Touch-trigger measurement of micro-cavity by optical fiber coupling

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Abstract

In order to measure the geometric dimension of a micro-cavity, a touch-trigger measurement method is proposed, in which, the light coming from the incident optical fiber is transmitted in the reversal direction via the optical fiber coupling into the effluent optical fiber, the lateral displeacement of the touch-trigger sensor is transformed into the deflexion of light coming out from the effluent optical fiber, and the deflexion is transformed into an image signal by the object lens and CCD capturing system. The effectiveness of the proposed method is verified through experiments. Experimental results indicate that the proposed method can be used to measure the geometric dimension of a micro-cavity. A blind hole of 1.5mm deep and about 0.2mm in diameter is measured with the touch-trigger sensor and self-developed micro-hole diameter measuring machine with a repeatability uncertainty of less than 0.2μm.

Keywords: Measurement of micro-cavity, optical fiber coupling, reversal transmission

1. Introduction

With the fast development of manufacturing technologies in space and national defence industries, more and more micro-cavities with base dimension ranging from hundreds to several μm are widely used in different fields. For instance, the grooves with several tens μm and aspect ratio up to 40:1 in space engine are appearing, and their dimensional precisions determine the performance of the space engine. How to measure the dimension and form of a micro-scale structure has become one of the major research subjects in the field of measurement and instrument [1], and the conventional methods can not be used to fulfil the tasks. In recently teens years, scholars have proposed some methods based on different theories. For example, Japanese scholars reported the vibroscanning method used for nondestructive measurement of a micro hole of 1.0mm deep and of about 0.2mm in diametersmall holes [2]. The scholars of Tianjin University and Physikalisch-Technische Bundesanstalt used single optical fiber with micro-contact force to measure a micro hole of 1.0mm deep and of about 0.2mm in diameter [3~4]. B. Muralikrishnan presented the fiber deflection measurement method in 2004, and used it to measure a micro hole of 0.5mm deep and of 0.129mm in diameter [5~7]. These methods meet the needs of some applications with their special needs. But they have the following weaknesses, low measurement precision with less then 1μm, and inevitable influence caused by extraneous component and sentus inside a micro-cavity. Therefore we present a micro-cavity touch-trigger measurement method in which, the light coming out from the incident optical fiber is transmitted in reversal direction by optical fiber coupling, the lateral displacement of touch-trigger sensor is transformed into the deflexion of light coming out from the effluent optical fiber, and the deflexion is transformed an image signal by the object lens and CCD capturing system.

2. Touch-trigger theory of optical fiber coupling

As shown in Fig. 1, the touch-trigger sensor mainly consists of incident optical fiber, coupler and effluent optical fiber, and its probe can be inserted into the micro-cavity. The light focuses through the optical coupling lens, enters the coupler through the incident optical fiber, and comes out in reversal direction through the effluent optical fiber. The lateral displacement of the sensor is then transformed into the deflexion of light coming out from the effluent optical fiber, and then the deflexion is transformed into an image signal by the object lens and CCD capturing system. During the image processing, a multiscale generalized mathematical morphological filtering with multiple structuring elements algorithm is used to eliminate noise in the image, OFMMs is used to location the image edge with subpixel precision, and the center position of light energy coming out from the effluent optical fiber is obtained. According to the relationship between the center position of light energy and the position of the touch-trigger in the cavity, the dimension measurement of micro-cavity is achieved.

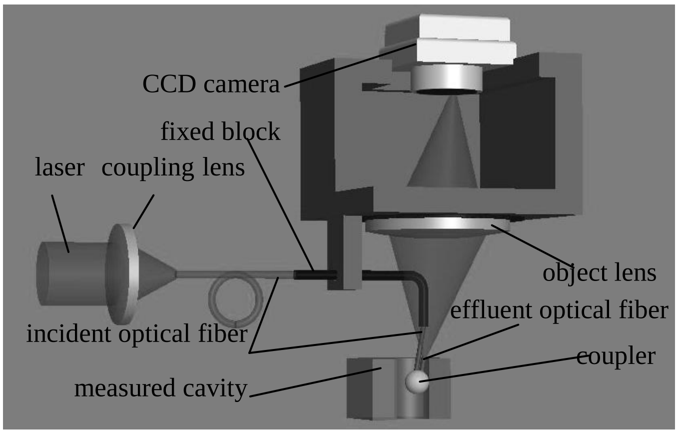

Fig. 1. Optical setup for optical fiber coupling measurement.

