공학석사 학위논문

인쇄회로기판의 마이크로 드릴링 가공성에서의 박음질 가공 경로의 효과

Effect of Backstitch Tool Path on Machinability of Micro-drilling for Printed Circuit Board

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문종설의 공학석사 학위논문을 인준함

2013 년 2 월

위 원 장 이 건 우 (인)

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Abstract

Effect of Backstitch Tool Path on Machinability of Micro-drilling for Printed Circuit Board

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As electronic components have become smaller, micro-drilling tools have been developed and used to drill holes in the hundred-micrometer range on printed circuit boards. To improve the productivity of the drilling process, printed circuit boards are generally stacked in several layers and drilled simultaneously. In this process, however, misalignment of the drilled holes on the top and bottom layers occurs, and this consequently degrades the overall product quality. To solve this problem, a new tool path strategy is proposed, which we refer to as the backstitch tool path. This approach is compared with a conventional tool path by examining the hole positioning error, drilling thrust force, drilling torque, and drilling duration under various drilling conditions. Applying the backstitch tool path strategy to a micro-drilling operation improved the productivity and product quality.

Keywords: Micro-drilling, Micro-machining, Printed circuit board, Tool path planning

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0 Introduction

The miniaturization of electric devices, such as mobile phones and medical devices, demands high precision in the manufacturing process. Therefore, many manufacturing methods have been investigated for the fabrication of micro-components [1–11]. Micro-drilling of printed circuit boards (PCBs) has become a critical manufacturing process. A PCB, which consists of a polymer matrix and glass fiber, is used to support mechanical components and transfer electrical signals. Drilling micro-holes at hundred-micrometer intervals on PCBs is necessary. Micro-drilling tools have been developed to enable this, and the characteristics and machinability of micro-tools for PCB manufacturing have been studied extensively [12-22].

Additionally, tool path planning, which is closely related to productivity efficiency and machine-tool life, has been considered in manufacturing operations in response to increasing concerns about productivity [23-25]. For an efficient drilling process, PCBs are generally stacked in several layers and drilled simultaneously. In this process, however, misalignment of holes from the ideal drilling coordinates occurs, particularly in the bottom layer (Figure 1). Therefore, it is necessary to minimize the factors that result in misalignment of drilled holes to reduce the hole positioning error. There are many reasons for this behavior. One factor is the fault of the device: spindle run-out with vibration can cause inaccuracy of the drilling point at high rotational speeds. This problem can also appear when the air bearing and collet supporting the spindle and tool are in poor condition. Controlling the spindle speed and checking the condition of the machining equipment can alleviate this problem. Another factor is contamination of the workpiece. Severe dents in the entry board and the in-flowing of foreign substances from the workpiece material can cause shifting of the drill tool during the machining process. Also, it has been reported that machined holes are often inclined because the adjacent holes machined a priori influence the orientation of the drill.

A new type of tool path planning is proposed in this study to improve the machinability of material during the micro-drilling process. Several experimental tests are conducted to compare the proposed tool path with a conventional tool path.

