

Measuring Internal Geometry of Fiber Ferrules

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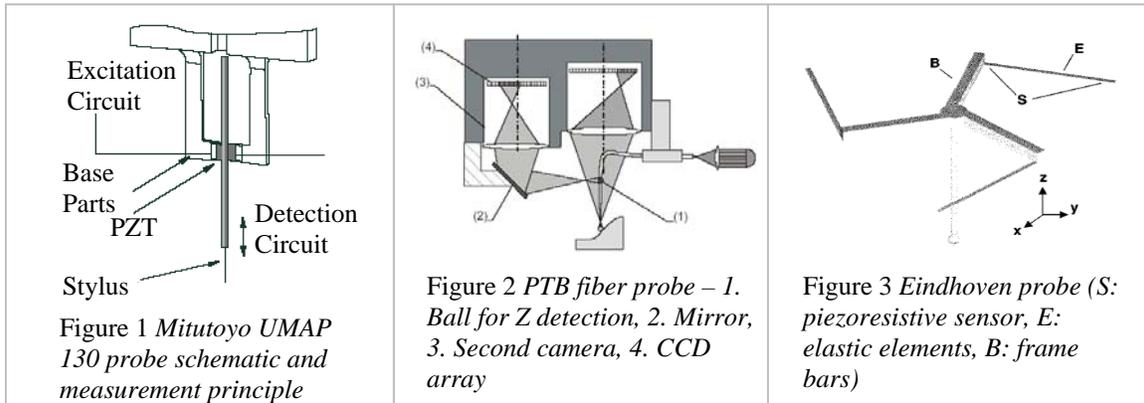
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1. Introduction

Dimensional measurement of deep aspect ratio micro holes is a challenge. Traditional Coordinate Measuring Machines (CMMs) are limited to measuring holes with diameters greater than about 300 μm . Measurement of smaller holes and Micro-Electro-Mechanical-Systems (MEMS) structures requires thinner styli and low probing forces. In this paper, we review recent developments in probing technologies for dimensional metrology of micro holes (approximately 100 μm diameter or smaller), found in applications such as fiber ferrules, ink jet printer cartridges, fuel nozzles, medical syringes, wire dies, etc. We also discuss ongoing work at the National Institute of Standards and Technology (NIST) to meet US calibration needs in this area.

2. Review of small hole/micro feature probing technologies

A variety of novel probing technologies have been reported in the literature for low force dimensional measurement of micro features. We review some of the technologies here.



Vibroscanning Probe The vibroscanning technology, reported by Masuzawa *et al.* [1], uses a vibrating micro probe that contacts an electrically conducting surface. Upon contact, the circuit comprised of the probe and the part closes, thus sending out a signal. The signal is intermittent as the probe is vibrating. The duration of contact with the surface in relation to the time for one period of probe vibration provides an index of proximity of the probe to the surface. Masuzawa *et al.* [2] refined this technique using a twin probe to measure non-conducting surfaces as well. The vibroscanning technology is capable of measuring 125 μm diameter holes with an accuracy of 0.5 μm .

Mitutoyo UMAPTM Mitutoyo Corporation's UMAP 130 [3,4] is a vision system retrofitted with a minute touch probe to also measure internal geometry of small holes.

The technology appears to be derived from the vibroscanning method. A small vibrating stylus contacts the surface, as shown in Fig. 1. The change in amplitude upon contacting a surface provides the signal necessary to detect contact. The probe stylus is 3 mm long, 10 μm in diameter with a 30 μm diameter ball at the end. The claimed repeatability is under 0.1 μm .

PTB/Werth Fiber Probe Physikalisch-Technische Bundesanstalt (PTB), Germany, has recently reported on the development of a fiber probing technique [5] with sub-micrometer uncertainties to measure holes of the order of 50 μm diameter. A thin fiber (15 μm diameter) with a ball (25 μm diameter) on the end is used as the probe. For measurements in the XY plane, light enters through the fiber and is incident on the ball at the end of the fiber (see Fig. 2). The back scattered light is imaged using a charge coupled device (CCD) camera. The clear advantage of this technique is that the position of the ball is directly observed, thus requiring minimal contact forces and eliminating any sensitivity loss. For z axis measurements, a second ball is attached to side of the fiber and observed by a second camera.