The minimal dimension of micro-cavity depends on the dimension of optical fiber and coupler, and may go down to a range of 10μm ~20μm. During the measurement, the functions of the detecting and sensing fibers are separated to ensure the depth of measurement. And the method is easy to measure not only the dimension and form of micro-cavity, but also the relative position between different micro-cavity in a particular or compound.

3. Multiscale generalized morphological filtering algorithm

Mathematic morphological filtering algorithm is based on the geometric construction of an image, the defined structuring element can be used to match or reverse image, and the characteristic information of image can be obtained through the structuring element, or the noise is eliminated. However the detail of the image will be lost if only one type structuring element is used in the image processing. So a morphological filtering algorithm with multiple structuring elements is used to eliminate the noise in the image.

If $f(x,y)$ is the digital image defined in the 2D digital space Z^2, where Z is the assemble of integer, $B(k,l)$ is the structuring element defined in the Z^2 subset, that is, $B(k,l) \subset Z^2$. Then the dilation and erosion of morphological can be defined as shown below:

$$(f \oplus B)(x,y) = \max_{(k,l)\in B}[f(x-k,y-l)+B(k,l)] \quad (1)$$

$$(f \ominus B)(x,y) = \min_{(k,l)\in B}[f(x+k,y+l)-B(k,l)] \quad (2)$$

If $B_i(k,l)(i=1,2,\cdots,n)$ is the structuring element, j is the filtering scale, $B_{i,j} = B_i \oplus B_i \oplus \cdots \oplus B_i$ is j order dilation of the structuring element $B_i(k,l)$, and the open and close filtering algorithms are defined:

$$(f \circ B_{i,j})(x,y) = [(f \ominus B_i) \oplus B_i](x,y),(j=1,2,\cdots,m) \quad (3)$$

$$(f \bullet B_{i,j})(x,y)=[(f \oplus B_i)\bigcirc, -B_i](x,y),(j=1,2,\cdots,m) \quad (4)$$

If the normal structuring element is used to eliminate the noise, some detail information of the image will be lost. So the scale of the structuring element must be calculated using the mean value of the multiscale accumulative value, and the multiscale generalized morphological filter with multiple structuring elements $\overline{F}(x,y)$ is presented as following:

$$\overline{F}(x,y)=\frac{1}{n}\sum_{i=1}^{n}\frac{1}{m}\sum_{j=1}^{m}\frac{1}{4}[(f\circ B_{i,j-1})\bullet B_{i,j}+(f\bullet B_{i,j-1})\circ B_{i,j}+ (f\circ B_{i,j})\bullet B_{i,j-1}+(f\bullet B_{i,j})\circ B_{i,j-1}] \quad (5)$$

Filter $\overline{F}(x,y)$ can be used to eliminate the noise whose size smaller than the dimension of structuring element, and can preserve the detail information of image. In this paper, the structuring elements is the three points linear multiple in 3×3 region, as shown in Fig. 2, and the characteristic of the presented multiscale generalized morphological filter with multiple structuring elements is space invariance, preserving the detail information of the image, simple calculation, and parallel processing.

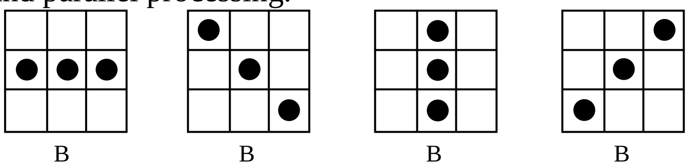

Fig. 2. Multiple structuring elements of morphological filters.

