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DIMENSIONAL MEASUREMENTS OF ULTRA DELICATE MATERIALS USING MICROMETROLOGY TACTILE SENSING

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DIMENSIONAL MEASUREMENTS OF ULTRA DELICATE MATERIALS USING MICROMETROLOGY TACTILE SENSING

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INTRODUCTION

Quality inspection of microscale parts is very challenging. The need to measure smaller feature sizes, higher aspect ratio features such as side walls, and more complex shapes for example free-form engineered surfaces is becoming prevalent. Inspection tools for microscale parts typically fall into two categories, non-contact and contact based metrology. Non-contact tools are generally optical based technologies such as white light interferometry or confocal microscopy. A distinct advantage with optical metrology is the ability to rapidly measure parts with high throughput as well as avoiding touching the part. However, optical methods have many drawbacks including sensitivity to ambient conditions such as lighting, and detailed understanding of the refractive index of the specific material being measured. Additionally, steep curvatures, narrow microscale features, and transparent or highly reflective parts are difficult to measure optically.

Contact based sensing, generally refers to tactile sensors. A survey of the microscale probing industry reveals that probes are designed in a wide variety of tip sizes ranging from 20-250 µm diameter, with contact forces typically quoted as 1-500 µN and probe stiffnesses specified from 10-500 N/m [1]. Most microscale probing systems on this scale produce contact forces that have high Hertzian contact stresses that elastically or plastically deform the measured surface [2]. As a consequence, the characterization of both 3D surface topography and dimensional features of components made of delicate materials and shapes remains a significant challenge.

METROLOGY SENSOR

The aim of this presentation is to discuss dimensional metrology of ultra delicate, thin and complex form components using standing wave microscale probes [3,4,5]. The sensor technology comprises a small microscale fiber which is 7 µm in diameter and up to 3.5 mm in length providing an aspect ratio of 500:1. The fiber is vibrated at 32 kHz using a quartz crystal oscillator which produces a pronounced mechanical standing wave in the fiber. The contact force calculated based on beam bending theory is <50 nN. During scanning, the probe has two normal modes of operation referred to as near-field scanning (out of contact) and contact scanning, FIGURE 1.

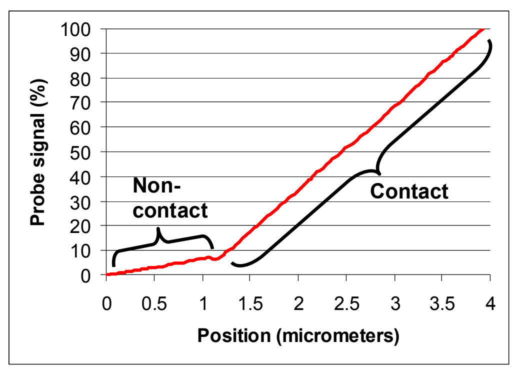

FIGURE 1. Example sensitivity slope vs. preload

EXPERIMENTAL APPARATUS

The instrument used during the experiments presented in this work comprises an engineered gauge head that is rigidly attached to a Moore 1.5 machine frame as shown in FIGURE 2. The gauge head is composed of a precision spindle and scanning head which are used to position the microscale standing wave probes. The measured components are positioned with an

Aerotech™ FiberMax 5 axis positioning platform. The *X, Y* and *Z axes* are located on the Moore 1.5 and subsequently used only for coarse alignment. Once the fiber probe and workpiece are positioned within the correct working volume of the FiberMax, the stages on the Moore 1.5 are locked and are not used during the measurement process.

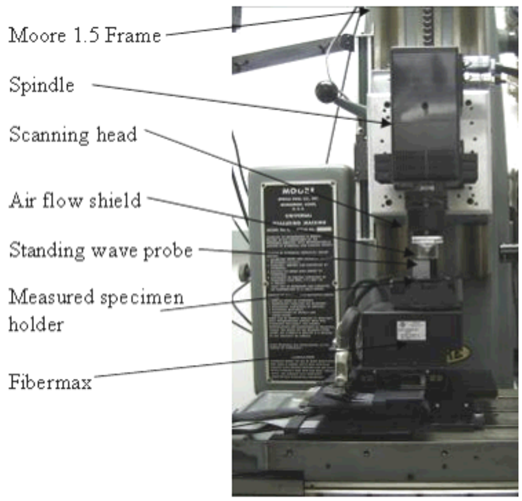

FIGURE 2. Test bed used during experiments.

