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 third domain we will discuss, is ‘Finishing near-net shape (NNS) components’.

Increasingly complex components are being generated through near-net shape (NNS) technologies, but finishing operations remain necessary to achieve the required level of precision or surface quality. New 3D laser scanning, realignment procedures and clamping solutions make the connection between additive and subtractive technologies, meaning that the design freedom of additive technology has found its way into precision components.
MARKET NEED

NNS components, produced from powder by means of additive technology, are finding their way into the machine toolbuilding, automotive and medical sectors. Additive manufacturing is a booming business. Worldwide growth is estimated at 75% per annum. Major leading technological players such as Airbus and General Electric are starting to embrace this technology, not only for prototyping but also for large-scale production. Factors attracting these industries to metal structures are their design freedom and lightweight potential and the innovative product characteristics resulting from gradient materials.

However, additive technology in its current form is not capable of producing components at the level of precision that is demanded of these sectors, leading to a need to integrate additive and post-machining technology into flexible and cost-effective production platforms.
POTENTIAL & CHALLENGES

Having spent many years focusing on prototype applications, additive technology is on the verge of becoming a production technology for fully functional mechanical components. It is safe to say that in the years ahead, conventional machining technologies will have to adapt or even be replaced by this new technology. The current weaknesses of additive technology, namely limited dimensional accuracy and low surface quality, present opportunities for creating additive-subtractive machining platforms capable of producing innovative precision components by combining the best of both worlds: innovative design potential through metal-powder structures and high precision through conventional machining technology.

Creating a cost-effective, flexible additive-subtractive machining platform involves a number of challenges, starting with the product design, as designers need to take into account the impact of their decisions on the whole production chain. While additive technology offers almost complete design freedom, the post-machining process still has its limitations. When a high level of dimensional accuracy is required, component design should be optimised to ensure rigid clamping, accurate reference points, surplus material, and so on. A second challenge resides in the transfer from one technology to the other. To guarantee high levels of precision during the post-machining process, the actual dimensions, location and orientation of printed near net shapes should be known or measured. The third challenge lies in seamlessly connecting technologies through automated solutions. Manual interventions should be eliminated or at least minimised in a bid to create a cost-effective machining platform capable of producing large series at competitive prices.
The final challenge is posed by the use of so-called gradient materials whose specifications vary throughout the product from very easy to machine to hard to machine, with all the different levels in between. This leads to evolving post-machining parameters throughout the development of the product with a view to ensuring dimensional accuracy.
RESEARCH RESULTS

Different NNS products were machined to obtain the required level of precision. When crucial features are present, a smart strategy has to be adopted. The figure on the next page (left-hand side) shows a product in which the yellow surfaces demanded a tolerance of 5 µm. The NNS was created by means of electron beam shaping, an additive manufacturing technology. Finishing was carried out on a turn-milling machining centre with two spindles to be able to machine the part on two sides in a fully automated fashion and achieve the desired cost-effectiveness. However, since the design did not take into account the finishing step and more specifically the need for clamping, the walls of the product were too thin, and so the slightest clamping force led to product deformation. Even special tooling (right-hand side of the figure) could not solve the problem. The solution lies in either redesigning the near-NNS with finishing in mind or selecting another machining centre (e.g. a five-axis milling centre) for finishing, requiring an extra manual intervention (reclamping so as to finish the backside). To deal with the challenges of fragile, thin-walled products and the need for very accurate repositioning, several novel clamping technologies are being looked at.
Principle of clamping by means of vacuum

Tailored clamping tool

High precision turning of sphere
To finish a sphere with micrometric precision, in the case of an ultra-precision Moore Nanotech 350FG, vacuum clamping is used. The sphere is clamped on one side, turned just over halfway through the process and then clamped on the other side and finished on the back. The starting diameter is 31 mm, and the final diameter 30.5 mm.
A Nanochuck (3R Systems) and a glue that can be hardened with UV curing are used to clamp a part and keep it in place. Three pins of the Nanochuck are used to make contact with the product surface. The glue can be loosened with acetone without leaving any marks on the surface. It ensures a stable mounting of the free-form product and enables accurate finishing. The displacement caused by the curing process is then measured. The stiffness of the three pins is 50 N/µm, which allows for stable clamping and repositioning in the micrometric range.

