Experimental Study on Cutting Force of High-speed Micro-drilling Flexible Printed Circuit Board

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Abstract: Drilling force is one of the most important parameters in the drilling process of FPC (flexible printed circuit board), the size of the force has a directly affect on the drill-bit’s life and the micro-hole’s quality. It causes the FPC delamination, pulling of the plastic, the burr of exit hole and other processing defects. In this paper, some experimental investigations of cutting force of high speed micro-drilling are carried out to improve the drilling quality of flexible printed circuit board. The results indicate that the drilling parameters (spindle speed, feed speed and drill-bit diameter) have significant influence on micro-drilling thrust force.

1. Introduction

The FPC (flexible printed circuit board) is a promising branch of printed circuit board industry which is developing rapidly and prospects. It has been always seen as a prefect solution to electronic packaging needs for its highly reliable, perfect flexible. It leads to electronic packages being smaller, lighter and more functional. So it has been abundantly used in the aerospace, military, mobile communication, digital cameras and other fields.

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 usually is one of the problems of the PCB manufacturers’ production. But because of the layer-to-layer constructions of FPC and the viscosity of polyimide, there will bring kinds of defects in FPC micro-drilling. The defects include FPC delamination, pulling of the plastic, the burr of exit hole and so on. Most of the drilling defects are caused of the size of the drilling thrust force. In additional, the quality of drilling process has a directly impact on the mechanical assembly performance and electrical connectivity of flexible printed circuit board, determining the final quality of the printed circuit board [1-5].

Studies of drilling force always focused on rigid board on the printed circuit board industry before. Hinds[6] studied micro-drilling (0.1 and 0.25mm in diameter) of double-sided PCB, and found that thrust force and torque increases with the increasing drill wear, feed rate, depth to diameter ratio. Yang [7] studied chip morphology when drilling a 3.2mm hole in PCBs and found that the chips from the resin/glass fibre cloth layer were continuous chips with five different morphologies. The research of how to improve the drilling quality of flexible printed circuit board effectively have not a detailed experimental study so far. This paper making some experiments on a high-speed PCB drilling machine with double-sided flexible copper clad laminate composites and make some analysis on drilling thrust force.

2. Experiment procedures

Three different PCB drill-bits with diameter of 0.15mm, 0.2mm and 0.3mm were used in this experiment. These three different diameter drill-bits are also mostly used in actual production. The messages of those drill-bits and the drilling conditions are shown in Table 1 and its structure is shown in Fig. 1.

<table>
<thead>
<tr>
<th>Drill Material</th>
<th>Diameter</th>
<th>Overall length</th>
<th>Point angle(°)</th>
<th>Helix angle(°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WC Carbide</td>
<td>0.15mm</td>
<td>120</td>
<td>38.1mm</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>0.2mm</td>
<td>130</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.3mm</td>
<td>130</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Drills used in the experimental work
Fig. 1 Structure of micro-drills

Fig. 2 Structure chart of flexible double-sided copper clad laminate

FPC material used in this drilling test was flame-resistant type polyimide film based flexible copper clad laminate (Double side). 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. The structure shown in Fig. 2. We stacked five this double side FCCL material into a workpiece. Phenolic aldehyde entry board was placed on the top of the five-layers FCCL material and paper backup board was placed beneath the PCB during the drilling process.

The experimental work was carried out on a PCB drilling machine which was developed by ourselves and this machine with a maximum spindle speed of 250 krpm. All drilling tests were conducted coolant free at spindle speeds of 120 krpm 140 krpm, 160 krpm 180 krpm, 200 krpm and feed speed of 50, 100, 150, 200, 250, 300 cm/min.

Measurement system of drilling thrust force was shown in Fig.3. Cutting force (thrust forces) were measured using a Measurement instruments include the DYTRAN 1051 micro-force sensor that made in United States and its sampling frequency is 5000Hz, an amplifier module that is the U.S. DYTRAN ACC amplifier, it also consists of Germany SICK the OD MAX-type laser displacement sensor and Germany SICK AOD-type controller.

3. Results and Discussion

3.1 Drilling thrust force analysis of the flexible board in the drilling process

It is shown in Fig.4 that the law of thrust force changes with drilling time when the micro-drill drilling the flexible double-sided copper clad laminate. The curve in Fig.4 is available on the condition that the spindle speed is 160 krpm and the feed...
speed is 50cm/min. Fig.4 (b) is the enlargement of Fig.4 (a), and Fig.4 (c) is the enlargement of the first peak in Fig.4 (b).

Thrust force can be divided into three stages (I, II and III) as is shown in Fig.4 (b). Stage I represents the drilling thrust force when the micro-drill cuts the entry board. Stage II shows the thrust force when the drill drills in five-story FCCL. And stage III shows the thrust force when drilling in the backing board. In this paper, only this thrust force that produced when the micro-drill drills five layers FCCL is studied. It is the stage II that is shown in Fig.4 (b). It can be seen that the drilling thrust force peak is of little difference when the micro-drill drills five-stacked flexible board in Fig.4(b). In this experiment, three holes are drilled in every laminated board, and in which, there is a five-stacked flexible copper clad laminate. That is to say, 15 holes are drilled in one flexible laminated board under each drilling parameters. To analyse the drilling force, the mean of the 15 maximum thrust force of every hole would be discussed.

