Development of Positioning Jig for Glass Capillary Bending Mechanism

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***Abstract*—In a bending mechanism for glass capillary, the positioning jig to hold the capillary in place is one of the most important components to ensure the bending quality. The tapered shoulder of the capillary is used as the positioning reference. Since the dimension of the shoulder of individual capillaries varies slightly, the geometry of the capillaries is studied to identify the desired positioning spot on the shoulder. Upon determination of the positioning spot, a positioning jig is designed, which is composed of positioning, holding, and clamping units. A prototype is made and assembled onto the bending mechanism for testing. The testing results show that the mechanism is able to achieve the desired functionalities demanded by the delicate bending process.**

***Keywords*—glass capillary, jig, positioning, clamping**

I. Introduction

This paper presents the design process of a positioning jig for a bending mechanism of glass capillaries. An unbent capillary has three sections: tip, tapered shoulder and barrel, as shown in Fig. 1. The tapered capillary is fabricated from a straight capillary with diameter of 1mm by a heated pulling process. After pulling, the straight capillary becomes two tapered capillaries with tip and shoulder sections. The tip is then cut and polished to a specified dimension. The diameter of the tip end is 0.12mm, and the barrel section remains 1mm. The tapered capillary is to be bent to a desired shape with two bends. The bend A is at the shoulder section and B at the barrel section with a distance of 10±0.5mm in between. The diameter of the shoulder at point A is required to be 0.325±0.025mm.

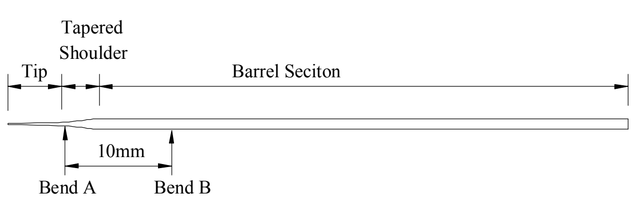

Figure 1. Sektch of unbent glass capillary

Currently the capillaries are bent manually so the end-product quality heavily relies on the experience of operators. The temperature and the softening condition of the capillary are very difficult to control, which results in quality inconsistency, high reject and rework rate, and low productivity. Therefore, a bending mechanism that can produce products of consistent good quality is urgently demanded.

The bending mechanism has to ensure the positions of the bending points and meet other specifications beyond the scope of this paper. It is obvious that a jig for locating and holding the capillary precisely on the bending mechanism is decisive for this task.

There are several constraints in the design of the positioning jig.

Firstly, the jig has to be small and effective. The capillary is bent at points A and B (Fig.1) where two heating elements are located. The heating elements are to be fixed on the bending mechanism for the sake of design simplicity so the section between point A and B of the capillary has to be fixed in the bending process. This demands the jig be miniature since the distance between A and B is only 10mm and some more spaces have to be reserved for the heating elements.

Secondly, the positioning reference point has to be on the tapered shoulder section. Normally, for a bar-shaped part without step, either end of the bar can be used as the reference point for positioning. However, the diameter of the capillary tip end is only 0.12mm with wall thickness less than 0.05mm. This makes it too fragile to be a reference point - even a light touching may break it. On the other end of the capillary, the length of the barrel section is different from one to another since it is not a control parameter in the pulling process. Thus, the reference point has to be at the shoulder section and be identified prior to the design of the positioning jig.

Thirdly, the capillary is very fragile for clamping. The maximum wall thickness of the capillary is only 0.2mm. It is very easily to be broken, which increases the difficulty in the development of the clamping method.

Two types of instruments are mainly used for processing glass capillary - micropipette puller and microforge. In these

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instruments, the capillary is typically clamped between a pair of plates and tightened by a screw, or is placed on a pair of V-shaped supports and held with a spring chip [1] [2]. A capillary clamp described in [3] uses a quartz rod with a V groove to align the capillary and hold it in place by an aluminum clamp. An alignment jig is used in [4] to guide the capillary tip for a rough positioning but it does not have a clamping element to hold the capillary in place. One common disadvantage of these jigs is that positioning of the capillary is performed only after the capillary is fixed by adjusting the mounting stage. It means that positioning has to be made for every capillary loading, which takes up much longer working cycle time. Moreover, more space is required for the stage. For the clamps described in [3] and [4], the capillary is loaded by sliding into a round-shaped clamp. Once the capillary is bent at the two points, it is impossible to be taken out of the clamp. Therefore, they are not suitable for the capillary bending application. Unfortunately, very few other publications are found on the positioning and fixing device for glass capillary processing.

This paper will demonstrate how this design addresses the above delicate requirements.