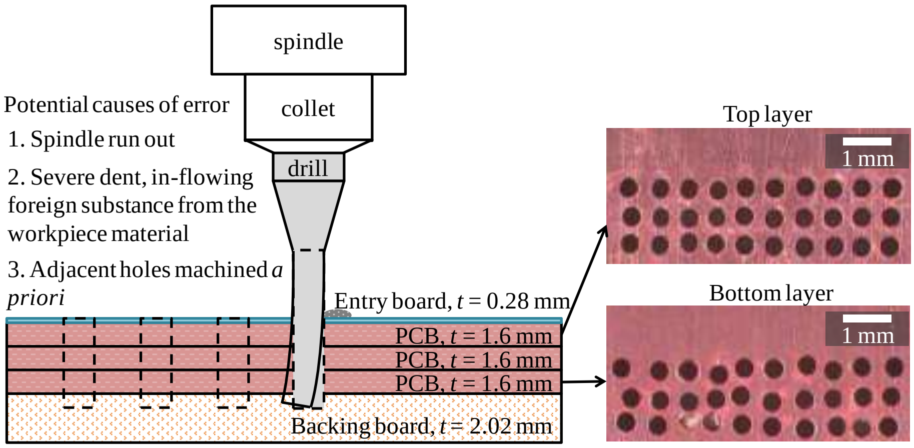


Figure 1: Hole misalignment

1 Experiment details

1.1 Experimental apparatus

The experimental apparatus is schematically shown in Figure 2. The PCB drilling system consisted of a three-axis stage (Justek, Korea) with 0.1-μm resolution for each axis, and a high-speed spindle (D1733, Westwind Air Bearings, UK) with a maximum rotational speed of 25 × 104 r/min, which was connected to a cooler and an air compressor. A dynamometer (9256C1, Kistler, Switzerland), an amplifier (5070A11100, Kistler, Switzerland) and a controller board (DS1103 PPC, dSPACE, Germany) were used to measure the drilling thrust force and torque. The drilling forces were measured in three dimensions along the x, y, and z axes from the moment when the drill bit contacted the entry board; the drilling thrust force and torque values were calculated from the obtained data. The drilling force signal during the drilling process is shown in Figure 3. An optical microscope (SV32, Sometech Vision, Korea) was used to image the hole. MATLAB/Simulink was used to obtain the dynamometer data and to analyze the hole positioning error through image processing.

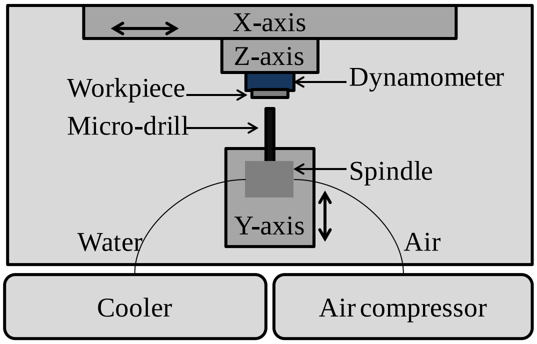


Figure 2: Experimental setup

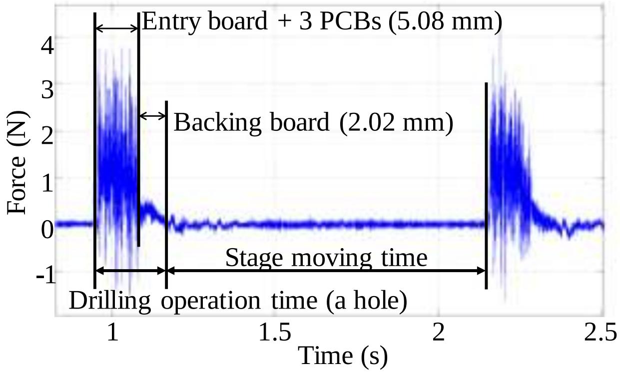
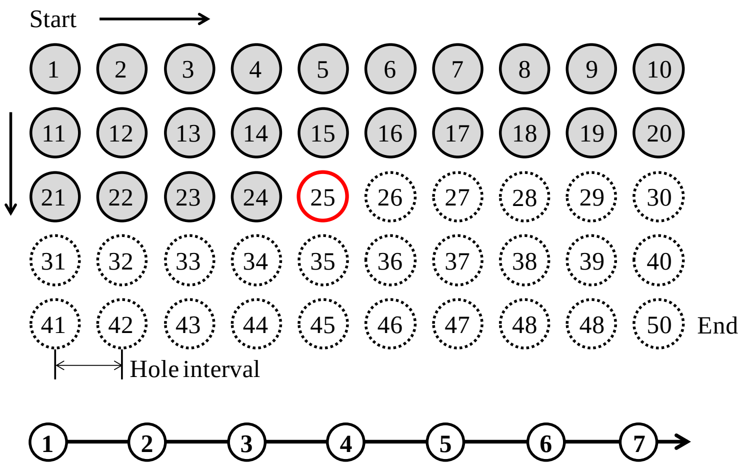


