Fabrication of Integrated Optic Fibre Tip for Micron CMMs Touch Trigger Probe Application

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ABSTRACT

In the last decade the general miniaturisation of complex products has lead to an increased importance of high precision machining and assembly. Together with increasing precision of products, the need for highly accurate dimensional inspection increases. CMMs (Coordinate Measuring Machines), a versatile and widespread dimensional metrology tool, can efficiently perform complex measurement with a resolution of the order of 0.1μm and a repeatability of 0.3μm. The existing probes for CMMs tend to be very bulky and result in high probing forces for geometrical measurements of high accuracy on small parts. In this paper, an economical and flexible method, which is developed for optical fibre fusing splicer system, is proposed to fabricate an integrated micro scale silicon probe with a spherical tip for micron CMMs. Based on the Taguchi method, an optimal combination of process parameters has been obtained to control the fabrication conditions that will ensure the manufacturing of tips of a high and consistent quality. With proper control of the process parameters, an optic fibre probe tip with the diameter dimension in the range of 200 to 400 μm is achieved and there is a great potential to fabricate a smaller tip with a diameter of 50-100μm in the future.

Key words: CMMs probe, optic fibre splicer, fused integrated spherical tip

1. INTRODUCTION

CMMs (Coordinate Measuring Machines) are powerful, versatile and widespread dimensional metrology tools. They can fulfil complex measurement tasks with a resolution of about 0.1μm and with a repeatability of about 0.3μm[1]. The traditional CMMs' probe tip is manufactured by attaching a spherical metal or ruby ball to a metal or alloy stem, as shown in Figure 1. This type of probe for CMMs is too bulky for measurement of small parts. Bulky dimensions also restrict precision and limited application to the measuring of micron structure of small parts. There also is a challenge to fabricate a high precision micron scale tip using traditional fabrication and assembly process.

Fusing the stem end to form a spherical probing tip can minimize the errors introduced by the traditional assembling process. This integrated micron probe does not have the limitations of the traditional probe and improves the measurement accuracy and resolution of micro CMMs. Various technologies[2-5] for the formation of integrated optical fibre tip based on the methods of fusion have been reported. All these technologies have their own advantages and disadvantages. One Pulse Electro Discharge (OPED) method[2] has been developed for metal probe tip or micro cavity on metal surfaces. But the power it applies is too high to fabricate silica material tips; therefore, laser-mechanical methods[3,4] are good alternatives for fabrication of fibre-optic tools for optical communication and fibre-optic medical applications. Although laser fusion of micro spherical tips to optical fibres is feasible, it is too expensive when comparing with the one using optical fibre splicers. Recently, optical fibre splicers from optical communication applications have been

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successfully used to fabricate micro optical fibre probe tips[5]. However, the existing fusion-splicing systems lack the flexibility of adjusting splicing parameters for this special purpose. In this paper, an economical and flexible arc discharger system has been developed to fabricate an integrated silica probe with a spherical tip for Micron CMMs.

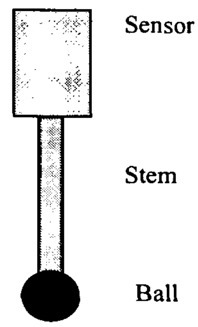


Figure 1. Schematic diagram of a traditional probe.

The quality of the tip is closely related to the fabrication conditions of the discharger, such as voltage of the circuit (fusing power), fusing time, discharge frequency and gap distance. The offset of the ball centre from the fibre axis and the roundness of a ball are two major quality measures used in quantifying the shape quality of a probe. Based on the Taguchi method[6], a robust design method for improving the function of the process, optimal conditions for tip fabrication are achieved. Tips with diameters ranging from 200 μm to 400 μm and with a centre offset less than 4μm have been fabricated.