Tests are carried out to determine the roughness during machining. It turns out that the roughness that is achievable (60 nm for a finishing operation on an aluminium disc) is better than when applying a classic clamping method (110 nm under the same conditions). The glue between the pins and the workpiece provides for a little damping, which improves the machining process.
When a transfer has to be made, it is not only the clamping that is important but also the alignment, which has to be perfect. A relevant method was set out in the industrial gear example (see White Paper 4). Measuring the workpiece is the last step (but no less important than the previous steps). When the shapes are complex, this can also be a tough task. In the research, a comparison was performed between a dedicated measuring device (Klingelberg) for gears on the one hand and a standard measuring tool with smart programming on the other.

The next figure shows a method with a 3D CMM machine with standard probe touching and a programming cycle which makes it possible to immediately show the gear run-out (blue line). In this case, it was outside the limits (red lines).

With dedicated gear measuring devices, this kind of measurement is also possible but these machine infrastructures are less flexible and only suitable for one type of product.
INDUSTRIAL EXAMPLE

RapidFit+ produces smart customised jigs, fixtures and quality control solutions. Their modular fixtures are made by means of additive manufacturing involving (a mixture of) advanced materials. For automotive jigs used in bumper quality inspection, the powder-based modular parts (250 x 250 x 250 mm) proved to be inaccurate. A post-machining step was needed but the complex curved shapes posed some challenges to achieving post-machining accuracy.

The solution found was to equip the post-machining setup with reference spheres, conducting 3D scanning of the clamped product and programming five-axis milling strategies into the measured 3D model. By using three reference spheres, the position and orientation of the printed product can be identified by the measuring probe on the (five-axis) milling machine.
The position of the spheres in relation to the product is established by means of the 3D scan. By measuring the spheres (contact with four points), the centre point and the exact diameter are determined. This provides a new coordinate system for the CAM programmer. This realignment method achieves an accuracy for the complex curved surface of well below 0.05 mm on a Hermle C800U five-axis milling unit. Furthermore, the surplus material needed for the post-machining is reduced from 3 mm to 1 mm, thereby reducing the build-up time. This has proven to be the key to successfully integrating the additive and subtractive technology, thus unlocking a whole new market segment for RapidFit+ products.

SEIZING THE OPPORTUNITY

Realising a cost-effective, flexible machining platform combining additive and subtractive technology requires you to take a look at the whole production chain. Right from the start, at the design stage, the right decisions need to be made allowing you to get the most out of 3D printing technology while ensuring post-machining accuracy. In many cases the key to success does not reside in just one of the two technologies but in the integration of the two. Making innovative use of commercially available solutions like 3D scanning, measurement probes, clamping systems and CAM software is the secret for success.

It is worth pointing out that many more problems arise when combining these technologies into one platform (e.g. powder removal or heat treatment) for which no ready-made solutions are available. As a result, this issue is addressed in the final chapter of this publication, presenting as it does one of the major opportunities for the years ahead.
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.

Peter ten Haaf
*Program Manager - Precision Manufacturing*

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

Olivier Malek
*Expert Machining Advanced Materials and Surface Functionality*

Olivier is responsible for research and industrial projects on high precision machining. His interests lay in non-traditional machining technologies and advanced materials in particular.

Krist Mielnik
*Expert High-precision Milling*

Krist focuses on the finishing process optimisation of the gear prototype, realignment problems and precision finishing of additive manufactured parts and methods to evaluate and improve machine precision.

Tom Jacobs
*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.
PARTNERS

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