

ULTRAPRECISION MICROSCALE HOLE SCANNING METROLOGY

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INTRODUCTION

Measurement of high aspect ratio microscale features such as holes and channels remains a challenging metrology problem. For example, to assess a high aspect ratio small hole it is currently common to cut away a cross section and measure the features of interest using an AFM, SPM or SEM. Typically, these metrology tools may be suitable for surface finish measurement but often lack the capability for dimensional metrology measurement over these feature sizes. On the other hand, microscale probing systems currently exist which are based on the same principle of operation as systems suited for macroscale measurements. In particular, these types of probing systems often utilize a probe in the form of a shank which

attaches a precision sphere on the end. As a result manufacturing complexities, the aspect ratio of these probes is small and operating frequencies are low, moreover adhesion related problems are usually difficult to overcome. During the previous annual conference, a novel probing methodology referred to as a standing wave force probe was presented and some experimental work was reported. The aim of this paper is to present measurements from this standing wave probe technique that has been integrated with a roundness measuring machine. As a result, accurate feature measurement of holes with diameters less than $100\ \mu\text{m}$ are demonstrated. Moreover, the holes are scanned with thousands of data points for circular trace to correspond to information with high UPR variations.

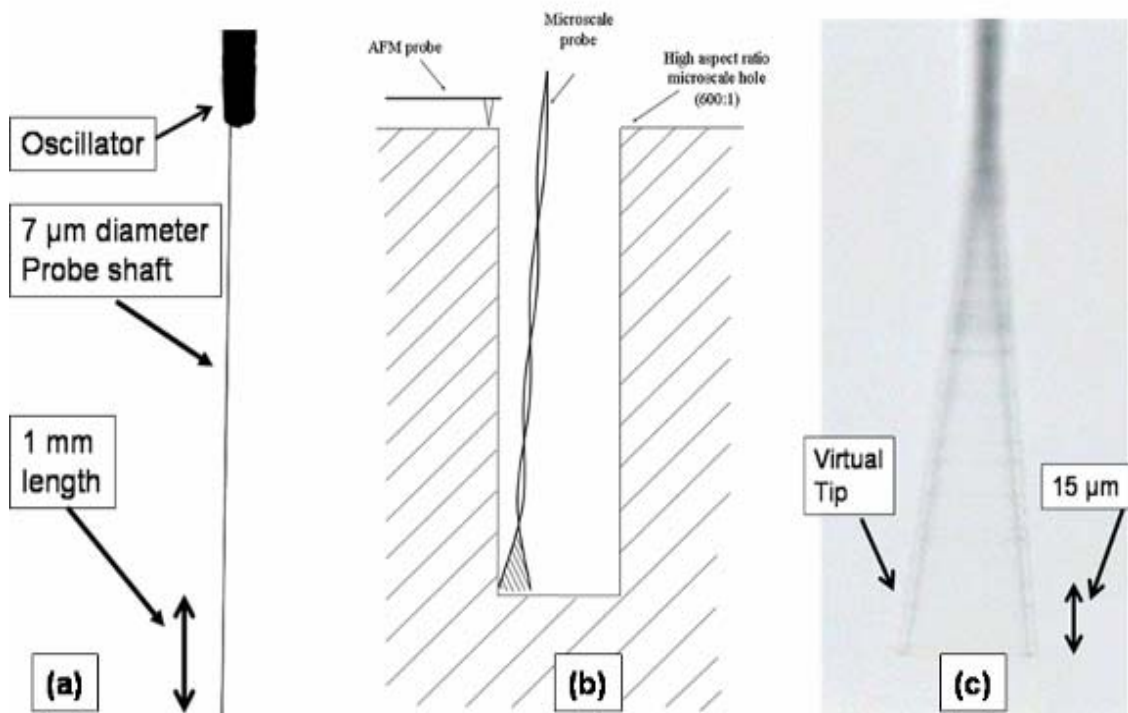


FIGURE 1. Illustrations of standing wave force probes

STANDING WAVE FORCE PROBES

The standing wave force probe uses a high aspect ratio (typically $> 600:1$) shaft which is mechanically bonded to an oscillator, Figure 1(a). The oscillator's resonant frequency which is currently operating at 32.76 kHz generates a forced response in the shaft, Figure 1(b). As shown, the single directional oscillation of the shank causes a point on the free end to move in a one dimensional locus. The amplitude of the oscillation located at the end of the shaft is a function of the amplitude of the signal applied to the tuning fork. Therefore, reducing or increasing the amplitude of the carrier wave to the tuning fork will result in a corresponding reduction or increase of the amplitude at the end of the fiber. Due to this characteristic behavior, this is referred to as a standing wave probe utilizing a virtual tip [1]. Moreover, as a result of the standing wave's inertia and intermittent contact, the mechanical contact interactions are not susceptible to attraction forces. A surface mount phase lock loop (PLL) circuit is employed wherein the tuning fork is locked onto a desired part of the characteristic response and the changes in frequency, phase, amplitude, or products thereof are measured. Once in contact, the PLL integrator signal changes the natural frequency to maintain a constant phase relationship. Typically, the frequency of the carrier signal is only changed by up to a few Hz during contact measurements and this is not currently monitored.

