Highly accurate machining of intricate, filigree parts

HSC milling of high-tech components

For the production of support structures and kinematics of precision optics in small batches, Carl Zeiss in Oberkochen is convinced of the advantages of HSC milling. The highest precision is a must when milling standard as well as free-form geometries in soft as well as in hard materials at high speed. These requirements were fully met by a 5-axis-machining centre, type Röders RXP 500 DS.

"Our products really deserve the designation "high tech" since many of them are in service high above our heads – in airplanes and space craft", says Alfred Langer, head of the special products manufacturing business segment in the production facility of Carl Zeiss in Oberkochen (Germany). In addition to producing intricate mechanical parts, his division realizes high-end solutions in the field of optical components and complex assemblies. Thanks to close ties with in-house design and R&D departments, customers can already be offered full support in the early stages of product design. Carl Zeiss, a market and technology leader in the field of optics and optoelectronics whose products and services are widely used in biological and medical research and in medical technology, also develops complete system solutions for the semiconductor, automotive and machine-building industries. Many of these cutting-edge products are either one-offs or produced in very small batches. The special products manufacturing business segment is in charge of providing the related mechanical parts, such as supports, frames and kinematics. It goes without saying that this implies the highest requirements with respect to quality and precision. The department currently operates about 25 machine tools, mostly cutting-edge CNC-controlled lathes and 3 or 5-axis milling centres.

In line with the broad range of applications, the bandwidth of materials that have to be machined is much wider than for conventional production departments and encompasses not only standard materials, such as aluminium and carbon or high alloy tool steels, but also numerous "exotic" materials e.g. exhibiting special physical properties. This includes materials that are extremely hard or difficult to machine. Due to the fact that the company often pursues such projects with partners at a national as well as international level, a significant proportion of the orders comes from external customers.

Advantages of HSC milling

"Many of the structural parts we manufacture are very filigree and thin-walled, as in the case of support structures for precision optics. The force exerted by the cutting tool can lead to distortion of the structure resulting in reduced accuracy of the part", adds Richard Kaak, Project Manager of Technology Development Process Engineering. Of course, one might theoretically try to reduce this problem by drastically cutting back the machining speed. But this would not only lead to rocketing machining costs, it would also result in unacceptably long project delays. Further problems he urgently wanted to address were machining-induced vibrations matching the resonance frequencies of the structures as well as warming of the parts resulting in related dimensional deviations.
For those three problem areas, noticeable improvements were expected by switching from conventional milling to HSC machining characterised by its fast chip formation and removal, lower cutting forces and a higher vibration frequency stimulation range induced by the increased rotational speed of the spindle.

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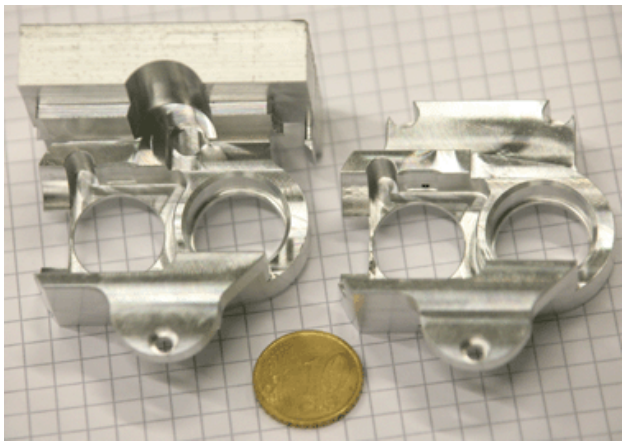
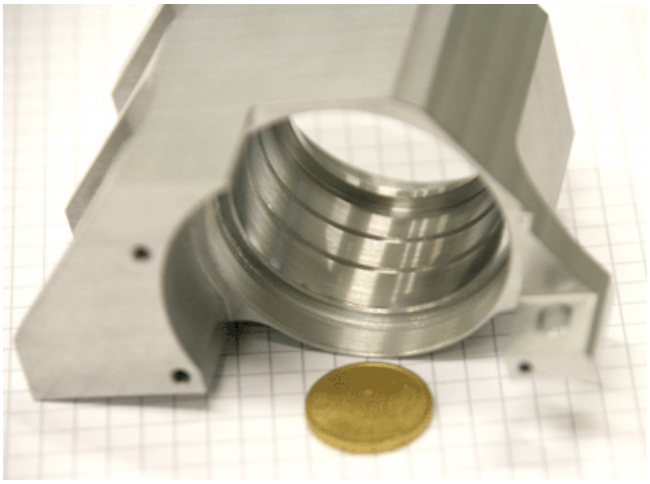
A further important aspect of the decision was economic efficiency. Even in this highly specialised market segment, costs are an important factor and final decisions are seldom taken by technicians alone, who have to discuss the matter together with the purchasing department.



