Measurement devices with accuracies of less than 30 nm

The demand for **ULTRA-PRECISELY** manufactured components is constantly increasing. But how can these components be properly characterised when coordinate measurement devices are no longer up to the job? LT Ultra decided to tackle this issue for themselves, and ended up establishing a flourishing new business area.

Figure 1. Basis for ultra precise measurements: different rotary tables equipped with aerostatic bearings from LT Ultra

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Ultra-precision machining (UP technology) enables workpieces to be produced that already represent a significant challenge for measurement technology. At the same time, however, the measurement approaches used in quality assurance need to be better than those used during production. In particular for UP technology this is a recurring issue – production methods have become already so advanced that metrological evaluation in the same or better quality is only possible with a great deal of effort.

Upturn in UP measurement systems

Measurement machine manufacturers have been supplied with UP components for some time. These include UP rotary tables with aerostatic bearings and direct drive to achieve concentricity errors of less than 50 nm, or aero or hydrostatic axes with minimal running errors **(Figure 1)**.

For some years now, LT Ultra has registered an increasing interest in complete measurement approaches, as in some cases it is no longer sufficient to replace only individual key components with UP components, resulting in the need for an integrated approach. LT Ultra has been able to perfect this approach over the last few decades in its own UP production machines. Their accumulated know-how in piezo technology, for example for fast tool axes and their own Fizeau interferometers, is also an advantage **(Figure 2)**.

Which measurement equipment is suitable?

As with conventional coordinate measurement devices, those from LT Ultra use a tactile approach where required. However, in particular for less hard workpieces, for example those made of non-ferrous metals, it is important to note that alone the tactile force of the measurement ball (or tip) can cause damage to the workpiece surface. In order to limit this issue, the LT Ultra LVDT (linear variable differential transformer) measurement sensor utilises air bearings for movement and the tactile force exerted is implemented using a precisely adjustable pneumatic system **(Figure 3)**. As the air bearing does not generate any measurable friction and the position measurement of the ball tip on the LVDT is also contactless, the tactile force can be reduced to an absolute minimum.

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Figures: LT Ultra-Precision

Figure 2. ›FTA100‹ piezo actuator based fast tool axis with 100 µm stroke for diamond machining of free-form surfaces and for micro and nano-structuring

Depending on the overall system, an LVDT measurement sensor can be used to measure individual points or line sections with accuracies of around 10 nm.

Fizeau interferometers are ideal for full-surface measurement of the form **(Figure 4)**. The widened, collimated laser beam is reflected from the surface of the workpiece and creates interference with the reference surface in the same beam path. The interference fringe distribution is monitored by a camera system when phase shifting (movement of the reference using piezo actuators) or by wavelength shifting of the light source. The measurement accuracy is primarily determined by the reference, for which accuracies in the range of $\lambda/10$ are common. In the software used to evaluate the fringe distribution, to obtain the workpiece topography the error in the reference can be further reduced by assignment of a correction matrix. Typically, 6 or 12-inch interferometers are used. Larger surfaces can be accommodated via stitching. A compact 20-inch interferometer is also currently being developed at LT Ultra.

Chromatic confocal sensors, which are the optical counterpart to the LVDT measurement sensor, offer a different optical measurement method. Here, targeted use is made of the chromatic aberration, i.e. the colour distortion of a lens. The wavelength that is in focus is reflected and then determined using a spectrometer, which in turn allows the position of the reflection in the working area to be determined in absolute terms. In contrast to the LVDT measurement sensor, reflective surfaces are necessary. The resolution and accuracy of the sensor are primarily determined by the measurement range, the spectrometer and the installed lenses, and are typically in the range of less than 10 nm.

The highest resolutions are achieved using atomic force microscopes (AFMs), which have been used in laboratories for a long time now. However, these are exceptionally sensitive to external interference as determination of the topography is the result of scanning and takes a comparatively long time. The typically very small measurement ranges of well below 100 μm^2 can be extended by integration into an appropriate measurement system to enable reliable and highly automated measurement of workpieces with larger areas.

