# PROCESS PARAMETER OPTIMIZATION IN DRILLING PROCESS OF PRINTED CIRCUIT BOARD USING TAGUCHI METHOD

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**ABSTRACT**

*PCB is laminated composite material consisting of copper foils, resin and glass fiber cloth. So it is troublesome to drill deeper holes at high productivity and high exactness. In this work, different entry materials were micro drilled for printed circuit board. The optimization of different parameters is done by using Taguchi Approach. In this experiment $L_{16}$ orthogonal array is used with three controllable factors like spindle Speed, feed and material with four levels of each to find out optimum level of parameters to minimize the surface roughness. The ANOVA results used to find out significant factor and percentage contribution of individual factor. From ANOVA analysis it is found that Spindle speed is most contributing factor for surface roughness with contribution of 67.66%.*

**Keyword:** - *Drilling[1], Taguchi method[2], Surface roughness[3], ANOVA[4], Minitab 16[5].*

## 1. INTRODUCTION

In recent years, the production of printed circuit boards (PCBs) has not only increased in quantity but also improved in quality. One demand has been that the packaging density of PCBs be improved. High packaging density technology has allowed downsizing. For instance, from the point of view of the public, the downsizing of televisions and telephones has made it possible to change these from stationary to portable devices. Thus, high-quality micro-machining is necessary for PCBs. Specifically, small diameter drilling in PCBs has attracted attention because the packaging density must be improved; in other words, the PCBs must have a large number of holes.[3] In recent years, the printed circuit board (PCB) industry in Taiwan has become the largest of the three major manufacturing regions in the world. With the aid of advanced production technology and continuous improvement in quality, the output value and production capacity of Taiwan in 1998 were around 10 and 18%, respectively, versus that all over the world. These statistics reveal that the competition among the PCB factories in Taiwan is very critical because the output value is 8% less than the production capacity. In such a competitive environment, enlarging the production capacities, raising the yield, improving the manufacturing process, and reducing the cycle time are commonly used strategies to enhance the profits. [2]

PCB is laminated composite material consisting of glass fiber cloth, copper foils and resins. Therefore it is very difficult to drill deep holes at high precision and productivity. Right now during drilling, microdrills are easy to break. Therefore, it's serious for PCB production that additional conservative drilling conditions chosen for safety bring lower productivity and great cost. [5] Printed circuit boards (PCBs) are widely used in industries such as aviation, microelectronics, instrumentation, precision machinery and medical equipment. The base material of PCBs is always a copper clad laminate (CCL), which is a multi-material sheet. It consists of dielectric layer (resin/glass fibre cloth) and a high purity metal conductor (copper foil). CCL is a heterogeneous, anisotropic material. The machining properties of copper clad laminate (CCLs) are quite different from homogenous metallic materials. [10]

There are three major types of printed circuit boards (PCBs) construction: single-sided, double-sided, and multi layered. In single-sided construction, all components are placed on one side of the board. Double-sided PCBs are used when the number of components is too large to allow single-sided construction within the designated space. A multi-layered board has several printed circuit layers separated by layers of insulation. The electronic components on the surface are connected through plated holes drilled down to the appropriate circuit layer, which simplifies the circuit. The most common substrate used for PCBs is made of glass-fiber-reinforced epoxy resin with copper foil bonded to the surface (single or double-sided). [16]

With the rapid growth of printed circuit board (PCB) technology today, board density is becoming an important concern. In every facet of production, productivity and cost are decisive matters. Manufacturing process makes great effort to keep up with industry demands and drilling remains a bottleneck due to the limitations in conventional drill machine technology. PCBs are rarely made in quantities of just one or two, the usually batch size being from several hundreds to thousands pieces. Depending on PCB thickness it is possible to drill through at least two which are stacked, and it is often possible to drill through ten or perhaps twenty depending on the length of the drill and the thickness of the PCB stack.[6] With the advancement of technology, the application of multilayer printed circuit boards (PCBs) in electronics, MEMS, automotive, aerospace, etc. industries have been increased immensely. Multilayer PCBs consist of a large number of small diameter holes to accommodate inter-layer connections and plug connectors in high speed circuits. Precise and accurate holes are very essential for the smooth functioning and reliability of the fabricated electronic components. Micro-drilling is the most commonly used machining operation for drilling such small diameter holes (generally less than 1 mm). [22]