In-depth selection process

"Before reaching our final decision we ran through a very thorough assessment process", recalls A. Langer. The first step was an intense 360° screening of all relevant manufacturers on the market, quickly leading to the de-selection of all but a handful of producers. In a second step the remaining systems were compared in an assessment matrix, resulting in some more being sorted out. The next and nearly decisive step was the machining of a test piece featuring all the intricacies Carl Zeiss wanted to see mastered. The final decision in favour of the 5-axis Röders RXP 500 DS with rotary/tilting table was then taken on the basis of its fast und highly accurate linear drives together with the rigidity of its machine base.

The new system was put into production in August 2006. It is equipped with frictionless, highly dynamic linear drives in combination with "classic" roller guides. The highest accuracy is achieved by a number of features, such as a high-resolution position-measuring system, a sophisticated temperature management system with a total of ten different tempering circuits, including a cooling sleeve around the spindle as well as an additional control circuit detecting and compensating for spindle length deviations. The 42000 RPM spindle is equipped with an HSK 40-tool fixture and has a power rating of 14 kW. Further highlights are cleaning devices for the tool and the workpiece, a temperature-control circuit for the cooling lubricant, as well as a contact point measuring system and a high- precision tool-dimension control system equipped with a laser.



The particular "knack" of the machine is a specially developed correction feature for the rotary/ tilting table based upon measuring the position of more than 400 reference points distributed over the workspace. Using these data, the control system then computes correction values making it possible to achieve the highest accuracy even in the case of multisided or simultaneous machining without any need for intervention by the operator.

"With these features, the Röders machine achieves outstanding precision over all axial positions in conjunction with high machining speed. That was exactly what we had been looking for", summarizes A. Langer.

Performance record

"After operating the system for one and a half years, we can now state that our expectations have been met with respect to all vital aspects", says R. Kaak. This applies to the accuracy achieved as well as for the machining speed. To give an example, in the case of a complex receptacle featuring several cylindrical precision fits whose axes have to be aligned with high accuracy, it was possible to dependably achieve a precision of 5 µm with respect to axis positions as well as to inside calliper gauging, while roundness deviations were securely restricted to just 2 µm. A further example is a filigree spacer ring with cone-shaped surfaces whose axes have a relative inclination angle of 5.3°. The position tolerance for

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the intersection point of these axes – located far outside the part itself – is just 0.02 mm.
A special highlight of the system is the accuracy achieved with an inclined table. In such cases the sophisticated internal deviation measuring and compensating feature of the system makes is possible to achieve accuracies that in certain cases surpass those attained with the technologies formerly used in the department by a full order of magnitude.
Another outstanding feature of the Röders system is its automation equipment enabling it to work overnight in unattended "ghost-hour shifts". The 18-fold workpiece pallet exchanger and a chain magazine accommodating 100 tools thus greatly contribute to reducing costs.

