Process Enhance of PCB Micro-Drilling

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Abstract

In this growing world of technology miniaturization is a key word. Drilling is one of the most fundamental machining technologies and is moving toward high precision/high speed application for productivity enhancement. The drill tools play a critical role is increasing the productivity of a cutting process. Although the price of a cutting tool itself is relatively low, the costs caused by tool failures are considerably higher. Therefore, from the viewpoint of cost and productivity, modelling and optimization of drilling processes are micro drilled holes are utilized in many of today's fabrication processes. Precision production processes in industries are trending toward the use of smaller holes with higher aspect ratios, and higher speed operation for micro hole drilling .Experiment was conducted on FR-2 as a work piece material using carbide drill having 0.7 mm diameter.FR-2 sheet with copper foil lamination on one or both sides is widely used to build low-end consumer electronic equipment.In the present work, spindle speed and feed are chosen as machining parameter to see the effect of circularity and taper angle on workpiece.Usingtaguchi methodology, L27 orthogonal array has been chosen and experiment has been performed as per orthogonal array design. For validation of the predicted value and optimization result, confirmation experiments have been performed with optimum levels of machining parameters. It is experimentally found that spindle speed is more influencing parameter for hole quality in terms of circularity and taper angle.

Index Terms—*Micro-Drilling, PCB, Speed, Feed*

I. INTRODUCTION

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 a copper clad laminate (CCL), which is a multi-material sheet. It consists of dielectric layer (resin/glass fiber cloth) and high purity metal conductor (copper foil).CCL is a heterogeneous, anisotropic material. The machining properties of CCLs are quite different from homogenous metallic material. Qualities of holes are one in which the deposited copper layer can be connected stably at each layer of circuit with repeated thermal shock. Controlling the quality of the holes drilled and increasing the wear resistance of micro-drilles have become an important issue. To optimize the PCB micro-hole drilling, the drilling mechanism, drilling force, circularity and taper of hole should be studied systematically. Many studies of chip curling in machining had been performed.J.Prasanna [1] said that higher spindle speed engendered to lesser thrust force and produce holes with good circularity and lesser taper angle .Micreaancau [2] said that as the number of stacked PCBs increases, the stack thickness to be drilled increases and so the drill rout for a single hole increases accordingly. Lijuanzheng [3] said that the PCB drilling process was complex because it included both continuous chip formation and brittle chip formation. The continuous chip formation mainly occurred at the glass fiber cloth layer.H.Nakagawa [4] said that a reduction in the workload caused by friction is effective for improving the quality of micro drilled hole. In this study, several experimental tests were conducted to quality of hole when drilling PCBs. It was important to study circularity and taper of hole during the PCB drilling process as this process affected the hole quality. The drilling process was digitally photographed and the basic removal mechanism of the PCB was analyzed. Additionally, the hole quality including entry hole diameter and exist hole diameter were observed, measured and analyzed. The influence of drilling conditions (feed and spindle speed) on the drilling process and hole quality were also studied.

II. EXPERIMENTAL DETAILS

In this experiment, small holes of diameter 0.7 mm were drilled on FR2 plate of thickness 4.8 mm under different combinations of spindle speed and feed rate. The drill used was twisted carbide tool. The accuracy of the drilled holes was analyzed in terms of circularity and taper angle. Each experiment was repeated 3 times in order to make the database reliable.

Machining Setup

The drilling experiments were conducted on a high speed drilling process. The thrust force measurements were made using a Kistler dynamometer and simultaneously the values were sent to Kistler charge amplifier and stored in a personal computer. The work piece was fastened on to the dynamometer which was placed on the machine table as shown in Fig. 1. The hole quality assessment was done by 2D Vision System, which is shown in Fig.2