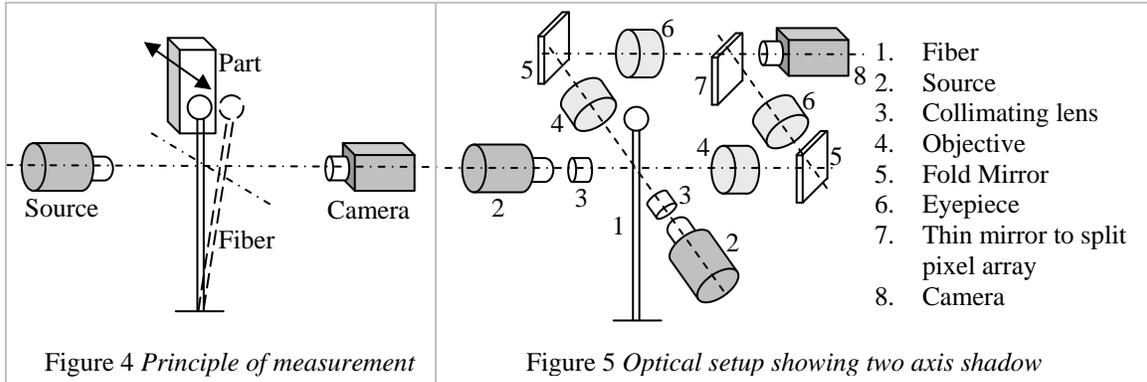
Eindhoven Probes Researchers at the Technical University of Denmark [6,7] have developed a variety of probes for low force dimensional measurement of microstructures. In Fig. 3, one design based on embedded piezoresistive sensors is shown. It is manufactured using silicon micro machining techniques. The probe stylus assembly is attached to the three silicon elastic elements with embedded piezoresistive material for sensing the deflection. From changes in resistance of the strain gages, it is possible to infer the deflection of the probe in three dimensions. The uncertainty obtained using this probe is estimated to be smaller than 0.1 μm .

NPL Microprobe National Physical Lab (NPL), UK, has recently developed a probe [8] based on silicon machining technique reported by researchers at Eindhoven. The tip ball diameter is 50 μm and it is mounted on a shaft of 30 μm diameter. The deflections of the stylus are detected by optical means. A diode laser shines light on the central island of the frame. Reflected light is focused onto a quadrant detector. Preliminary repeatability measurements are reported to be 0.2 μm .

While we have only reviewed a few technologies here, there are a number of other techniques reported in the literature. Wekenmann *et al.* [9] present a comprehensive review on probing technologies in dimensional metrology. In the next section, we present a summary of recent small hole probe development work at NIST.

3. Small hole probe development at NIST – the Fiber Deflection Probe (FDP)

In order to meet US calibration needs in the small hole/micro feature domain, we are currently developing a new micro probe, which we refer to as the Fiber Deflection Probe [10]. The measurement principle is shown in Fig. 4. A thin fiber (50 μm diameter, 20 mm long), with a microsphere (75 μm diameter) bonded at the end, serves as the probe. The deflections of the probe upon contacting a surface are detected by optically imaging the stem, a few millimeters below the tip of the ball.



In order to detect the motion of the fiber stem in both X and Y , the stem is illuminated from two orthogonal directions in a plane perpendicular to the fiber axis, at about 5 mm below the tip of the ball, as shown in Fig. 5, and the resulting shadows are imaged using objectives and a camera. Upon contact with a test surface, the fiber deflects and also bends. By determining the position of the fiber in the deflected state and also in the free state, and using a previously determined calibration factor (in units of $\mu\text{m}/\text{pixel}$), we can correct the machine's final coordinates to determine surface coordinates.

