The expanding role of optical metrology in precision engineering

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Abstract

Over the past few decades, the horizon of application of optical metrology has extended continuously; overcoming limitations in surface texture, correlation to mechanical gauging, complex form and environmental conditions previously considered inappropriate for high precision optical methods.

1 Optical metrology in the service of precision engineering

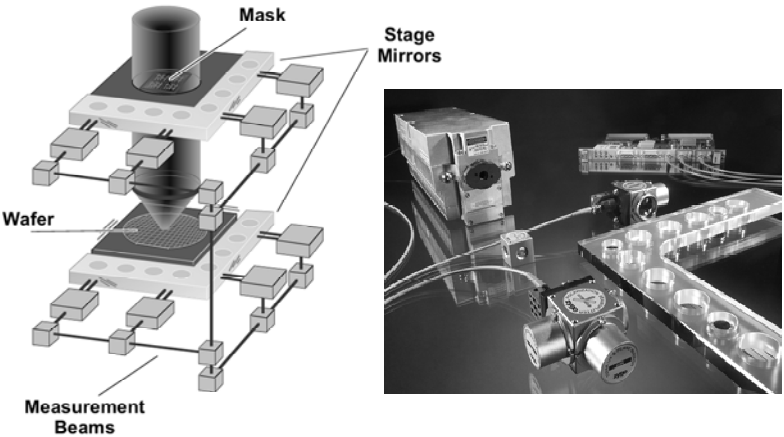

Figure 1: Interferometric stage control—a traditional example of optical metrology in the service of precision engineering.

Many of the early examples of interferometric optical metrology relate to length standards, including in the particular providing a portable standard based on wavelength, and comparison of gage blocks using interferometry.[1] These applications fall into the category of metrology for calibration and validation, still the dominant role played by interferometry, for both distance measurement and for surface form and texture profiling. In the role of a validating technology, optical methods play a complementary role to mechanical and electrical metrology for process development and yield enhancement, including the measurement of surface texture, which plays a vital role in component functionality.[2]

An additional role for optical metrology is integrated, continuous feedback in a precision-engineered mechanical system. Here a recongizable example is stage positioning systems for diamond turning, coordinate measurement, machining and stage control in demanding applications such as photolithography (Figure 1).[3] Interferometric methods are an interesting test case for the expansion of optical measurement methods in precision engineering, because these methods are often simultaneoulsy the most precise but the most difficult to implement effectively.

2 Obstacles to the expanded use of optical metrology

Even though there are recognized advantages of speed, precision and non-contact measurement; optical methods for machine control and quality assurance have often been set aside for mechanical methods. Some of the reasons for this include:

- Complex shapes with high slopes, rough surfaces and transparent films
- Inadequate correlation to established mechanical and eletronic gaging
- Environmental effects, including in particular vibration and air turbulence

3 Complex shapes

Optical surface metrology found immediate and permanent application for evaluation of optical components, particular polished flats and spheres, and those complex surface shapes that could be made to "appear" flat through comensating elements.

Automated data acquisition and processing has facilitated the application of advanced methods, including spatial coherence, multiple wavelengths, broadband sectra, and polarization. In interferometric micrometrology, a major breakthrough has been in white light interferometry, capable of analyzing surface shape, texture and dimensions of highly varied and complex shapes. To these methods have been added specialized objectives, fixturing and methods to improve data capture, extend the measurement range, accommodate partially transparent films and substrates, and allow for relational measurements such as thickness, angle and parallelism.[4]

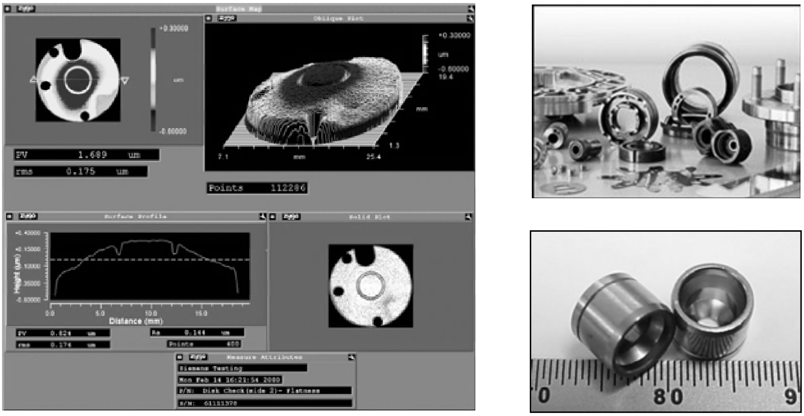

Figure 2: Surface profiling of automotive parts using white light interferometry.

4 Correlation to mechanical gauging

The extension of optical metrology into areas traditionally considered the domain of stylus gaging has highlighted the need to bridge the gap between these techniques, which can seemingly or actually have highly different response characteristics. Here the burden has been primarily on optical tools to overcome this perceived barrier, through changes in the measureement geometry, measurement principle and filtering. International standards have played a critical role in this effort: The emerging ISO 25178 600-series documents the nominal characteristics of both contact and non-contact (optical) methods.[2]

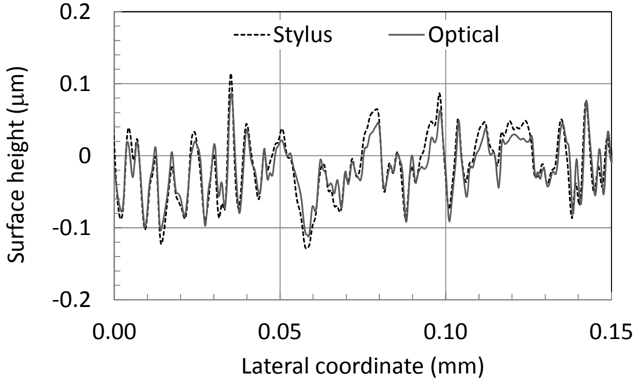

Figure 3: Comparison of cross-sectional profiles obtained with an optical profilometer and with a mechanical stylus tool.[5]

5 Strategies for difficult environments

Interferometry is a highly sensitive measurement of motion, which can be both a benefit if the application is motion monitoring and an encumbrance if the environment is plagued by unexpected motions or air currents. Today alternatives to the traditional air table and environmental controls allow for precision metrology of even dynamically changing events. High speed allows for averaging of air turbulence, and interactive part setup.[6]

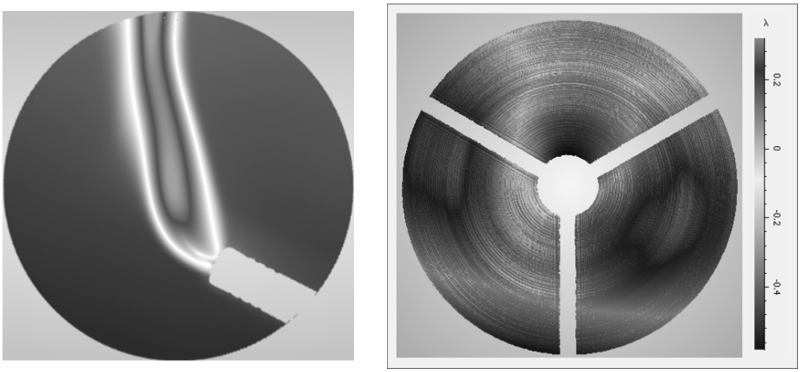

Figure 4: Dynamic measurements using single-camera frame laser interferometry. Left: an air-density profile within a candle flame. Right: Surface of diamond turned part having a 500nm of surface departure. The field of view is 100mm.

References:

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