EXPERIMENTAL MEASUREMENTS

The case studies that will be discussed in detail include thin foils, aerogel foams and miniature optic lenses.

Delicate foam - aerogel

Aerogels represent one of the most challenging and delicate materials to measure. Optical methods can not measure the material because the reflectivity at normal incidence is very low. While other techniques such as grazing incidence interferometry for surface measurements and transmission based techniques maybe realized for some portion of the overall required part metrology, they are limited to specific geometries and require a detailed understanding of the refractive index of the specific material. The combination of potential density variation throughout the bulk coupled with complex geometries inhibits the use of most optical techniques.

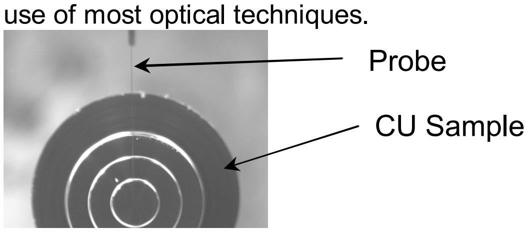

FIGURE 3. Image showing alignment of the probe and part during measurement.

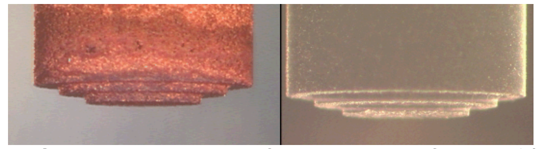

FIGURE 4. Image of the copper foam 5% full density (left) and SiO2 55 mg/cc foam (right).

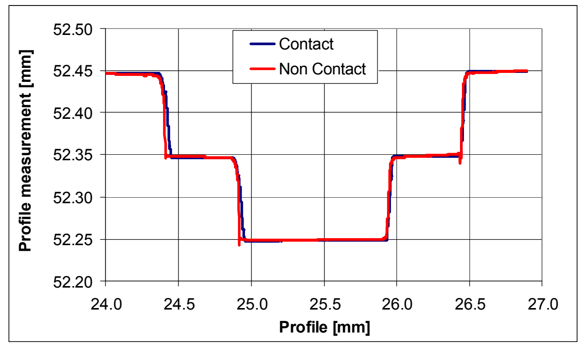

FIGURE 5. Measurement of the copper sample using contact and non contact method.

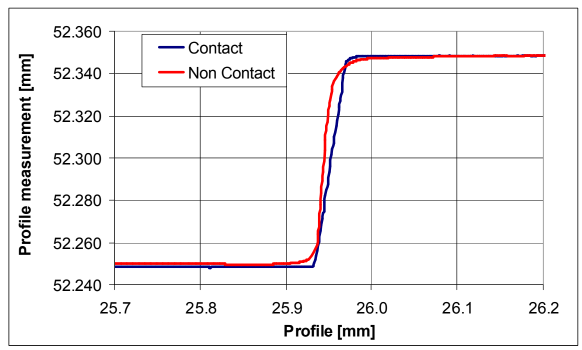

FIGURE 6. Zoom in on the step measured using contact and non-contact method.

A study was undertaken to assess the capability of employing standing wave probes for scanning profiles of these materials. Three cylindrical materials that included copper, 5% copper foam and SiO2 55 mg/cc foam were diamond turned with 100 micrometer steps, (FIGURE 3, 4). The solid copper material was scanned in both non-contact and contact mode (FIGURE 5, 6). Steps were calculated from this data using a least square method to determine the heights. The results reveal an approximately 1 µm discrepancy between those two methods with 56 nm standard deviation for contact and 229 nm standard deviation for non-contact measurement as shown in TABLE 1. Next, the two aerogel samples were both measured in contact and non-contact modes. The contact mode damaged the aerogel surfaces of the sample but the non-contact mode demonstrated sub micron repeatability (FIGURE 7, 8) and TABLE 1. It is important to mention the contact mode has not shown to damage other soft materials such as gold deposition, plastics. Aerogel foams are the only known instance in which damage appears to occur when contacting the part.

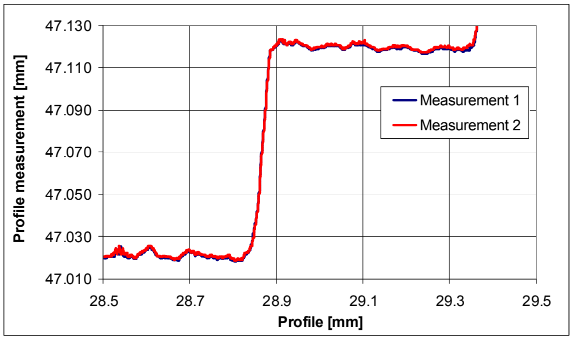

FIGURE 7. A Step measured twice for the CU foam using the non-contact method.