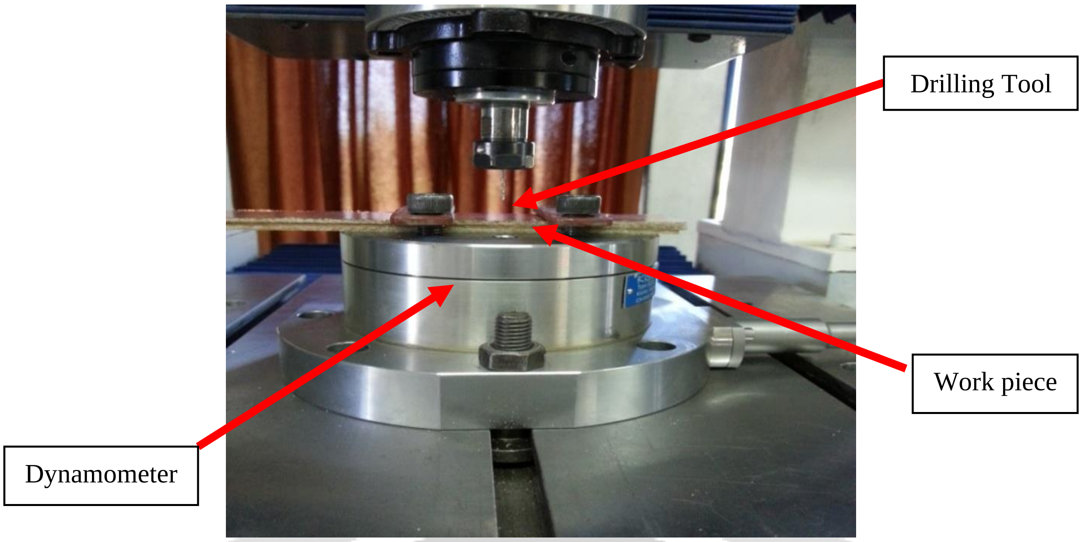

Fig.1. Experimental set-up

Fig.2. 2D vision system.

Measurement Procedure of Performance Parameter

Circularity: The roundness error of the machined hole is proposed in terms of circularity. The error of circularity is defined as the distance between the minimum circumscribing circle diameter and the maximum inscribing circle diameter .The circularity error exists both at the entrance and the exit of the machined hole, their maximum value was used for evaluating the circularity of the machined hole [1].

Taper: Taper angle between the entry and exit surface was calculated by using the formula given below

$$\tan\theta = \frac{(D-d)}{2L}$$

Where D is the average diameter of the entry surface, d is the average diameter in exit surface; L is the depth of cut [1].

Optimization and Modeling

The experiments were conducted using Taguchi L9 design approach. The significance and contribution of each process parameter on the performance characteristics were found out using ANOVA method. The objective of this research was to determine the process parameters required to achieve minimum circularity and taper. Therefore, the quality characteristics of ‘smaller is better’ for all performance characteristics were engaged in this study. The ANOVA results were developed by using the statistical software MINITAB. Each process parameter was designed to have three levels which are shown in Table 1 and the experimental results are presented in Table 2.

Table.1 Experimental Parameters and Their Levels

Process parameter	Symbols	Level 1	Level 2	Level 3
Feed rate(mm/rev)	f	0.02	0.03	0.04
Spindle speed (rpm)	N	20000	22000	24000

Table.2 Experimental Data

Exp.no	Speed	Feed	Force	SN ratio	Circularity	SN ratio	Taper	SN ratio
1	20000	0.02	6.8	-16.8797	0.0755	-16.8797	0.1191	-13.8702
2	20000	0.02	7.6	*	0.0912	*	0.1191	*
3	20000	0.02	6.5	*	0.1123	*	0.0595	*
4	20000	0.03	8.3	-19.6889	0.0551	-19.6889	0.1191	-16.6787
5	20000	0.03	9.9	*	0.0332	*	0.0595	*
6	20000	0.03	10.6	*	0.0568	*	0.1191	*
7	20000	0.04	8.6	-19.6107	0.0936	-19.6107	0.0595	-16.6011
8	20000	0.04	9.6	*	0.1079	*	0.1191	*
9	20000	0.04	10.4	*	0.1393	*	0.0595	*
10	22000	0.02	8.8	-18.2199	0.0891	-18.2199	0.1787	-15.2101
11	22000	0.02	7.8	*	0.0865	*	0.1191	*
12	22000	0.02	7.8	*	0.0894	*	0.0595	*
13	22000	0.03	10.9	-19.8289	0.0707	-19.8289	0.1787	-16.8189
14	22000	0.03	9.6	*	0.0951	*	0.1787	*
15	22000	0.03	8.8	*	0.0809	*	0.0595	*
16	22000	0.04	9.6	-21.1377	0.0991	-21.1377	0.0595	-18.1277
17	22000	0.04	12.2	*	0.1205	*	0.1191	*
18	22000	0.04	12.2	*	0.0871	*	0.1787	*
19	24000	0.02	4.5	-16.899	0.0537	-16.899	0.0595	-13.8891
20	24000	0.02	8.3	*	0.0595	*	0.0595	*
21	24000	0.02	7.6	*	0.0795	*	0.1191	*
22	24000	0.03	8.3	-18.327	0.1103	-18.327	0.0595	-15.3171
23	24000	0.03	8.8	*	0.0641	*	0.1787	*
24	24000	0.03	7.6	*	0.0427	*	0.1191	*
25	24000	0.04	9.1	-19.7548	0.0262	-19.7548	0.1191	-16.7446
26	24000	0.04	9.4	*	0.0638	*	0.0595	*
27	24000	0.04	10.6	*	0.0325	*	0.0595	*

III. Result and Discussion

The experiments were conducted using L27 orthogonal array. The force, circularity and taper were calculated as per discussed erlier.The experimental results for force, circularity and taper is given in table 2.

