Effect of Cutting Parameters on the Quality of *Micro Drill* Process Results on PCB (Printed Circuit Board) Products

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Abstract

PCB (*Printed Circuit Board*) is an important requirement in the world of electronics. Currently, printing PCBs is less efficient because the time required is quite long and the manufacturing process is also less efficient. This study analyzes the quality of the machining process of PCB products with tools 0.8 mm which includes the quality of the hole dimensions. Data collection was carried out with variations in spindle rotation and feeding. The hole quality analysis method used includes analyzing the accuracy of the hole using a microscope. The results of the analysis show that the accuracy of the hole dimensions has changed significantly in some tests. Tests were carried out with spindle rotations of 5,500 and 5,600 rpm, and the feeds used were 160 and 170 mm/min. In this study, the largest value obtained was 0.82 mm at 5500 rpm and 160 mm/min and 170 mm/min and the lowest value was 0.80 mm. This research provides an overview of the quality analysis of hole dimensions on PCBs. The results of the study can be a reference for the development of *Micro Drill* on PCB material by varying more machining parameters used, type of cooling media, tool shape, tool type and measurement method used.

Keywords: Dimensional Quality, *Micro Drill*, PCB (*Printed Ciruit Board*)

1. Introduction

PCB (Printed Circuit Board) is an important part in the world of electronics. However, PCB printing is considered not very efficient because it takes a long time in the manufacturing process. Previously, several studies have been conducted to find ways to make PCBs more efficiently, including research by Budiharjo Daniel who tried to automate the printing process using MCS-51 in 1994. In this research, PCB penblblonan is done using markers that are automated to facilitate the drawing process [1].

The drill step is a key step in determining the layout of components on the PCB. The more complex the electronic circuit, the more holes are required for the components. In this case, problems can arise during manual work that result in some points being missed without being punched. The quality of component placement affects the resulting holes. If component placement errors occur on the PCB, the consequences can be serious including broken component legs and disconnected paths on the PCB, especially on small paths which when interrupted can result in the entire system not functioning properly [2].

One fundamental process in the manufacturing industry is "drilling", which involves making holes in components. As the size of components gets smaller, the hole-making process also has to adjust to a size of a few microns. In situations like this, the term "Micro Drilling" is used. The definition of Micro Drilling depends on the size of the hole diameter required. There is no specific standard that measures the size of drill bits that fall under the category of micro machining. For example, Sphinx, a Micro Drill manufacturer from Switzerland, defines that the hole size that falls under the Micro Drill category ranges from 0.05 mm to 2.5 mm[3]. The purpose of this research is to analyze the effect of cutting speed and feed on the quality of *micro drill* process results on PCB products with a 0.80 mm drill tool and determine the machining process parameters that affect the quality of PCB results.

HSS Chisel

High Speed Steel (HSS) is an alloy steel capable of maintaining hardness at high temperatures better than high carbon and low alloy steels. The good hot hardness allows tools made of HSS to be used under high cutting speed conditions. When compared to other types of tools at the time of its development, this type of tool truly deserves to be called "*High Speed*"[6]. A wide variety of *High Speed Steel (HSS)* tools are available (Table 1), but this type of tool can be divided into two types, namely:

a. Tungsten-type, T-grade defined by the American Iron and Steel Institute (AISI). Tungsten type HSS contains tungsten (W) as its main alloying material, while the additional alloying elements are Cromium (Cr) and vanadium (V). One of the most famous types of HSS is T1 or High Speed Steel 18-4-1, containing an alloy of 18% W, 4% Cr and 1%V.

b. Molybdenum-type, M-grade as defined by the American Iron and Steel Institute (AISI). Molybdenum-type HSS contains combined grades of tungsten and Molybdenum (Mo), plus additional alloying elements equal to T-grade. Sometimes Cobalt (Co) is added to HSS to increase its hot hardness value. Of course, High Speed Steel contains carbon, an element common to all types of steel.

Table 1 Types and functions of alloying elements in High Speed Steel[6].