Key advantages/features of our method are

- Capability to measure 100 μm diameter holes to a depth of approximately 5 mm
- Large over travel protection of about 1mm before probe damage in X and Y
- Extremely small measurement uncertainty of 0.07 μm ($k = 2$) on diameter
- Probes manufactured in house and are inexpensive and easy to replace
- Low contact forces (0.5 μN) to prevent part damage

Fig. 6 shows a screen shot of the fiber stem as imaged by the microscope and camera. The fiber acts as a cylindrical lens that focuses light into a bright band. This band provides a very sharp fiducial line running down the center of the fiber. The size of the band is limited by diffraction of our optics. When using a special test bed, we can measure displacements of the fiber below the 10 nm level, but additional sources of noise and drift degrade performance when the probe is mounted on a CMM.

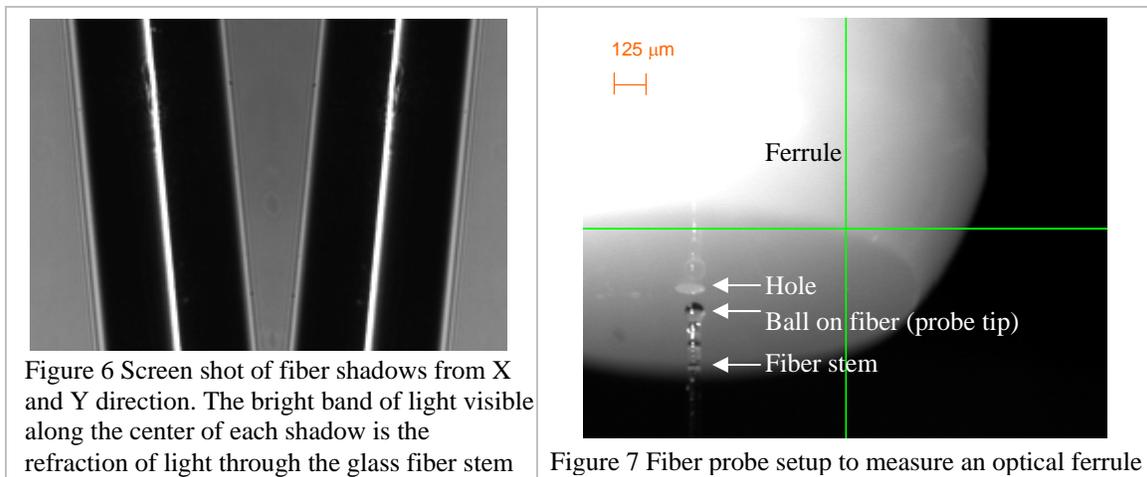


Fig. 7 shows the fiber probe setup to measure a 129 μm hole in a fiber optic ferrule. The large object in the picture is the ferrule. The probe is the small transparent object extending upward toward the hole in the ferrule. At present this orientation is our standard method of operation: the object to be measured (which is usually very small) is mounted on the moving ram of the CMM, while the probe is mounted on the bed of the CMM.

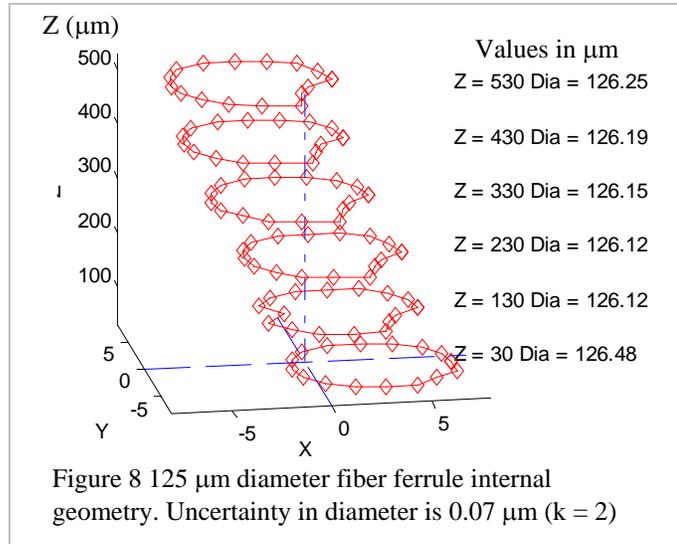
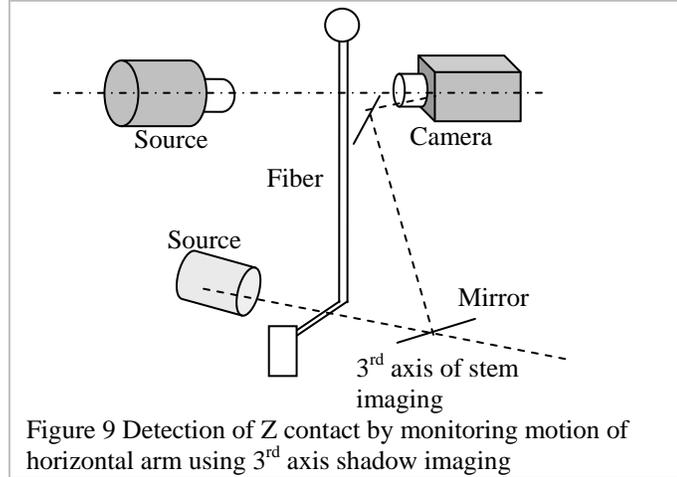