Analysis on Thrust Force

In order to see the effect of machining parameter on thrust force, Experiments were conducted using L27 OA.The experimental result data for thrust force is given in table 2.The thrust force is smaller the better type quality characteristics. So S/N ratio is calculated for smaller the better criteria. Main effect plot for S/N ratio are plotted in figure 3.

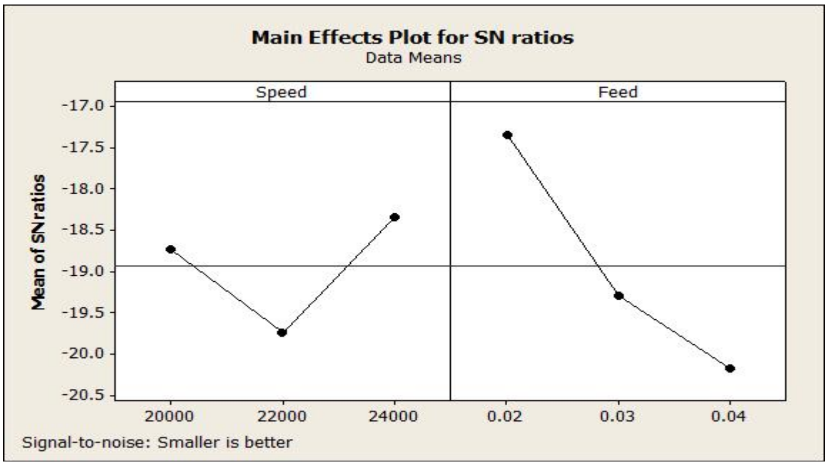

Figure 3Main effect plots for SN ratios for Thrust Force

Figure. 3 shows that feed has main effect on thrust force as the speed increases feed also increase. From taguchi analysis the range of speed and feed 22000 rpm and 0.04 mm/rev respectively are better for creating the good hole accuracy. The speed has not significant effect as much as feed on thrust force. It is seen from the figure 4 that there is very weak interaction between the machining parameters affecting the thrust force since the performance at different levels of machining parameter value are almost parallel.

In order to study the significance of the machining parameter on thrust force, taguchi analysis was performed.Taguchi analysis for thrust force versus speed and feed is given in table 3.The table includes rank based on delta statistics, which compare the relative magnitude of effects. The delta statistic is the highest minus the lowest average for each factor. Minitab assign rank based on delta values, Rank 1 to the highest delta value, Rank 2 to second highest delta and so on. The rank indicates the relative importance of each factor to the response. From table 3, the rank and delta values show that feed has the greatest effect on Thrust force. As thrust force is the 'smaller is better' type quality characteristic, it can be seen from figure 3 that second level of speed (22000) and third level of feed (0.04) provide minimum value of thrust force.

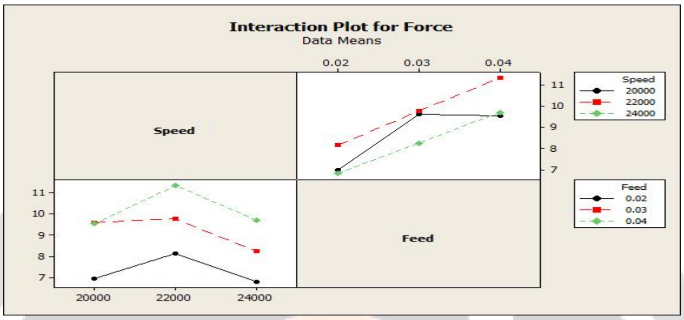

Figure 4. Interaction plot for SN ratios for Thrust Force

Table 3. Response table for S/N ratio

Level	Speed	Feed
1	-18.73	-17.33
2	-19.73	-19.28
3	-18.33	-20.17
Delta	1.40	1.65
Rank	2	1

Analysis on Circularity

In order to see the effect of Machining parameters on the Circularity, experiments were conducted using L27 OA.The experimental data for circularity is given in table 4.

