Precision Engineering 38 (2014) 691–696

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Technical note

Effect of backstitch tool path on micro-drilling of printed circuit board

Jong-Seol Moon [a], Hae-Sung Yoon [a], Gyu-Bong Lee [b], Sung-Hoon Ahn [a,c,*]

[a] School of Mechanical and Aerospace Engineering, Seoul National University, Seoul 151-744, Republic of Korea
[b] Korea Engineering Plant Technology Center, KITECH (Korea Institute of Industrial Technology), Hanyangdaehak-Ro 55, Sangrok-Gu, Ansan, Gyeonggido 426-791, Republic of Korea
[c] Institute of Advanced Machinery and Design, Seoul National University, Seoul 151-744, Republic of Korea

ARTICLE INFO

Article history:
Received 7 January 2013
Received in revised form
24 September 2013
Accepted 4 March 2014
Available online 14 March 2014

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

ABSTRACT

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*. The basic scheme of the suggested strategy is to make a balance on the substrate. We compared this approach with a conventional tool path by examining the hole positioning error, drilling thrust force, drilling torque, and drilling duration under various drilling conditions. The effects of each process parameters were analyzed, and the suggested backstitch tool path has a positive effect on low bending stiffness tool, too much adjacent holes, and higher in-feed rate, respectively. Applying the backstitch tool path strategy to a micro-drilling operation improved the productivity and product quality.

1. 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 [1–4] and its assembly [5]. Various techniques such as Electro Discharge Machining (EDM) [6,7] or Electro Chemical Machining [8,9] have been developed in micro-scale, however among them mechanical machining is the most common process due to its marketability [10].

Following the developments in High-Speed Machining (HSM) technologies and micro-size carbide-tool fabrication, products feature size has been shrinking even under a hundred micrometer [11]. However in micro-scale machining, it is very difficult to control the process precisely because the portion of uncontrollable errors to process dimensions are relatively larger compared to the conventional scale process [11]. Moreover in micro-scale, tool has a relatively rounded edge compared to the conventional size tool, which causes sliding or plowing [12,13]. It results in increase in specific cutting energy.

This paper focuses on mechanical drilling printed circuit boards, which is a critical process in PCB manufacturing. 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 [14–16].

The most important product quality is a hole roughness and position accuracy. Since micro-holes performed a role as a conductive path after plating process, defects in micro-hole is very critical on entire circuit product quality. Hence hole quality has been seriously investigated based on theory and experimental data [17]. Cheong et al. performed dynamic modeling on spindle for micro-drilling [18], and Watanabe et al. performed investigation on relationships between radial run-out of spindle and hole quality [19]. Zheng et al. revealed chip formation characteristics in micro-drilling of multi-material [20], and Park et al. evaluated machinability and wall quality while end-milling printed circuit boards [21]. Burr is also a critical issue on hole quality, so burr-control chart for micro-drilling has been developed [22].

Main concern on this research is the position accuracy of drilled holes. In general industries, PCBs are usually stacked in

* Corresponding author at: Room 1205, Building 301, School of Mechanical and Aerospace Engineering, Seoul National University, Gwanak-Ro 1, Gwanak-Gu, Seoul 151-744, Korea. Tel.: +82 2 880 7110; fax: +82 2 888 9073.
E-mail address: ahnsh@snu.ac.kr (S.-H. Ahn).