The aim of this research is to find out the effect of drilling process parameters at the point of view surface roughness of printed circuit board by employing Taguchi's orthogonal array design and analysis of variance (ANOVA). In this experiment $L_{16}$ orthogonal array is used with three controllable factors like Spindle speed, Feed and material with three levels of each to find out optimum level of process parameters for CNC Turning operation. The ANOVA results used to find out significant factor and percentage contribution of individual factor.

## 2. LITERATURE REVIEW

**Leszek Kudla (2001)**, studied Influence of feed motion features on small holes drilling process. Mechanical drilling is the basic method of machining of round small holes, less than 1 mm in diameter. By drilling in such variety of sizes, it's needed to use special exactitude machines. The paper describes and discusses feed drives applicated in exactitude drilling machines, strategies and attributes of feed execution, with regard to minimizing the risk of drill breakage, to improve the hole quality, and to limit the increase in production time. [1]

**Hidehito Watanabe et al (2008)**, studied Microdrilling for printed circuit boards (PCBs)—Influence of radial run-out of microdrills on hole quality. This paper represents the drilling of dense printed circuit boards (PCBs) using microdrills. The relationship between the radial run-out of drills and the hole quality was examined with experimentation using 0.1-mm diameter drills at a rotational speed of 3×105 min−1. The drilling behavior at contact with a work surface was dynamically registered utilizing a high-speed video camera. It was concluded that Orbital revolving drills with the radial run-out significantly move toward the centripetal direction, just after beginning the contact with a work surface. The entry sheet effectively intensifies the centripetal action. The radial run-out is insensitive to drill wear as well as hole quality, because of the centripetal action. [5]

**Mircea Ancau (2008)**, investigated optimization of printed circuit board manufacturing by improving the drilling process productivity. The aim of this research analysis is that the optimisation of printed circuit board manufacturing by enhancing the process productivity. Attention was centered on reducing tool path length and the processing time. The paper is divided in two main parts. First part presents an original hybrid heuristic algorithm, for solving traveling salesman problem. The algorithm relies on the structure of a general optimisation procedure, and is employed to cut back the tool path length. Also, it's developed a sensible mathematical model for printed circuit board processing time calculation. The case study on the second part of the paper shows the efficient use of the above given algorithm in finding the optimal length of the tool path. It clearly shows the influence of stacked printed circuit board on process productivity. By means of its concepts management, the paper represents a real guide for optimal design of printed circuit board drilling technology. [6]

**Azlan Abdul Rahman (2009)**, investigated Effect of Machining Parameters on Hole Quality of Micro Drilling for Brass. This paper shows the influence of drilling parameter like as spindle speed, feed rate and drilling tool size on material removal rate (MRR), surface roughness, dimensional accuracy and burr. In this work, a detail study on optimum drilling parameter for HSS drilling tool in micro-drilling processes is done in order to find the best drilling parameter for brass as a workpiece material. Micro drilling experiment with 0.5 mm to 1.0 mm drill sizes were performed by changing the spindle speed and feed at three different level. From the result, the surface roughness are mostly affected by spindle speed and feed rate. As the spindle and feed rate increases, the surface roughness will decrease. The tool diameter offers less influence on the value of the surface roughness. The value of MRR is reduced when the tool diameter, spindle speed and feed rate are decreases. As drilling tool diameter, feed rate and spindle speed raise the dimensional accuracy of drilled hole will decrease. The increment of spindle speed and feed rate value mostly will affect the tool wear and size of burr on the edge of drilled holes. [8]