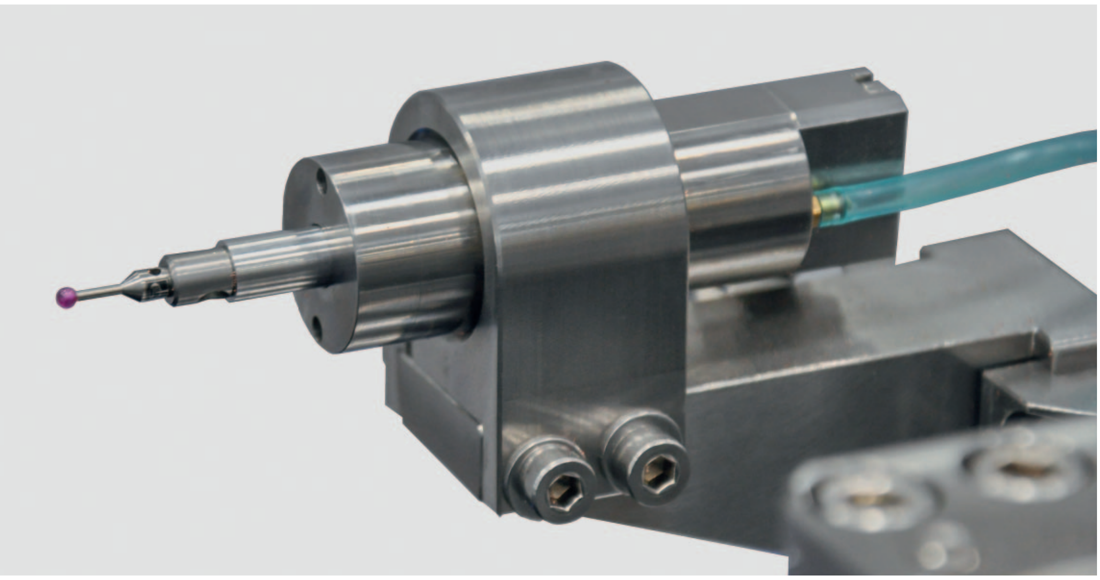

Figure 3. LT Ultra LVDT measurement sensor with high-resolution measurement system and aerostatic guidance for tactile workpiece measurement

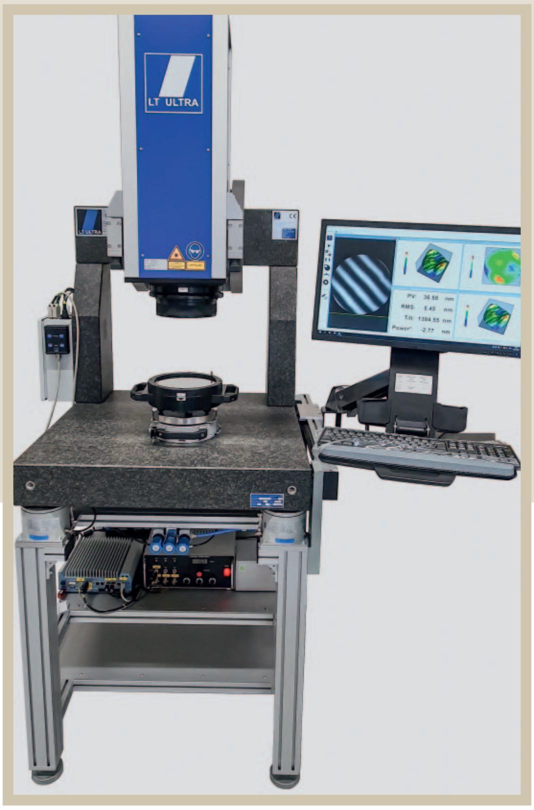

Figure 4. 6-inch Fizeau interferometer from LT Ultra as stand-alone solution

An integrated concept also allows additional measurement technologies to be incorporated. If so required, only a highly accurate positioning of the workpiece and measurement equipment is provided. Importantly, the principle used for measurement is only of secondary importance as long as the process is suitable for the workpiece and there are no interactions with the machine. Even systems that subsequently undergo white label branding are not uncommen here.

Combination of measurement equipment and drive systems

As measurement machines in the UP range are required to exert no or very low tactile force, aerostatic bearings are the method of choice. Compared to hydrostatic bearings, which are frequently used in UP production machines, they have lower rigidity for the same installation space, although the negligible force exerted means that this is of minimal interest. However, the peripheral support required for aerostatic bearings is much simpler as no hydraulic processing is required. In addition, less heat is generated and aerostatic bearings are particularly well suited to cleanroom applications. And, as none of the bearing parts touch each other, there is no particle abrasion.

When it comes to positioning the individual axes, LT Ultra utilises a combination of different measurement equipment and drives. Linear direct drives have consistently proved themselves as the primary drive. Particularly in a direct closed control loop with high-resolution glass scales, tiny positioning steps of less than 10 nm can be implemented as the drive is direct, and the aerostatic bearings utilised mean that there is no detectable hysteresis in terms of backlash. For the most stringent requirements, additional length measurement interferometers are used, although these place extremely high demands on the ambient conditions.