Alloying Element	*Typical Content in HSS, % by Weight*	*Functions in High-speed Steel*
Tungsten	T-type HSS: 12 - 20	Increases hot hardness
	M-type HSS: 1.5 - 6	Improves abrasion resistance through formation of hard carbides in HSS
Molybdenum	T-type HSS: none	Increases hot hardness
	M-type HSS: 5 - 10	Improves abrasion resistance through formation of hard carbides in HSS
Chromium	3.75 – 4.5	Depth hardenability during heat treatment
		Improves abrasion resistance through formation of hard carbides in HSS
		Corrosion resistance (mirror effect)
Vanadium	1 - 5	Combine with carbon for wear resistance
		Retards grain growth for better toughness
Cobalt	0 - 12	Increases hot hardness
Carbon	0.75 – 1.5	Principal hardening element in steel
		Provides available carbon to form carbides with other alloying elemnt for wear resistance

Commercially, *High Speed Steel* (HSS) is one of the most commonly used cutting tool types today, despite the fact that HSS was introduced more than a century ago. *High Speed Steel* (HSS) is particularly suitable for applications involving complex tool geometries, such as *drills, taps, milling cutters,* and *broaches.* These complex shapes are usually easier and cheaper to produce from unhardened HSS than other tool materials. HSS tools have better toughness values than non-steel tool materials used for machining, such as cemented carbide and ceramics[6].

PCB (Printed Circuit Board)

Printed Circuit Board (PRT) or better known as PCB, is a board used to place electronic components and has a connection path formed through a layer of copper printed on it. The formation of pathways on PCBs is done by an etching process where certain copper parts are chemically removed from a blank copper-clad board (blank). After this process, the copper part that remains on the board along with the base will form the connecting paths on the PCB.

Boards coated with a layer of copper are also known as Copper Clad Board. The manufacture of copper clad boards involves a lamination process, which combines thin sheets of copper with a thickness between 0.0014 to 0.0042 inches over a substrate or base layer. This substrate is generally made from Phenolic or glass fiber (fiberglass) materials. Circuit boards using Phenolic substrates are not suitable for frequencies above 10MHz as they can cause signal degradation. Phenolic boards usually have a brown color. On the other hand, circuit boards that use glass fiber substrates can handle frequencies up to 40 MHz. These boards have a green color and have limited transparency[7]. A board of electronic components so as to form an electronic circuit or a place where these electronic components are connected to each other without the need to use additional cables. The term "circuit board" is used because PCBs are produced in large quantities by printing methods[8].

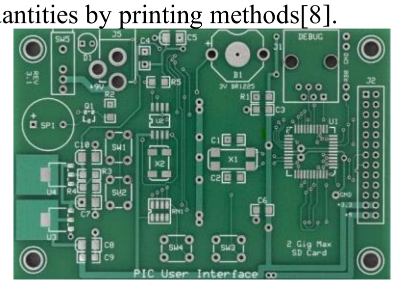

Figure 1. Physical Shape of PCB

There are three common variants of PCBs that are often used, namely single side, double side, and multi-layer. Single side refers to a PCB that has only one side covered with a layer of copper. Double side indicates that it has two sides covered with a layer of copper, with a fiber layer in between. This makes it possible to create paths in both the top layer and the bottom layer (figure 1). Multi layer involves several layers of copper that are conductive and arranged in sequence[8].

The PCB manual fabrication method is a simple and practical way of making printed circuit boards. In addition to its affordable cost, the results are also no less attractive when compared to other manual methods such as using permanent markers, screen printing techniques, or even using transfer paper which requires higher costs [9].

Quality of Machining

The demand for high-accuracy *micro-parts* and *micro-scale* products is on the rise in several industrial sectors today. While efforts are made to minimize deviations that may occur during the manufacturing process, it is not always possible to eliminate them completely. Therefore, in the process of manufacturing machine components using machine tools, tolerances for deviations in size and shape are allowed.

The main factors affecting tool life and hole quality can be summarized as follows: debris formation process, excessive cutting edge formation, cutting angle and radius, use of coolant, initial drilling location, conditions during machining, tool blade angle point, and "*peck drilling*" machining method.

a. *Burr*

Burrs refer to unwanted material protrusions that appear in most manufacturing processes. In operations that require high accuracy, burr removal and edge refinement can account for more than 30% of the total production cost of a part. The possibility of fracture is also highly dependent on the geometry in the drilling process, as drilling with large cutting edges tends to generate higher forces in the center of the hole, as can be seen in the illustration in figure 2 below.