**L.J. Zheng et al. (2011)**, studied A Review on Drilling Printed Circuit Boards. This review article clearly shows the report regarding tool materials and geometrics, cutting force, cutting temperature, radial run-out and damages occurring in drilling processes. And as a interpretation, some of these critical issues are proposed to take up the challenges in analysis and optimization for PCB drilling. PCB is composite materials with anisotropy. Even a little defect in PCB might cause heavy losses. Both the drilling process and PCB structure design have been researched by many scholars. [9]

**Xin Zhang et al. (2012)**, investigated experimental Study on Cutting Force of High-speed Micro-drilling Flexible Printed Circuit Board. In this review paper, some experimental investigations of cutting force of high speed micro-drilling are carried out to refine the drilling standard of FPC. The results indicate that the drilling parameters (spindle speed, feed speed and drill-bit diameter) have vital influence on micro-drilling thrust force. 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 the smallest. The larger the thrust force is, the bigger the exit burr is. [11]

## 3. EXPERIMENTAL METHODOLOGY

### 3.1 Experimental Design

In this work drilling operation was performed on printed circuit board material. The parameters identified for investigation are Spindle speed, Feed and material. The selected process parameter and their levels are shown in Table 1. Levels of experimental parameters consist of cutting speed ranging from (400-700), Feed rate (0.11-0.14) and Material A= Copper + Backup, B= Backup + Copper + Backup, C= Aluminium + Copper + Backup, D= Bakelite + Copper + Backup.

**Table -1:** Control factors and their levels

| Control Factors | Units | Level I | Level II | Level III | Level IV |
|---|---|---|---|---|---|
| Spindle Speed | rpm | 400 | 500 | 600 | 700 |
| Feed | mm/min | 0.11 | 0.12 | 0.13 | 0.14 |
| Material | - | A | B | C | D |

### 3.2 Taguchi Method

Orthogonal array is one of the Taguchi tool, which takes out the quantity of test required, decreases the cost, and reduce the time of trials. The Orthogonal array $L_{16}$ is shown in Table 2. Taguchi gives three types of quality characteristics Smaller the better, Nominal the better and Larger the better.

### 3.3 ANOVA Analysis

Analysis of variance (ANOVA) of the overall set is done to show the important parameters. If the P value for a factor becomes less than 0.05 then that factor is considered as significant factor at 95% confidence level. Statistical software with an analytical tool of ANOVA is used to decide which parameter importantly affects the performance characteristics.

**3.4 S/N ratio**

The signal-to-noise (S/N) ratio evaluates how the response vary relative to the nominal or target value under varied noise conditions. You can select from various S/N ratios, depending on the target of your experiment. Taguchi introduced three types of quality characteristics Smaller is better, Nominal is better and Larger is better

The signal-to-noise (S/N) ratio is always calculated for each factor level combination. The formula for the smaller-is-better S/N ratio using base 10 log is:

$$\text{S/N Ratio} = -10\log \left[ \frac{1}{n} \sum_{i=1}^{n} (Y_i^2) \right] \quad \text{---------------} \; (1)$$

Where Y = responses for the given factor level combination and n = number of responses in the factor level combination.

**Table -2:** Taguchi $L_9$ Orthogonal array

| Run | Factor 1 Spindle Speed (rpm) | Factor 2 Feed rate (mm/min) | Factor 3 Material |
|---|---|---|---|
| 1 | 400 | 0.11 | A |
| 2 | 400 | 0.12 | B |
| 3 | 400 | 0.13 | C |
| 4 | 400 | 0.14 | D |
| 5 | 500 | 0.11 | B |
| 6 | 500 | 0.12 | A |
| 7 | 500 | 0.13 | D |
| 8 | 500 | 0.14 | C |
| 9 | 600 | 0.11 | C |
| 10 | 600 | 0.12 | D |
| 11 | 600 | 0.13 | A |
| 12 | 600 | 0.14 | B |
| 13 | 700 | 0.11 | D |
| 14 | 700 | 0.12 | C |
| 15 | 700 | 0.13 | B |
| 16 | 700 | 0.14 | A |

## 4. EXPERIMENTAL PROCEDURE

The experiments are conducted using Lenz PCB drilling machine. The photograph of experimental set up as shown in Figure 2.