EXPERIMENTAL SETUP

A roundness gauge consisting of the standing wave microscale probes attached to scanning head in conjunction with a precision spindle was constructed and employed to perform experiments in order to investigate high aspect ratio microscale holes is shown in Figure 2. The scanning head uses constant force approach in controlling; therefore, the force probe is attached to the translator's carriage and the translator's actuator is used in closed loop control with the force gauge to maintain constant scanning forces. A displacement sensor located inside the translator monitors the displacement relative to a fixed frame [2]. This concept is the same as used in the profilometer of the previous reference except that the translator is connected, through slip rings, to a precision, custom air-free spindle that provides a rotational axis. The asynchronous radial error motion in

those experiments was in a region of ± 20 nm. Furthermore, the translator in the scanning head provides a single axis of motion along the radial direction of a workpiece. The roundness gauge assembly was retrofitted to Moore 1.5 measuring machine. As shown, a large scale precision spindle is retrofitted to the Z column and the scanning head is shown on the lower end of the spindle. The spindle houses a Heidenhain rotary encoder (ERN-120) with 16,348 TTL counts per revolution and is synchronized with the scanning head's displacement sensor. The spindle is rotated using an Aerotech frameless motor (S130-81) and linear amplifier (NL-drive). Custom slip rings are also designed and implemented to transfer electrical signals to and from the rotating scanning head.

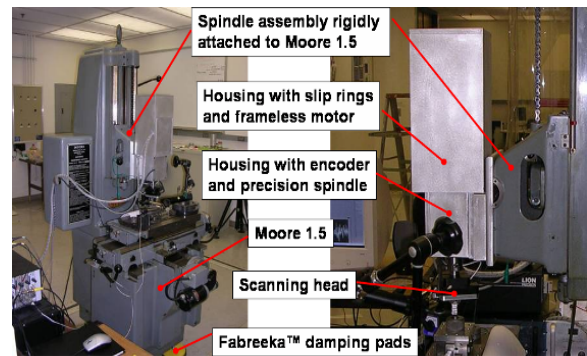


FIGURE 2. Experimental test stand using a Moore 1.5 and precision roundness gauge.

EXPERIMENTAL RESULTS

Form error measurements within a 128 μm hole.

As an artifact a glass ferrule made by Ozoptics Inc, Canada was chosen. The ferrule has a through hole with a diameter of 128 μm , and depth of several millimeters. In the following roundness measurement, the resulting data represents the combined radial and axial error motions that include the instrument spindle, hole's out-of-roundness, misalignments between axes of hole and spindle, electronic and mechanical system noise, and controller dynamic following errors. The glass ferrule hole was scanned at a constant applied force having a calculated value of 10-20 nN with a closed loop bandwidth of 20 Hz and approximately 14,000 data points were collected during one

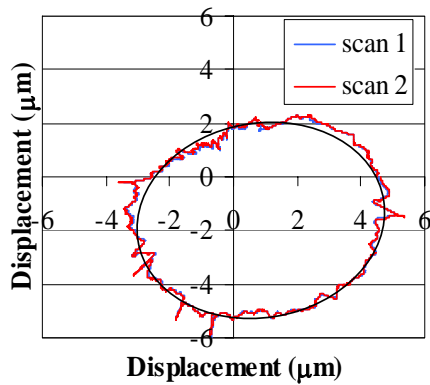


FIGURE 3. Form error measurements for the 128 μm diameter hole scanned twice.

