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8.6 Experimental Study of Micro-holes Position Accuracy on Drilling Flexible Printed Circuit Board

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Abstract
Drilling through holes is an important procedure in the manufacturing process of flexible printed circuit board (FPCB). The main influencing factor of micro holes quality is holes position accuracy. Holes position accuracy directly influences the FPCB electrical performance, reliability and the realization of the installation requirements. Therefore, it is very necessary to analysis the influencing factors of holes position accuracy. In this paper, single factor experiment method is used to study the relation of holes position accuracy and those influencing factors, obtaining the influence law of each factor on the holes location accuracy. The accuracy will get better with the increasing of spindle speed, retraction speed and drill diameter， however the accuracy will get worse with the increasing of thickness of entry board and number of FCCL stack. Choosing appropriate entry board use-pattern will greatly improve the holes position accuracy.
Keywords: micro-holes, position accuracy, high speed, micro-drill, FPCB

1 INTRODUCTION

With the development of electronic devices and communications tools tends to be more shorter and more thinner, Printed circuit board (PCB)， as the carrier of the electronic devices，also tends to the high-rise, high-density, micro-holes and fine lines. Then a higher requirement of micro-drilling, which is the most basic and necessary process in the production of PCB, has been proposed. Flexible printed circuit board(FPCB) is a promising branch of printed circuit board industry, which is developing rapidly. It should be always seeking a perfect solution to electronic packaging needs for its highly reliable, perfect flexible. It leads the electronic packages to smaller, lighter and more functional. So it has been abundantly used in the aerospace, military, mobile communication, digital cameras and other fields.

In general, after the micro-hole is drilled in the FPCB, a cleaning and desmearing processes is performed followed by a two-step copper deposition. Quality holes are ones in which the deposited copper layer can be connected stably at each layer of circuit with repeated thermal shock. One or more holes lose effectiveness can make the whole circuit even the electrical appliance stop working.

A flexible printed circuit board usually consists of a conductive material layer of traces bonded to a dielectric layer. Copper is a very common metal as the conductive material layer. The dielectric layer is usually polyimide or polyester. Usually an adhesive is used to bond the conductive material layer to the dielectric layer. Micro-hole is an important part of the flexible printed circuit board, the process of micro-drilling is one of the problems of the PCB manufacturers' production. However, it’s not easy to control the quality of the production process of micro holes. One of the most important influencing factors of micro holes quality is holes position accuracy. With the influence of the drill bits and equipment, hole shift occurs easily in micro-drilling. Holes location accuracy directly influences the electrical performance, reliability and the realization of the installation requirements about FPCB. So holes location accuracy is always the most important control point in the manufacturing process of FPCB [1-6].

The author’s research group had published several papers in this area. Huang [7,8] studied the conventional drilling of PCBs and the mechanism of the creation of the holes using finite element technology. Yang [9] studied chip morphology when drilling a 3.2 mm hole in PCBs and found that the chips from the resin/glass fiber cloth layer were continuous chips with five different morphologies. Tang [10, 11] studied a high-speed drilling machine suitable for PCBs with 0.1-mm-diameter micro holes. The machine had functions that can measure the drilling force. Tang also published an introduction to the simulation of ultra-high-speed drilling of the copper foil layer of PCBs using the finite element method (FEM). A complete review of drilling PCBs had been performed as well [12].

Studies of micro holes location accuracy were always focused on rigid board on the printed circuit board industry before. The research of how to improve the drilling quality of flexible printed circuit board effectively dose not have a detailed experimental study so far. Tang [13] studied the influence factors of holes location accuracy such as vibration in micro-drilling process, micro-drill diameter and micro-drill wear, and found that the holes location accuracy increased with the increasing of the bit diameter, decreased with the increasing of vibration acceleration and micro-drill wear. Watanabe [14] did experiment in the spindle speed of 300 krpm with 0.1 mm diameter micro-drill to study the relationship between the bit radius run-out and micro-holes surface quality, and found that the drill point swing radius have a certain influence on the hole position accuracy and surface roughness. Zheng [15] studied that the wear of micro-drill, increase of feed speed and spindle speed which will lead the holes position accuracy of rigid-PCB get worse. Zheng [16] found that the resin adhered to the tip would influence the accuracy of the micro-holes location.