**Fig -2**: Photograph of experimental set up

After Machining the Surface Roughness of machined component is measured using a contact type surface roughness tester. The Table 3 shows the results for Surface Roughness.

**Table -3:** Experimental result for Surface Roughness

| Run | Factor 1 Spindle Speed (rpm) | Factor 2 Feed rate (mm/min) | Factor 3 Material | Surface Roughness (µm) |
|---|---|---|---|---|
| 1 | 400 | 0.11 | A | 0.47 |
| 2 | 400 | 0.12 | B | 0.54 |
| 3 | 400 | 0.13 | C | 0.31 |
| 4 | 400 | 0.14 | D | 0.48 |
| 5 | 500 | 0.11 | B | 0.71 |
| 6 | 500 | 0.12 | A | 0.56 |
| 7 | 500 | 0.13 | D | 0.70 |
| 8 | 500 | 0.14 | C | 0.44 |
| 9 | 600 | 0.11 | C | 0.59 |
| 10 | 600 | 0.12 | D | 0.78 |
| 11 | 600 | 0.13 | A | 0.81 |
| 12 | 600 | 0.14 | B | 0.89 |
| 13 | 700 | 0.11 | D | 0.80 |
| 14 | 700 | 0.12 | C | 0.71 |
| 15 | 700 | 0.13 | B | 0.94 |
| 16 | 700 | 0.14 | A | 0.96 |

## 5. RESULT & DISCUSSION

The Signal to Noise (S/N) Ratio for Surface Roughness is calculated by using Smaller the better characteristic. The S/N Ratio result for Surface Roughness is as shown in Table 4.

**Table -4:** Calculated S/N ratio for Surface Roughness

| Run | Factor 1 Spindle Speed (rpm) | Factor 2 Feed rate (mm/min) | Factor 3 Material | Surface Roughness (µm) |
|---|---|---|---|---|
| 1 | 400 | 0.11 | A | 6.56 |
| 2 | 400 | 0.12 | B | 5.35 |
| 3 | 400 | 0.13 | C | 10.17 |
| 4 | 400 | 0.14 | D | 6.38 |
| 5 | 500 | 0.11 | B | 2.97 |
| 6 | 500 | 0.12 | A | 5.04 |
| 7 | 500 | 0.13 | D | 3.10 |
| 8 | 500 | 0.14 | C | 7.13 |
| 9 | 600 | 0.11 | C | 4.58 |
| 10 | 600 | 0.12 | D | 2.16 |
| 11 | 600 | 0.13 | A | 1.83 |
| 12 | 600 | 0.14 | B | 1.01 |
| 13 | 700 | 0.11 | D | 1.94 |
| 14 | 700 | 0.12 | C | 2.97 |
| 15 | 700 | 0.13 | B | 0.09 |
| 16 | 700 | 0.14 | A | 0.35 |

**5.1 Analysis of Surface roughness**

The Analysis of variance result for Surface Roughness as shown in Table 5. From the result of ANOVA for Surface Roughness the Spindle speed shows more contribution of 67.60 %, material shows 27.96 % contribution and feed rate has lowest contribution of 0.16 %. Here the residual error was found as 4.27 %.

**Table -5:** ANOVA for Surface Roughness

| Source | DF | Seq SS | Adj MS | F | P | % Contribution |
|---|---|---|---|---|---|---|
| Spindle Speed | 3 | 76.104 | 25.3679 | 31.67 | 0.000 | 67.60 |
| Feed rate | 3 | 0.179 | 0.0598 | 0.09 | 0.971 | 0.16 |
| Material | 3 | 31.487 | 10.4955 | 13.10 | 0.005 | 27.96 |
| Residual error | 6 | 4.806 | 0.8010 | | | 4.27 |
| Total | 15 | 112.576 | | | | 100 |

Figure 4 shows the main effect for S/N Ratio of Surface Roughness. From figure 5 the optimum level of cutting parameters is obtained at Spindle speed of 400 rpm, feed of 0.11 mm/min and material of C (Aluminium + Copper + Backup).

