Feasibility Study of the Formation of Micro Spherical Probes with Optical Fibbers

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Abstract

The paper will discuss the feasibility of manufacturing of a 3D micro probe using the cleaning function of a commercial fibber fusion splicer. By utilising the arc discharging energy and the surface tension of the melting optical fibber a micro sphere is formed at the tip of the optical fibber. Experimental results have shown that a spherical probe tip with about 300 micrometer in diameter could be formed using a 125 micrometer diameter single-mode optical fibber and the roundness for the tip is about 5 to 6 micrometer. The offset distance between the centre of the spherical and the fibber central line due to the gravity is less than 3 micrometer. This new approach can shorten dramatically the manufacturing lead-time of making a 3D micro probe and can overcome the difficulty of making complicated 3D structure associated with the MEMS approach. The micro probe can be used for micro/nano-scale coordinate measuring machines (CMMs) to enhance the measurement accuracy and resolution.

1. Introduction

Ultrahigh precision 3D surface measurement technologies have been paid so much attention in research during the last ten years. Although many 1D nano-scale measurement systems have been developed and commercialised successfully. However for macro/nano-scale 3D geometric measurement, the system design and integration has become so important, and the development of micro/nano-scale 3D CMM has thus emerged as a new research area due to the need of measuring micro parts [1]. This kind of CMMs requires higher measurement accuracy and resolution than conventional macro-scale 3D CMMs. The design and manufacturing of the micro touch trigger probe becomes one of the critical factors to achieve the measurement accuracy.

For most of the existing probes used in 1D measurement systems, they are manufactured by using micro-electro-mechanical-systems (MEMS) processes. However, these MEMS processes can only process semiconductor materials and are unable to make 3D spherical probes. Other approaches using computer numerical control (CNC) through a layer by layer machining method to manufacture complex 3D parts and micro probes have been reported in research articles [2, 3] but they are quite time consuming and the surface finish is rough due to the electro discharge craters. In order to resolve the material constraints and the long processing time, a new approach on the basis of micro-electro discharge machining and surface tension has also been proposed recently [4].

In this paper a new approach that utilising the cleaning feature of a commercial fibber fusion splicer to manufacture 3D micro probes will be discussed in detail. The optimal manufacturing strategy that involves the arc power, the cleaning arc power offset, the cleaning time, and the compensation of the offset distance of the spherical tip centre from the fibber central line has also been identified. The micro probe can be used in micro/nano CMMs to achieve the required measurement accuracy and resolution.

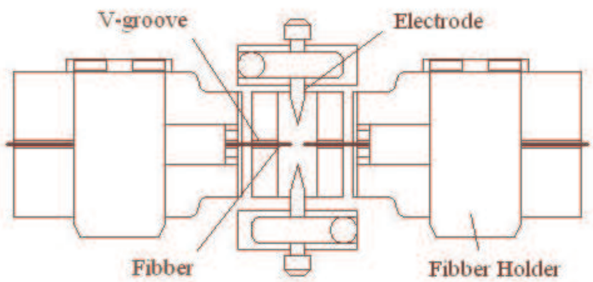
2. Experiments

2.1 Experiment method Most fibber fusion splicers provide the cleaning feature to clean the fibber endfaces before the fusion joining operation, and the arc check feature to optimise the splicing conditions [5]. In this study the cleaning feature of a commercial fibber fusion splicer is utilised to manufacture the micro probe. The geometric profile and dimension of the probe is measured using an image coordinate measuring machine.

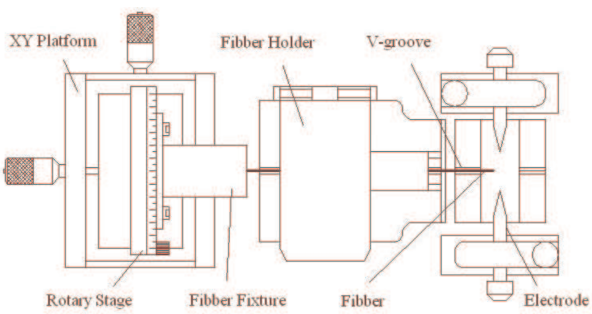
2.2 Experiment set-up and procedure The fibber fusion splicer used in this study is the FITEL S199S single fibber fusion splicer (as shown in Figure 1) from Furukawa Electric Co. Ltd. in Japan. Parameters involved in the fusion process are (1) discharge voltage, current, and frequency; (2) electrode parameters, such as material, shape and gap length; and (3) atmospheric conditions, such as kind of gasses, pressure, temperature, moisture, and gas flow [6]. In addition the location of the fibber tip with respect to the electrodes is also critical to the energy absorbed by the optical fibber [7]. Since this splicer has been set up in such a way that the splicing result is optimised and thus only limited parameters such as the discharge time, the discharge strength, and the distance between the fibber and the discharge electrodes can be varied during the experiment. The electrodes used in S199S are made of tungsten with the diameter of 2mm, the apex angle of 30° and the electrode gap of 4mm. The discharging environmental temperature is the normal room temperature. The optimal results can be achieved by adjusting most of those parameters mentioned above. In this study single mode optical fibber is used.