One example here is the ›MPR 700‹ (mandrel profilometer rotondimeter) from LT Ultra **(Figure 5)**, which was used to characterise the master optical systems for the ›eRosita‹ space mission. The drive is based on linear direct drives, controlled using high-resolution glass scales, whose error is recorded in real time using length interferometers. A chromatic confocal sensor is used to measure the profile of the workpiece.

Figure 5. ›MPR 700‹ mandrel profilometer rotondimeter from LT Ultra

Fusion of measurement equipment for the best results

The smart fusion of different measurement approaches and drive types delivers the best results. Although measurement equipment such as length measurement interferometers deliver good results under laboratory conditions, but alone in terms of system reliability, they are often not intended for industrial applications, for continuous use and for the very high levels of automation sometimes required. For safety measurement systems, high-resolution glass scales and length measurement interfero-

Figures: LT Ultra-Precision

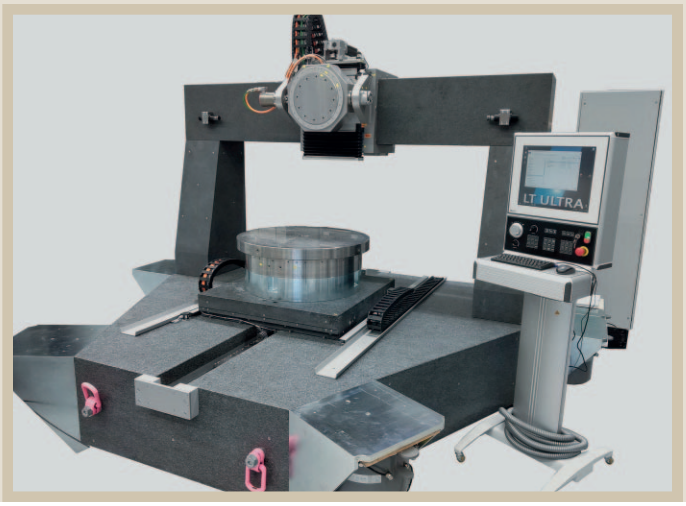

Figure 6. Multi-axis system from LT Ultra, in this case with no Fizeau interferometer

meters can be combined as required to get the best of all worlds. In special cases capacitive distance sensors, which are otherwise only used in the semiconductor industry, can also be useful.

The situation regarding drives is similar. Linear direct drives are the most suitable solution, but do not always meet all of the requirements. Where necessary, the drives are therefore supplemented with piezo actuators to improve overall performance.

If required, the LT Ultra systems operate fully autonomously and are loaded and unloaded using robot arms. Dedicated solutions are integrated in close cooperation with the customer's automation engineers. For some years, the OPC-UA standard is increasingly being used as the communication interface and is now established with many users, allowing seamless communication between different systems. This is also the case when components come from differing sources.

Like all machines from LT Ultra, every UP measurement system is delivered with CE conformity. This quality mark confirms the highest requirements in terms of operator and workpiece safety. In many cases, redundant safety mechanisms are also integrated to prevent the slightest damage – a faint touch is enough to ruin an optical surface.

As with UP machines, almost all conventional measurement machine manufacturers now tend to use a granite system base due to the thermal and vibration-damping properties. Thermal inertia in particular is crucial as the small residual errors from typically well temperature controlled measurement chambers tend to have short duration and are thus neutralised by granite. In conjunction with vibration isolation systems such as multi-chamber air systems, stable conditions can be created. This kind of setup can be clearly seen in the example multi-axis measurement system shown in **figure 6**. This system is used to measure large workpieces up to 1500 mm in diameter and 300 kg in weight using a Fizeau interferometer. On the workpiece side (bottom) are a rotary table and a linear axis. This has an exceptionally long travel distance to enable it to reach the loading position. After loading, ideally using a crane, the workpiece is moved under the measurement gantry. On the measurement head side (top) is a further linear axis along the horizontal direction of the cross beam. The interferometer is positioned in the z direction (up/down) using an adjusting axis. Two further rotational axes are used to tip the interferometer. This specialist system does not have an additional booth as the cleanroom chamber at the installation location performs this function and is integrated into the system’s safety engineering.

Ultra precision from every angle

LT Ultra is well equipped to deal with the increasing demand for UP manufacturing and measurement systems and, at the beginning of the year, opened a new building to extend its total production and assembly space by 1000 m^2 to around 11,000 m^2. To guarantee that close collaboration with end customers and suppliers is maintained, 50 additional office jobs were created at the same time. This means that LT Ultra is still able to offer UP machines and measurement systems in variable quantities from 1 to over 100. With more than 25 years of experience in UP technology, the company is constantly developing this expertise. In addition to the wide range of manufacturing, measurement and customised special machines, LT Ultra also offers contract manufacturing of UP and micromachined parts. ■

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