Figure 3: Typical drilling force signal from the dynamometer

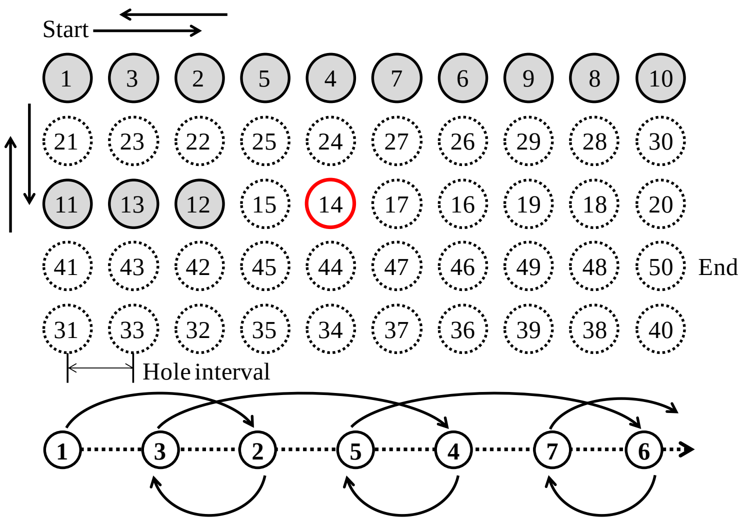
1.2 Experimental conditions

1.2.1 Tool path planning

A conventional tool path and the proposed backstitch (named after a stitching method) tool path are illustrated in Figure 4. While a conventional tool path moves in a single direction, the backstitch tool path includes an iteration process. It proceeds backwards and forwards in the x and z directions to maintain workpiece balance and minimize the effect of adjacent holes.



(a) Conventional tool path



(b) Backstitch tool path

Figure 4: Comparison of the backstitch tool path with a conventional tool path

The holes were machined in order of the hole number

(○: machined hole, ○: current hole, ◌: not machined hole)

1.2.2 Drilling conditions

The workpiece components consisted of an entry board (LE800, t = 0.28 mm), three-stack PCBs (epoxy + Cu, t = 1.6 mm × 3 stacks) and a backing board (wood, t = 2.02 mm). The entry board and backing board were used to minimize the burr formation and improve the machinability. Table 1 gives the specifications of the micro-drill bits (Neo Technical System Co., Korea) and the drilling conditions. Four different diameters of drill bits were used. Micro drill bits have geometric variables such as tool diameter, flute length, point angle, helix angle and web thickness. The main tool geometries considered for our experiments were the tool diameter and flute length. The flute length is shorter than the overall bit length and is tapered. For the best-quality drilled parts, the machining conditions, which include the spindle speed and in-feed rate, must be selected appropriately for the particular drill bit design. To do this, the reference drilling conditions of the spindle speed and in-feed rate are used. To relate the hole location error with the tool geometry, the hole interval (the distance between the centers of two adjacent holes) was set at twice the tool diameter. When a tool diameter of 400 μm was used, three different hole interval conditions, i.e., 0.6, 0.8, and 1.0 mm, were applied to evaluate the drilling thrust force, torque, and duration.

Table 1: Machining conditions

<table>
<tr><th>Conditions</th><th colspan="5">Values</th></tr>
<tr><td>Cutting diameter (µm)</td><td>250</td><td>300</td><td colspan="2">400</td><td>600</td></tr>
<tr><td>Flute length (mm)</td><td>5.5</td><td>6.5</td><td colspan="2">7.0</td><td>7.0</td></tr>
<tr><td>Spindle rotational speed (r/min)</td><td>95,000</td><td>95,000</td><td colspan="2">90,000</td><td>72,000</td></tr>
<tr><td>In-feed rate (mm/s)</td><td>35</td><td>40</td><td>20,
30</td><td>40</td><td>32</td></tr>
<tr><td>Chip load (µm/r)</td><td>22.11</td><td>25.26</td><td>13.33,
20</td><td>26.67</td><td>26.67</td></tr>
<tr><td>Hole interval (mm)</td><td>0.5</td><td>0.6</td><td>0.8</td><td>0.6,
0.8,
1.0</td><td>1.2</td></tr>
<tr><td>Tool path planning</td><td colspan="5">Conventional tool path, Backstitch tool path</td></tr>
</table>

Reference drilling conditions are indicated in bold

1.3 Method of measuring positioning errors for drilled holes

Figure 5 shows the method used to establish the hole positions. An image of each layer was obtained using the optical microscope after a drilling operation. Next, the image was processed using MATLAB to define the horizontal diameters by scanning the contours of the holes. Finally, the hole centers were determined from the centers of the horizontal diameters and were compared with the ideal drilling coordinates.