II. Concept Design

The jig is to be designed with functions of both positioning and holding.

A. Positioning unit

As described in section I, the positioning point is set on the capillary shoulder, as shown in Fig. 2. The proposed positioning unit has a pair of stoppers ($M_1O_1N_1$-$M_2O_2N_2$) with a small slot of G. The width of G is smaller than the barrel section diameter (1.0mm). When the capillary is inserted from the tip end into the slot, it is stopped at the point O where the diameter of the shoulder equals G. This point on the capillary shoulder is defined as the reference point.

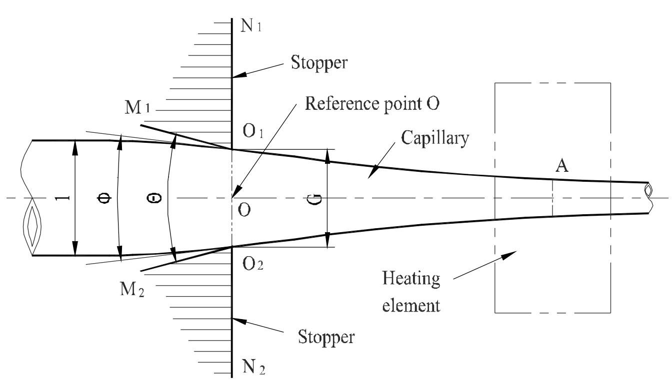


Figure 2. Working layout of positioning unit

In order to identify a desired and effective positioning reference point, the capillary shoulder is studied regarding its shape, dimension and quality consistency from the pulling process. The measurements on randomly picked samples reveal that the maxium diameter variation is 0.02mm with a deviation of 2.9%.

According to the measurement, the average distance between the bending point A and the root of the shoulder is about 3.8mm. The refenence point is to be set as close to the root as possible to allow more space for locating heating filament at point A. The point with a diameter of 0.85mm is then studied for the suitability of being the reference point.

A magnified view at point O_{85} of 0.85mm diameter on the shoulder is shown in Fig. 3. Line L_1 and line L_2 represent two boundary lines of the diameter variations at the shoulder around point O_{85}. All measured diameters of capillaries lie within the two boundaries. Distance $X_{O1\text{-}O2}$ is a positioning variation (PV1) along the capillary axis caused by the variation of the shoulder diameters. Since the boundary line L_1 and L_2 are very close to each other with maximum difference of 0.02mm, $X_{O1\text{-}O2}$ is less than 0.03mm, which can be ignored. Distance $X_{O3\text{-}O4}$ is another positioning variation (PV2) resulted from the variation of the slot width G. The bigger the PV2 is, the less accurate the reference point for the positioning is.

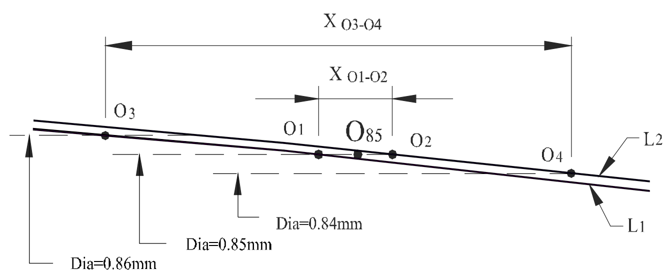


Figure 3. Detailed view of point O_{85}

If the slot G has a tolerance of ±0.01mm (i.e. G = 0.84-0.86mm), the resultant PV2 is 0.192mm at point O_{85}.

The points around point O_{85}, where diameters are 0.8mm (O_{80}) and 0.9mm (O_{90}), are also studied and shown in Fig. 4 to compare the sensitivity of the PV2 to the relevant slot width with tolerance of ±0.01mm at this points. In other words, it is to find out at which point the least PV2 is produced. The result reveals that PV2 is 0.194mm at point O_{80}, 0.23mm at O_{90}. Obviously, the least sensitive point is at O_{85} since the slope at O_{85} is the steepest among the three points. Therefore, point O_{85} is used as the reference point. The distance between point O_{85} and the bending point A is 2.8mm, which is sufficint for the heating element. The slot width G of the positioning unit is, consequently, set as 0.85mm. The designed positioning variation is ±0.1mm (max.).