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In this paper, as a part of a large research project on FPCB micro-drilling, several experimental tests were conducted to study micro-holes position accuracy when drilling FPCBs. It was important to study micro-holes position accuracy during the FPCB drilling process as part of hole quality. The drilling process was photographed and the CPK(Complex process capability) was measured and analyzed according to the test results. The influence of drilling conditions (spindle, feed and retraction speed) and wear of micro-drill on the CPK were also been studied.

2 THE INFLUENCE MECHANISM OF HOLE LOCATION ACCURACY

In the FPCB micro hole drilling process, cutting force and torque will be formed, and the cutting force can be decomposed into XYZ three directions. The size of these forces depends on the geometry of the micro-drill, property of printed circuit board (such as workability, vertical plate surface roughness) and drilling process parameters (spindle speed, feed rate, retraction speed, cover plate combination).

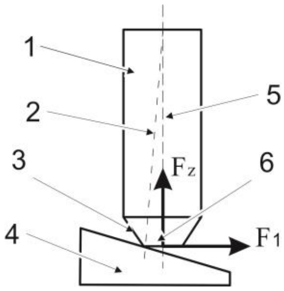


Figure 1: Changes of rotary centerline and the force of drill tip

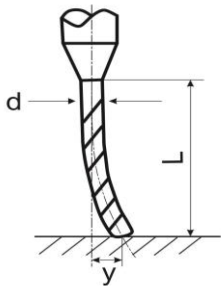


Figure 2: Drill positioning diagram

When the micro drilling of the flexible printed circuit board began, as the chisel edge of the drill bit just came into contact with the surface of FPCB, if the drill chisel edge area is relatively large, it will produce a large lateral force F1 (the resultant force of x and y direction), it will deflect the tip of the drill and cause drill tip slipping. The result is that the drilling position of micro hole generates a random displacement, so that the drilling process would not be carried out in accordance with predetermined position. When the surface of the sheet being drilled inclined or uneven, this effect will be more significant. As is shown in Fig. 1 the surface of a sheet being drilled inclined at a predetermined angle, the chisel edge sharp corners come into contact with the sheet, the micro-drill's axis of rotation will be deflected.

When the cutting edge of micro-drill starts cutting, the chip will also impact the motion direction of the micro-drill. With the drill drilling into the plate, the drill would be bending as is shown in Fig. 2. The bending of the drill bit will generate a bending moment, bending moment from the drill's tendency to return to its starting position, and thus cause roundness error as the drill bit drilling into the FPCB.

3 TESTING EQUIPMENT AND CONDITIONS OF MICRO-DRILLING

3.1 Testing equipment and workpiece

The micro-drilling processes were performed on a Hitachi MARK-16 drilling machine with a spindle speed of up to 160 krpm. The measurement of hole position accuracy was performed on a hole-bit precision measuring instruments named PM-2824 Hole Inspector. The schematic of the experimental setup was shown in Fig. 3.

(a) Hitachi 6 axis (160 krpm) (b) PM-2824 Hole Inspector

Figure 3: Testing equipment

The workpiece was SF305 flame-resistant type polyimide film based flexible copper clad laminate (Double side) made by Guangdong Shengyi SCI Tech Co., LTD. The structure of the SF305 was shown in Fig.4. It is 101 μm in thickness, laminated by polyimide (PI) film of 25 μm. Both sides are clad with a copper foil of 18 μm thickness. Among polyimide (PI) film and copper foil is adhesive of 20 μm thickness.

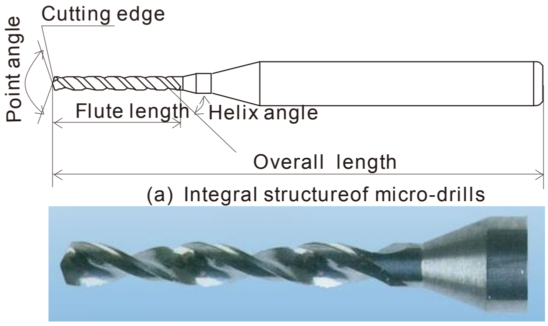
Figure 4: Structure chart of flexible double-sided copper clad laminate

The entry board in this paper have two types: Cold shock（LC-110）entry board and MVC lubrication aluminum. The backing board was phenol formaldehyde plate (FZ-120). The entry board and backing board were both made by Shenzhen LiuXin industrial Co., LTD. The basic parameters of the entry board and backing board were shown in Table 1.

