Successfully competing in a global market requires a combination of having a range of unique advantages and ways of standing out from the crowd. Precision manufacturing offers this opportunity, but at the same time it poses challenges in terms of machinery, control and tooling. Six domains were identified in which a company can make the difference.

SIX DOMAINS PROVIDING OPPORTUNITIES TO EXCEL

A wide-ranging survey of Belgian manufacturing industry, Original Equipment Manufacturers and Tier 1 and Tier 2 subcontractors have identified six domains providing opportunities to excel within precision manufacturing. The second domain we will discuss, is ‘Achieving a high-quality surface finish’.

State-of-the-art tools for high-quality surface finish machining operations and innovative finishing technology can achieve surface roughness with nanometric precision while reducing lead times and production costs. Automation, by means of robot-assisted polishing, has cut lead times by 50%.
MARKET NEED

An extremely low level of surface roughness is required for various purposes, a variety of sectors: the optical industry (lenses), tool and mould making (e.g. injection moulds with a high-quality gloss finish), sealing function between two surfaces, anti-stick surfaces and surfaces with a low friction coefficient (e.g. turbine components and engine parts). The desired surface roughness will vary depending on the functionality of a surface. Typical Ra values of injection moulds for highly polished plastic parts range from 0.03 to 0.05 μm. For optical lenses, Ra values between 1 and 5 nm are common. The current solution for obtaining this level of surface finish is often, if not always, manual polishing, which is a time-consuming and costly operation. To reduce lead times and production costs, new and innovative technologies for achieving extremely low levels of surface roughness need to be introduced.
POTENTIAL & CHALLENGES

Manual polishing is the commonest technology used today but is a time-consuming and thus expensive operation, with the result depending on the polisher’s level of experience. Manual finishing of moulds can take up to 50% of the total production time, thereby representing 12 to 15% of the manufacturing costs. Shorter lead times and reduced production costs can be achieved in two ways: optimising the finishing (machining) operation, thus eliminating the need for polishing, and/or innovating the polishing process. Both solutions are already being applied on the market.

In terms of the finishing step, grinding technology using optimised, often custom made, grinding wheels can result in bringing the surface roughness down to 0.025 µm. Also electrochemical machining processes can be used to achieve results below 0.020 µm. When looking to replace the manual polishing stage, solutions can already be found in a rotary vibrator (down to 0.020 µm) or roller burnishing (40% reduction of the Ra obtained after turning).

Besides these well-known solutions, research has shown the potential of new innovative technologies using one of these two strategies.
## Conventional Super Finish Technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Achievable surface roughness Ra</th>
<th>Speed</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual polishing</td>
<td>Manual operation using polishing paper and paste</td>
<td>0.001 µm</td>
<td>10 – 30 min/cm²</td>
<td>+: No shape limitations</td>
<td>-: Loss of dimensional accuracy&lt;br&gt;-: Variable quality&lt;br&gt;-: Slow</td>
</tr>
<tr>
<td>Grindings</td>
<td>Rotating grinding wheel with abrasives</td>
<td>0.025 µm</td>
<td>2 – 40 mm²/s</td>
<td>+: Well-known technology</td>
<td>-: Shape limitations&lt;br&gt;-: Residual stresses</td>
</tr>
<tr>
<td>Roller burnishing</td>
<td>Plastic deformation of surface by means of a ceramic sphere under constant hydraulic pressure</td>
<td>40% decrease in Ra after turning</td>
<td>Similar speed to turning</td>
<td>+: Increased hardness (2-3 HRC)&lt;br&gt;+: Less residual stresses than grinding&lt;br&gt;+: Higher fatigue resistance</td>
<td>-: Shape limitations (rotary symmetrical parts)</td>
</tr>
<tr>
<td>Rotary vibrator</td>
<td>Vibrating bowl filled with abrasives and fluid</td>
<td>0.02 µm</td>
<td>Ranging from minutes to hours depending on the desired surface finish</td>
<td>+: Deburring effects</td>
<td>-: Loss of dimensional accuracy</td>
</tr>
<tr>
<td>Electrochemical Machining (ECM)</td>
<td>Shaped and vibrating electrode removes material by means of electrochemical process</td>
<td>&lt; 0.02 µm</td>
<td>1.5 cm³/min</td>
<td>+: No residual stresses&lt;br&gt;+: No tool wear&lt;br&gt;+: High-volume</td>
<td>-: Slow shaping process</td>
</tr>
</tbody>
</table>
RESEARCH RESULTS