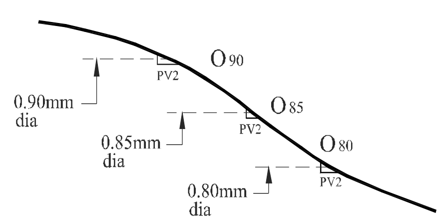


Figure 4. Comaprision of PV2 at points aroung O_{85}

As shown in Fig. 2, the angle of the slot (M_1O_1-M_2O_2), θ, is designed bigger than that of the capillary shoulder at point O (Φ) to prevent the capillary from being stuck by the M_1O_1 and M_2O_2 surfaces. When the capillary is slid into the slot from the left side of the stopper, it will be stopped at the reference point O just between points O_1 and O_2. This ensures that the bending point A is consistently located in the middle of heating element.

B. Holding and clamping unit

The holding unit is used for supporting the capillary, and the clamping unit is to hold the capillary still for bending (Fig. 5).

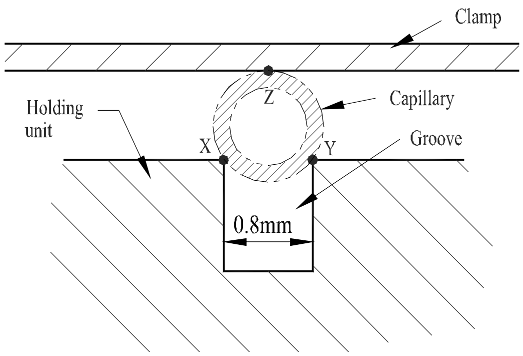


Figure 5. Sectional view of the holding and clamping units

The holding unit has a groove with width of 0.8mm. The capillary is seated on the groove with supporting point X and Y. The clamp presses on the top of the capillary at point Z. The three points in Fig. 5 represent three lines that hold the capillary in place firmly to prevent it from moving or rotating in the bending process.

III. Engineering Design Of The Positioning Jig

A. Design of the positioning/holding component

The positioning unit and the holding unit are integrated into one single component as capillary seat, by having the stopper located on the top of holding unit as shown in Fig. 6. The seat is made of stainless steel to avoid rusting and prevent contamination to the capillary. Heating elements are to be mounted to the bending mechanism on both sides of the seat with a small distance of 2.8mm and 2.3mm respectively from the side surfaces.

In order to precisely position the capillary, several important dimensional and geometrical tolerances have to be controlled. The width of the slot is to be controlled with a tolerance of ±0.01mm. The two vertical surfaces of the groove has to be parallel to each other, and top and bottom surfaces of the seat must be parallel to each other as well to ensure the capillary to be held parallel to the top surface of the mechanism.

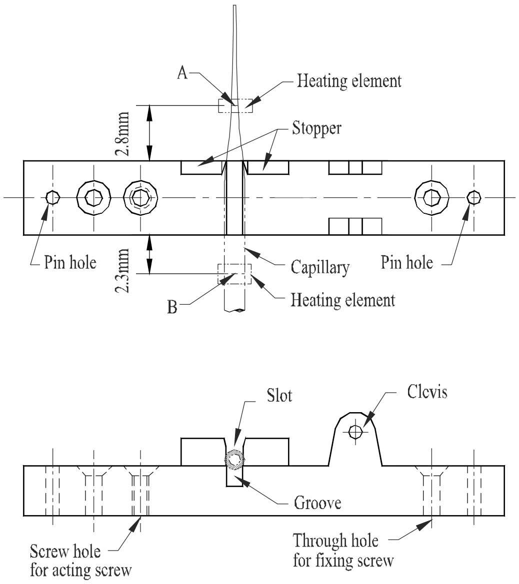


Figure 6. Positioning/holding component (capillary seat)

The pin holes in the capillary seat ensure the jig to be assembled onto the bending mechanism in correct position. The dimensions and tolerance of the holes determine the position of the seat on the bending mechanism and consequently, determine the positioning accuracy of the capillary.

The seat is to be fastened onto the mechanism by two screws. Two through holes are for the fixing screws. The screw hole is for the screw acting with the magnet on the clamp that will be detailed next.

It is important that the contact edges of the component with the capillary, i.e. X and Y of the holding unit in Fig. 5, and O_1 and O_2 of the stopper in Fig. 2, have to be polished (without sharp edges) to prevent the glass surface from being scratched.

B. Design of the clamp

The clamp includes three parts: a clamp arm, a magnet embedded in the arm, and a soft pad adhered to the bottom of the arm (Fig. 7).

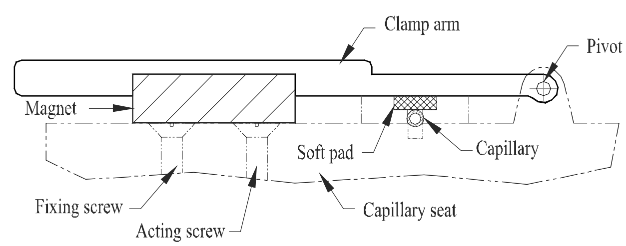


Figure 7. Sketch of the clamp

The magnet is used to attract the clamp onto the capillary seat by acting on the acting/fixing screws since the seat is made of stainless steel, which does not work with the magnetic field. The vertical position of the acting screw is adjustable so that the clamping force on the capillary can be fine tuned.