Support "decisive building block of the overall package"
"Another very important factor is the excellent support we experienced from the system manufacturer", explains A. Langer. This was all the more important since with the purchase of the new machining centre the company had moved into uncharted territory because the Röders control system does not comply with the standards commonly used by other manufacturers. On the other hand, the holistic concept of a machine whose PC-based control system had been specifically developed and carefully optimized by the manufacturer himself to exactly match his machining hardware was convincing. In this context, a particularly interesting feature was the easy way the control system could be updated. This greatly facilitated installing and using the improvements and special functions Röders partly tailor-made for Carl Zeiss immediately upon their completion by simply installing them from a CD-ROM. In all these cases, support by Röders proved to be excellent, as was the quality of their technical service.

Advantages along the process chain
"A further noticeable point comprises additional benefits we experience along the value-generating chain", explains R. Kaak. The high machining accuracy significantly reduces expenditure for downstream process steps such as deburring and polishing. Furthermore, it has now become easier to avoid having to resort to casting as an alternative production technology. In the past, this often proved to be unavoidable because many of the components are so thin-walled and filigree that they would not have been able to withstand the machining-related loads exerted upon them using conventional milling technology. But even when resorting to casting, a certain level of machining operations remains necessary, e.g. in the case of tight fits and sealing faces. Another disadvantage was that as-cast surfaces cannot be anodized to the necessary quality level. Switching to HSC machining results in significantly reducing the forces exerted on the workpiece, thus contributing to expanding the window of opportunity for milling technologies.
Klaus Vollrath

Proposals for captions
Workplace: The Röders RXP 500 DS used by Carl Zeiss for special products manufacturing (Photo: Klaus Vollrath)
"HSC milling characterized by lower cutting forces and lower heat generation within the workpiece is particularly advantageous when machining filigree, thin-walled structures" Alfred Langer (Photo: Klaus Vollrath)
Precision technology: The GageMax coordinate-measurement system is an example of high-tech engineering made by Carl Zeiss (Photo: Carl Zeiss)
"After operating the system for one and a half years, we can now state that our expectations have been met with respect to all vital aspects" Richard Kaak (Photo: Klaus Vollrath)

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Exception: These high-precision receptacles have to be produced in a batch size of between 250 and 300 (Photo: Klaus Vollrath)
High alignment: In the case of this receptacle featuring several cylindrical precision fits whose axes have to be aligned with high accuracy, it was possible to dependably achieve a precision of 5 µm with respect to axis positions as well as to inside calliper gauging, while roundness deviations were securely restricted to just 2 µm (Photo: Klaus Vollrath)
Intersection point: This filigree spacer ring has cone-shaped surfaces whose axes have a relative inclination angle of 5.3°. The position tolerance for the intersection point of these axes – located far outside the part itself – is just 0.02 mm. The part is intended for NIRSpec, the "super-eye" of the satellite replacing the Hubble telescope (Photo: Klaus Vollrath)
Ghost-shift: The 18-fold workpiece pallet exchanger and a chain magazine accommodating 100 tools enable the Röders RXP 500 DS to work overnight in unattended "ghost-hour shifts", thus greatly contributing to reducing costs (Photo: Klaus Vollrath)

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The Röders TEC RXP 500 DS
The 5-axis-machining centre RXP 500 DS is the typical "workhorse" for HSC milling of hard materials. The axes have working ranges of 800 x 500 x 300 mm, with a rotary/tilting table providing the fourth and fifth axis.
The design of the system particularly focused on speed, sturdiness and accuracy. The highest dynamism and precision are achieved using frictionless linear direct drives in combination with "classic" roller guides featuring outstanding rigidity. Compared to the widely used ball rolling spindles, the linear direct drives excel not only by their higher path control accuracy: at comparable energy consumption, they are frictionless and thus not subject to wear and tear since they contain no moving mechanical parts in direct mutual contact. The 42000 RPM spindle has a power rating of 14 kW.
The highest accuracy – well beyond what can be expected from comparable systems currently available on the market – is achieved by a number of features such as a sophisticated temperature management system, a spindle length deviation compensation device and an integrated tool-measuring system using a laser. A further feature in this context is a highly accurate contact-point measuring system for the workpiece.

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