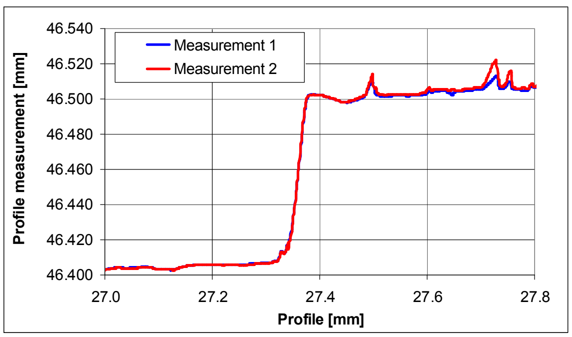

FIGURE 8. A step measured twice for the SiO_2 foam using the non-contact method.

TABLE 1. Calculated step heights based on least squares curve fit

	SiO_2	CU foam	CU - contact mode	CU - non contact mode
Average step (micrometers)	97.872	98.740	99.561	98.599
Standard Deviation based on 3 measurements (micrometers)	0.416	0.110	0.056	0.229

Thin foil

Dimensional metrology of thin foils of less than 100 µm thickness is another challenge in tactile sensing due to the ability to elastically deform during the measurement process. A case study was undertaken to measure a 60 µm nominal thick foil with a manufactured sinusoidal pattern of 2 µm amplitude and 50 µm wavelength (FIGURE 9, 10). Additionally, the profile was scanned above the impression on both sides of the foil part by rotating the probe 180 degrees for each scan. The probe tip offset was calibrated by scanning on either side of a XXX 450 micrometer gauge block. The thickness variation is measured across one height of the foil is presented, FIGURE 11. The results indicate the outer edges are thicker compared to the center. This could be due to the manufacturing process because the part was polished. In general, despite the thin structure there was no noticeable bending of the part during the measurement.

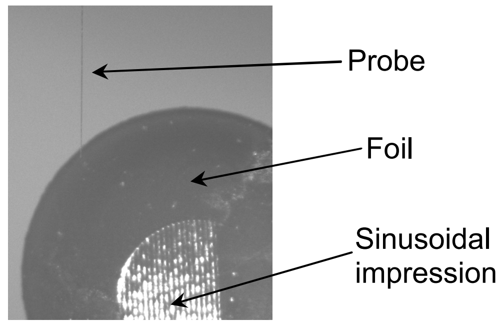

FIGURE 9. Image of thin foil 63 µm nominal thickness and sinusoidal impression.

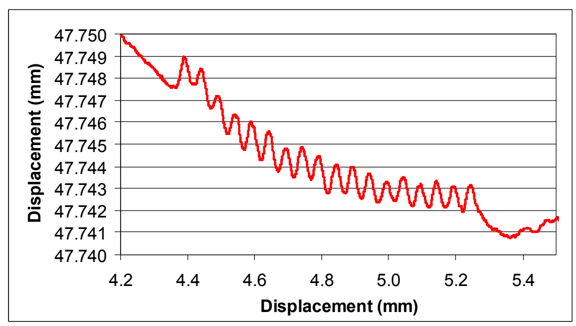

FIGURE 10. Measurement of the sinusoidal impression with 2 µm nominal amplitude.

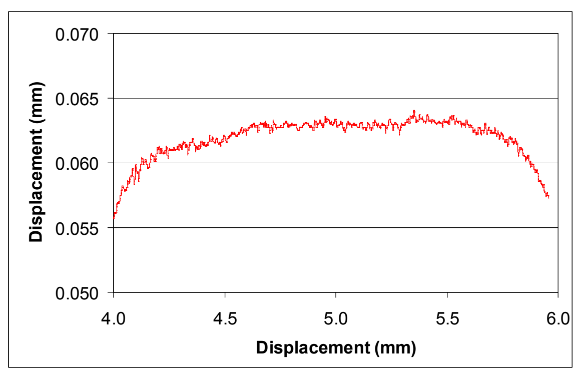

FIGURE 11. Measurement of thickness distribution across polished thin foil.