The soft pad underneath the clamp body is used to press the capillary firmly onto the groove of the seat without damaging the glass. The pad contacts directly to the clamp arm and the section of capillary between the two bending points A and B. Since the capillary is fine and transparent, it is hard to measure its surface temperature [5]. The temperature of the clamp arm around the pad is measured of 60-70˚C after 10 seconds of heating (within one working cycle). The temperature can reach 100˚C or higher after several working cycles. Therefore, the soft pad has to be heat durable.

Since the glass capillary is bent around its softening point, at which glass can deform under gravity, the required bending force is very small (<0.01N). As a consequence, the clamping force required is small as well. A small piece of magnet is then used for the clamp.

The magnetic force can be calculated with (1),

$$F = \frac{B^2 A}{2\mu_0} \qquad (1)$$

where, F is magnetic force, B magnetic flux density, A contact area, and μ_0 permeability. The designed magnetic force is 3.5N. The clamping force on the capillary is calculated as 7.75N.

When the capillary is clamped in the jig, the distributed clamping force is loaded on the top of the capillary through the soft pad. Two other concentrated forces act on the capillary at the supporting points of the seat. A computational simulation of the stress distribution in the capillary is conducted with ANSYS as shown in Fig. 8. The maximum stresses appear at the two supporting points with the value of 30.9MPa. It is much smaller than the compressive strength of the glass, 200MPa [6] so the designed clamping force is safe for the capillary.

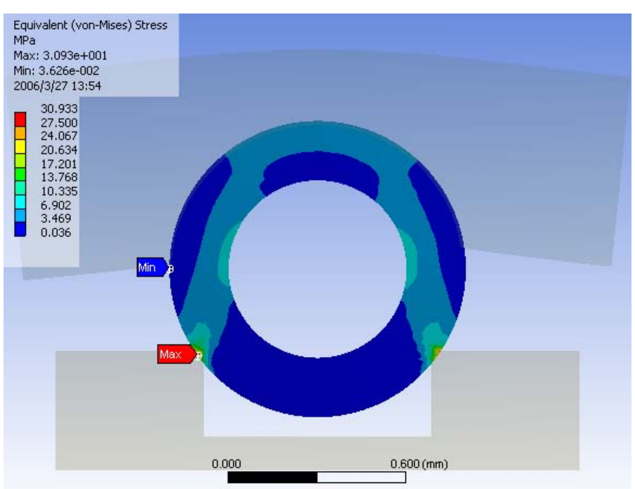


Figure 8. Stress distribution in the capillary under clamping

C. *Positioning jig assembly*

The assembly of the positioning jig is shown in Fig. 9. The clamp arm can rotate about the jointing pin that connects the clamp and the capillary seat.

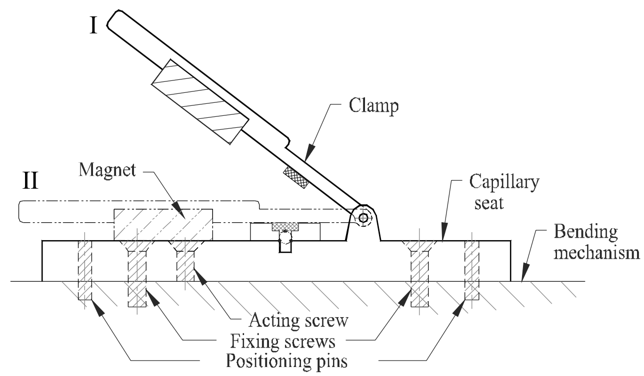
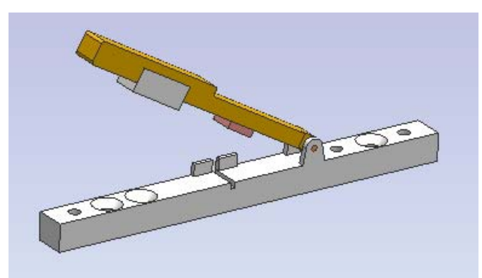


Figure 9. Sketch of positioning jig assembly

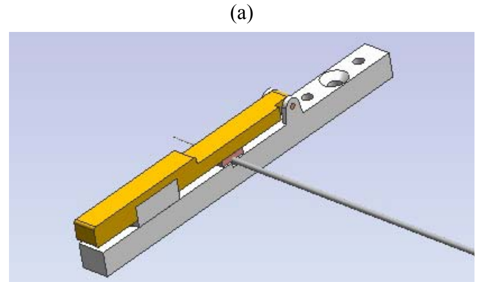
Position I is for loading the capillary. Once the capillary is positioned at slot G, the clamp is lowered to position II. The clamp is then connected firmly to the seat due to the magnetic force between the magnet and the screws. If the acting screw is turned up, the clamp will be lifted with a small angle to the top surface of the seat. The clamping force on the capillary can therefore be reduced slightly.