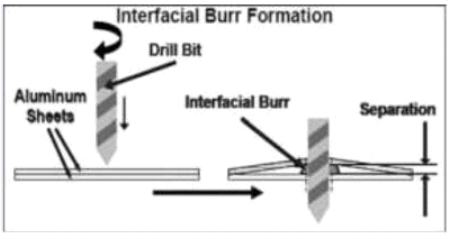

Figure 2. Interfacial Burr Formation in Aerospace Hole Making Stacked [11]

The micro hole machining process involves creating very small (micro) holes using a drilling machine. In addition to producing holes with targeted diameters, the result of this drilling process is often the formation of small bumps or burrs around the lips of the inlet and outlet holes. These burrs appear as a residue of the drilling process, similar to small chips or pieces. However, burrs are an undesirable element in the machining process, because in addition to being aesthetically disturbing, they can also negatively impact product quality. They can reduce the tightness, durability of the product, as well as hinder the assembly process. Therefore, efforts should be made to minimize and if possible, eliminate these burrs [11].

b. Hole Dimension Quality

In the drilling process, parameters must be set with the aim of achieving the desired results, including good-quality surfaces, superior hole quality, accurate component dimensions, long-lasting tool life, smooth separation of debris, and the like see figure 3. In addition, these parameters must also meet economic criteria, such as minimal production costs or maximized production. However, poor hole quality is a major cause for rejection of composite structures, as surface finish and hole geometry play a key role in the drilling process. The parameters that control the mechanics aspect of drilling include cutting speed, feed rate, cutting force, and material removal rate. The drilling process, in addition to producing damage such as delamination and cracks in the matrix around the hole, can eventually result in a decrease in the tensile strength of the remaining components that have undergone drilling [12].

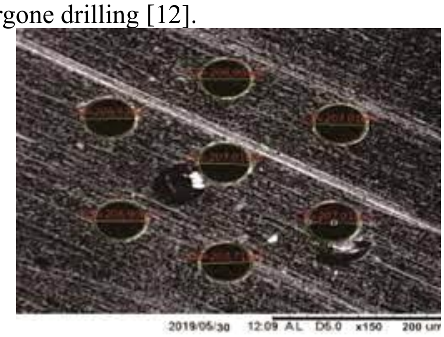

Figure 3. Hole dimensions after drilling

Experiment Design

In 1930, Sir Ronald Fisher introduced the Design of Experiment (DoE) method to address research problems by identifying the optimal solution of various test parameters. The DoE method technically consists of factors, levels, and responses. Factors refer to input elements in a process that can be classified as controllable or uncontrollable variables. These factors take the form of variables that can be physically adjusted and change their settings from the existing levels. Each factor has levels that represent different levels of settings, which can be adjusted to create the desired combination of tests, based on the response of specific parameters in the study. Responses refer to the output results of tests conducted based on the factor level settings. Responses can be single or grouped, often referred to as multiple responses, indicating that there are multiple output parameters. Responses can be effectiveness, efficiency, quality, performance, and similar values, as long as they can be concretely measured.

The Design of Experiments (DoE) method aims to achieve optimal solusion by reducing experiments so that experiments can be carried out efficiently. DoE encompasses a variety of methods, including screening designs, factorial designs, response surfaces, mixed designs, Taguchi methods, and others. Each method results in the formulation of a mathematical model that is then optimized to maximize, minimize, or achieve a t-test of the relevant factors. The optimization process can utilize methods such as optimization plots, gray relation analysis, and metaheuristic methods. Each DoE method has implementation requirements according to specific situations and needs, and in some cases, these methods can be used together to identify optimal solutions while accounting for possible errors in the mathematical model. One method, factorial design, combines all factor levels with other factor levels to measure the impact of changes in each combination of factor levels. Factorial design has various types, including half-fractional factorial design and full factorial design [13].

To carry out an ANOVA analysis, there are three assumptions that must be met by the residuals:

1. **Identical Assumption:** To fulfill the identical assumption, the residuals should be randomly scattered around the zero value and not form a special pattern. The results of the identical assumption test can be seen in the following figure.
2. **Independent Assumption:** To test the independence assumption, the autocorrelation function (ACF) is used. The results from the ACF plot shown in the figure indicate that there are no ACF values that fall outside the boundary

interval at any lag. This indicates that there is no correlation between the residuals, so the independence assumption is met.