Table 1 Physical performance of Entry Board and Backing Board

Physical performance	LC-110	MVC	FZ-120
Physical shape			
Thickness	0.3/0.5/0.8 mm	0.16 mm	1.5mm
Thickness Tolerance		±0.1mm	
Warpage(Diagonal length)	Less than 0.3mm		Less than 0.6mm
Dimensional tolerances		±3mm	
Density	----------		1300-1450 kg/ m^3
Surface conditions	Smooth	Smooth	Smooth

All cemented acrbide micro-drills(6-9% Co and 91-94% WC; vickers hardness 1750-2150HV30) were made by Shenzhen Jinzhou Precision Technology Corporation and have diameters of 0.15 mm,0.25 mm,0.35 mm. The structure of the micro-drills are shown in Fig. 5.



(b) Sideview of micro-drills

Figure 5: Structure of micro-drills

3.2 Drilling conditions and evaluation index of hole position accuracy

In the drilling experiments, the feed rate , the spindle speed the combination of entry board and backing board were carried as shown in Table 2.

In this paper, CPK (Complex process capability) index was used to evaluate the accuracy of the holes position. CPK refers to the degree of the ability of the process to meet product quality standards (e.g. specifications, range, etc.). The greater the value of CPK is, the better the quality of the holes position accuracy is. The schematic of CPK measurement is shown in Fig.6.

Table 2. Drilling conditions

Parameters	Diameter of drills (D) (mm)		
	0.15	0.25	0.35
Spindle speed (n) (krpm)	100-158		
Feed rate (v_f) (mm/s)	15-50		
Retraction speed (v_r) (mm/s)	100-300		
Number of drilled holes	1000, 2000, 3000		
LC-110 thickness (mm)	0.3, 0.5, 0.8		
Entry board use	No entry board, LC-110, MVC+LC-110		
Stack of board layers	3		
Environmental temperature	22 ℃		
Relative humidity (%)	66		

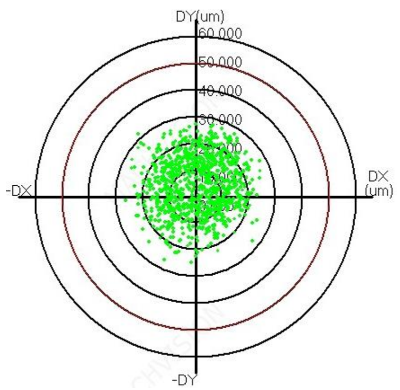


Figure 6: Photographs of CPK measurement

4 RESULTS AND DISCUSSION

4.1 The surface topography of micro-hole under different drilling depth taken by SEM

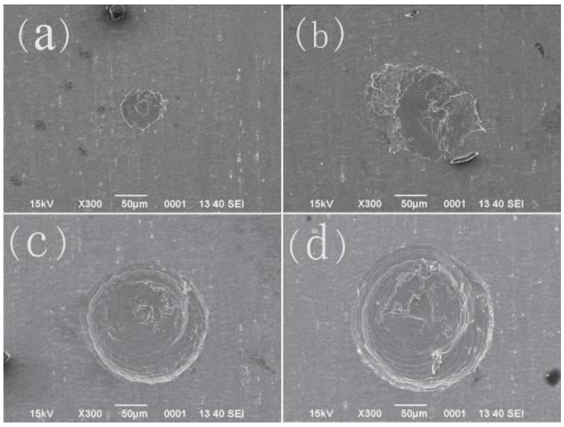


Figure 7: Surface topography of micro-hole under different drilling depth(Drill depth :a=20 μm, b=40 μm, c=60 μm, d=80 μm, D=0.25mm, v_f =50 cm/min, n=140 krpm, v_r=300 mm/s)

Figure 7 shows the surface topography of micro-hole with different drilling depth. It is shown in Fig. 7 (c) and Fig. 7 (d) that a partiality phenomenon of the drill occured as the drilling depth increased during drilling FCCL. The main reason may be the unbalance force of the drill taken by the unsuitable drilling parameters or the surface of FCCL is not flat or even enough.