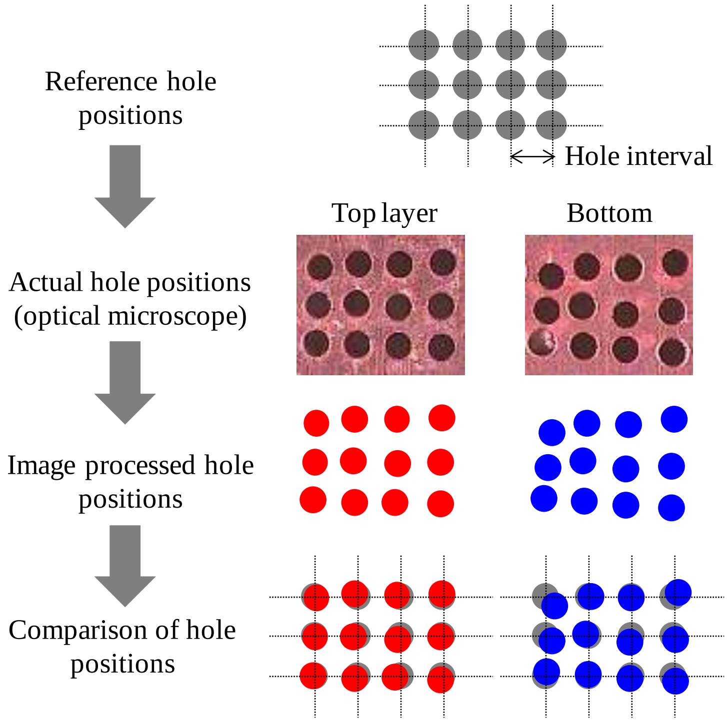


Figure 5: Method of measuring the positioning errors for the drilled holes

2 Results and discussion

2.1 Hole positioning error

2.1.1. Effect of the tool diameter

Figure 6 shows the positioning errors of the holes from their ideal positions for different tool sizes under the reference drilling condition. It is clear that the hole positioning error for the 0.4-mm tool was the greatest of all the tools. The hole positioning error for the bottom layer was greater than that for the top layer for all tool diameters, and the deviation increased with depth. In all the cases, the backstitch tool path reduced the hole positioning error by 4.6 – 55.8%.

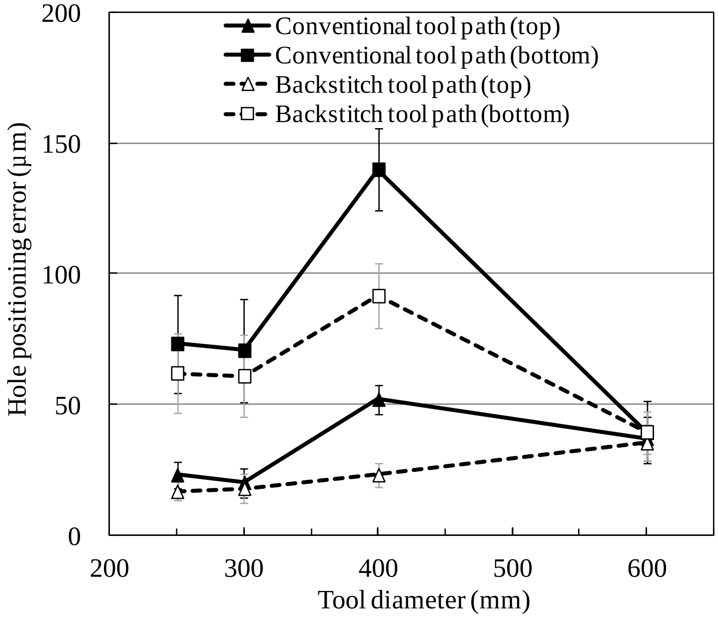


Figure 6: Effect of the tool diameter on the hole positioning error. The hole interval was twice the tool diameter