2. MATERIALS AND EXPERIMENT SET-UP

Optical fibre has several advantages, making it a good candidate as a probe tip material. Small dimension of the fibre ensures that micro probe tip can be made. As fibre material has low-density, it generates smaller probing force and

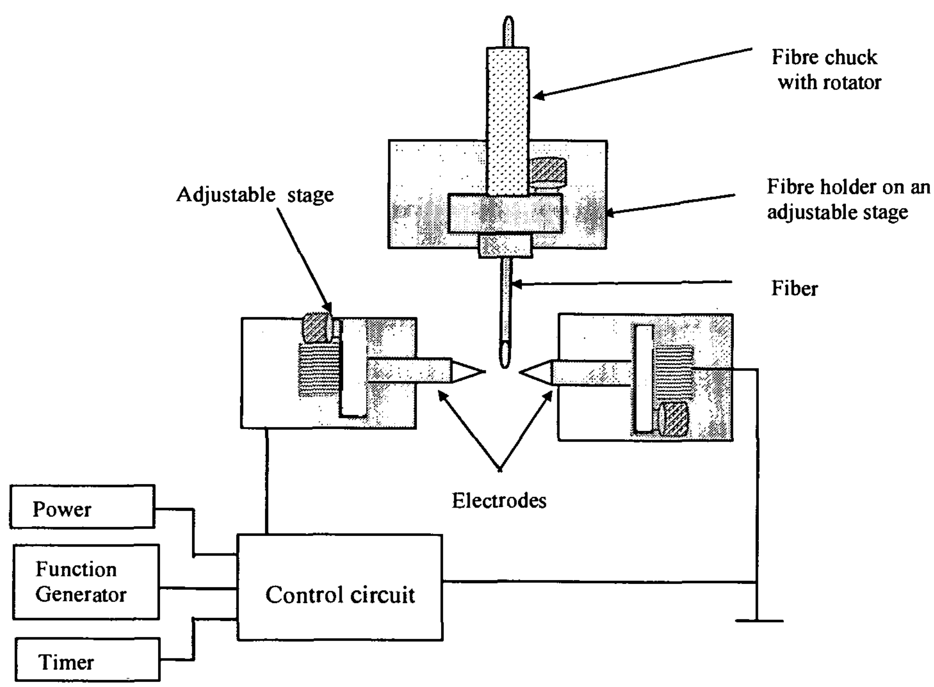


Figure 2. Experiment setup for tip fabrication indicating adjustment of electrodes separation and fibre rotation.

does little damage to the surface to be measured. Optical fibre also has high degree of transparency that allows an optical sensor to be integrated in the fibre possible. It also has sufficient mechanical strength to perform contact measurements. For silica optical fibre with good thermal properties, they can be easily fused within an appropriate heating field.

The experimental setup is shown in Figure 2. A car ignition circuit (modified from K3303 Hi Energy Ignition system) together with an adjustable power supply were used to control the discharge strength. The discharge frequency and hence the arc temperature were controlled by a function generator. A timer was linked to the discharge circuit to control the fusing fabrication time. Three high precision translational stages with a resolution of 0.5μm were used to adjust the distance between the electrodes and the end of the optical fibre in the field of the discharge arc. A fibre chuck rotator with strain relief was used as the fibre holder during the fabrication. It can rotate the fibre during the processing to compensate the effect of the force of the gravity and control the centre offset of the spherical ball tip from the stem axis. The whole setup is more economical and flexible than the optical fibre splicer and laser fusion systems.

3. FIBRE TIP FABRICATION PROCESS

3.1 Fabrication

The experiments were carried out to find the relationship between fabrication conditions and the dimension as well as the quality of fused spherical tip. The fabrication process is shown in Figure 3. The optical fibre with a standard diameter of 125 μm is held in the optical fibre chucks and is moved into the discharger by adjusting the drive with sub micrometer resolution. The distance between the two chucks is controlled by an adjustable stage. As power distribution between two electrodes along the electrodes axis is increasing from the centre point to the electrodes, the centre point between the electrodes has a relatively lower power than that of the neighbour area[7]. The end of the fibre is located to a point about 0.5mm offset from the centre of the arc to improve the efficiency of power usage.