Figure1. Fibber fusion splicer FITEL S199S

In order to conduct the experiments effectively and efficiently, the original system configuration, as shown in Figure 2(a), has been modified into the experimental system configuration, as shown in the Figure 2(b).



(a) Original configuration



(b) Experimental configuration

Figure 2 Experimental splicer set up

The preparation of the fibber is identical to the preparation of fibbers for fusion splicing. Firstly stripping off a portion of fibber coating by using a fibber stripper, then wiping the bare fibber with cotton soaked with denatured alcohol to remove coating chips adhere to the fibber after removal, and finally cleaving the fibber with a fibber cleaver so that 10mm of the bare fibber extends past the fibber coating. After preparing the fibber, open the windshield of the splicer, and then open both the fibber holders and the fibber clamps for loading the fibbers. Load the prepared fibber in each the holder with the stripped portion in the V-groove and make sure that each fibber is properly aligned in the V-groove before closing the fibber holder. The fibber clamp (not shown in Figure 2) is closed afterward to hold the fibber on the V-groove. Once the fibbers are loaded correctly, the windshield is closed and the splicer is ready to conduct experiments.

By setting the arc power, the cleaning arc power offset, and the cleaning time, the micro probes can be manufactured using the cleaning feature of the splicer. In order to monitor the progress and control the quality, the fibbers are put under the CCD camera of an image coordinate measuring machine after each arc cleaning cycle to find the diameter, the roundness of the spherical tip and the offset distance between the centre of the spherical and the fibber central line, as shown in Figure 3.

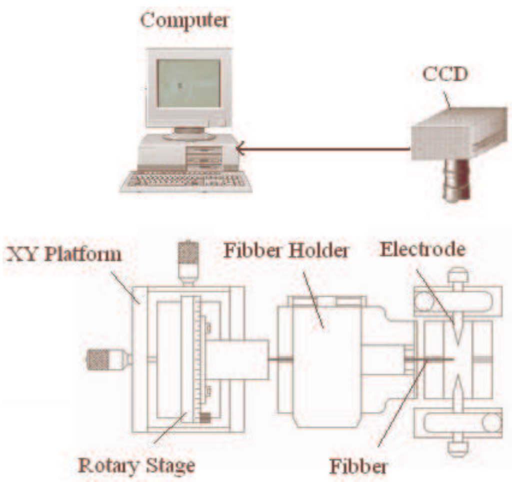


Figure 3 Probe forming process monitoring and geometric dimension measurement system

This offset distance is mainly due to the influence of gravity; therefore, the fibbers are loaded 180° alternatively with respect to the fibber axis to compensate the bending of the probe tip. All the geometric attributes are measured every 90° with respect to the fibber axis so that the shape of the micro probe can be recorded as the manufacturing process proceeded.

3. Results

3.1 Experiment results The fibber tip absorbs the arc discharging power and melts instantaneously. Due to the surface tension the melting part of the fibber starts to form a spherical shape of tip gradually. As the spherical tip growing bigger, the gravity force is becoming larger and pulling the tip towards to the gravity field. This is causing the bending of the spherical tip and thus contributes to the offset distance between the centre of the spherical and the fibber central line. Figure 4 shows the relationship between the diameter of the spherical tip and the number of arc cleaning cycle when all the parameters are fixed.

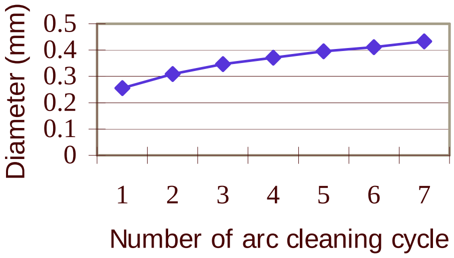
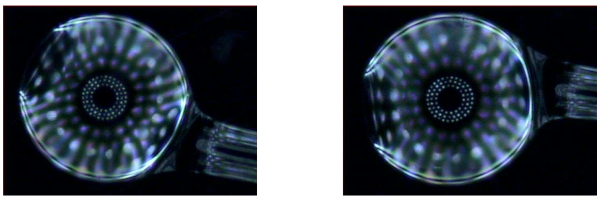


Figure 4. The relationship between the spherical tip diameter and the number of arc cleaning cycle, Arc power: 230, Cleaning arc power offset: 230, Cleaning time: 6000μs

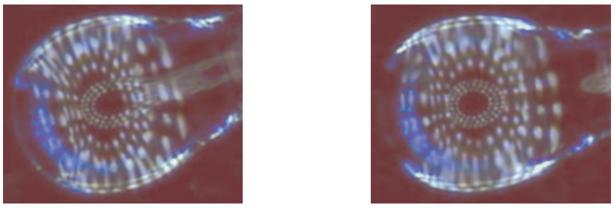
The effect of gravity can be minimised by rotating the fibber 180° with respect to the previous offset direction of the spherical tip. However, the offset will never be eliminated completely by only rotating the fibber if the power of the arc cleaning cycle remains unchanged. Because the energy will be still too large so that the spherical tip will go toward the gravity field again due to the increase of the weight of the tip instead of staying at the correct position; therefore, the offset distance can never be eliminated completely. This over-compensation phenomenon is shown in Figure 5, where (a) illustrates the tip after 180° rotation of the original bending and (b) shows the over-compensation of the tip in (a).