2.1.2 Effect of the hole interval

Figure 7 shows the hole positioning error as a function of the hole interval. The hole intervals were 0.6, 0.8, and 1.0 mm. When the hole interval was 1.0 mm, the hole positioning errors were very small. As the hole interval increased, the positioning errors for the first and bottom layers decreased. The hole positioning error was reduced by 12.7 – 55.8% by using the backstitch tool path.

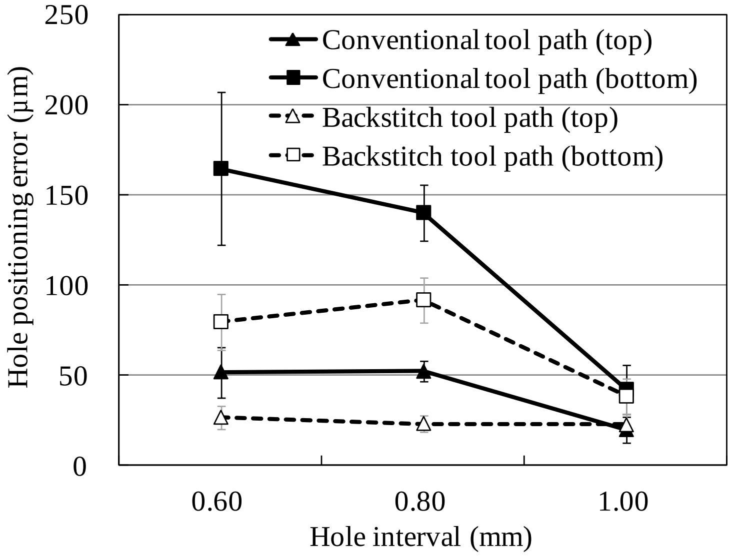


Figure 7: Effect of the hole interval on the hole positioning error (tool diameter: 400 µm, spindle speed: 90,000 r/min, in-feed rate: 40 mm/s)

2.1.3 Effect of the in-feed rate

Figure 8 shows the hole positioning error for different in-feed rates for a 400-µm tool. The spindle rotational speed was fixed at 90,000 r/min and the in-feed rate was changed from 20 to 40 mm/s for each condition. The in-feed rate is an important factor that influences the hole quality and productivity. The results show that the hole positioning error was lower when the in-feed rate was less than the reference in-feed rate (40 mm/s). In such cases, the backstitch tool path had no effect when compared with a conventional tool path. However, as the in-feed rate increased, the hole positioning error increased, and this could be reduced by using the backstitch tool path. Thus, the hole positioning error and drilling productivity could be improved simultaneously when the backstitch tool path was used.

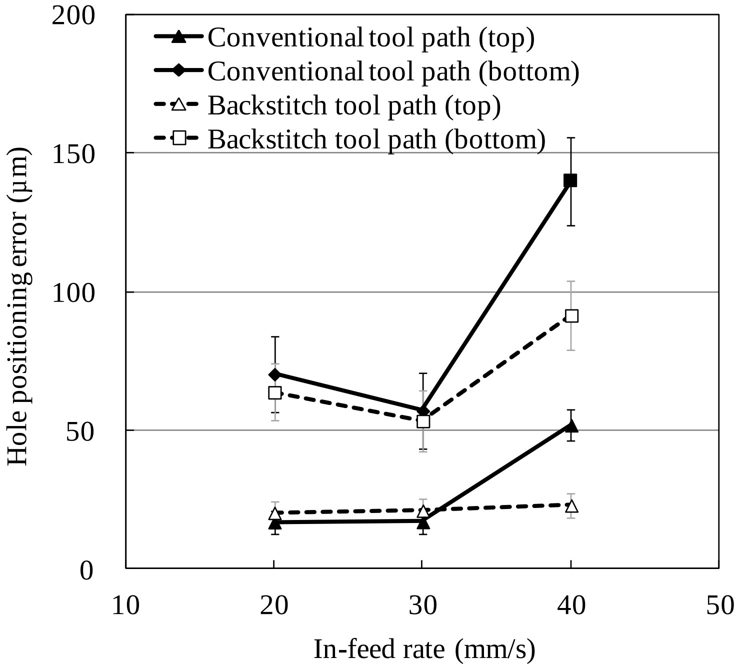


Figure 8: Effect of the in-feed rate on the hole positioning error (tool diameter: 400 µm, spindle speed: 90,000 r/min)