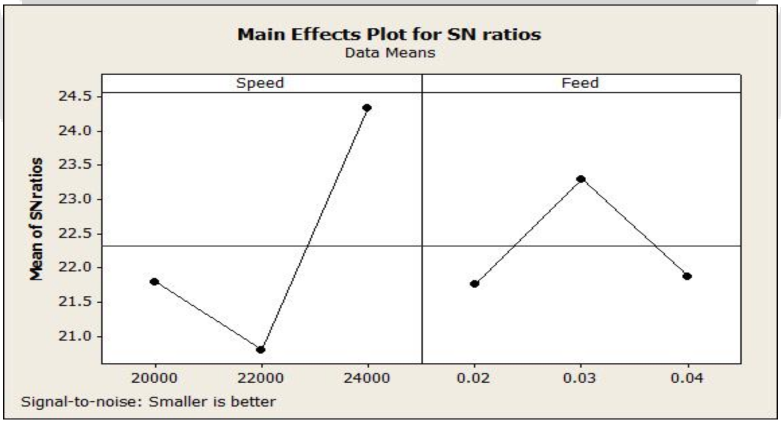

Figure 5Main Effect plot for SN ratio

Circularity is smaller the best type quality characteristic so the S/N ratio was calculated for smaller the better criteria. The main effect plot for circularity is plotted as shown in figure 5.It is seen from the figure 5that speed has the most significant effect on the circularity. Circularity increases with increase in speed of spindle. Circularity increases sharply when feed rate increases from 0.02 mm/rev to 0.03 mm/rev and circularity again gradually reduces from increase in feed rate from 0.03 mm/rev to 0.04 mm/rev.It is observed from the figure 6 that there is a slight interaction between spindle speed and feed rate.

The response table for signal to noise ratio for circularity is shown in table 4.The rank and delta values show that speed has the greatest effect on circularity.

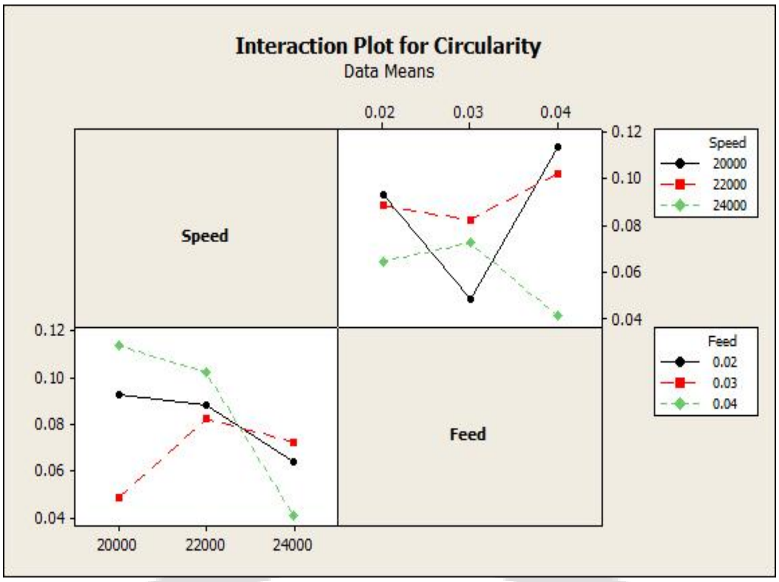

Fig 6 Interaction Plot for Circularity

Table 4 Response table for S/N ratio

LEVEL	SPEED	FEED
1	21.80	21.77
2	20.81	23.31
3	24.35	21.88
DELTA	3.53	1.54
RANK	1	2

As circularity has "lower is better" characteristic, from the figure 5, second level of speed (22000), first level of feed rate (0.02), third level of feed rate (0.04) for reducing circularity.

Analysis on Taper

In order to see the effect of machining parameters on the taper, Experiments were conducted using L27OA.The experimental data is given in table 2. Taper is smaller the better type quality characteristic so S/N is calculated for the Smaller the better type. The main effect plot for S/N is given figure 7.when spindle speed increases from 20000 rpm to 22000 rpm the taper angle reduces and when spindle speed increases from 22000 rpm to 24000 rpm the taper angle increases.Increasing in feed rate from 0.02 mm/revto 0.03 mm/rev, first taper is reduces but after increases feed rate from 0.03 mm/rev to 0.04mm/rev, taper angle is increases. It is clear from the figure 8 that there is moderate interaction between speed and feed rate.