http://dx.doi.org/10.1016/j.precisioneng.2014.03.002
0141-6359/

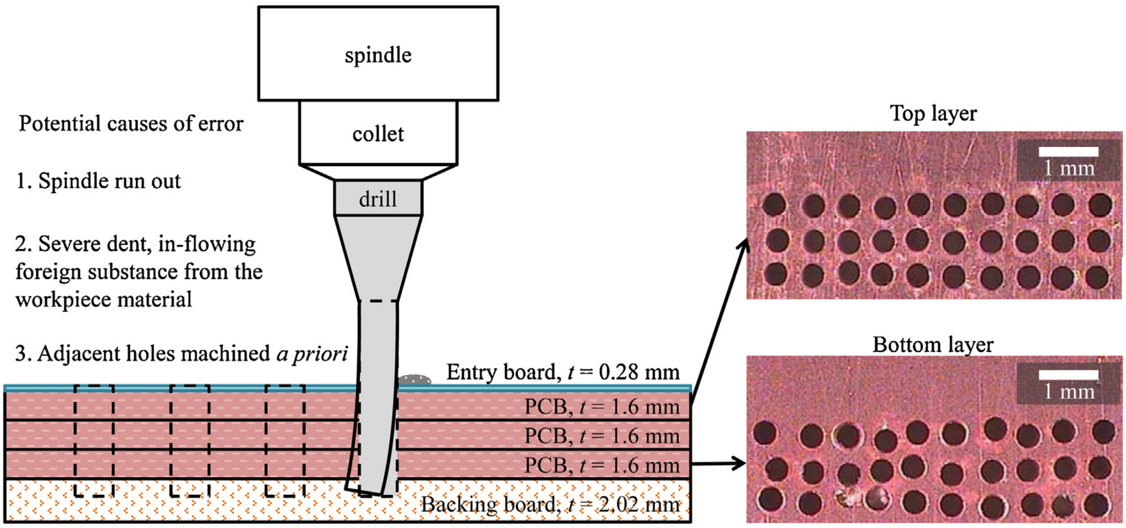

Fig. 1. Hole misalignment.

several layers and drilled simultaneously, for an efficient process. In this process, however, misalignment of holes from the ideal drilling coordinates occurs, particularly in the bottom layer (Fig. 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 [19]. In order to overcome this problem, peck drilling is widely adopted in drilling high aspect ratio hole [23], however it consumes significantly larger time in drilling compared to the continuous feed drilling. Longer lead time decreases both productivity and process efficiency, so it is not preferable particularly for PCB drilling industries. Moreover following the growing demands on energy concerns nowadays, research for efficient process has been investigated by controlling process parameters [24,25] and part orientation [26], and even for tool fabrication methods [27]. Therefore a novel approach needs to be suggested to acquire higher product quality and efficient process simultaneously.

In this research, a new type of tool path planning is proposed to improve the product quality of material during the micro-drilling process. 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 in general [28,29]. However the suggested tool path named *backstitch tool path* considered both product quality and efficiency simultaneously.

The basic principle of the suggested path is to make equivalent stress in whole workpiece material. In order to reduce positioning error in drilling, dynamic vibration of the tool and workpiece needs to be suppressed. Several experimental tests are conducted to compare the proposed tool path with a conventional tool path, and the results were analyzed in order to investigate the effect of tool geometry, hole intervals, and process parameters. Positional accuracy of hole was acquired using image processing after the drilling. Drilling force and lead time were measured using a dynamometer to evaluate performance of drilling.

2. Tool path planning

A conventional tool path and the proposed backstitch (named after a stitching method) tool path are illustrated in Fig. 2. While a conventional tool path moves in a single direction, the backstitch tool path includes an iteration process. Backstitch tool path proceeds backwards and forwards in the *x* and *z* directions to maintain workpiece balance and minimize the effect of adjacent holes. In conventional tool path, tool proceeds into workpiece having adjacent hole on only one side. For example as shown in Fig. 2, hole 25 has two adjacent holes, hole 15 and hole 24. However with backstitch tool path, adjacent holes are equivalently placed with the balance. In Fig. 2(b), hole 15 is drilled after hole 12 and 14. Hole 14 is drilled right after hole 13, however effect of hole 12 is relatively smaller compared to the conventional tool path. Backstitch tool path gives more clearance and equivalence to adjacent holes.

3. Experimental

3.1. Experimental apparatus

The experimental apparatus is schematically shown in Fig. 3. 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 25×10^4 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 Fig. 4. 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.