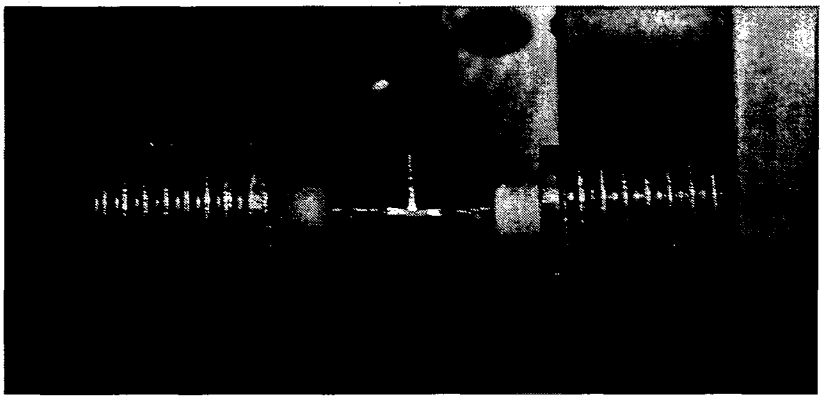


Figure 3. Image of actual fabrication of a tip with the development of a microsphere on the fibre end.

3.2 Tip Profile Measurement

If the process is not well controlled, there will be an offset in the optical fibre tip. To compensate the offset *d* of the ball from central line DD' of the fibre stem produced by the gravity effect (Figure 4 (a)), the fibres are rotated 180 degree after each fusing. The smaller the centre offset, the better the quality of the tip. The maximum total fusing time is 25 seconds for a tip of 400μm. Therefore, the fabrication process is very efficient.

To improve the accuracy of the measurement with CMMs, every spherical probe tip is calibrated before the measurement. Therefore, it is very important to accurately measure the profile of the tip for all probes. Image processing has been used for the measurement of ball profile and the offset of the ball from central line of the fibre stem. The image is taken using a digital camera installed on a microscope. Figure 4 (b) shows an example of this calibration process with image processing. For this specific sample, it is found that there is an obvious offset between the ball and the stem while the quality of the ball is quite acceptable.

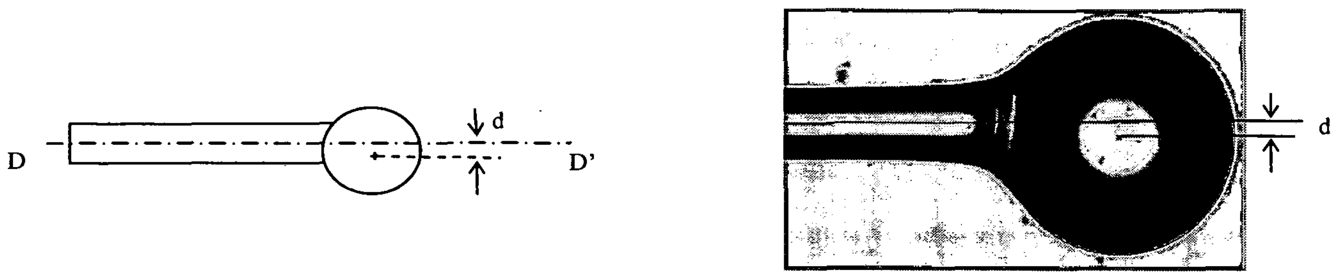


Figure 4. (a) Schematic of the tip ball centre offset from ball centre; (b) Measured tip profile overlaid with image processing.

