Microelectronics Reliability xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Development of a capacitive sensing technology for the measurement of perpendicularity in the narrow, deep slot-walls of micromolds

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ARTICLE INFO

Article history:
Received 10 January 2017
Accepted 27 March 2017
Available online xxxx

Keywords:
Narrow deep slot-wall
Capacitive sensing technology
Hybrid measurement-center
Automatic optical inspection-assisted technique

ABSTRACT

This paper presents a novel approach to narrow, deep slot-wall measurement in micromolds. A tabletop hybrid measurement-center combining micro spark erosion and automatic optical inspection technique (AOI) with Capacitive Sensing (CS) technology is developed for measuring the perpendicularity of slot-walls in the very narrow and deep slots of precision molds. A microprobe is machined *in-situ* using micro wire spark erosion while the AOI system acquires images to help fast position the completed microprobe precisely over the narrow slot to be measured. Capacitive sensing with a high-frequency, low-voltage electric signal is employed between the probe and slot-wall to precisely sense the perpendicularity of the wall. A four-step probe feed approach is utilized to improve measurement accuracy. The technical feasibility of capacitive sensing technology is experimentally confirmed.

1. Introduction

The trend toward diminutive consumer electronics of high functionality places increased demands on manufactures to find cost efficient ways of producing ever-smaller yet effective 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 [4,7]. 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 as measurement accuracy needs to be within tens of micrometers. Moreover, pseudo contact between styli and workpiece occurs once the oxide layer exists on the workpiece [3], which may lead to worsened measurement accuracy and styli wear. Optical measurement can capture clear images of a feature's profile at the surface of a workpiece. However, it is also difficult if not impossible to measure surface topography from the Z-axis direction. Giving consideration to both the pressure sensor and measurement accuracy, a tabletop hybrid measurement-center combining micro spark erosion, Automatic Optical Inspection technique with Capacitive Sensing (CS) technology is developed in this study. The microprobe is machined *in-situ* using micro spark erosion. Capacitive sensing offers non-contact measurement of micromolds with high aspect ratio slot-walls. Verification of perpendicularity in the narrow, deep slot-wall of micromolds is achieved successfully by the proposed capacitive sensing technology.

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2. Methodology

To avoid the microprobe and workpiece being unloaded and repositioned repeatedly, an '*in-situ* technique' that combines micro spark erosion with micro measurement at the measurement-center is proposed. The microprobe and workpiece are not unloaded, reloaded or readjusted until all the tasks are completed, maintaining machining and measurement accuracy. The microprobe is formed using micro spark erosion (*i.e.* micro wire electric discharge machining) at the measurement-center (Fig. 1(a)). The temperature between the wire-electrode and workpiece (microprobe) can reach as high as 8000–12,000 °C [6] during spark erosion. To stabilize movement of the brass wire during machining, a SKD11 disk guide on which a precise V-groove is made around the circumference of the guide is designed to ensure accurate leading of the brass wire [1]. Micro rectangular-shaped notches designed at the front edge of the guide provide for machining different sized microprobes. To ensure the wire is in tight contact with the V-groove, a set of permanent magnet tensioning brake is employed along the axial direction of the wire. The finished microprobe moves into an ultrasonic cleaning tank for cleaning at the measurement-center. Capacitive sensing technology using an electric signal of very low-voltage and high-frequency is conducted *in-situ* (Fig. 1(b)). As the signal passes through the capacitance area the position of the slot-wall can be precisely sensed. 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 microprobe), and a constant (k) of the dielectric which fills the space between the plates. It is postulated that 'epsilon (ε_0)' is the

http://dx.doi.org/10.1016/j.microrel.2017.03.029
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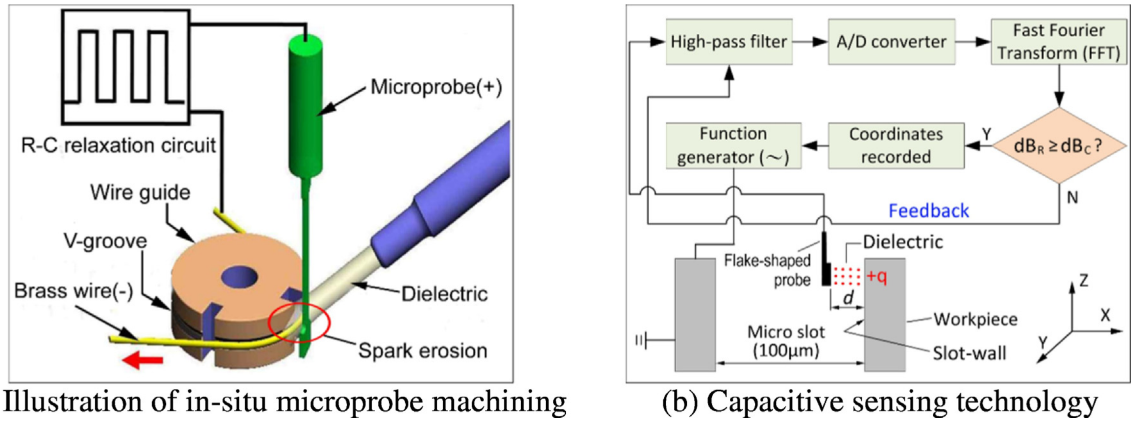

Fig. 1. Proposed methodology. (a) Illustration of *in-situ* microprobe machining. (b) Capacitive sensing technology.