4. Experiment

The prototype touch-trigger sensor has been developed as shown in Fig. 3, and the probe of the sensor is shown in Fig. 4. The performance of the touch-trigger sensor is examined through some experiments, and it is used to measure the diameter of a micro-hole with self-developed micro-hole diameter measuring machine together according to the Calibration Specification for Micro-hole Diameter Measuring Machine with numbering JJF(HEI)7-2008.

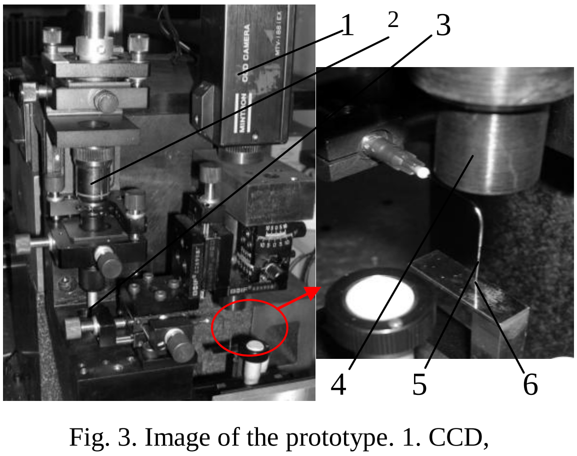

Fig. 3. Image of the prototype. 1. CCD, 2. Coupling lens, 3. Incident optical fiber, 4. Object lens, 5. Effluent optical fiber, 6. Measured hole.

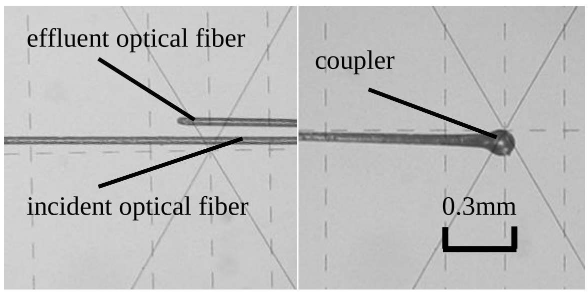

Fig. 4. Image of the probe.

The sensor is fixed on the basic shaft of micro-hole diameter measuring machine, and the output of the sensor is sampled to verify its drift in different time range. Fig. 5 and 6 are the drift curve of the sensor in 200s and 30 minutes for short and long time. From Fig. 5 and 6 we can know that the drift of the sensor is less than 0.08μm in 30 minutes.

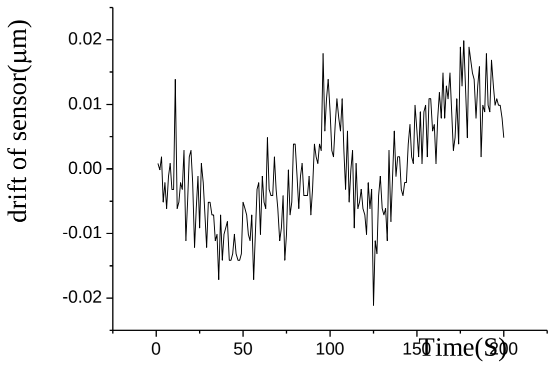

Fig. 5. Drift curve of the sensor in short time.

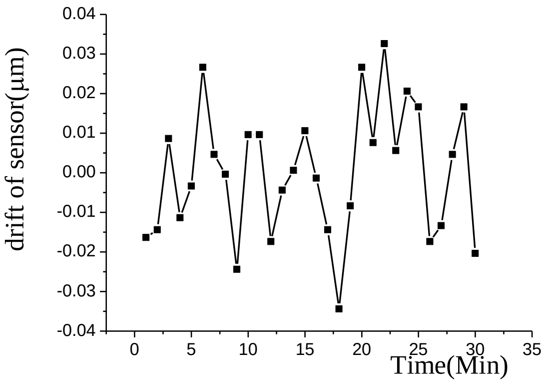

Fig.6. Drift curve of the sensor in long time.