revolution, Figure 3. The depth was set and limited to approximately 0.5 mm due to lack of automation in the setup and alignment. Local features such as those shown in Figure 4 are highly repeatable in a range of 30 nm and the observed local misalignments are mostly related to asymmetric radial error motion of the spindle as well as possible electrical drift of the probing system. The measurement shows a 1 μm out of roundness of the measured part the dominant component of which can be observed as a 2 UPR out of roundness. Additionally, local scratches and defects are observed thereby revealing surface finish which is difficult to measure by other microscale probing systems. The repeatability of long and short wavelength features clearly demonstrates the potential of this standing wave technology. Additionally, features as high as 10-15 nm can be repeatably observed on consecutive scans. Moreover, it is possible to measure even smaller workpiece diameters; however, an automated alignment system will be necessary and is anticipated in the near future.

Touch triggering.

Touch triggering is the most commonly used method in CMM technology for both macroscale and microscale applications. Therefore, it was important to investigate the standing wave probe's ability to additionally function as a touch trigger probe. To assess this, repeatability experiments were conducted where the probe was moved towards a surface until a specified trigger voltage was reached and the

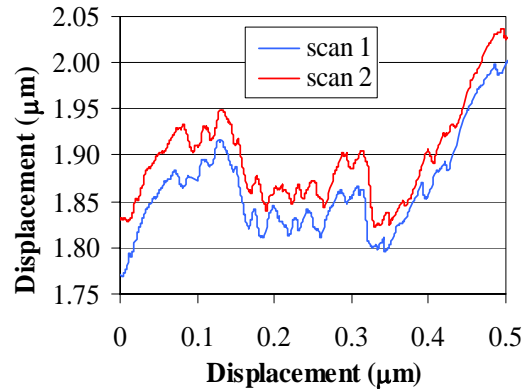


FIGURE 4. Zoom in of the scan for the 128 μm hole showing repeatability and resolution of local features.

corresponding reading from the displacement sensor located in the positioning mechanism was recorded. After 'contact', the probe was reversed until it was free from the surface of the specimen and the measurement then repeated, see Figure 5. As shown, 13 consecutive contacts and corresponding position at contact demonstrates a repeatability of ± 9 nm pk-pk. The time between the first and last contact measurement was approximately 6 minutes. This repeatability is expected to be a function mainly of mechanical drift of the metrology frame. The metrology loop in this experiment was greater than 2 meters. Additional uncertainties are due to electrical drift of electronics and exposed wires, and possible

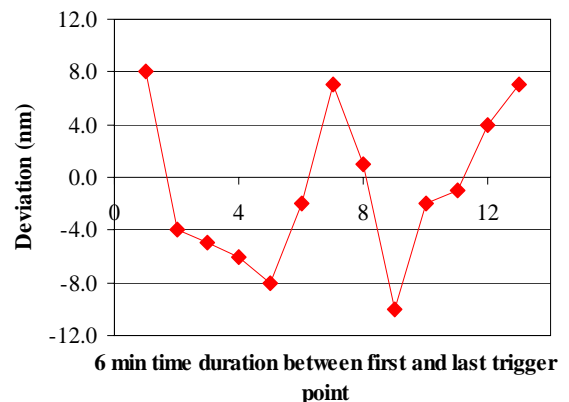


FIGURE 5. Touch trigger test as a function of the probe's sensitive oscillating axis. Note there was a 6 min. time duration between the first and last data point.

probe instability. Next steps for this research will involve designing a smaller metrology loop in the experimental setup with a significantly more compact gauge head and spindle assembly. As a result, higher repeatability is expected in future experimental results.

CONCLUSIONS

Since the space in proceedings is limited, for brevity, only two different measurements are presented. However a great number of experiments have been undertaken in an effort to establish the performance characteristics of this probe technology. Results from the tests will be presented at the conference and will include susceptibility to environmental factors (i.e. temperature and humidity), tip wear and repeatability.

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