3. **Normal Distribution Test: The** normal distribution test uses the Kolmogorov-Smirnov. The hypothesis used is:
   - H0: Residuals have a normal distribution.
   - H1: Residuals do not have a normal distribution. H0 will be rejected if the p-value is less than 0.05.

After ensuring that the data met these three assumptions, an ANOVA analysis was performed to determine whether the process parameters had a significant influence on the response regarding the surface roughness of the workpiece resulting from the defraving process. The results of the ANOVA analysis showed that the F-value of each independent variable was compared to the critical value of F(0.05). A decision is made based on this comparison: if the F-value is less than F(0.05), then H0 (null hypothesis) is accepted, but if the F-value is greater than F(0.05), then H0 is rejected [14].

2. Methods and materials

2.1 Research Stages

Workpiece testing is carried out using the AGMA A-8 Vertical Machining Center CNC machine (Figure 4) with specifications as shown in Table 2 below,

Table 2. Agma A-8 CNC Machine Specifications

Brand	Agma (A-8)
Table size	970 x 510 (38.19 x 20.08) mm
Max. Table Load	500 kg
X axis	800 mm
Y axis	510 mm
Z axis	510 mm
Machine Weight	5,000 kg

Figure 4. Agma A-8 CNC Machine

The tool blade to be used on the *Micro Drill* CNC (Figure 6) with a diameter of 0.8 mm as shown in table 3. and the figure 5 below.

Table 3: Specifications of the cutting tool used

Weight	200 g
Materials	Tungsten Carbide
Total *Length*	38 mm


Figure 5. 0.80 mm Tungsten Carbide Chisel

The material that will be used is a PCB plate with the sizes owned, namely: length (P) 20mm, width (L) 10 mm and thickness (T) 1.6 mm,. Perencanna making holes on this PCB board as shown in Figure 6 below.

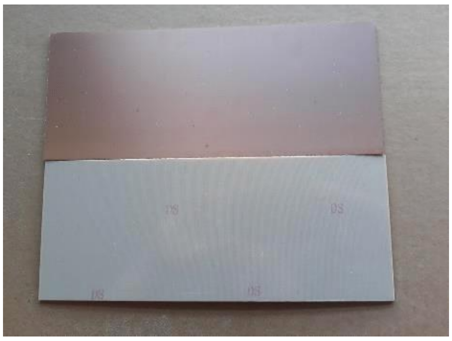
Figure 6. Physical Shape of PCB Plate

The PCB (*Printed Circuit Board*) plate is divided into 2 layers, namely the top layer and the bottom layer. On the top layer there is material made of copper and the bottom layer there is material made of white fiberglass.

Figure 7. Optical Microscope

Measurement of PCB board holes is carried out using an optical microscope measuring instrument and amscope software with specifications Magnification Ratio 500x, Trinocular Image Tube (Figure 7).

Cutting Conditions

The Micro Drill process was carried out using Tungsten Carbide tool blades with a diameter of 0.80 mm. Feedrate variations are 160 and 170 mm/min with 2 spindle speed variations of 5,500 and 5,700 rpm. *Micro Drill* is done 5 times making holes on each variation of spindle speed and feedrate. So the total number of holes that will be done *Micro Drill* process amounted to 20 holes for each layer.

Machining Parameters

The selection of machining parameters, also known as machining conditions, is very important. Therefore, the selection of process parameters such as cutting speed, spindle speed, depth of cut, feed rate, drill geometry and drill process strategy plays an important role in realizing excellent product quality and increasing tool life.

Full Factorial Design

Input the result data to the stastical analisis software (Design of Expert®). this application was used to analys the experimental data full factirial design method using annova to find out the machining parameters that affect the quality of the PCB (*Printed Circuit Board*) product.

3. Results and discussion

Micro Drill Process Results

From the machining parameters and PCB plates used in this study, the number of holes was made as many as 20 holes. And the 20 holes are divided into 4 variations including variations in spindle rotation and feed. The first variation has a rotation of 5,500 rpm and 160 mm/min, 5,500 rpm and 170 mm/min, 5,600 rpm and 160 mm/min and 5,600 rpm and 170 mm/min. Each variation was made in 5 tests. Below is Figure 8 of each test.