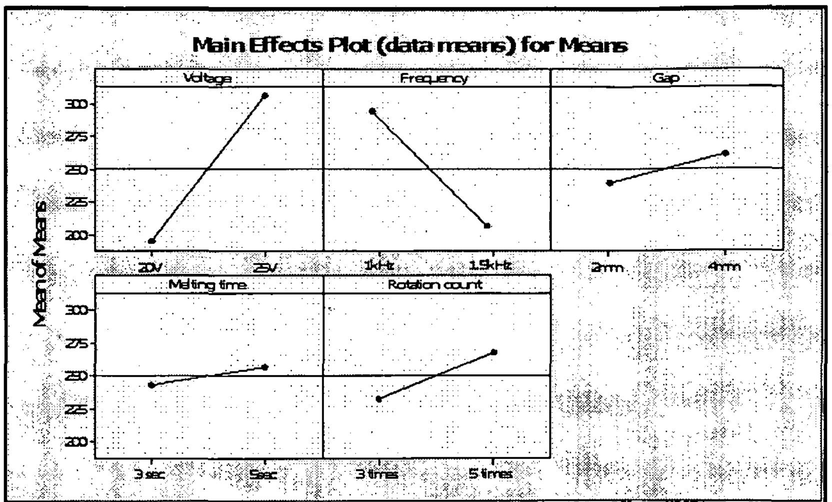
4. RESULTS AND DISCUSSION

The dimension and the quality of the fused fibre tip are affected by several process parameters and different combination of these parameters has different fabrication results. The parameters include voltage of the power supplier, discharge frequency, distance between the electrodes, fusing time for each rotation and number of rotation, which are selected for Taguchi analysis because of their most influence on the tip shape. The required fusing temperature is very high for forming the spherical ball on the end of the fibre under surface tension at which the silica fibre is in a liquid phase. To meet this condition, the voltage of the power supply needs to be set to an appropriate level. The discharge frequency and fusing time also need to be appropriately selected. A L8 orthogonal array is used in the Taguchi analysis.

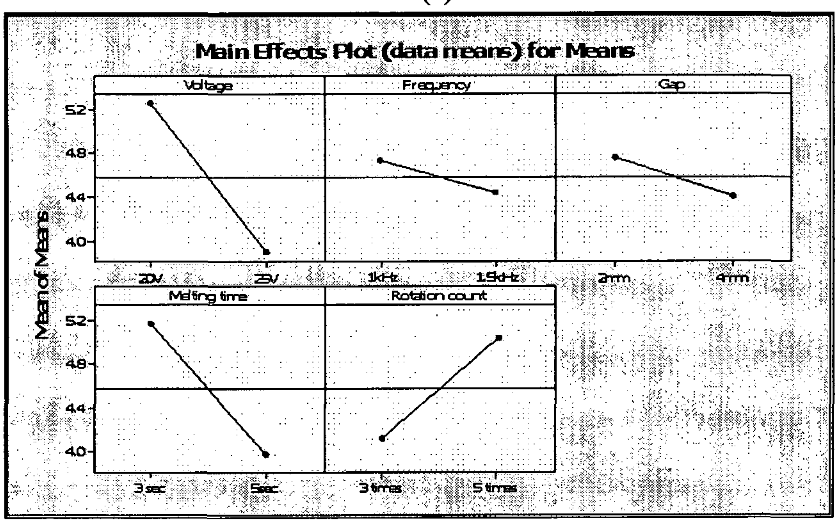
Table 1. Tip attributes results for a range of fabrication conditions.

Tip No.	Voltage (V)	Frequency (kHz)	Gap (mm)	Fusing time/per rotation (sec)	Number of Rotations	Average Diameter (μm)	Offset (μm)	Roundness Deviation (μm)
T1	20	1	2	3	3	205.4	4.5	0.8
T2	20	1	2	5	5	249.0	6.7	0.5
T3	20	1.5	4	3	3	132.4	6.3	0.8
T4	20	1.5	4	5	5	188.4	3.5	0.7
T5	25	1	4	3	5	365.7	4.1	0.8
T6	25	1	4	5	3	356.9	3.6	1.0
T7	25	1.5	2	3	5	270.5	5.8	1.5
T8	25	1.5	2	5	3	233.4	2.0	0.7