To achieve micrometric precision levels on a five-axis milling machine, all the influencing parameters need to be known, controlled and optimised. In many if not all cases, this kind of precision level will be reached through many small steps rather than in one giant leap. Therefore, the initial stage is to identify all the influencing parameters, e.g. the positional accuracy of the machine-tool axis, clamping accuracy, reference-point accuracy, tool diameter accuracy, machining conditions and also the workshop environment.

Milling with monocrystalline and polycrystalline diamonds in non-ferrous metals leads to an extremely low level of surface roughness compared with machining with carbide tools. Both face milling and free-form milling operations have been tested on a five-axis high-precision milling machine. In the case of face milling of aluminium 7022, the use of monocrystalline diamonds resulted in surface roughnesses of 0.021 µm for Ra and 0.15 µm for Rz, i.e. an improvement by a factor of 3 on the use of carbide tools, which lead to a roughness of 0.063 µm in the case of Ra and one of 0.43 µm for Rz. The benefits of monocrystalline diamond also emerged when free-form milling was used, producing brass surfaces with a roughness Ra of 0.167 µm.

Mirror face milling of aluminum
However, the cutting tool is only one part of the equation. Milling conditions and strategies are equally important to achieving a high-quality surface finish. Research on ferrous materials, which are not suited to being machined by diamond tools, has led to an optimized strategy for obtaining a high-quality surface finish using carbide tools. When free-form milling was used on titanium (Ti6Al4V), an Ra value of 0.331 µm was obtained, while for stainless steel 316L, this was 0.367 µm.

In recent years, research has investigated hybrid technologies using a chemical or physical process to support the main cutting process. A promising technology that has found already its way onto the market is ultrasonic assisted grinding (UAG). This technology makes use of a cylindrical tool fitted with diamond paste to remove material while rotating at high speed as a result of milling, and vibrating at ultrasonic frequency. A surface quality Ra of below 0.003 µm is particularly suitable for hard and hardened materials.
## Innovative super finish technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Achievable surface roughness Ra</th>
<th>Speed</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plasma polishing</td>
<td>Electrochemical process</td>
<td>≤ 0.01 µm</td>
<td></td>
<td>+: Deburring effect</td>
<td>-: Toxic waste of electrolyte</td>
</tr>
<tr>
<td>Laser polishing</td>
<td>Surface remelting</td>
<td>0.05 µm</td>
<td>1 min/cm²</td>
<td>+: Small heat-affected zone</td>
<td></td>
</tr>
<tr>
<td>ELID grinding</td>
<td>In-process dressing of grinding wheel</td>
<td>0.005 µm</td>
<td>1 mm³/s</td>
<td>+: Maintaining dimensional accuracy</td>
<td>-: Shape limitations</td>
</tr>
<tr>
<td>Ultrasonic Assisted Grinding</td>
<td>Vibrating and rotating cutting tool</td>
<td>&lt; 0.003 µm</td>
<td>5 µm/rev</td>
<td>+: Low cutting forces</td>
<td>-: Identifying optimal process parameters</td>
</tr>
<tr>
<td>Robot-assisted polishing</td>
<td>Rotating tool mounted on a robotic arm</td>
<td>≤ 0.03 µm</td>
<td>5 – 20 min/cm²</td>
<td>+: Faster than manual polishing</td>
<td>-: Robot programming</td>
</tr>
</tbody>
</table>
Grinding hard and brittle materials to yield a high-quality surface finish (Ra of 0.005 µm) can be achieved using extremely abrasive grinding wheels. However, during grinding, these abrasive wheels tend to experience wheel loading and glazing, producing scratches and subsurface damage. To overcome this problem, a new process, called electrolytic in-process dressing (ELID) grinding, in which the grinding wheel is continuously dressed while the part is machined, looks highly promising. The ELID process minimises wheel loading and glazing problems, enabling uninterrupted grinding and a mirror surface finish on materials that are difficult to machine with fine-grained wheels (numbers 6000 to 8000).