Figure 8. Micro Drill Results on PCB (Printed Circuit Board)

Results and Analysis

From the tests conducted, the dimensions of the holes were measured and the results are shown in table 3 below.

Table 3. Table of hole dimension measurement results with variations in spindle rotation and feed (5 tests for 4 specimens)

Specimen	Test	Spindel rotation (RPM)	Feed rate (mm/min)	Hole dimension (mm)
1	1	5500	160	0.82
	2			0.82
	3			0.82
	4			0.80
	5			0.81
2	1		170	0.81
	2			0.82
	3			0.80
	4			0.80
	5			0.80
3	1	5600	160	0.81
	2			0.80
	3			0.81
	4			0.80
	5			0.81
4	1		170	0.80
	2			0.80
	3			0.80
	4			0.81
	5			0.80

In the table above, the results of the hole dimensions vary. Although the resulting data is not so consistent, it is observed that the hole dimensions are more consistent and less deviation occurs at n = 5600 and F = 170 mm/min. while the largest deviation occurs at n = 5500 and F = 160 mm/min. Figure 9 below is a sample photo for PCBs with holes that have the highest deviation (Figure 9) and the lowest deviation (Figure 10).

Figure 9. Dimension of the hole with the largest deviation.

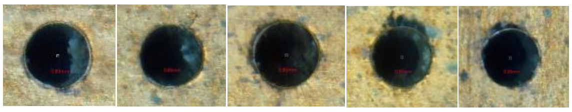

Figure 10. The hole dimension with the least deviation.

The graphs in Figure 11 below are the test and measurement data and can be clearly seen the difference in hole dimension deviations that occurred in the test results clearly based on variations in spindle rotation and feed rate. In graph below the feed rate 160 mm/min have the deviation higher than feed rate 170 mm/min so for feed rate 160 mm/min the hole dimension of the 1^{st}, 2^{nd} and 3^{rd} testing were 0.82 mm instead of 0.80 mm. Meanwhile the 3 experiments for feed rate 170 mm/min the holes dimension were 0.80 mm.

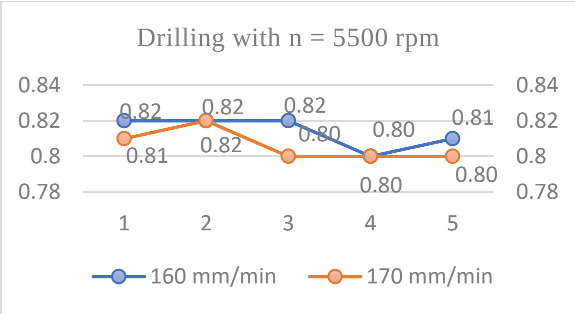

Figure 11, Deviation graph of spindle rotation and feed variation with n = 5500 rpm

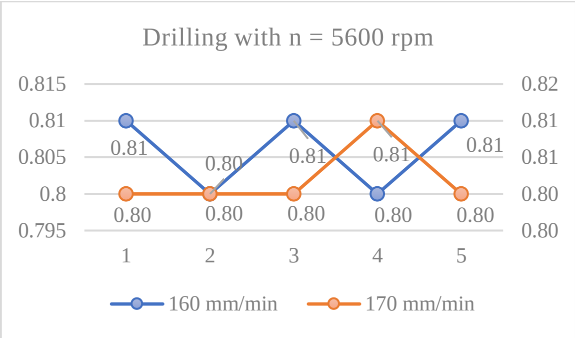

Figure 12. Deviation graph of spindle rotation and feed variation with n = 5600 rpm

Figure 12, was shown above, for the feed rate 160 mm/min have the deviation inconsistent but the higher value was 0.81 mm (0.01 deviation). Meanwhile for feed rate the hole dimension of the 1st, 2nd, 3rd and 4th testing were constant 0.80 mm.

Analysis of Variance

Analysis of Variance (ANOVA) needs to be done on the data to see the influence of variables on the *Micro Drill* process. Analysis of Variance (ANOVA) can be seen from the following table 4.