2.2 Drilling thrust force and torque

Figure 9 shows the drilling thrust force and torque data from the dynamometer as a function of the hole interval. The drilling thrust force and torque are important from the perspective of tool breakage and, consequently, productivity. In this experiment, a 0.4-mm-diameter drill bit was used with a spindle speed of 90,000 r/min and an in-feed rate of 40 mm/s. The drilling thrust force was reduced by 20.7 – 32.0%, or 0.37 – 0.60 N. Although the torques were close to zero, they nevertheless decreased as the drilling thrust force was reduced when the backstitch tool path was used. This would lead to longer tool life and therefore improved micro-drilling productivity.

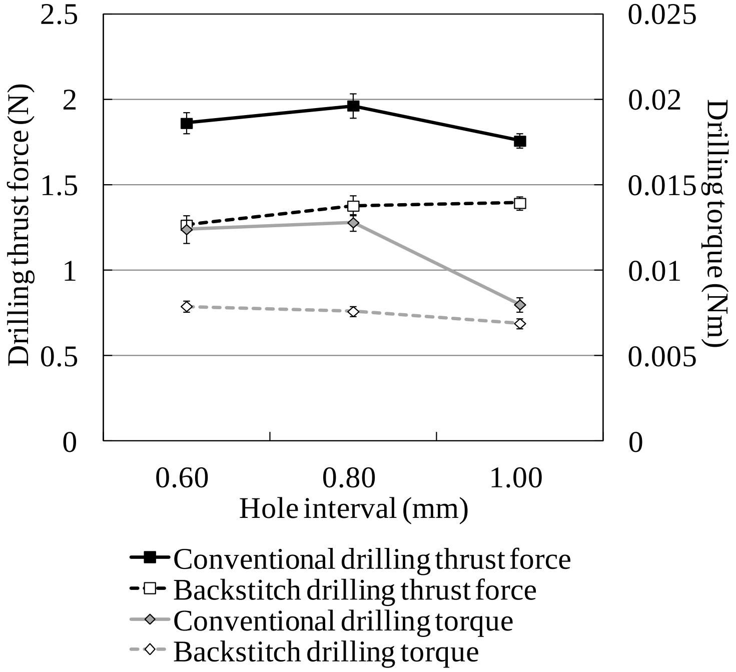


Figure 9: Drilling thrust force and torque (tool diameter: 400 µm, spindle speed: 90,000 r/min, in-feed rate: 40 mm/s)

2.3 Drilling time

The drilling time is important because it is directly related to productivity. The drilling time includes both the cutting time, which depends on the in-feed variable, and the moving time between cutting holes. Figure 10 shows the time required to drill ten holes with a 0.4-mm-diameter tool at a 0.8-mm interval and an in-feed rate of 40 mm/s. Because the backstitch tool path includes a back-and-forth movement, the drilling time was expected to be double that of a conventional tool path. However, the measured drilling times showed that it took only 0.02 – 0.04% longer to drill ten holes. The time difference was very small because the moving time between the holes was much shorter than the cutting time for a hole. Longer drilling times would be noticeable when the backstitch path is used to drill over a thousand holes. However, a PCB drilling code is not designed to drill a large number of consecutive holes. Consequently, the time difference is negligible between the conventional and backstitch tool paths.