If polishing cannot be avoided, there is the possibility of using new technologies, such as plasma or laser polishing. The laser will melt the surface while the plasma will remove metal ions during an electrochemical process. Both can achieve Ra values of as little as 0.05 µm. If conventional polishing is still required, automation is an option. Robot polishing achieves similar results to manual polishing but once programmed, results can be repeated easily and consistently.
**INDUSTRIAL EXAMPLE**

Niko, a company offering interior building solutions, has in-house control buttons producing a high-quality gloss finish as part of its product portfolio. These buttons are produced by means of injection-moulding technology and require high-quality surface moulds (Ra of between 0.03 and 0.05 µm). Pre-work processes, among which EDM features particularly prominently, achieve a surface finish that is still too rough to be directly used in injection moulding (Ra between 0.8 and 2.5 µm). Therefore the functional surfaces need to be subjected to a post-finishing operation that currently takes the form of manual polishing. The cavity, which has dimensions of 44 x 22 mm, is manually polished for about 15 hours to reach its finished quality in.
In the case of robot-assisted polishing, a six-axis industrial robot equipped with a spindle (with process control force) and a translational module (based on an excentre) is used. The total polishing time for the bottom and flanks is 5.5 hours, yielding a surface finish Ra of 0.014 µm, with the quality exceeding that of manual polishing. Moreover, this operation can be performed at night-time. The initial setting-up, programming and preparation of the tools takes eight hours. For the first mould cavity the total polishing time is 13.5 hours, so already lower than the manual operation. For the second cavity only 5.5 hours is needed, as all the preparatory work has already been done. In the case of a four-cavity mould, all of this results in a 50% reduction in the lead time (30 hours of robot-assisted polishing as opposed to 60 hours of manual polishing).

**SEIZING THE OPPORTUNITY**

When looking to achieve high-quality surfaces and reduce lead times and costs, in the first instance the machining processes leading up to the polishing operation need to be optimised. New cutting tools, an optimised strategy or even a new technology can already achieve a surface roughness in the nanometric range, thereby reducing or even eliminating the need for polishing. If an even higher surface quality is required, robot-assisted polishing is a very promising solution on the basis that the time for the initial setting-up and programming can be written off for multiple components (e.g. mould cavities).
EXPERTISE AND FACILITIES AT YOUR DISPOSAL

The Precision Machining Lab at Sirris:

• the Fehlmann Versa 825 five-axis high-precision milling centre;
• the high-precision Erowa clamping system;
• the Mitutoyo Apex-S 3D coordinate measuring machine;
• a laser texturing machine for surface functionalization
• an acclimatised chamber.

Various specifications:

• milling of precision components to an accuracy of 3 μm;
• machine travel range: X: 820 mm; Y: 700 mm; Z: 450 mm;
• spindle: 20,000 rpm, 24 kW and 120 Nm at 50-1,920 rpm;
• clamping with micrometric repeatability;
• CNC-controlled (scanning) measurements from CAD;
• measurement accuracy of 1.7 μm + 0.3 L/100 μm (L in mm).

The precision machining lab, its infrastructure and engineers, are at your service to:

• realise your prototype precision components for new applications;
• become conversant with precision machining before investing yourself;
• provide you with support with regard to the machinability and cost-effective manufacturing of precision components.
THE AUTHORS

Sirris is the collective centre for the Belgian technology industry. The Advanced Manufacturing Department boasts more than 60 years of experience in the field of machining technology. Sirris was the first organisation in Belgium to introduce NC programming, damped-boring bars, tool management, high-speed milling, five-axis simultaneous milling, hard turning and laser ablation. Over the last four years the focus has been on achieving micrometric precision levels on five-axis milling machines that, while high-end, is within the reach of SMEs. Working with industry, our applied research has led to game-changing results.

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As responsible for the Precision Manufacturing department Peter defines the research strategy and supports industry in detecting their own opportunities.

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Expert High-precision Milling
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Expert Machining Advanced Materials and Monitoring Solutions
As a senior engineer, Tom is helping companies with research on methods to control precision during production with the help of sensors and real-time data.
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PMA

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RWTH AACHEN UNIVERSITY

Fraunhofer IPT

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B-PHOT BRUSSELS PHOTONICS TEAM

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