METROLOGY TRENDS
IN PRECISION MANUFACTURING

(Photo: Nicole Minneboo)

It can be argued that the story of precision is an arc driven by a search for perfection and the need for interchangeable parts to drive manufacturing volumes. With that comes accuracy and tolerance needs that must be met by measurement innovations. Metrology, from the ancient Greek metron (measure) and logos (study of), is the science of measurement. As precision engineers we understand that a scientific approach to measurement is critical to assure precision outcomes.

It has been reported that there are now more transistors in the world than leaves on all the trees. As metrologists we would say this must be proven, but what is certain is that when it comes to semiconductor fabrication equipment, such as lithography machines, the hunger for precision does not stop. For integrated circuit production typical layer-to-layer accuracy (overlay) during fabrication is now at 1.5 nanometer. And the mirrors integrated in the latest generation of lithography machines require a form accuracy one hundred times smaller again.

As the targeted precision increases, so too does the skill required to control potential disturbances. Unwanted temperature gradients, for example, or unintended vibrations at extremely low levels, can have significant impacts on performance and must be managed. As each functional part of a machine becomes more complex, the measurement strategy needed to achieve precision also becomes more challenging. This strategy must take into consideration each of the parts and their interrelationships.

Printing has required precision for many decades as the human eye is very sensitive to accurate registration of colours. Today however, large cylindrical printing equipment parts must achieve sub-micron ($< 10^{-6}$ m) level accuracy over ~5 m. With advanced printing technologies, not only visuals are printed but also devices such as electronics. This requires control of the substrate during the printing process with sub-micron accuracy, whether the substrate is thin (glass) or flexible (plastic foils). In-line inspection interferometers can be applied to verify these accuracies.

Moving from 2D to 3D printing, these accuracy requirements become spatial. Here, precision motion components are key to achieve the required volumetric repeatability. The latest 3D (polymer) printers have the capability for sub-micron feature printing. For production this requires extremely accurate x-, y- and z-stages. Air bearings allow to move without friction at high speed, essential to achieve both accuracy and productivity.

In the area of machine tools, demands grow for complex shapes such as turbine blades, impellors and medical protheses. Today, 5-axis machine qualification demands sub-micron measurement of the kinematic accuracy over the full machine working volume in under a minute. Further, the trend is moving from only measurement and correction to prediction and intervention.

Precision timekeeping is inescapably linked to precision instruments. Today's official standard of time is generated by hundreds of caesium atomic clocks around the world operating at microwave frequencies. Progress with optical clocks in the last decades has reached accuracies of one part in 10^{+18}; this value corresponds to losing less than a second over the age of the Universe. This progress has been achieved through precision components and in turn feeds the precision timing needs of tomorrow's complex machines.

IBS has been part of this precision ecosystem for 30 years. We now design to the picometer. Making virtual machines has become the norm. And big data strategies have become a standard requirement as machines become more intelligent. In the field of precision engineering, the challenges never stop. Luckily, neither does the ingenuity of the engineers who love to meet these challenges.

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