Miniature optics

The metrology of optics and free form surfaces is dominated by white light interferometry. General interferometry methods are very accurate when measuring deviations from a curved surface. However, these instruments have difficulty measuring the radius of curvature better than 1-5 micrometer. A low contact force profilometrery could offer the ability to measure highly accurate radius of curvatures assuming the stylus forces are low enough to not damage the surface while the interferometry tool could still yield accurate measurements of the deviations from a curved surface. A short study is currently underway to measure miniature optics using the standing wave probes. An plano-convex optic with specified radius of curvature of 3.4 mm and a diameter of 2 mm was used for this study. The probe was scanned across the center of the optic and two scans are overlaid, (FIGURE 12, 13). The calculated radius of curvature was determined to be 3.411 μm. Further studies will compare results with optical methods as well as perform measurements on smaller scale optics.

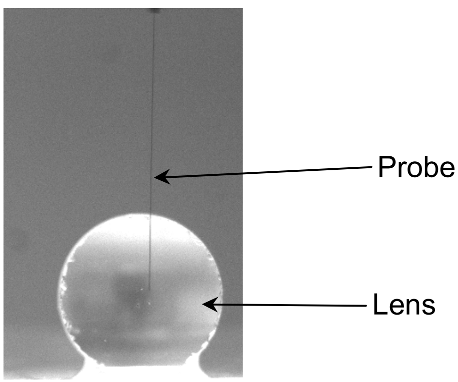

FIGURE 12. Image of miniature lens during measurement.

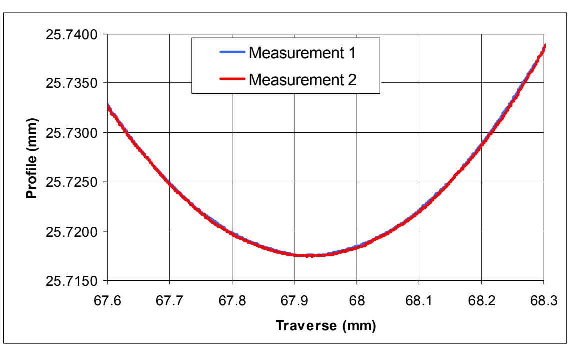

FIGURE 13. Two consecutive measurements of miniature lens with 3.4mm nominal radius.

CURENT WORK

Most all of the work to date has been performed with a 5 axis motion platform that was not designed for metrology applications and introduces undesirable errors in the measurement. Current work is now ongoing to interface the AccuSurf gauge head and standing wave probing system with a Zeiss scanning CMM, FIGURE 14, to provide a unique metrology platform capable of measuring delicate materials, thin foils as well as high aspect ratio features such as holes channels and microscale features of complex parts. As a result higher repeatability of dimensional measurements along with surface texture and form measurements will be achievable.

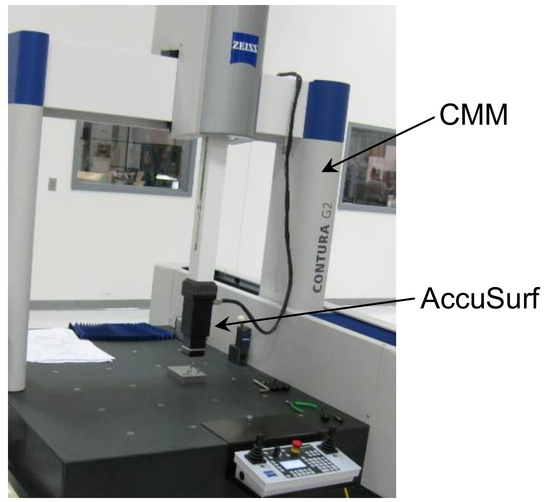

FIGURE 14. Image of AccuSurf being integrated to Zeiss scanning CMM.

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REFERENCES

[1] Weckenmann A., Estler T., Peggs G., McMurtry D. Probing Systems in Dimensional Metrology. Annals of the CIRP

[2] Bhushan B. Nanoscale tribophysics and tribomechanics Wear 225-229 (1999) 465-492.

[3] Bauza M.B., Hocken R.J., Smith S.T., Woody S.C., Development of a virtual probe tip with an application to high aspect ratio microscale features. Rev. Sci. Instrum. 76, 095112 (2005)

[4] Bauza M.B., Woody S.C., Woody B.A., Smith S.T. Surface profilometry of high aspect ratio features. WEAR, 2010.03.028.

[5] Bauza M.B., Woody S. C., Smith S. T., Seugling R. M., Darnell I. M., Florando J. N., Microscale metrology using standing wave probes, Proc. of 23rd ASPE, 2008.