(a) (b)

Figure 5. Over-compensation phenomenon

On the other hand, if a lower discharge power is set in order to control the mass of the melting tip so that the tip does not bend significantly and thus to minimize the offset distance between the centre of the spherical and the fibber central line. This will still result in an unacceptable probe tip even though the fibber has been rotated 180° after each discharge cycle, as shown in Figure 6. It is due to the fact that there is a gradual converge segment generated in between the tip and the stem and thus the tip shape is similar to a droplet as shown instead of a sphere.



0 deg 90 deg

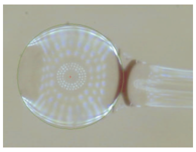
Figure 6 Unacceptable "droplet" tip shape

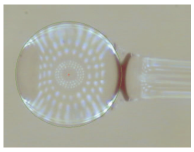
In order to compensate the bending of the previous cycle, the parameters have to be adjusted accordingly so that the offset can be eliminated completely. After analysing the experiment results and investigating the phenomenon closely, an optimal manufacturing strategy has been derived accordingly to firstly make a spherical tip with required roundness by applying higher arc power, larger cleaning arc power offset and longer cleaning time, and then to compensate the offset by applying lower arc power, smaller cleaning arc power offset, and shorter cleaning time. Table 1 shows the details of the optimal manufacturing strategy.

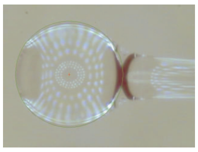
Table1. Values of experiment parameters

	Step 1	Step 2
Arc power (units)	230	100
Cleaning arc power offset (units)	230	230
Cleaning time	30,000 μs	500 μs

3.2 Measurement results The strategy has been applied to manufacture a number of micro probes and these probes are measured by using an image coordinate measuring machine. Figure 7 shows the image of one of the probes at four angular positions with respect to the fibber, and the corresponding measurement results are summarised in Table 2.


0 deg


90 deg


180 deg

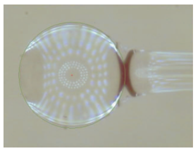
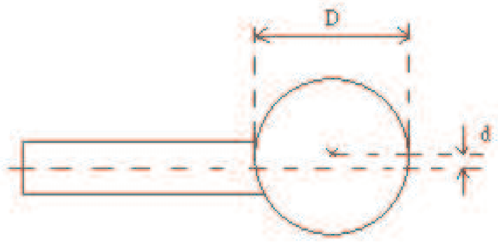

270 deg

Figure 7. Imagines of the fibber tip

Table2. Measurement results of the tip at various rotational angles (in μm)

deg	0	90	180	270
D	344.31	345.09	344.77	343.21
R	6.13	5.30	5.98	5.60
d	2.50	0.41	0.93	1.54



Where, D: diameter, R: roundness, d: The offset distance between the centre of the spherical and the fibber central line

It is obvious from the Figure 4 that the bending of the probe tip has been minimised and the over-compensation phenomenon does not appear again. This implies that the strategy does work to the extent that the existing experimental apparatus can handle. Although the measurement results indicates that the bending has not been eliminated completely due to the inaccurate control on the rotation of the fibber, and the roundness due to residual stress induced by the temperature profile of the fibber tip is significant, improvement of experimental apparatus and better control of the environment will further improve the offset and the roundness of the spherical tip and the quality of the micro probe.

4 Summary and Conclusions

The investigation of utilising the cleaning feature of a fibber fusion splicer to manufacture micro probes for nano/micro CMMs is conducted in this study. On the basis of arc cleaning function of the splicer, a manufacturing strategy has been derived to produce micro probe for nano/micro CMMs. The strategy firstly focuses on making a spherical tip with required roundness by applying higher arc power, larger cleaning arc power offset, and longer cleaning time, and then concentrates on compensating the offset due to gravity force by applying lower arc power, smaller cleaning arc power offset, and shorter cleaning time. The study also reveals the importance of controlling the rotation of the fibber and the temperature profile of the fibber tip. Different setting on the parameters will produce different shapes of the micro probe. By using the combinations of the parameters specified in Table 1, an optimal shape of micro probe has been achieved after 5 cleaning cycles. The measurement results show that the diameter of the spherical probe tip is about 300 micrometer, the roundness for the tip is about 5 to 6 micrometer, and the offset distance between the centre of the spherical and the fibber central line is less than 3 micrometer.

The next stage of this investigation will focus on the refinement of the splicer set up for better process control, the derivation of the optimal combination of control parameters, the optimisation of the discharge environment, and the characterization of the probe tip. It is expecting that a reliable and cost-effective micro probe with minimum offset distance and better roundness can be achieved for nanoCMM application.

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