The touch-trigger sensor is moved in the machine to touch the sidewall of micro-cavity to verify the trigger repeatability of the sensor. During the experiment, the micro-cavity is immovable, the touch-trigger sensor moves in X axis direction of the machine, and its displacement is recorded by the machine. The trigger location can be extrapolated by fitting the different position of sensor displacement and center position of light energy coming out from effluent optical fiber, as shown in Fig. 7. The same sidewall of micro-cavity is aimed 8 times, and the trigger positions are shown in Table1 which shows the trigger repeatability is less than 0.06μm.

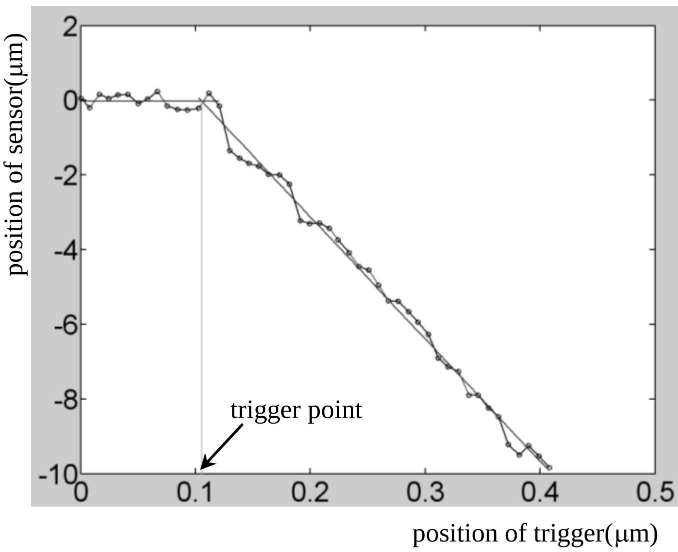

Fig. 7. Point-by point data from coupler deflections to extrapolate the trigger point.

Table 1. Experiment results of trigger position.

Trigger time	1	2	3	4	5
Trigger position(μm)	0.084	0.083	0.129	0.195	0.032
Trigger time	6	7	8	9	10
Trigger position(μm)	0.166	0.094	0.25	0.167	0.135
Mean(μm)	0.133				
Repeatability (μm)	0.06				

The diameter of a micro-hole special manufactured is measured using the touch-trigger sensor. The diameter of the hole is about 0.2mm, and it is manufactured on a gauge block with depth 2.0mm. When the hole is measured, one end of the hole is stopped, and thus it is formed as a blind hole. The measurement is made in the blind hole. The gauge head of the sensor is inserted the inner of the blind hole about 1.5mm, and the diameter measurement is made in the cross section. The measurement is repeated 10 times, and the measured values are shown in Table 2. It can be seen from the table 3 that the touch-trigger sensor can be used to measure the diameter of micro hole with self-developed micro-hole diameter measuring machine together with a repeatability uncertainty of less than 0.2μm.

Table 2. Experiment results of diameter measurement.

Measurement time	1	2	3	4	5
Trigger position(μm)	194.65	194.21	194.19	194.24	194.45
Measurement time	6	7	8	9	10
Trigger position(μm)	194.67	194.33	194.51	194.17	194.37
Mean(μm)	194.39				
Repeatability (μm)	0.18				

5. Conclusion

One micro-cavity touch-trigger measurement method is presented in which the light coming out from the incident optical fiber is made to transmit in the reversal direction via the optical fiber coupling, the lateral displacement of the sensor is transformed into the deflexion of light coming out from the effluent optical fiber, and the center position of the light energy is obtain through OFMMs algorithm with subpixel precision by analyzing the location error caused by OFMMs and compensation algorithm proposed. The method solves the problem of "barrier" when the gauge head inserted into the micro-cavity. With the self-developed micro-hole diameter measurement machine together, the touch-trigger sensor fulfils the task of diameter measurement of a blind hole of 1.5mm deep with a diameter of about 0.2mm with repeatability less than 0.2μm. The developed method comprehensively utilizes the rapidity and high precision of opitcal method and the reliability of mechanical method, and it is one solution of micro-cavity geometric dimension measurement.

6. Acknowledgements

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