Fig. 8 shows preliminary measurement results from a fiber ferrule hole. Six traces are measured over a total depth of 0.5 mm. The visible tilt is due to misalignment of ferrule with machine's axis. Also, a small dimple is visible in all traces except at the lowest level, which we believe is the result of the stem contacting the surface instead of the tip ball. This problem is currently being addressed by mounting the fiber on a two-axis goniometer to adjust its tilt. The ferrule will also be mounted on a two-axis goniometer on the ram of the machine to align its axis with that of the fiber.



We are currently considering various options for extending the capability of our fiber probe to full 3D, so as to measure the complete geometry of blind holes. Using our existing setup, we can determine Z location to within 0.1 micrometer using a technique that is still under development but will be described in the near future. A different approach involves using a bent fiber to allow free motion along the axis of the fiber, as shown in Fig. 9. We have explored this option in preliminary experiments on a test bench and have obtained one standard deviation linearity errors of the order of 30 nm.

4. Conclusions

Dimensional metrology of small holes and micro features requires novel probing technologies with low contact forces. We have reviewed some of the promising technologies and commercial products. Also, we have summarized probe development efforts at NIST to meet the calibration needs of the US industry in this area. Our novel

fiber probe can measure the internal geometry of deep aspect ratio micro holes with extremely small uncertainties.

5. References

1. T. Masuzawa, Y. Hamasaki and M. Fujino, Vibroscanning method for nondestructive measurement of small holes, *Annals of the CIRP*, 42, 1993, 589-592
2. T. Masuzawa, B. J. Kim, C. Bergaud, M. Fujino, Twin-probe vibroscanning method for dimensional measurement of microholes, *Annals of the CIRP* 46/1/1997, 437-440
3. Commercial equipment and materials are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.
4. <http://www.mitutoyo.com>
5. H. Schwenke, F. Waldele, C. Weiskirch, H. Kunzmann, Opto-tactile Sensor for 2D and 3D Measurement of Small Structures on Coordinate Measuring Machines, *Annals of the CIRP* 50/1/ 2001, 361-364
6. H. Haitjema, W. Pril, P.H. J. Schellekens, A Silicon-Etched Probe for 3-D Coordinate measurements with an Uncertainty Below 0.1 μm , *IEEE Transactions on Instrumentation and Measurement* 50 (6) December 2001, 1519-1523
7. H. Haitjema, W.O. Pril and P.H. J. Schellekens, Development of a Silicon-based Nanoprobe System for 3-D Measurements, *Annals of the CIRP* 50/1/2001, 365-368
8. R. K. Leach, J. Murphy, The design of a co-ordinate measuring probe for characterising truly three-dimensional microstructures, *Proc. of 4th euspen International Conference- Glasgow, Scotland (UK), May-June, 2004*
9. A. Weckenmann, T. Estler, G. Peggs, D. McMurthy, Probing systems in dimensional metrology, *Annals of the CIRP*, 53/2/2004, 1-28
10. B. Muralikrishnan, J. Stone, S. Vemuri, C. Sahay, A. Potluri, J. Stoup, Fiber deflection probe for small hole measurements, *Proceedings of the ASPE Annual Meeting, 2004, 24-27*