As is shown in Fig.4 (c), according to the feed rate and the relationship between drilling depth and drilling time, the thrust force of a through-hole can be divided into five stages in one drilling process: A (Upper copper foil: 0.00216s) - B (Adhesive: 0.0024s) - C (Polyimide PI: 0.003s) - D (Adhesive: 0.0024s) - E (Lower copper foil: 0.00216s). Drilling thrust force changes as follow: First, when the drill begins to drill the upper copper foil of the flexible board after drilling through the entry board, because of the gap between the different layers of flexible board, it must press the material layers together before the micro-drill begins to cut the upper copper foil. Then the tool begins to drill the flexible board. Among this transitional time, the thrust force would increase from scratch gradually. Secondary, the drill bit began to cut the flexible board of copper foil. With the depth of drilling increasing, the drilling thrust force, to some degree, increases till gets to the peak value which would approximately remain stable until the drill drills through the upper copper foil. Subsequently, the bit starts to drill the adhesive, and the drilling thrust force begins to reduce. When the main cutting edge gets through the upper copper foil completely and enters into the adhesive layer, the drilling thrust force no longer reduces. Thirdly, when drill bit gets through the adhesive layer and starts to drill the polyimide (PI) layer, the drilling thrust force starts to reduce again and when drilling polyimide (PI) layer, the drilling thrust force reaches the minimum of the whole drilling process. Then the drill bit entered the stage of cutting the second adhesive layer, and the drilling thrust force has a certain extent increase. The thrust force is almost equal to that of drilling the first adhesive layer. Fourthly, as the depth of drilling increase, the drilling thrust force begins to rise when drill bit drill into the bottom copper foil.

3.2 The influence of spindle speed and feed speed on thrust force

Fig.5 shows the relation curve about spindle speed, feed speed and thrust force. It can be seen that when the drilling speed changes from 120000 r/min to 200000 r/min, in every speed stage, the thrust force gradually increase as the feed speed increases from 50cm/min to 300cm/min. And the higher the feed speed is, the greater the thrust force is. The reason is that in the process of micro drilling, increasing the feed speed in an invariable spindle speed is equal to increasing the feed amount per revolution. However, according to the knowledge of cutting theory, along with the feed increases per revolution, the theoretical thickness of cutting increases, and so does the resistance force of the material. Thus, the thrust force also increases correspondingly.
It can be seen from Fig. 5 that the drilling thrust force get smaller while spindle speed become bigger under the same feed speed. The reason is that increasing spindle speed could greatly reduces the feeding amount per revolution when keeping the feed speed. The theoretical thickness of cutting also reduces correspondingly. Therefore, the resistance force of the material decreases, and the axial cutting force also decreases correspondingly.

3.3 The influence of drill diameter on thrust force

The two graphs in Fig. 7 show the relationship between drill diameter and thrust force with the spindle speed being 160krpm and 200krpm. From the graph, when in a single variable conditions, the larger the diameter drill bit is, the bigger the thrust force is. The reason is that the increase of diameter drill bit will lead to the cutting area increase, however, cutting area is one of main factors that effects the magnitude of cutting force. Therefore, it is obvious that increasing cutting area will lead to drilling force increase. The diameter size of the drill has almost the same influence on cutting force in the two different spindle speed, the difference is that the thrust force become smaller while the spindle speed is higher.

3.4 The relationship among spindle speed, speed and hole quality

In the micro-drilling process of FCCL, as the drill-bit drill through the surface of lower surface of the double side FCCL material, around the exit hole usually would generate exit burr. The exit burr has serious impact on assembly accuracy and performance of the products. So after drilling it usual has a deburring process to ensure the quality of products. High speed drilling has a significant effect to reduce exit burr. Fig.7 shows the influence of spindle speed, feed speed on exit burr. It can be seen that the size of exit burr increase with the increase of feed speed, and decrease with the increase of spindle speed. And in addition, when the spindle speed arrive 200krpm, the influence of feed speed become smaller. The reason is that, with the increase of spindle speed and the decrease of feed speed, the drilling thrust force become smaller, and the larger the thrust force is, the smaller the exit burr is.
<table>
<thead>
<tr>
<th>Feed speed</th>
<th>50cm/min</th>
<th>100cm/min</th>
<th>200cm/min</th>
<th>300cm/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle speed</td>
<td>120krpm</td>
<td>160krpm</td>
<td>200krpm</td>
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<tr>
<td>120krpm</td>
<td><img src="image1.png" alt="Image" /></td>
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<td><img src="image4.png" alt="Image" /></td>
</tr>
<tr>
<td>160krpm</td>
<td><img src="image5.png" alt="Image" /></td>
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<tr>
<td>200krpm</td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Conclusions

Making measurement and analysis to the drilling thrust force of drilling double-layer flexible printed circuit board in high spindle speed, this issue can get the following conclusions:

Because of the layer structure of the materials, when micro-drill drill the FCCL composite materials, the magnitude of cutting force is obvious difference in drilling different material layer (copper/adhesive/PI/adhesive/copper). The thrust force of drill copper foil is larger than the thrust force of drill adhesive layer, and the thrust force of drill PI layer is smallest.

The higher the drilling speed is, the smaller the thrust force is, the greater the feed speed is, the greater the thrust force is. The thrust force increase with the increase of drill diameter.

The size of exit burr increase with the increase of feed speed, and decrease with the increase of spindle speed. And in addition, when the spindle speed arrive 200krpm, the influence of feed speed become small.

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Reference