4.2 The influence of the main drilling parameters on holes position accuracy

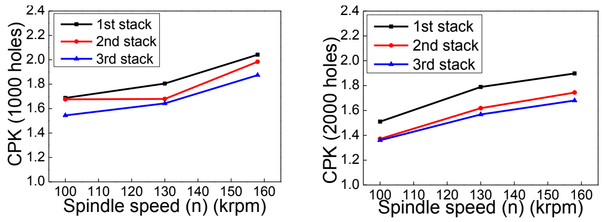


Figure 8: Influence of spindle speed on CPK（D=0.25 mm, v_f=30 mm/s, v_r=300 mm/s）

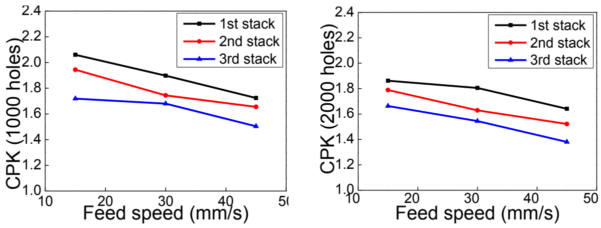


Figure 9: Influence of feed speed on CPK（D=0.25 mm, n=158 krpm, v_r= 300 mm/s）

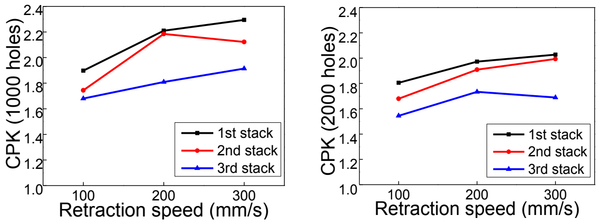


Figure 10: Influence of retraction speed on CPK（D=0.25 mm, n=158 krpm v_f=30 mm/s）

Figure 8, 9, 10 showed the influence of the main drilling parameters (spindle speed, feed speed, retraction speed) on CPK. In Fig. 8, it can be seen that when the drilling speed changed from 100 krpm to 158 kprm, in every stack, the CPK increased as the spindle speed's increased. In Fig. 9, it can be seen that when the feed speed changed from 15 mm/s to 45 mm/s, in every stack, the CPK decreased as the feed speed increased. It was thought that this may due to the thickness of material removal per revolution would affect the force status of the tip of micro-drill. The more thickness the material removal per revolution was, the more unbalanced the force acting on the micro-drill. Therefore, the increase of spindle speed equaled the decrease of the thickness of material removal per revolution, the increase of feed speed equaled the increase of the thickness of material removal per revolution.

In Fig. 10, it can be seen that when the retraction speed changed from 100mm/s to 300mm/s, in every stack, the CPK increased as the retraction speed's increases. It was thought that this may due to that the diameter the micro-drill was small and there will adhesive drilling chips in the spiral groove inevitably, which makes the drill tip have a unstable stress in high speed rotation will affect the accuracy of hole position. When the retraction speed increased, the time the unbalance force affected the accuracy of the hole position would be shorted. Therefore, the accuracy of hole position will improve when the speed of drill retraction increases.

4.3 The influence of micro-drills on holes position accuracy

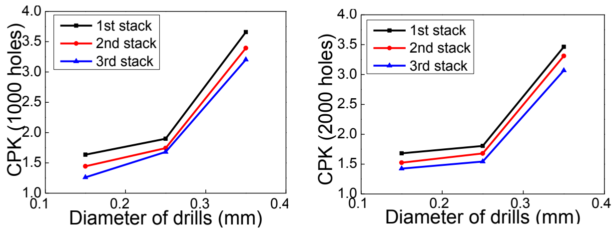


Figure 11: Influence of diameter of drills on CPK（n=130 krpm, v_f=30 mm/s, v_r=300 mm/s）

One of the most important factors for the hole-position accuracy of PCB is the rigidity of micro-drill, which may increase by a trend of the drill diameter. It is shown at the Fig. 11 about the situation of flexible double-sided copper clad laminate. The hole-position accuracy will increase when the diameter of the drill bit increases. The CPK can reach above 3.0 as a superior rank, when a 0.35mm-diameter drill was used in the same process of drilling.

