

MEMS in Motion: *a New Method for Dynamic MEMS Metrology*

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Introduction

Manufacturers of MicroElectroMechanical Systems (MEMS) rely on metrology to control their processes and to verify how their products will perform once they are packaged and in service. Since the introduction of the first MEMS accelerometers and sensors, micro-device manufacturers have performed static measurement of surface shape and dimensions using optical profilometry (white light interferometry), which provides a combination of high speed, resolution and vertical range. Manufacturers have then attempted to correlate the measured dimensions to device performance. For controlling MEMS production processes, this method has proven quite useful. For determining a device's ability to perform its function (actuate, deform, rotate, etc), the information has been incomplete.

A new metrology method, developed by CalTech and exclusively licensed to Veeco, combines optical profilometry with stroboscopic illumination for dynamic measurement of MEMS devices in motion. Stroboscopic illumination effectively "freezes" the motion of MEMS structures, allowing nanometer-resolution measurement of their surface shape. By varying the amplitude, phase and frequency of the drive signal, multiple measurements can be taken to describe the device's full range of actuation/deformation. Moving MEMS structures can then be analyzed for flatness variation, tilt, lateral translation, linearity of motion, stiction, and other key device parameters.

Optical Profiling Plus Strobed Illumination

In a white-light optical microscope, the illumination source is traditionally a tungsten-halogen bulb, coupled into an optical system with several interferometric microscope objectives. Light from the source is split in the objective, with part of the beam traveling to the device under test and the other part to a high-quality reference surface. The light recombines to form a pattern of interference "fringes". The reference surface is then translated relative to the test surface, and multiple frames of data are obtained during the translation. The resulting series of fringe patterns are analyzed to calculate the surface profile of the device.

Optical profilers can employ several techniques to obtain 3D topographic data of static samples. Phase Shifting Interferometry (PSI) measures smooth surfaces with steps up to approximately 160nm. Vertical Scanning Interferometry (VSI) measures rougher surfaces and steps up to 8mm. Enhanced VSI (EVSI) combines the best aspects of the PSI and VSI techniques for measuring smooth surfaces with large discontinuities.

The main obstacle to measuring moving devices with an optical profiler is that a vibrating structure can blur or distort the

interference fringe pattern, even at low frequencies and amplitudes. However, if the device motion is periodic and of primarily one frequency, as is true of many MEMS structures, one can strobe the illumination source in synchronization with the MEMS drive signal to effectively freeze the motion. This arrangement extends the use of standard optical profiling techniques to the measurement of moving devices.

In the "dynamic measurement" optical profiler, an additional LED source provides the strobed illumination (a standard illuminator remains in place for static measurements). Employing a strobed LED source requires careful hardware and software design to maximize its efficiency. The illumination level must nearly saturate the camera to maintain a high signal-to-noise ratio in the surface measurement; yet even the brightest single LEDs emit less than 35 candelas, some 30 times dimmer than a tungsten-halogen bulb. To achieve sufficient intensity, the viewing angle of the LED must be carefully matched to the existing optical design. Overdriving the pulsed LED beyond the normal maximum current or lengthening the pulse's duty cycle will further increase the intensity. These two factors must be carefully balanced in the drive software, a) to avoid overheating the LED, and b) to avoid image blur due to excessively long duty cycles.

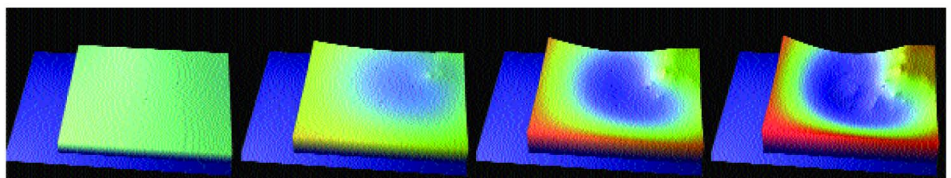


Figure 1. Dynamic measurement reveals a hidden defect in a micro-mirror (Courtesy Texas Tech University).

