Study of a capacitive sensing technology for the measurement of perpendicularity of narrow-deep slot-walls in precision molds

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Abstract

This paper presents a novel approach to slot-wall measurement in precision molds. The method measures the perpendicularity of slot-walls in the hard to measure very narrow and deep slots in precision molds. A tabletop hybrid measurement centre combining micro-wire electrical discharge machining (w-EDM) with automatic optical inspection (AOI), and capacitive sensing (CS) is developed. Microprobes are machined using micro w-EDM on the measurement centre. AOI facilitates the designed machine vision system to acquire images from the mold's features. These images are binarized for recognition, which helps the microprobe speedy position into the contour. Capacitive sensing, by which a signal with very low voltage and high frequency is employed between the probe and slot-wall, is conducted for precise detection of perpendicularity. A four-step probe feed approach is proposed for improved measurement accuracy. The technical feasibility of capacitive sensing was experimentally confirmed.

1. Introduction

The trend toward thinner, light weight, consumer electronics of small volume and high functionality continues to place high demands on manufactures' ability to find cost efficient, effective tools for the manufacture of ever-smaller parts. Micro measurement, for example, requires the development and fabrication of special measurement tools. Measurement technologies, such as the coordinate measuring machine (CMM), have long been incorporated in the manufacturing process [1, 2]. Typically, a CMM employs a variety of styli to perform contact measurement using pressure sensors that ensure maximum measurement accuracy. However, contact measurement is very difficult to use when measuring the geometrical features of micro-contours needs to be within tens of micrometres, especially the deep, narrow-slots and holes of machine parts. In these cases, probe size, contact forces (between the probe and measured surface), and the oxide layer of the measured object are all important issues, which may affect measurement accuracy. In consideration of these limits, a tabletop hybrid measurement centre, offering non-contact measurement of the deep, narrow-slot-walls of molds, is constructed (Fig. 1). The closed-loop measurement system is equipped with three translation linear stages (X-, Y- and Z-axis) and has a resolution of 20 nm. Micro w-EDM is used *in situ* to produce appropriately shaped micro-probes. AOI is then used to gather visual information on contour features to save-time for positioning the probe. In this study, fabrication of various microprobes is conducted (Fig. 2) and the resultant measurement voltages and frequencies evaluated.

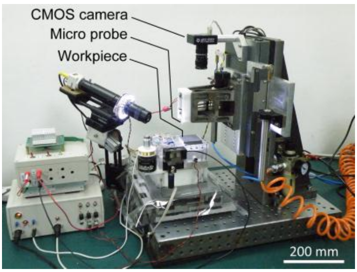

Fig. 1 The hybrid measurement centre

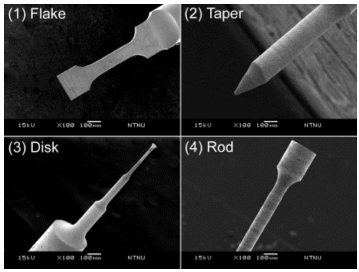

Fig. 2 Finished various microprobes

2. Methodology

To produce the desired microprobe, a WEDG (Wire Electrical Discharge Grinding) mechanism [3] is designed and employed *in situ* on the measurement centre. Using WEDG, a flake-shaped probe, which can be safely dipped into a deep, narrow-slot of 100 μm in width, is machined down to a thickness of 30 μm (Fig. 3). The finished microprobe does not need to be unloaded. It is directly moved into an alcohol tank for cleaning with ultrasonic vibration. Capacitive sensing uses a signal of very low voltage and high frequency. As the microprobe passes through the capacitance area the position of objects can be precisely detected. The capacitor is composed of a pair of conducting parallel-plates that are close to one another but not in contact. An ideal capacitor is described by a single constant value for its capacitance (***C***) (charge ratio). Capacitance is a function of the distance between the two plates (***d***), the area (***A***) of the plate (i.e. the flake-shaped microprobe), and a constant (***k***) of the dielectric which fills the space between the plates. It is postulated that 'epsilon (***ε***)' is the permittivity constant of the dielectric. Capacitance can be expressed as:

$$C = \frac{k\varepsilon_0 A}{d} \tag{1}$$

As shown in Fig. 4, signals in the frequency spectrum can be easily detected as the probe passes through the capacitance area. The strength of the frequency spectrum signal increases as $\boldsymbol{d}$ lessens. As $\boldsymbol{d}$ approaches zero the signal is very strong. The frequency spectrum at both terminals of the capacitor is defined as the 'Real-time frequency spectrum $\boldsymbol{dB_R}$'. In so doing, constant detection of $\boldsymbol{dB_R}$ can be used as a parameter for the measurement of distance. Measured $\boldsymbol{dB_R}$ can be compared with a predetermined benchmark frequency spectrum $\boldsymbol{dB_C}$. The perpendicularity of the deep, narrow-slot-wall can thus be obtained. Since the finished microprobe is not unloaded, the geometrical accuracy of the machined microprobe can be kept within the positional accuracy of the measurement centre (< 3 μm).

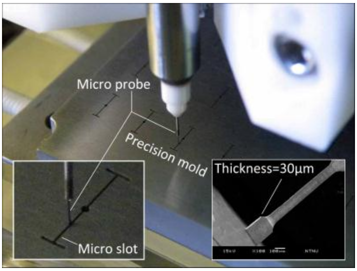

Fig. 3 The measurement arrangement

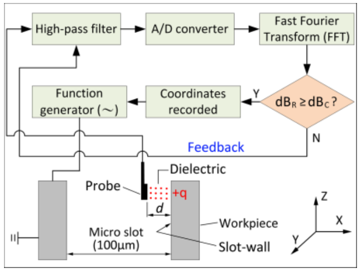

Fig. 4 Proposed capacitive sensing

3. Verification

To ensure the microprobe fits neatly into deep, narrow-slots without touching their edges, images showing mold contour features are acquired and previewed before the microprobe is used. This information determines the coordinates needed for the probe to enter the narrow-slot unimpeded. Previewing is done via an on-machine AOI system using image binarization, edge detection, and image-centre determination. This process allows the probe to recognize the features of each slot. For improved measurement accuracy, a four-step feed (10, 1, 0.1, 0.02 μm/step) method is used during the probe scanning (Fig. 5). Experimental results indicate a measuring voltage of 0.5 V is best for supplying power between the inter-electrodes. The corresponding measurement frequency is 50 KHz. An actual example of perpendicularity measurement of a deep, narrow-slot-wall in an IC lead frame mold is successfully accomplished (Fig. 6). As a non-contact measurement method is used, measurement accuracy is not affected by the oxide layer on the work-piece.

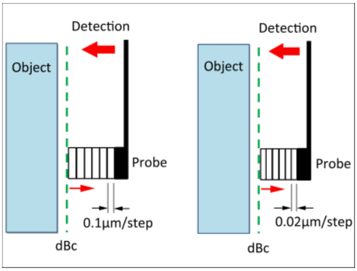

Fig. 5 Proposed four-step probe feed

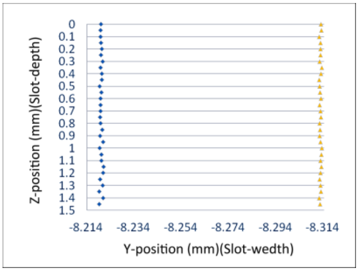

Fig. 6 Measurement results

4. Conclusions

A precision capacitive sensing technique for the measurement of perpendicularity in the fiddly slot-wall of precision molds is successfully developed in this study. A closed-loop tabletop measurement centre was designed and employed. Approaches for fabricating the high precision microprobe on-machine by micro w-EDM and imaging to determine the image center of contour features to help the microprobe enter micro-slots unimpeded are proposed and implemented. Perpendicularity measurement in a deep, narrow-slot 100 μm in width was successfully performed. Due to the positioning accuracy of the used translation stages, measurement centre error is less than 3 μm. The proposed approach could be extended to submicro- and even nano-scale measurement in particularly small holes and slots. It is expected that the results of the study will contribute substantially to precision micro fabrication applications.

Acknowledgments

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