IV. PROTOTYPING AND TESTING

A prototype of the positioning jig is constructed as shown in Fig. 10. Fig. 10 (a) depicts that the clamp is lifted for loading of the capillary. Fig. 10 (b) is a view of the capillary that has been loaded and clamped in the jig.



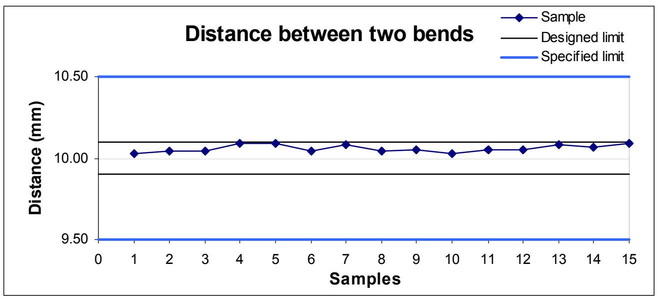
(a)



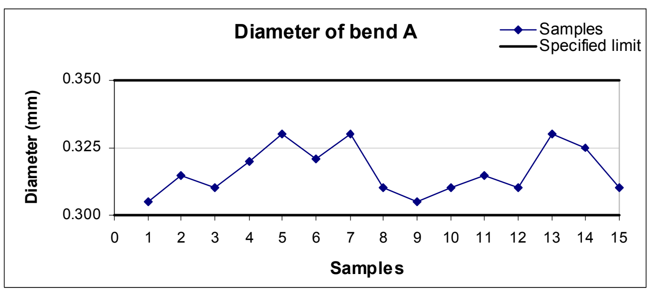
(b)

Figure 10. Positioning jig (a – unloaded position I, b – loading position II)

The jig is installed onto the bending mechanism for testing. It is found that the jig is well fitted in the mechanism and provides an efficient and effective positioning and holding functionality to the capillary as required by the bending process. The measurements on the randomly picked testing samples reveal that the average distance between the two bending points is within 10±0.1mm with good consistency (Fig. 11 (a)). It greatly satisfies the specification of 10±0.5mm. Meanwhile, the diameters of the samples at the bend A are also measured within the specified tolerance 0.325±0.025mm (Fig.11 (b)).



(a)



(b)

Figure 11. Measurements of testing samples

From Fig. 11, it can be seen that the distribution of the distances between the two bends of the testing samples offsets a bit above the specified mean value 10.0mm and the average diameter at bend A is in the lower range (<0.325mm). To improve it, the distance of the two bends can be adjusted to a normal distribution about 10.0mm by slightly moving the heating element at bend A towards the jig. In consequence, the diameter at bend A will become bigger and be distributed around the specified mean value (0.325mm) as well.

V. CONCLUSION

This paper presents the design process of a positioning jig of a bending mechanism for glass capillaries. The capillary has three sections: tip, tapered shoulder and barrel. Two bending points are located at the small end of the shoulder and the barrel section respectively, with a distance of 10mm in between.

In order to identify a desirable and effective positioning reference point on the capillary, the geometry of the capillaries is studied. The tip of the capillary is too tiny and fragile to be a reference point. The other end of the capillary cannot be used as a reference point either due to the inconsistency of the barrel section length. Therefore, the reference point for positioning the capillary in the jig is set at the shoulder section.

Based on a comparison of several points on the shoulder, by considering the positioning accuracy and space for heating elements at the bending points, the reference point is determined at the point where the diameter is 0.85mm.

Upon determination of the reference point, the jig is designed consisting of positioning, holding and clamping units. The positioning unit has a pair stoppers with a slot of 0.85mm.The holding unit has a groove for the capillary to be seated. These two units are integrated into a single component as capillary seat. The clamp connected with the seat by a pivot is to press on the top of the capillary to hold it firmly on the groove.

A prototype of the jig is constructed and assembled onto the bending mechanism for testing. The result reveals that the jig is fitted very well with the mechanism and fulfills the desired functionalities required by the delicate bending process.

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