With proper power supply, the electric arc between the electrodes provides a high temperature field. The end of silica optical fibre at such a high temperature is melted and forms a spherical surface due to the surface tension. The dimensions and alignment with the fibre axis are determined by the surface tension and the force due to the gravity on the spherical ball in liquid phase. The experimental scheme designed for Taguchi analysis is listed in Table 1. The main effects for the diameter and centre offset obtained from Taguchi method using MINITAB software are shown in Figure 5. Using the image processing method outlined in section 3, the average diameter, and tip centre offset and deviation are measured. The roundness deviation is the difference of the detected curve from the fitting curve of the tip ball, which demonstrates how accurate a sphere can be used to represent the ball. The smaller the roundness deviation value, the more accurate for the fused tip to be represented with a ball. As there are other fabrication conditions such as rotation adjustment time, cooling condition and tip end position adjustments that were not comprehensively studied, further study will be required to examine their influence.



(a)



(b)

Figure 5. MINITAB display of experimental conditions effect (a) on diameters (means for diameter); (b) on centre offset (means for centre offset)

As indicated in the effects plot, the greater incline of the line of any factor, the greater the effects of that factor. As shown in Figure 5 (a), voltage has the greatest effect while melting time has the smallest effect on the dimension of the ball. According to Figure 5 (b), voltage also has the greatest effect on the centre offset and the frequency has the smallest effect.

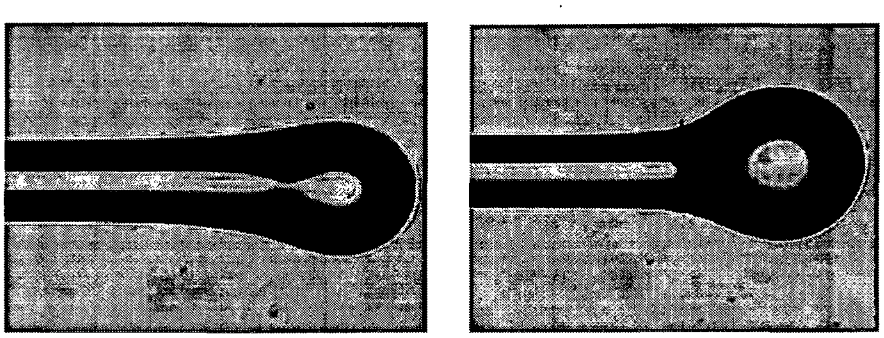


Figure 6. Examples of tips with suboptimal dimensions and poor tip centre-axis alignment.

The deviation for all tips is less than 1 μm except tip samples T3 and T7. When under suboptimal combinations of conditions, the fabrication tips are improperly formed or with significant offset, as shown in Figure 6.

Using Taguchi method, an optimised combination of the parameters has been chosen to fabricate a tip ball with dimension range 350-400 μm. Here the parameters are set as: voltage 25V for first 5 rotations and 20V for the last rotation, frequency 1kHz, gap 4mm, fusing time 5sec and total number of rotations 6. Figure 7. shows the images of this tip at four angular positions with respect to the fibre and the corresponding measurement results are listed in table 2.