4.4 The influence of number of drilling holes on holes position accuracy

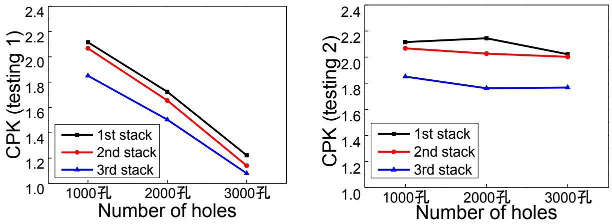


Figure 12: Influence of number of drilling holes on CPK（D=0.25 mm, n=130 krpm, v_f=30 mm/s, v_r=300 mm/s,）

A trend of influence between the amount of drilling holes and the hole-position accuracy is shown at Fig. 12. The hole-position accuracy will decrease when the amount of drilling holes increases. It was due to the wear of the drill. The cutting blade will be more and more dulled and compared with a new one, the accuracy may drop down for the reason of offset of the drill point. As the chips may be stuck on the dulled cutting blade during drilling FCCL, the performance of chip removal may decline, with worse and worse roughness of hole-wall and position accuracy.

4.5 The influence of entry board use on holes position accuracy

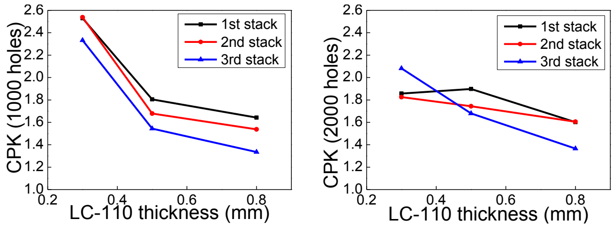


Figure 13: Influence of thickness of entry board on CPK（D=0.25mm, n=130 krpm, v_f=30 mm/s, v_r=300 mm/s,）

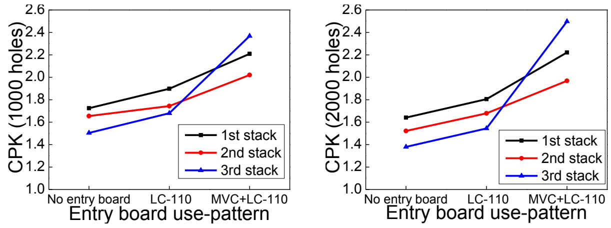


Figure 14: Influence of use-pattern of entry board on CPK（D=0.25 mm, n=130 krpm, v_f=30 mm/s, vr=300 mm/s）

Figure 13 shows the influence of thickness of entry board used in micro-hole drilling on CPK. It can be seen that the value of CPK decreased with the increase of the thickness of entry board. It was because that the drill may be mildly deflect unavoidably for many reasons during the drilling operation. Once it drills slantingly, the situation will get more deteriorated. It led to the decline of the hole accuracy. Thus, the value of CPK decreased with the increase of thickness of entry board.

Figure 14 shows the influence of use-pattern of entry board on CPK. It can be seen that among three use-pattern of entry board, the value of CPK was the largest when the use-pattern of entry board was ‘MVC+LC-110’, and when the micro-drill drilling without entry board, the value of CPK was the smallest.

5 CONCLUSIONS

To study the hole position accuracy of FPCB micro-drilling, the CPK (Complex process capability) was measured. The factors affecting micro-holes position accuracy was studied. The results can be summarised as follows:

(1) The value of CPK will increase with the spindle speed, retraction speed and drill diameter. And it will decrease with the increase of the feed speed, the number of drilled holes and the thickness of entry board.

(2) The use-pattern of entry board will influence the value of CPK. Choosing a suitable use-pattern will improve the hole position accuracy. In the process of micro-drilling, make the MVC lubrication aluminum upon the LC-110 as a use-pattern will obtain a higher holes position accuracy and avoid inlet burrs produced at the same time.

(3) The stacks of FCCL in drilling process had impact on hole position accuracy. The more the stacks was, the lower the value of CPK was.

6 ACKNOWLEDGMENTS

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