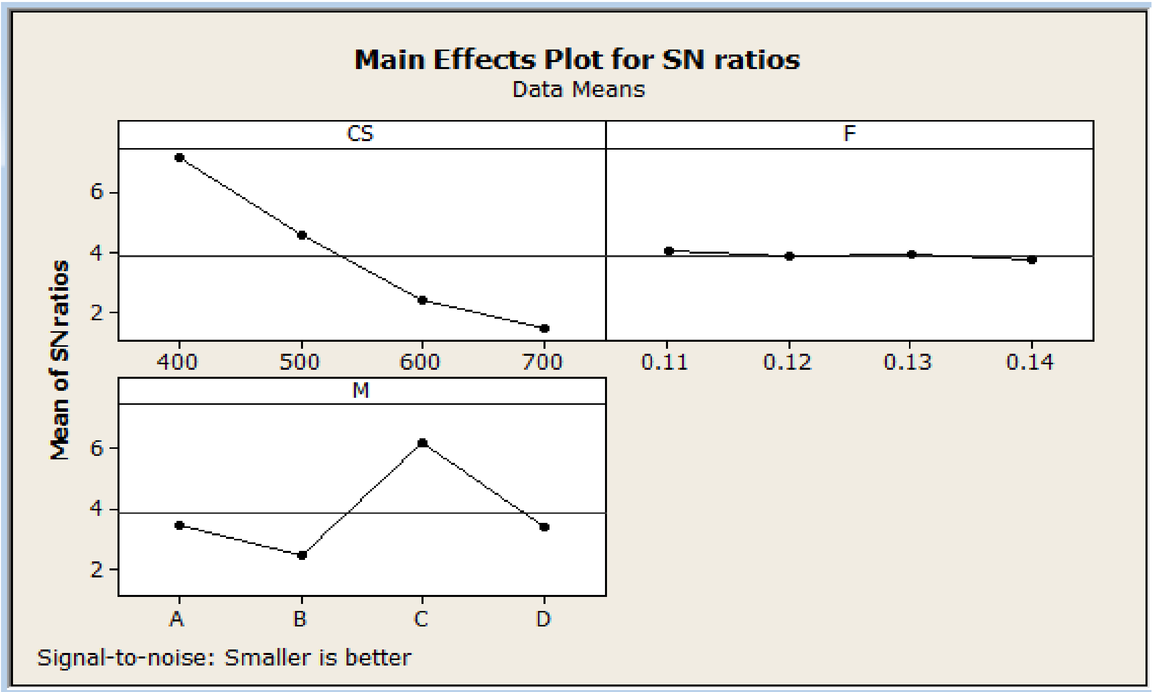


**Fig -4**: Main effect plot for S/N ratio of Surface roughness

From response Table 6 it is observed that that Spindle speed has the greatest influence on the S/N ratio also material has the next greatest influence followed by feed.

**Table -6:** Response of S/N ratio for Surface Roughness

| Level | Spindle speed | Feed rate | Material |
|---|---|---|---|
| 1 | **7.115** | **4.014** | 3.445 |
| 2 | 4.560 | 3.880 | 2.357 |
| 3 | 2.396 | 3.797 | **6.215** |
| 4 | 1.451 | 3.718 | 3.392 |
| Delta | 5.663 | 0.295 | 3.746 |
| Rank | 1 | 3 | 2 |

## 6. CONCLUSIONS

In this work sixteen experiments were conducted with four levels of drilling parameters. Influence of spindle speed, feed and material were investigated by using taguchi and ANOVA analysis. From analysis the following conclusions are drawn:

1. From ANOVA analysis it is found that Spindle speed is most contributing factor for surface roughness with contribution of 67.66%.
2. From ANOVA analysis it is found that Material is most contributing factor for surface roughness with contribution of 27.96%.
3. The optimum parameters level setting for surface roughness is found at Spindle speed of 400 rpm, feed of 0.11 mm/min and material of C (Aluminium + Copper + Backup).
4. Taguchi method successfully optimizes cutting parameters in Drilling machining process.

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