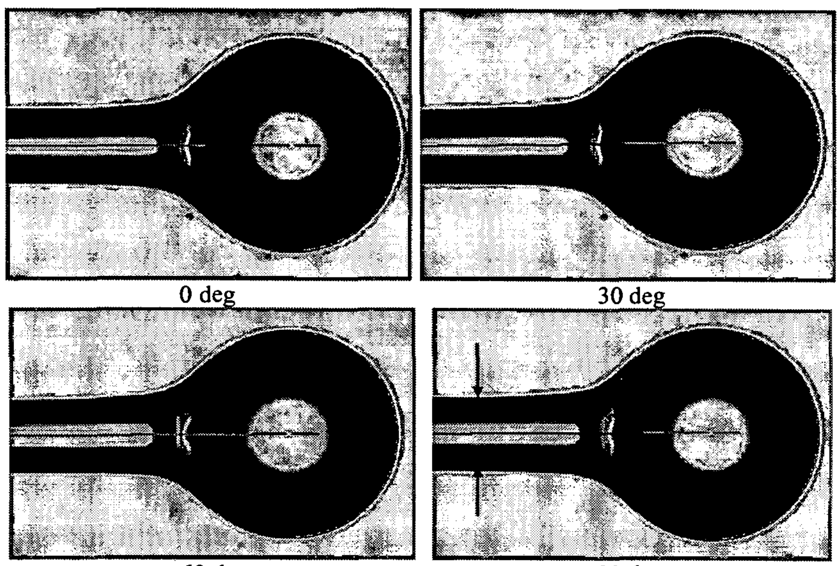


Figure 7. Images of a fibre tip viewed from different aspect angle. Note that the diameter of the fibre stem in the images above is 125μm.

It is shown that with the chosen conditions the resulting dimension is approximately 371μm that satisfies the requirement. The maximum centre offset is below 4μm. The roundness deviation of the ball profile is less than 0.7μm. It demonstrates the optimized condition does improve the fabrication efficiency and shape accuracy. Although the centre offset still present, there is a potential to fine-tune the rotation counts and fusing time to get a best compensation of the offset. This will be further investigated in the near future.

Table 2. Tip attribution measurement results at four rotational angles.

Deg. (degrees)	0	30	60	90
Diameter (μm)	369.8	374.8	368.4	374.5
Deviation (μm)	0.6	0.6	0.6	0.6
Centre Offset (μm)	0.8	1.6	0.9	3.2

5. CONCLUSION

Although other technologies can be used to fabricate the integrated optical fibre tip, an adjustable electrode discharger is an economical, highly efficient and flexible fabrication machine. Utilizing the arc discharging fusing technique, a spherical optical probe tip of low eccentricity is fabricated in this study. Based on the Taguchi method, the optimal procedure parameters are identified and applied to fabricate the tip with a proper dimension. A probe tip with a diameter of approximately 370μm, with a centre offset eccentricity less than 4μm has been achieved. Further investigation of other related conditions, such as the cooling speed of the fibre and the fusing position orientation, will be conducted next as well as refining the fabrication process to achieve the minimum centre offset.

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REFERENCES

1. Fan, K.C., Chu, C.L., Mou, J.I., *Development of a Low-cost Autofocusing Probe for Profile Measurement.* Measurement Science and Technology, 2001. **12**: p. 2137-2146.
2. Sheu, D.Y., *Micro Spherical Probe Machining by EDM.* 2003.
3. Veiko, V.P., et al., *New Method of Fiber Optic Tool Fabrication Based on Laser Technologies.* Laser Applications Engineering (LAE-96), 1997. **3091**: p. 122-128.
4. Vaidya, A. and Harrington, J.A., *Sculpted Optical Silica Fiber Tips for Use in Nd:YAG Contact Tip Laser Surgery: Part1-Fabricaiton Techniques.* Optical Engineering, 1992. **31**(7): p. 1404-1409.
5. Fan, K.C., Hsu, H.Y., and Hong, P. *Feasibility Study of the Formation of Micro Spherical Probes with Optical Fibers.* in *The 9th International Conference on Mechatronics Technology.* 2005. Kuala Lumpur, Malaysia.
6. Taguchi, G.i., *Taguchi on RobustTechnology Development : Bringing Quality Engineering Upstream.* ASME Press series on international advances in design productivity. 1993, New York: ASME Press.
7. Tachikura, M., *Fusion Mass-splicing for Optical Fibers Using Electric Discharges Between Two Pairs of Electrodes.* Applied Optics, 1984. **23**(3): p. 492-498.