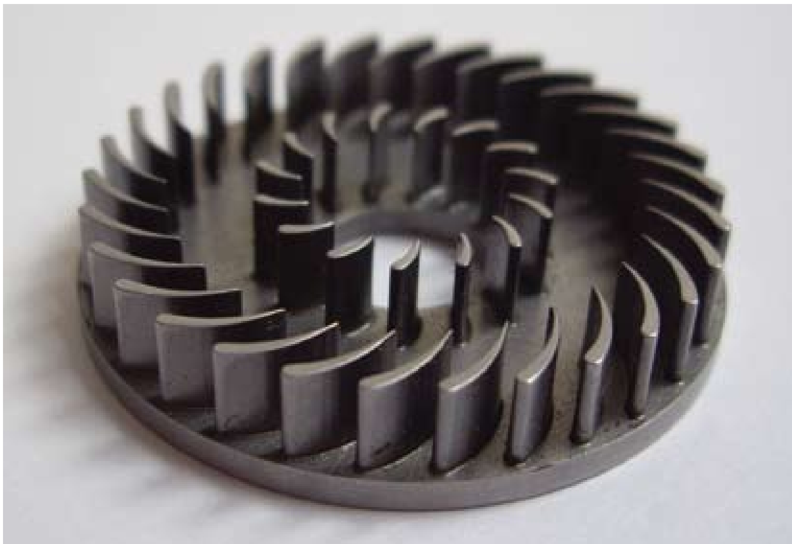

Figure 5. A turbine wheel produced by ECM with a process time of 12 minutes.

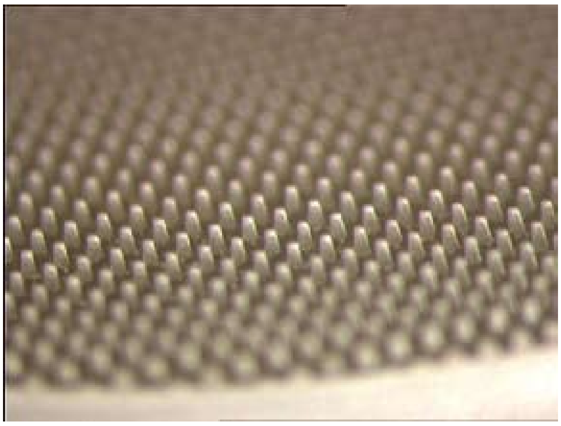

Figure 6. A microstructure realised by ECM with pillars of 60-70 μm diameter, 250 μm height and relative distances of 200 μm; process time 12 minutes.

Precision glass optics

Sebastian Nollau from Fraunhofer IPT in Aachen, Germany, covers the Production4μ project, an EU-funded production research programme in which European companies and institutes cooperate. The project specialises in precision glass moulding technology for the production of high-precision optical components, see Figure 7. The process cycle involves evacuating, flushing with inert gas, heating, moulding and at last cooling with nitrogen, see Figure 8. A coating step may be added.

Tungsten carbide material for moulding tools has been investigated: grain sizes should be lower than 20 nm and Co binder lower than 0.3%. At the Fraunhofer IPT institute a nanocoating facility was established and several new glass melts were evaluated. After this basic research the need for automation of the ultra-precision mastering and mould making procedures became clear. A major part of the automated process appeared to be the workpiece alignment procedure with a travel range of ± 20 μm and a resolution of 2 nm of the actuators, leading to a repeatable positioning accuracy of ± 0.25 μm. To support this, an active alignment chuck has been introduced.

Products that demonstrate the applicability of the Production4μ project include aspheric microlenses, cylinder lens arrays and diffractive aspheric lenses. They are producible with a form accuracy of 1/4 to 1/8 of the wavelength of the applied light, with short lead times, relatively low costs and low resource consumption.

Figure 7. The Precision4μ process for glass moulding.

Precision milling chain

Han Oosterling from TNO Science and Industry in Eindhoven, the Netherlands, explains that interface problems in the chain from design to precision milling production cause a number of inaccuracies. The chain consists of the following steps: CAD – CAM – postprocessing – machine control – milling machine.

Oosterling has estimated the tolerance losses during each step. Very often the CAD geometry has to be modified for CAM by designing additional geometry and planes. This causes tolerance losses in the range of 0.5 μm. The step from CAM to postprocessor in the form of a CL file causes tolerance losses of 3 to 10 μm, because of the translation of curved lines into straight line segments. This also causes a lower surface quality than theoretically expected. From milling machine control to the actual machining operations also inaccuracies occur, i.e. too many data points, which

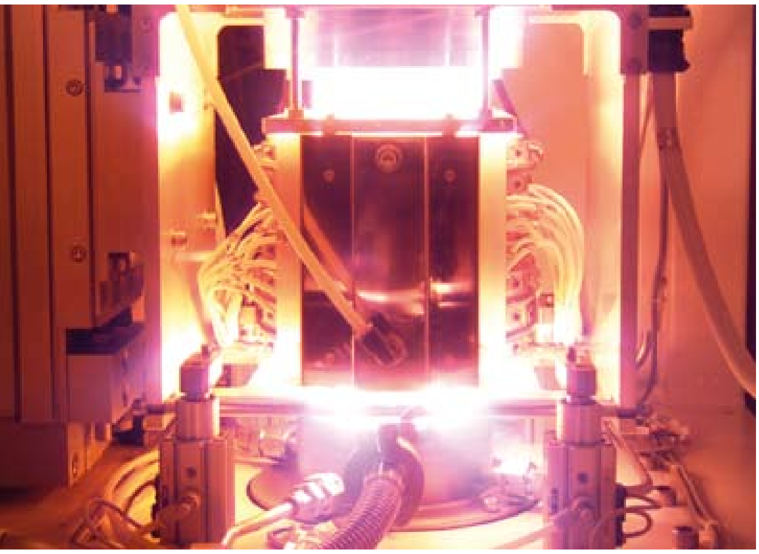

Figure 8. The moulding chamber within the glass moulding machine.

Figure 9. A simultaneously 5-axis milled product with excellent surface quality.

give a tool feed that is too low. Moreover the quality of the translation of control signals into real slide movements gives additional inaccuracy in this last step of the production chain.

Oosterling concludes that micro- and precision milling of products with curved surfaces provide a best attainable product accuracy of about 20 µm for 3-axis milling and about 40 µm for simultaneous 5-axis milling, see Figure 9. For prismatically shaped products this accuracy amounts to about 10 µm for 3-axis milling.

To conclude

Various micro- and precision production technologies appeared before the symposium footlights, including the influence of many kinds of machining process parameters on product accuracy. Again nanometers showed to come more and more in use when discussing modern fabrication technologies. The symposium and the subsequent visit of the workshops and measuring rooms of K.U.Leuven provided lots of discussion for all who are professionally involved in precision production problems.

Information

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