Table 4. ANOVA Table

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0,0006	3	0,0002	5,08	0,0117	significant
A- turn pindle	0,0003	1	0,0003	8,53	0,0100	
B-feeding	0,0003	1	0,0003	6,59	0,0207	
AB	0,0001	1	0,0001	2,26	0,1518	
Pure Error	0,0006	16	0,0000			
Cast Total	0,0012	19				

ANOVA (Analysis of Variance) data was used to identify factors affecting hole quality. The value of "p-value < α" if less than 0.0500 indicates that the model is significant. In the table above, it can be seen that the ANOVA data for spindle rotation and feed shows a p-value of (0.0100) and (0.0207). Where the p-value < α indicates that the model is significant.

Half Normal Plot Graph

The half normal plot graph can be seen in Figure 13 as follows.

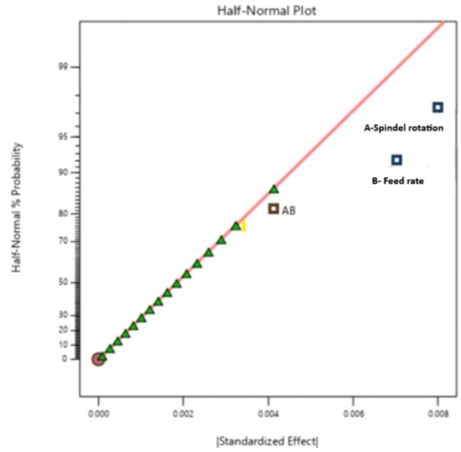

Figure 13. Half normal plot graph

As seen in graph 13 above, both spindle rotation and feed rate were found to have a substantial impact on the outcome of the micro drill process in the experiment due to these parameters are located far from the red line (zero line).

3D surface graph

The 3D surface graph is a 3-dimensional surface graph. Here is the graph in Figure 13.

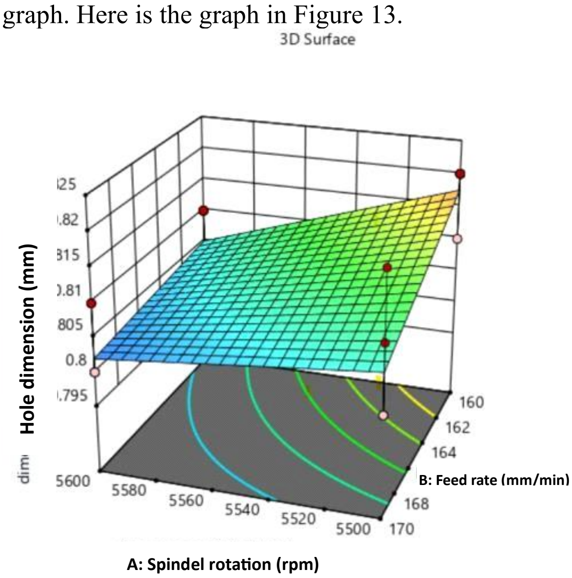

Figure 14. 3D surface graph of hole dimension againt spindel rotation and feed rate

The greatest value, 0.82 mm, is indicated in Figure 14 above and is colored reddish yellow. Conversely, the figure that is the lowest, 0.80 mm, is indicated in blue. Commercial PCB manufacturers state that the tolerance range for holes is 0.019 to 0.025, meaning that a greater value of 0.82 mm is still within the tolerance range. The quality of the board is undoubtedly impacted if the greater value is outside of the range.

4. Conclusions

Based on the results of the data obtained in the research that has been carried out, the following conclusions can be drawn:

- The spindle rotation and the amount of feed determined affect the quality of the hole dimensions that occur in the Micro Drill process on PCB material, where the largest deviation occurs at 5500 rpm spindle rotation and 160 mm.min feed while the smallest hole deviation occurs at 5600 rpm spindle rotation and 170 mm/min feed.
- The good hole dimension quality results obtained in hole making using 0.80 mm tool is with 170 mm/min of good feed at 5,600 rpm of tungsten carbide tool cutting.
- The ANOVA (Analysis of Variance) test for spindle rotation and feed showed p-values of (0.0126) and (0.0317). Where the p-value < α, the parameters used in this study are significant. It was similar shown at figure 13 and half normal plot.

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