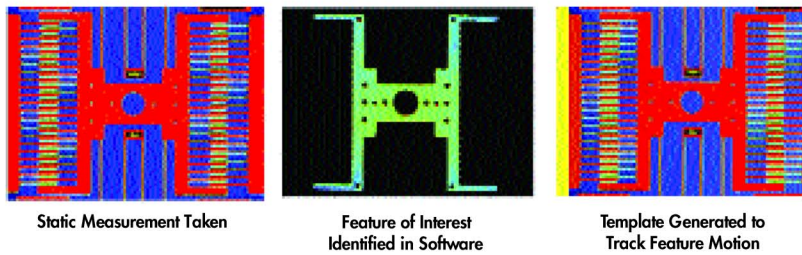


Figure 2. Template-driven analysis allows tracking of MEMS device features across multiple frames of data.

All of these techniques have been employed on a Wyko® NT1100 Optical Profiler (Veeco Instruments Inc.) and shown to produce effective measurement results. A variety of devices have now been analyzed using the dynamic MEMS measurement technique. By stepping through various combinations of frequency, voltage, and phase, MEMS device motion can be completely characterized.

One of the primary benefits of optical profiling, fast measurement speed, is an important feature of dynamic measurement as well. A measurement at each particular voltage, phase, or frequency requires only a few seconds, allowing full characterization of the device in a short span of time.

Measuring In-Plane and Out-of-Plane Dimensions

In the most basic data analysis, a series of data image frames can be combined to generate a video of the device in motion. Figure 1 shows several frames taken from a dynamic measurement of a micro-mirror in actuation. In its non-actuated state, the mirror appears to be of acceptable quality. By altering the drive signal voltage, the mirror is moved through its range of motion, revealing an otherwise undetectable defect.

In addition to simple device visualization, the dynamic profiler allows 3D measurement of critical dimensions and deformation across the range of actuation, for both in-plane and out-of-plane motion. A template-driven software analysis is employed to isolate and track features of interest across multiple frames of data. Figure 2 shows the template analysis for an in-plane resonator. By targeting the center of the device, its lateral and vertical motion can be tracked frame-to-frame.

Once the features are identified and tracked through the data frames, key device parameters can be derived. For in-plane devices (resonators, switches, comb drives, displacement multipliers, etc), dynamic measurement characterizes lateral dimensions, linearity of motion, X/Y deflection, distortion and rotation. For out-of-plane devices (cantilevered beams, diaphragms, pressure sensors, mirrors, etc.), the system can measure shape/distortion, radius of curvature, sag, bow, deflection and range of motion. These parameters provide the basis for software calculation of resonant frequency, modal behavior, settling time and switching time.

Figure 3 shows an analysis of an in-plane resonator, including a 3D map of the surface topography and a plot of lateral movement versus drive signal phase. The

plot shows translation of the large center section at the 22kHz resonance frequency, with an 80V peak-to-peak sine wave actuation. At the resonance frequency, motion remains quite sinusoidal. However, it can be seen that the resonator actuates more in one direction than the other, which would skew its sensitivity. Also, the maximum deviation occurs at 4.8 degrees of phase, as noted on the top of the plot. Thus, there is a lag between the applied signal and the motion of the device.

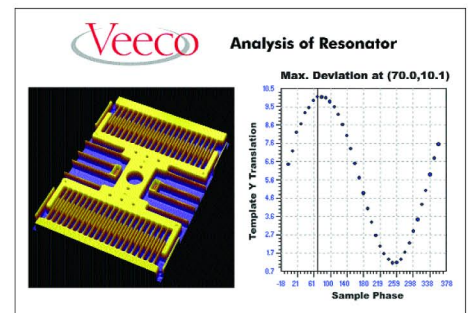


Figure 3. Data analysis of an in-plane resonator, showing a 3D map and a plot of phase vs displacement (Courtesy Sandia National Laboratories, SUMMiT™ Technologies).

Conclusion

As more types of MEMS devices move from the laboratory to full production, metrology becomes increasingly important for quality control and process yield improvement, as well as for product development. Through careful opto-mechanical design and good control software, a strobed illumination scheme allows rapid and accurate measurement MEMS devices in both their static state and during actuation. The technique extends to any micro-device with periodic motion, enabling direct measurement of device performance.



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