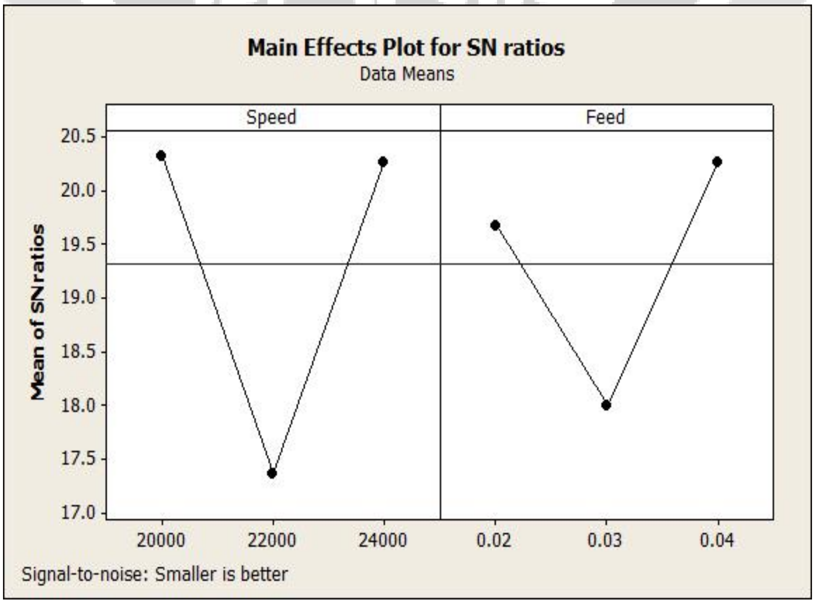

Figure 7 Main Effect plot for SN ratio

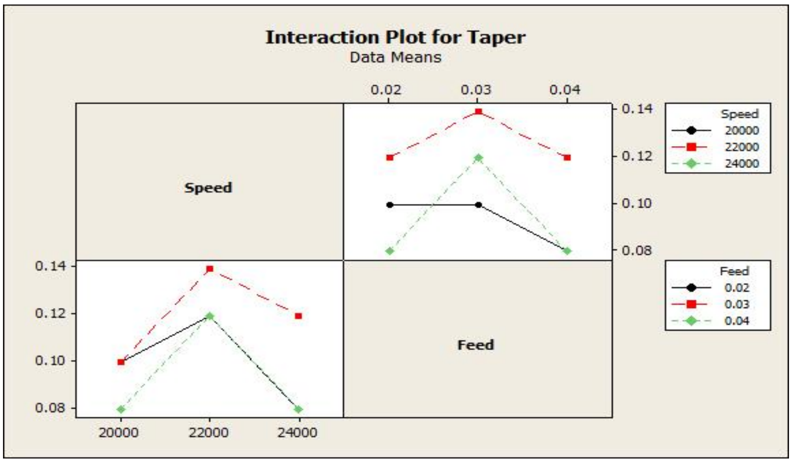

Figure 8 Interaction plot for Taper

The response table for Signal to Noise ratio for taper is shown in table 5.The rank and delta values show that speed has the greatest effect on taper.

Table 5 Response table for S/N ratio

LEVEL	SPEED	FEED
1	20.32	19.68
2	17.37	18.01
3	20.27	20.27
DELTA	2.95	2.26
RANK	1	2

As taper has “lower is better” characteristic, so from figure 7 second level of speed (22000), second level of feed rate (0.03) for reducing taper angle

IV. ESTIMATION OFOPTIMUM MACHINING PARAMETER

In this section, the optimal values of the process parameter i.e. thrust force, circularity, taper angle have been predicted. The optimal levels of the machining parameter for Performance parameter have been identified from taguchi analysis and S/N Ratio. The optimal value of machining parameter is predicated considering the significant parameter only. The response table 2 using Taguchi method is employed here to calculate the effect of each level of machining parameter on Process parameter. It is done by sorting the mean values of machining characteristics corresponding to levels of the process parameter in each column of the orthogonal array, and taking an average on those with same level

V. CONCLUSION

In the present study, the effect of machining parameter on process parameter i.e. thrust force, circularity and taper angle of the FR2 plate using carbide drill have been investigated for micro-drilling process. The experiments were conducted under various machining parameter setting of spindle speed and feed rate. L27 OA based on taguchi’sdesign was performed, Minitab 16 software was used for analysis the result an optimal set of process variables that yields the optimum quality features to machined parts produced by micro-drilling process has also been obtained. The important conclusions from the present research work are summarized in this chapter:

- The minimum thrust force is obtained at spindle speed of 22000 rpm and feed rate 0.04 mm/rev.
- The minimum circularity is obtained at spindle speed of 22000 rpm and feed rate 0.04 mm/rev.
- The minimum taper angle is obtained at spindle speed of 22000 rpm and feed rate 0.03 mm/rev.

VI. REFERENCES

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