permittivity constant of the dielectric. Capacitance can be expressed as:

$$C = \frac{k \times \varepsilon_0 \times A}{d} \quad (1)$$

Signals in the frequency spectrum can be easily sensed when the probe passes through the capacitance area. The strength of the frequency spectrum signal increases as (d) lessens. As (d) approaches zero the signal is strongest. The frequency spectrum at both terminals of the capacitor is defined as the 'real-time frequency spectrum dB_R'. In so doing, constant detection of dB_R can be used as a parameter for the measurement of distance. Measured dB_R can be compared with a predetermined benchmark frequency spectrum dB_C. The measured data are converted to digital data, and then transferred into the frequency domain from the time domain *via* Fast Fourier transform (FFT) to regulate the feed of the probe and record positions. The perpendicularity of deep, narrow slot-walls can thus be measured. Since the finished microprobe is not unloaded, the geometrical accuracy of the machined microprobe can be kept within the positional accuracy of the measurement-center (<3 μm).

3. Experimental apparatus

To realize highly precise measurement of perpendicularity in the narrow, deep slot-walls of micromolds, a closed-loop measurement-center encompassing three linear axes (X-, Y- and Z-axis), resolution of 20 nm, and positional accuracy of 3 μm is designed and built (Fig. 2(a)). Using

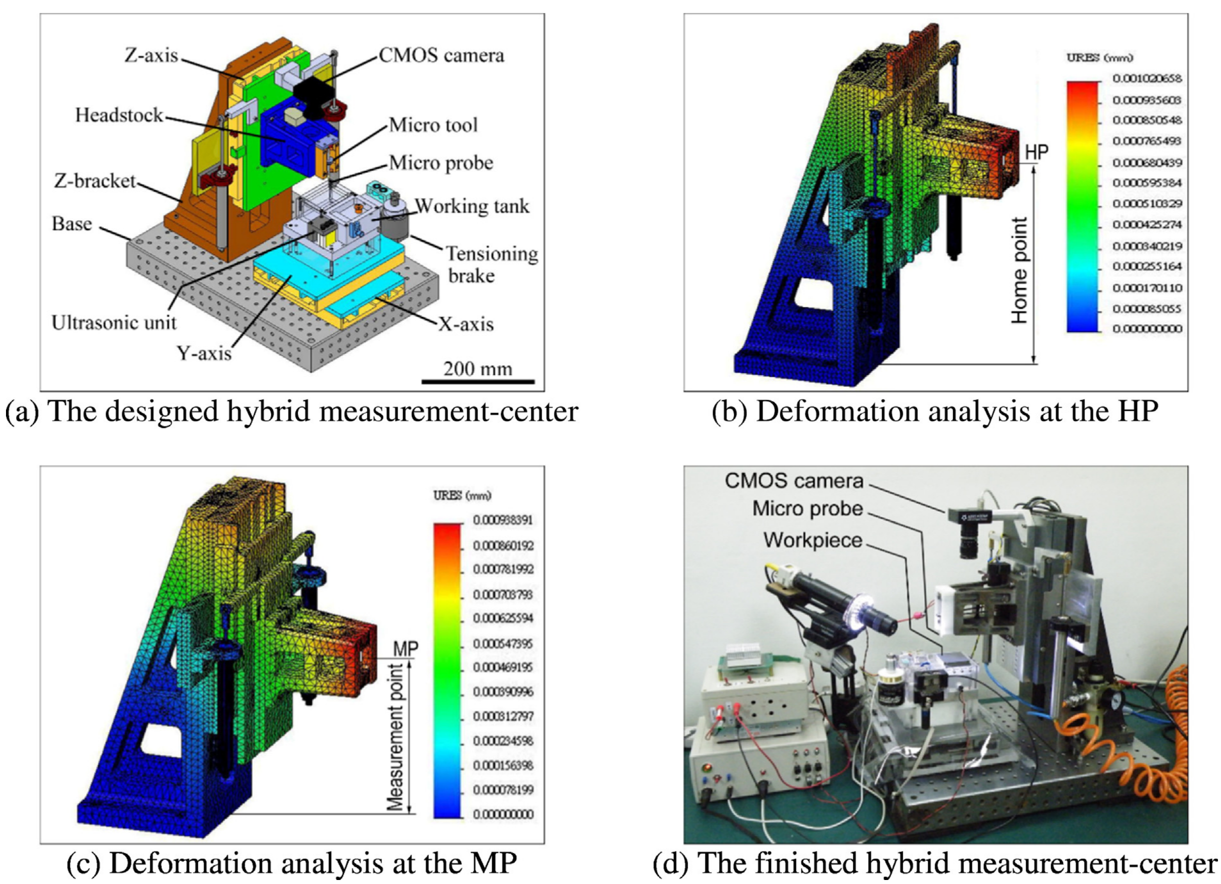

Fig. 2. Developed hybrid measurement-center. (a) The designed hybrid measurement-center. (b) Deformation analysis at the HP. (c) Deformation analysis at the MP. (d) The finished hybrid measurement-center.

Please cite this article as: S.-T. Chen, S. Lin, Development of a capacitive sensing technology for the measurement of perpendicularity in the narrow, deep slot-walls of micromold..., Microelectronics Reliability (2017), http://dx.doi.org/10.1016/j.microrel.2017.03.029