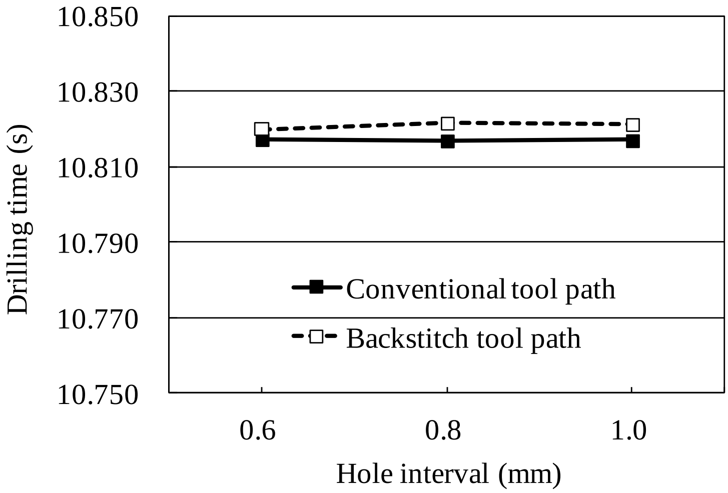


Figure 10: Drilling time for ten holes

3 Conclusions

A backstitch tool path was proposed and compared with a conventional tool path to study its effectiveness when drilling micro-holes on a multi-layered PCB. The backstitch tool path reduced the hole positioning error and the drilling thrust force and torque. The machinability and micro-drilling productivity when using a backstitch tool path for PCBs were higher than those obtained when using a conventional tool path; better-quality holes and reduced stress on the micro-drill tool were achieved without a significant loss of time.

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초 록

전자제품의 소형화, 첨단화 및 수요 증가는 전자회로기판(PCB, printed circuit board) 시장에 큰 영향을 미치고 있다. PCB는 전자부품들을 지지해 주며 절연기판 위에서 전기적 신호를 전달해 줄 수 있는 전기회로를 구성하는 부품으로, 소형 가전제품에서부터 첨단이동 통신기기에 이르기까지 모든 전자기기에 사용되고 있다. 이러한 배경에 있어 PCB 가공 정밀도는 경제적으로도 매우 중요하게 고려되는 요소이다.

PCB에 마이크로 스케일의 작은 구멍을 가공하기 위해서는 정밀도가 높은 직경이 수백 마이크로 정도 하는 드릴 툴이 개발되어 사용되고 있다. 작업의 효율성을 위해 2~3장의 PCB가 겹으로 쌓여 동시에 홀 가공이 이루어지는데 이러한 작업 과정에서 가공되는 홀의 위치가 실제 가공하고자 하는 위치로부터 벗어나는 현상이 발생하게 된다. 이는 홀 중심간의 간격이 드릴 직경보다 작게 되어 두 개의 홀이 중첩되거나 홀 중심간의 간격이 드릴 직경보다는 크지만 홀 간격이 매우 가깝게 되어 나타나는 현상으로 이러한 근접 홀의 정확한 가공은 아직까지 해결해야 할 과제이다.

본 연구는 상기 문제점을 해결하기 위한 수단으로 새로운 가공경로방법(Backstitch tool path)을 제시하고 있으며 기존의

가공경로(Conventional tool path)와 비교 연구를 수행하였고 그 우수성을 입증하였다. 4가지 다른 직경의 마이크로 드릴 툴로부터 툴 형상이 근접 홀 가공에 영향을 미치는 주요 요소라는 것을 확인하였고, 홀 간격, 이송속도, 스핀들 회전 속도 등의 다양한 가공 조건으로부터 새로운 가공경로방법의 타당성을 평가하였다. 상기 가공경로방법을 이용하면 정밀도가 개선되고 드릴링 가공 시 툴이 받는 추력이 감소됨을 본 연구를 통해 확인하였고 가공시간에 있어서 손실이 없음 또한 확인하였다. 상기 결과는 실제 산업현장에서 PCB 마이크로 홀 가공의 정밀도와 생산성을 높이는 데에 적용될 수 있으며 공작기계뿐만 아니라 집속이온빔, 레이저가공 등의 장치에도 적용될 수 있는 가능성을 보여준다.

주요어: 마이크로드릴링, 마이크로머시닝, 인쇄회로기판,
가공경로생성

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